SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

Report on monitoring results and analysis

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3	Katholieke Universiteit Leuven	KUL	Belgium
4	University of Gloucestershire	UoG	United Kingdom
5	University Hohenheim	UH	Germany
6	Research Institute for Knowledge Systems	RIKS	Netherlands
7	Technical University of Crete	TUC	Greece
8	Joint Research Centre	JRC	Italy
9	University of Bern	UNIBE	Switzerland
10	Milieu LTD	MLTD	Belgium
11	Norwegian Institute of Bioeconomy Research	NIBIO	Norway
12	Bodemkundige Dienst van België	BDB	Belgium
13	Aarhus University	AU	Denmark
14	Game & Wildlife Conservation Trust	GWCT	United Kingdom
15	Teagasc	TEAGASC	Ireland
16	Soil Cares Research	SCR	Netherlands
17	Instituto Politecnico De Coimbra	IPC/ESAC	Spain
18	National Research and Development Institute for Soil Science, Agrochemistry and Environmental Protection	ICPA	Romania
19	University of Padova	UNIPD	Italy
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21	Wageningen University	WU	Netherlands
22	University of Pannonia	UP	Hungary
23	Swedish University of Agricultural Sciences	SLU	Sweden
24	Agro Intelligence Aps.	AI	Denmark
25	Crop Research Institute	VURV	Czech Republic
26	University of Almeria	UAL	Spain
27	Fédération Régionale des Agrobiologistes de Bretagne	FRAB	France
28	Scienceview Media BV	SVM	Netherlands
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Deliverable 5.3:
Report on monitoring results and analysis

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[1]Main authors from WP5 are responsible for compiling this report, organizing the data storage in the database, executing the statistical and meteorological analysis, drafting framework reports for the Study-Sites

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Study-Sites partners are the main authors of the Experiment specific reports. They completed the framework reports for their Study-Site and added discussions, interpretations, conclusions and recommendations.

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Table of Reports & Annexes

Introductory note on navigation

Navigation in D5.3 is possible through this table, which allows the reader to jump immediately to the general introduction and the individual reports by Study-Site. Each Study-Site report and annexe has its independent page numbering. Before the page number, an identification of the Study-Site is provided.

In the table below the words **in a blue font within a rectangle** are linked to reports or sections. From the **title** of a Study-Site report or a collection of figures **within a rectangle,** it is possible to jump back to this table of reports by clicking on 'Back to TOC'.

Study-Site specific reports of all the SoilCare experiments

The illustrated main reports are in high resolution. The annexes with all the figures as extra material are provided in lower resolution.

5. Viborg, DK
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
6. Loddington, GB
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
7. Tachenhausen, DE
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
8. Draganesti Vlasca, RO
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
9. Legnaro, IT
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
10. Szaniawy, PL
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
11. Caldeirão, PT
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
12. Chania, Crete, GR
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis

13. Orup, SE
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
14. Prague-Ruzyně, CZ
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
15. Almeria, ES
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis
16. Brittany, FR
    a. Main report
    b. Collection of figures for the exploratory meteorological figures
    c. Collection of the figures for the biophysical analysis

Annexe I Figures for the meteorological analysis in reduced resolution

Navigate via the table of the Study-Site specific reports.

Annexe II: Figures for the biophysical analysis in reduced resolution

Navigate via the table of the Study-Site specific reports. All the summarizing figures per indicator are given but not the diagnostics of the fit.

Executive summary

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Methodology for managing and analysis experiments

The SoilCare project aims at developing soil-improving cropping systems. At 16 Study-Sites dispersed over Europe, experiments have been implemented. These were selected in collaboration with the stakeholders (WP3) and based on a literature review (WP2). The methodology for monitoring the experiments was compiled by WP4. The results are being compiled by WP5 into a common database (as described in D5.1). The combined findings by the Study-Sites are a very important input for the upscaling by WP6, the policy analysis by WP7 and the dissemination by WP8.

In the general introductory part, the analysis methods are described. Firstly, the datasets are extracted from the database leading to standard data structures with the measured indicators. WP5 developed R-scripts for a modern mixed-effect statistical processing of the measurements. This approach allows us to consider interaction and repeated measurements for well-designed experiments. Significant differences between treatments were tested by the Tukey group comparison.

The weather conditions during the short term experiments were quite specific, especially in 2018 droughts at several Study-Sites occurred. Moreover, all the years had high sometimes record-breaking temperatures. Local meteorological data and longer-term historical observations were combined to characterize the weather during the experiments. For most Study-Sites, longer-term data were extracted from the European Climate Assessment & Dataset project (ECAD).

In the past, most similar projects had a wide variety of reports by the Study-Sites, which made comparison very difficult. In SoilCare, WP5 supplied template reports to the Study-Sites containing the biophysical and meteorological analysis by WP5 and the socio-cultural-economic results by WP4. The Study-Sites added their interpretation, discussion and conclusions to the reports. Several Study-Sites also discussed those reports with their stakeholders. Although providing template reports to 16 Study-Sites was a major effort by WP5, it allowed a timely reporting of all the experiments with a consistent methodology while the Study-Sites could concentrate on the interpretation and the conclusions. The general methodology based on a shared database, a common monitoring plan, a unified statistical analysis and sustainability assessment can serve for future multi-site and -partner experiments in general and further investigations into SICS with their overall sustainability in particular.

Synthesis of the experiments

This deliverable D5.3 describes the analysis and compiles all short term experiments into Study-Site specific reports. The Study-Sites pooled the objectives of the short term experiments into 4 thematic clusters. They are *"Soil cultivation"*, *"Alleviation of compaction"*, *"Fertilizer/Amendments" and "Soil* *improving crops".* In the experiments, Soil-Improving Cropping Systems (SICS) were compared with a standard practice serving as a control. Biophysical data from these agronomic trials were monitored and assessed in environmental, economic and socio-cultural dimensions for sustainability and acceptability.

A large number of Study-Sites also had long term experiments, which are officially not part of the SoilCare project. Some Study-Sites integrated their short term experiments within the long term ones. In general, the SoilCare short term experiments were too short to show a lot of significant effects on Soil Productivity (by Yield or Relative Yield), Organic Carbon, Structure Stability (by Water Stable Aggregates), Infiltration Rate (by Hydraulic Conductivity), Biological Activity (by Earthworm counting) and Bulk Density. Besides, hydraulic conductivity and bulk density have a large spatial and temporal variability in the field, which makes it more difficult to detect significant differences without increasing dramatically the number of measurements. The Study Site in Poland illustrated this spatial variability well.

For most experiments, reduced tillage and non-inversion tillage had a positive effect on the soil characteristics and did not in general lead to lower yields. The UK experiment showed that ploughing negatively affected the earthworm population, but major issues remain such as weed control as mentioned in the Italian experiment, which often requires herbicides. Also, a more shallow rooting depth might result in more risks under drought. The Italian experiment indicated a higher risk of crop-failure under No-Tillage. The Czech experiment, which started in 1995, points out that zero tillage is difficult for heavy soils and root crops, like beets and potatoes. Also, pest control as mentioned in the Belgian experiments was a challenge under non-inversion tillage.

Tillage and compaction alleviation are interlinked. Subsoiling might be needed from time to time to keep the soil layers in position while breaking up compaction. In the Romanian experiment, it was suggested to subsoil 60 cm deep every 3 to 4 years. The Swedish experiment on a naturally compacted soil illustrated that mechanical subsoiling, with or without the incorporation of organic materials, has a positive impact on root growth and rooting depths.

At several Study Sites, different fertilizers and amendments were compared. The Belgian Study Site compared adding woodchips, compost, pig manure with or without lava grit with a control. The C/N ratio helped to explain the availability of nutrients to the crops. The long term experiments in Hungary that started in 1983 showed, as expected, significant positive effects on yield and soil structure (via Water Stable Aggregates and Bulk Density). Also, the Cation Exchange Capacity as an indicator of nutrient retention was different for control and SICS. Surprisingly the soil organic matter content in the long term experiments in Hungary was not significantly different despite the very positive effects on yield and soil structure. It shows that the absolute value of organic matter is not as important as the healthy microbial life and building-up of water-stable aggregates. In the UK Study Site adding an inoculant had a modest effect on improving aggregate stability. In the Portuguese Study Site, urban sludge from urban wastewater treatment plants increased soil organic carbon and nutrients. In the Danish Study Site, higher yields were obtained by using the chemical as compared to organic fertilizer. However, in this experiment cover crops, legumes and animal manure reduced the yield gap.

Nowadays cover-crops in between growing seasons are commonly applied. Additionally, "under-crops" during the growing season have been tested. The benefits of cover-crops are generally well accepted and also illustrated by the experiments. Due to global warming, which is very well visible in the meteorological analysis for every Study Site, the lack of freezing during recent winters caused cover- crops not to die spontaneously and to survive the winter. In such case, herbicides or mechanical measures are required to kill them in spring. This is an important issue for further investigation as also mentioned for the Italian experiment. In the German experiment, the possible negative effect of Glyphosate on soil health was investigated and found to be minor. Banning herbicides for different reasons will require a high precision shallow tillage/mechanical weeding before seeding of the crops so as not to destroy the benefits of cover crops on soils again.

In Greece and Spain, the cropping systems were vineyards, fruit and olive orchards. In Crete, erosion reduction was the major challenge. Crete had a historical high rainfall in October 2017 and some more heavy rainfall events afterwards. Almería as the driest and hottest place in Europe focussed on water savings by deficit irrigation.

For most experiments yields of the control and the SICS were similar, and the socio-cultural analysis showed a modest impact on sustainability. However, the majority of soil-improving cropping systems incur extra costs, which are not always compensated by extra benefits, so that for several SICS the profitability suffers without financial support.

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General introduction

It is strongly advised to read first the general introduction before any of the Study-Site reports.

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Introduction

Deliverable 5.3 reports the monitoring results of the experiments and their analysis as part of task 5.4 for Work package 5 (WP5). WP5 has to overview the implementation, monitoring and evaluation of the experiments on the soil improving cropping systems at the Study Sites. WP2 reviewed and preselected the promising Soil Improving Cropping Systems (SICS). Using this information, the experiments were selected by the Study-Sites in collaboration with the stakeholders guided by WP3. WP4 developed a comprehensive methodology for evaluating and assessing the experiments on the soil improving cropping systems. WP5 compiled the observations and information from the experiments following the methodology for monitoring the experiments compiled by WP4 and stored them in a common database consistently and uniformly. The construction and working of the database were reported in Deliverable 5.1. Having all the data for the experiments collected and stored allows access to results by project members and to use a unified, streamlined, and efficient statistical approach to analyse the experiments. This approach is relatively novel and avoids that Study-Sites report and analyse their experiments in separate heterogeneous documents, which are highly variable, might use different statistical approaches and are difficult to compare across Study-Sites. Some of the Study-Sites have little or no experience with the analysis while others have built up expertise during several decennia. Draft reports based on a unified statistical analysis of the database were supplied to the Study-Sites. The Study-Sites could then focus on the interpretation of the experiments taking into consideration the socio-cultural and economic analysis (facilitated by WP4) and the discussions with the stakeholders during the demonstration activities and field days.

A complementary task for WP5 was to compile the information on demonstration activities and field days of the selected cropping systems (Deliverable 5.2). In this way, the monitoring and assessment results shared and discussed with the stakeholders. Demonstration activities/field days were used initially to inform the end-users about the extra value of the tested cropping systems and the progress of the experiments by directly observing these. Additional targets were to allow them to evaluate possible benefits, drawbacks, costs and outcomes on-field by direct observations and finally to activate them into a more active role in monitoring, evaluating, reflecting on and adopting a novel soil-improving cropping system.

D5.3 reports the analysis of data collected and the assessment of the performance by the different SICS at a Study-Site level in a way that allows concluding which cropping systems are most suitable in each Study-Site. The analysis must unravel the most important factors that determine profitability and sustainability and also the most important drawbacks. This aims at a better holistic understanding of SICS.

This deliverable 5.3 is the capstone to the most important task 5.4 by WP5. In their turn, WP6, 7 and 8 must develop an interactive tool, derive policy recommendation and organize the dissemination, respectively, with this report as one of their key information sources. The Study Site level results in D5.3. are provided to WP6 to synthesise and integrate results from the different sites. It allows results to compare across pedo-climatic, environmental, socio-cultural and economic conditions. WP8 uses the results in the dissemination factsheets produced to be used in the last Stakeholder Workshop organised by WP7.

The cropping systems analysis includes three different aspects as specified in the assessment methodology (Deliverable 4.2). WP5 analyzed the biophysical and WP4 for the economical and socio-cultural aspects.

The biophysical aspect includes the statistical analysis of the monitoring results stored in the database for each experiment at the Study-Sites. The meteorological conditions during the experiments are very important. Therefore an analysis of weather-data monitored as close as possible near the experiments and a comparison with the longer-term weather was needed. WP5 executed both the statistical and the meteorological analysis consistently and systematically for all the experiments. Graphical representations (described later) of summaries of each statistical analysis were compiled and made available to the Study-Sites via the SoilCare cloud storage.

Subsequently, WP5 produced template reports and supplied those to the Study-Sites with the biophysical and meteorological results for each experiment. These precompiled reports following a template for all experiments and included all the information extracted from the database (description, design, soil profile, map, factors, management details etc.), the meteorological analysis summary, the results from the statistical analysis of the biophysical indicators, the results from the economic and socio-cultural analysis as well as the overall analysis by applying the assessment methodology. In this way, the Study-Site partners received a harmonized framework to reflect, interpret and draw conclusions. The template reports are however not meant as a straightjacket but rather as a starting point and support to produce comparable reports for the experiments. The Study-Site partners completed those reports by providing discussions leading to their conclusions and recommendations. The final report allows room to include extra results from their experiments that have not been treated by the WP5 analysis. The Study-Sites have executed not only the experiments but also interacted with local stakeholders. This approach fully recognizes and valorises the expertise of the Study-Sites while leading to comparable and complete reports.

The individual contributions of the case study partners are presented in the reports by Study-Sites.

Overall analysis – application of the assessment methodology

The overall assessment methodology used for the evaluation of a SICS evaluates and compares the benefits, drawbacks, profitability, soil quality, and sustainability of SICS. WP4 developed a tool in a spreadsheet format. There are two versions of the tool: (i) a simple one consisting of checking whether the difference between SICS and control reflects a positive impact, negative impact, or no (or zero) impact; and (ii) a more complex one based on threshold values. This distinction is based on the fact that the initial value of a given property of the control can be good or bad and can result in a higher number of variations when compared to the value of the same property of the SICS. The assessment methodology combines three dimensions: **biophysical**, **economic** and **socio-cultural**. More details about the methodology, required input and approach and guidance are given in Deliverable 4.1.

Biophysical dimension analysed by WP5

The biophysical dimension consists of the statistical analysis of the biophysical indicators as measured and assessed in each experiment and provided by the Study-Site partners in the SoilCare database. This dimension also contains the meteorological data analysis with data either provided by the Study-Site partners and/or extracted from the ECAD (Klein Tank et al., 2002; available on https://www.ecad.eu/).

The biophysical results of the field experiments and the weather data were supplied to WP5 by the Study-Sites via structured spreadsheets. Those spreadsheets were firstly checked to remove inconsistencies and errors. This process involved an intensive interaction between WP5 and SS's but was reasonably fast and often led to a better mutual understanding of the results from the experiments. Once a spreadsheet was complete and correct, it was entered automatically into the database by a Python script. The construction of the database and the procedure for using the database are described in more detail in D5.1.

Statistical approaches and analysis with R-scripts for the biophysical analysis

The famous long-standing agricultural trials at Rothamsted can be considered as one of the first experiments based on a statistical design. Breeding, fertilizer and other agricultural experiments were the pioneers to adopt the randomized completely blocked design (RCBD). Balanced design with the same number of replications in all experimental units and blocking were fundamental. Early analysis methods focused on the Analysis of Variance (also known as ANOVA). The classical ANOVA approach often regarded treatments as fixed and block effects as random, but in this statistical linear model, both effects were treated identically as the “real” fixed effects. So, mathematically in the classical ANOVA, the random and fixed effects are calculated in the same way. A major drawback is the weak analysis of interaction effects. Also repeated measurements in the same field either in space or time are not independent but are autocorrelated. Especially for longer-term experiments, measurements are repeated at least once a year on the same plot. Even in experiments lasting during only one-season some variables like water and nutrient content, the height of the crop are normally can be measured more than once during one growing cycle within the same plot. Another argument is that while the ANOVA assumptions are relatively acceptable for RCBD, they become more problematic for unbalanced, repeated measures and split-plot experiments. The modern mixed-effect model allows for a larger variety of designs and implementations (Smith et al., 2005). A balanced RCBD often becomes unbalanced by accident during the field trial. This could be caused by partial failures in measurements, accidental destruction/harvesting of some plots before the measurements were executed. Probably the most important reason is that the mixed model approach allows a better identification and interpretation of interactions and repeated measurements.

The mixed-effect model is more difficult to apply, requires more consideration for the hypothesis and has more room for interpretation.

One very general problem in modelling is that more complex models with more parameters always potentially fit better. However, the better fitting is rather due to fitting the residuals but leads to lower predictive capacity. Therefore, penalizing likelihood functions are used and one relies less on the goodness of fit. The most classical one is Akaike’s information criterion, which tries to indicate the most parsimonious.

Most current statistical software can handle mixed effect models. The R software was selected as it is open source and with a very large users’ community. As a large number of experiments needed to be processed R-scripts were developed. Those scripts are general for all the experiments and require a minimum of adjustments **depending on the different experimental designs.** The user-friendly R-Studio with R version 3.6.1 (RStudio Team, 2016) was the major tool. However, it is important to stress that judgement using diagnostics and interpretation remains very important. Although the procedure was well-organized and streamlined as well as possible it cannot be a fully automated procedure. SoilCare has a variety of Study-Sites with different experiments. The first step always started by identifying the experimental design. In a few cases, the experiment was not replicated and detection of statistically significant differences was not possible. In those cases, a purely descriptive visualisation was used.

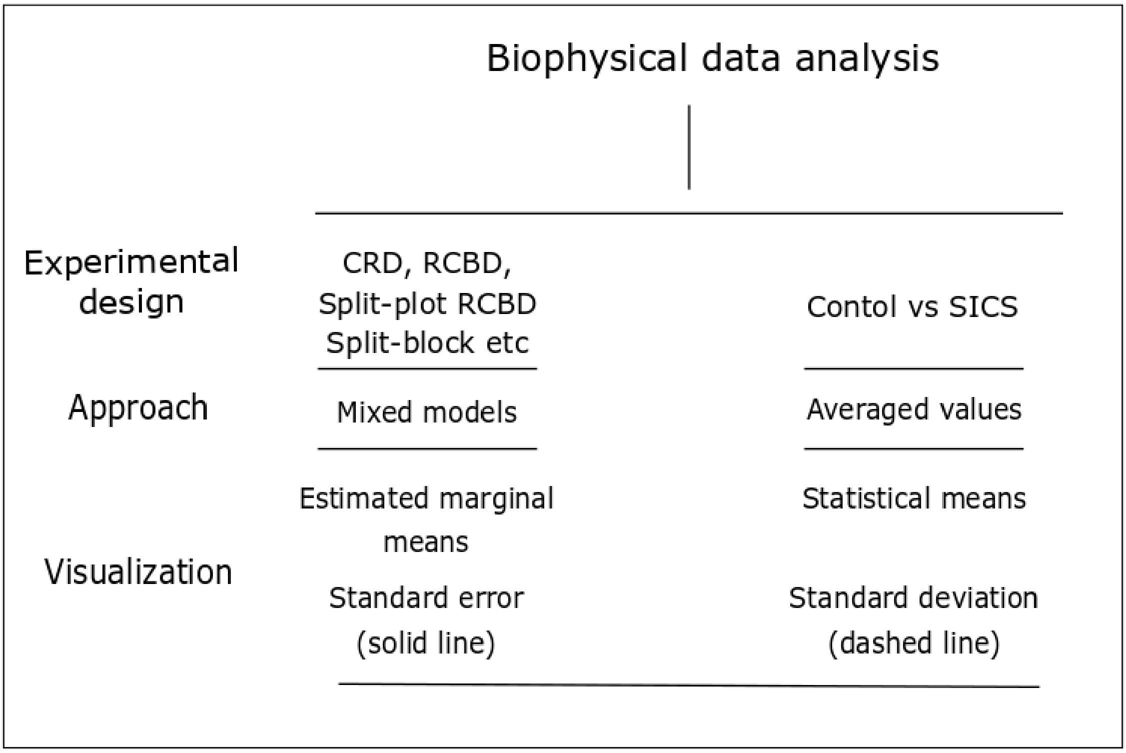


Figure 1: Graphical summary of the biophysical data statistical analysis approach

Datasets for the biophysical statistical analysis extracted from the database

From the database, datasets for statistical analysis or other purposes were extracted by queries. For this deliverable D5.3, the queries were organized per experiment. This allows producing the results to feed the SS reports based on a unified statistical approach. The filenames were standardized. The explanation on “XXX” for identifying and coding the experiments and treatments is found in Table 1 and Table 2.

Three spreadsheets are generated by querying the database:

1) XXX_test_data.xlsx: From the observation table only the columns with quantitative variables are extracted which have to be analysed. The empty columns and columns with qualitative variables are not included in this spreadsheet.
2) XXX_Indicators.xlsx: The list of variables to be analysed (column names in observation table), together with their units from the observational metadata table in the database and desired names to be displayed on the figures as the SS asked. In this way, the figures can be produced with captions in any national language and with the units on the axis.
3) XXX_design.xlsx: Detailed information of the experimental design from the plot table in the database (the type of experimental design, plots, main plot block etc)

The first step in most statistical software consists of entering data into the appropriate data-set. Those three spreadsheets are read by R-scripts to produce "*data.frames*" in R.

Mixed-effects model to analyse RCBD, split-plot RCBD, split-block, CRD designs

All the experiments which have a CRBD, split-plot RCBD, CRD and similar designs can be fitted by the Mixed-Effects Model. They all replicate each treatment. Often in agricultural experimentation 3 replicates are used, but there could be more or just 2.

For each response variable, a Mixed-Effect Model was fitted using the package "*nlme*" (Pinheiro et al., 2013) in the program R (R Core Team, 2019). The least squared means were calculated using the package "*emmeans*" (Lenth, 2020). Graphics were produced with the package "*ggplot2*" (Wickham, 2016).

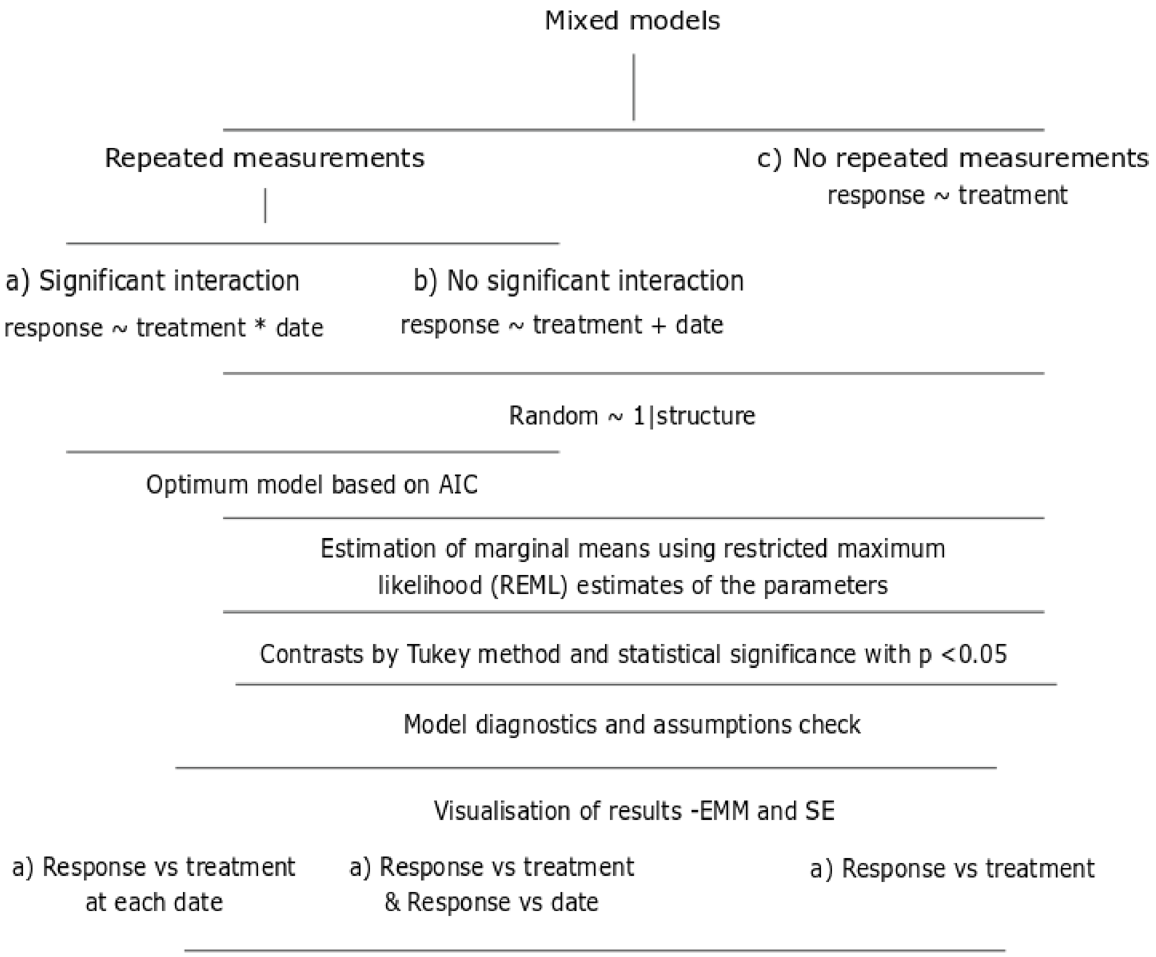
Differences between treatments or dates were analysed by a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. The model's optimum fixed structure selected for the best fit attaining the lowest value of Akaike's Information Criterion (AIC) using a maximum likelihood function (ML).

The experimental design structure effect (block-factor, whole plot factor etc.) was introduced in all models as a random effect, using the statement "*1|structure*" in the R language. Specifically, for the experimental designs that are using blocking the random effect statement is "*1|block*" and for the CRD designed that do not have blocks is "*1/plot*".

Estimated marginal means (also known as least-squares means) by factors were computed by the least square method and contrasted by the Tukey group comparison method. The Tukey method avoids accidental differences, especially with a large number of treatments. Degrees of freedom were approximated by the containment approximation and the coefficients of the random terms in the mixed models were estimated using the restricted maximum likelihood (REML). In the present work, statistical significance is fixed like in most work at a probability $p < 0.05$.

For most experiments, the number of plots is the number of treatments times the number of replicates. The total number is normally not enough for the testing of the normality and homoscedasticity of the residuals by statistical procedures. Therefore, visual inspection of the Q-Q-Plots of the residuals and the plots of the normalized residuals against the fitted values based on REML fit. If heteroscedasticity (or non-constant variance of the residuals) is present the observations were weighted using different variances structures (per stratum for a date, treatment or their interaction). The optimum was identified by the AIC criterion in combination with the visual assessment of the residual's plots. The final models were fitted using REML estimation.

For these experiments the estimated marginal mean and the standard error represented with **solid lines** is visualized, using the package ggplot2 (Wickham, 2016). The significantly different groups were assigned letters as common practice in agricultural experiments.



Experiments with control versus treatment but without the replication of treatments

Some experiments did not replicate plots per treatment. So only one plot with the control was compared with single plots per SICS treatment. In this case, a proper statistical analysis is not possible. The response variable values per treatment are visualized. In some cases, several measurements of the same indicator were made within the same plot. Then the average is shown for that plot and day and visualized using the package ggplot2 (Wickham, 2016) as a mean value for each day. The standard deviation of the measurements within the same plot is presented with **dashed lines**. However, it is important to stress that they cannot be used for group comparison between the treatments. Measurements within the same plot are spatially repeated measurements and are not independent of each other. The interpretation of the solid lines is fundamentally different from the dashed lines.

Biophysical analysis with mixed models -R-scripts flow

The script is stored in the SoilCare cloud storage (R script: Analysis_withsemmeans.R)

The general workflow by the script:

1. Loading the required packages
2. Import the data and tidying (merging, changing data type etc)
3. Loop for each response variable to statistically analyse, fit the relevant models and produce the relevant figures.

The figures with diagnostics to judge upon the residual assumptions (not given in this report) are supplied to the Study-Sites via the shared cloud storage.

The figures with group comparisons are supplied for a limited number of specific indicators in the report per Study-Sites. The Study-Site could decide to add a few more indicators into their report as they wished. The graphical representations for all indicators are included in Annexe II. In the Study-Site reports only selected indicators are shown.

Explanation of the R scripts for mixed-effect modelling.

1.Loading the required packages

The basic packages used in the R script used for the biophysical data analysis are:

- "*nlme*": used to fit and compare linear and nonlinear mixed-effects models. Hereby the function "*lme*" for fitting linear mixed-effects models used.
- "emmeans" v1.4.6: used to obtain the estimated marginal means (EMMs, also known as least-squares means), extract and display information on all pairwise comparisons of estimated marginal means.
- "ggplot2" v3.2.1: used for creating data visualizations

2.Import the data and tidying (merging, changing data type etc)

The data required are imported and manipulated (merged, filtered, defining data type etc.) to fit the needs of the packages described and the analysis needed.

3. Selection of relevant model and visualization for each response variable

A loop is subsequently used to analyse each response variable by selecting and fitting the optimum model. Hereby systematically the presence of repeated measures is the first binary determination. If repeated measurements are present interaction of factors is tested. For all the indicators the results of the analysis are visualised and stored.

The selection of the relevant model starts with the presence of repeated measures or not:

1) If **no repeated measures (NR)** (response variable is measured only once during the experiment

a. **Case 0**: Mixed model 0
Main effect structure: response variable ~ treatment
random effect structure: depending on the experimental design (block, main plot, plot etc)
   - Estimation of marginal means and determination using restricted maximum likelihood (REML) estimates of the parameters
   - Contrasts by Tukey method with p<0.05 for finding significant differences between groups
   - Normality and homoscedasticity assumptions are checked by creating and storing the model diagnostics (QQ plots, and residuals vs fitted values plots)
   - Plotting of the figure: response variable vs treatment (estimated marginal means and SE with solid line)
   - Saving of the fitted model's results

2) Else if **repeated measures** (variable measured several dates during the experiment) two different models are fitted and compared using the AIC criterion. We compare if the interaction between the treatment effect and the date effect is significant or not.

a. **Case 1: Significant interaction (SI)**: Mixed Model 1:
Main effect structure: response variable ~ treatment * time
random effect structure: depending on the experimental design (block, main plot, plot etc)
   - Estimation of marginal means and determination using restricted maximum likelihood (REML) estimates of the parameters
   - Contrasts by Tukey method with p<0.05 for finding significant differences between groups
   - Normality and homoscedasticity assumptions are checked by creating and storing the model diagnostics (QQ plots, and residuals vs fitted values plots)
   - Plotting of the figure: response variable vs treatment for each different date (estimated marginal means and SE with solid line)
   - Saving of the fitted model's results

b. **Case 1: <u>No</u> significant interaction (NSI)** of date and treatment: Mixed Model 2:

Main effect structure: response variable ~ treatment + time
random effect structure: depending on the experimental design (block, main plot, plot etc)
   - Estimation of marginal means and determination using restricted maximum likelihood (REML) estimates of the parameters
   - Contrasts by Tukey method with p<0.05 for finding significant differences between groups
   - Normality and homoscedasticity assumptions are checked by creating and storing the model diagnostics (QQ plots, and residuals vs fitted values plots)
   - Plotting of the figure: response variable vs treatment (estimated marginal means and SE with solid line) **(NSI_treat)**

- Plotting of the figure: response variable vs date (estimated marginal means and SE with solid line) if the effect of date is significant. **(NSI_date)**
- Saving of the fitted model's results

All the statistical analysis values for every variable are stored in a spreadsheet named "emmeans.xlsx", which is shared with the Study-Sites in Cloud storage but not included in this report.

Finally, the assumptions for normality and homoscedasticity are assessed by visually checking the diagnostics plots created.

1) If **normality and homoscedasticity** appear to be **acceptable** then the obtained figures can be accepted and used for interpretation by the SS.
2) Else the assumptions of **normality and** homoscedasticity **appear to be not valid**:
   - weighted variances are used to find the optimum variances structure using the AIC criterion
   - the fit model with **Significant interaction** of date and treatment as the main effect
   - the fit model with **No Significant interaction** of date and treatment as the main effect
   - Selection of optimum model (AIC)
   - Estimation of marginal means and determination using restricted maximum likelihood (REML) estimates of the parameters
   - Contrasts by Tukey method with $p<0.05$ for finding significant differences between groups
   - Normality and homoscedasticity assumptions are checked by creating and storing the model diagnostics (QQ plots, and residuals vs fitted values plots)
   - Plotting of the relevant figure (Check cases before)
   - Saving of the fitted model's results

The results are best represented by graphs. The files are systematically named by unique filenames according to a logical and mnemotechnic system:

1. Soil care partner (e.g. **BDB** Soil service Belgium)
2. Experiment (e.g. **EX1**; for the first experiment)
3. Model used (**NR** for no repeated measures; **SI** for significant interaction, **NSI_treat** for no significant interaction for the response vs treatment plot, **NSI_date** for no significant interaction for the response vs date plot,
4. Variable under scrutiny (e.g. crop_yield)

Bar plots are used with error bars in **solid lines** on them. Based on a Tukey group comparison letters are given for significantly different groups. This allows a judgement on a significant difference between treatments. This is only possible for replicated treatments.

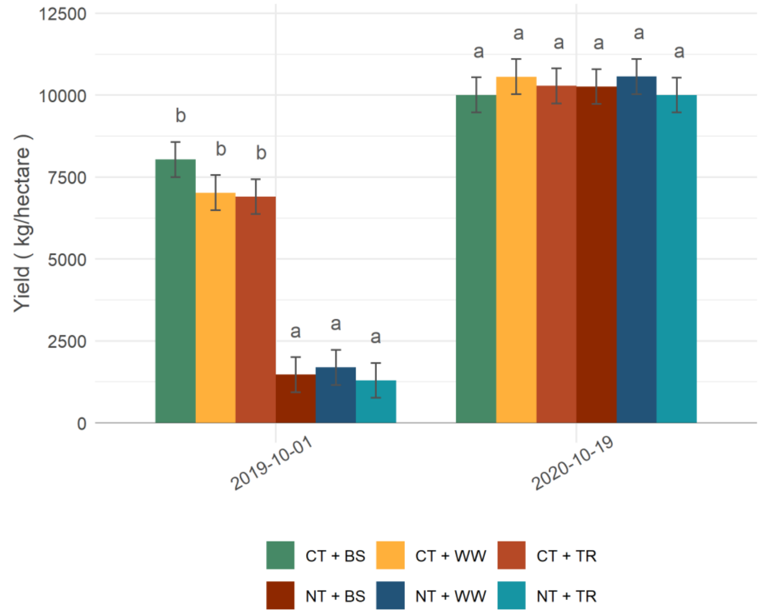


Figure 2: Example of a graph UNIPD_EX1_SI_crop_yield_ha.png

The underlying assumptions are always checked with different plots, called model diagnostics.

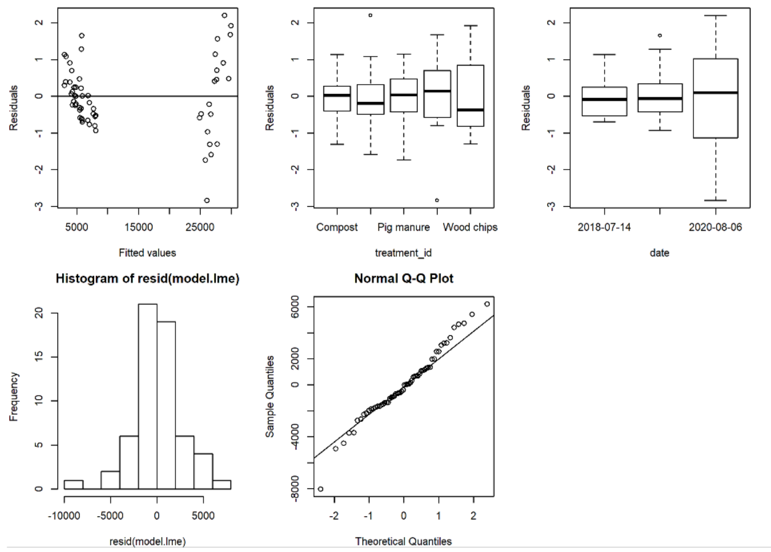


Figure 3: Example of diagnostics graphs BDB_EX1 _ crop_yield_ha _diagn.png

Please note that a similar graph is made for the experiments **without replications of the treatments**. In this case, statistical analysis and group comparison between treatments are not possible. If “error bars” are shown they are in **dashed lines** and represent the standard deviation of the measurements within that plot and not between the plots within the same treatment.

Specific analysis of crop-related characteristics when crop rotation is part of the cropping system

When different crops are present in each experimental field (e.g. crop rotation) the yield and the other crop-related characteristics cannot be compared using the raw harvest data. For this reason, the **relative differences of each treatment** from the control treatment are calculated to do the statistical analysis. By doing this we eliminate the crop type effect and we only examine the date and treatment effects.

If we have blocks, the relative difference of each treatment plot in this block with the relevant control treatment plot in this block is calculated.

Then the analysis is the same as in the previous R script using the response's relative value instead of raw value as the response variable.

Analysis of the meteorological data by R-scripts

During the experiments, the weather was an important factor. Especially in 2018 many experiments suffered from drought. Looking at the longer-term data as available for several ECAD stations it was also evident that global warming led to record-breaking warm temperatures in most Study-Sites during the SoilCare experiments.

The rainfall relative to the crop water requirements is a crucial indicator of the effect of water on the cropping systems.

Experiments on research stations normally have their local meteorological station, which is operated by the research station itself. However, most local observations covered mainly the most recent periods and rarely had long term observations. For the longer-term data were downloaded from the ECAD project. They compile and regularly update daily meteorological observations from more than 20 000 stations throughout Europe and the Mediterranean. At the time of performing the analysis, most stations included November 2020 and some even December 2020. So, for the longer-term perspective, ECAD data were combined with the shorter-term local weather data. Rainfall and temperature are always monitored by meteorological stations and are for most stations of good quality. As the R-scripts for ECAD data are ready updating can be done in 5 minutes in the future.

The crop water requirement is most commonly estimated according to the procedures in FAO Irrigation and drainage paper 56 (Allen et al, 1998). They recommend the use of the Penman-Monteith equation for the estimation of the reference crop evapotranspiration (ET0) as a first step.

SoilCare project started with the ambition to apply the recommended full Penman-Monteith equation. However, quickly it was obvious that collecting all the necessary meteorological variables for 16 Study-Sites was not feasible, even in Europe. Especially, the humidity, solar radiation and wind speed are quite often of more doubtful quality or even not available. Moreover, the local stations use a variety of instruments, which makes it very difficult to compare. For modern automatic weather stations, which have become a low cost, the wind speed and solar radiation are often very problematic.

As a second choice, the FAO recommends the Hargreaves-Samani approach. Hereby, only daily minimum and maximum temperature are needed. For consistency and comparison, it was concluded that the more simple Hargreaves-Samani equation was the better choice for the comparison of the experiment by 16 Study-Sites, dispersed over Europe.

For a fast judgement of a growing period, FAO compares rainfall with the ET0 per month. When rainfall exceeds ET0 we have a humid period without water stress for the crop. If rainfall is lower than ET0 but exceeds ET0/2 crops can be grown, the shortage of water could be compensated by rootzone reserve, capillary rise or irrigation and little or no drought is experienced. Otherwise, the crop growth is reduced and harvested yields are less. If rainfall is lower than ET0/2 it becomes to dry to grow crops without irrigation. In some experiments, supplemental irrigation was provided. For all the experiments such graphs were produced, using the most nearby data, which cover the entire period of the SoilCare Short term experiments.

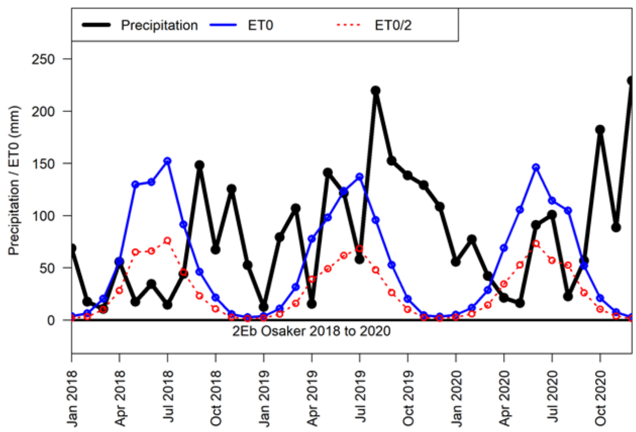


Figure 4: Comparison of ET0 with the rainfall for Øsaker in Norway; note the very low rainfall during the summer of 2018

In addition to the comparison, a graph with the average daily maximum and minimum temperature during the experimental period is given in the reports by the Study-Site. This is also useful information for cropping systems.

A climate is often characterized by a 30 year period, which is called a "normal". The assumption is that such a period represents average and homogeneous conditions in time. However, it is obvious that climate change over the recent years manifestly shows substantial trends of warming. Therefore, the last "normal" with relatively constant climate were selected: the 1961-1990 period. Another reason is that several Study-Sites run long-term experiments, which often were designed with former climate conditions in mind. Boxplots of the 1961-90 period were compared to 2018, 2019 and 2020, during which the majority of SoilCare experiments took place. Those plots were made for Precipitation, Tmax, Tmin and ET0 and are included in the annexe to the Study-Sites reports.

In the Study-Sites main reports, the boxplots comparing the rainfall for experimental years are given. Below are examples of 2018 for 4 different Study-Sites (Figure 5, Figure 6, Figure 7 & Figure 8). Such graphs allow us to compare the normal (be it for 1961-90) conditions with the 2018 weather during the experiments. In a few cases, the ECAD data did not cover the experimental years and therefore the longer term station was compared to the local station (e.g. Figure 8 for Coimbra in Portugal).

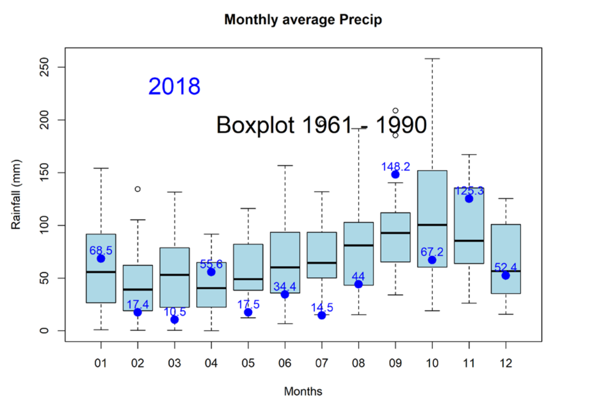


Figure 5: Boxplot 1961-90 compared with 2018 for Norway

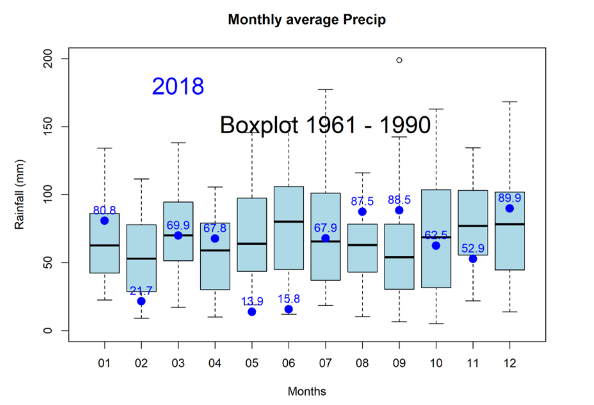


Figure 6:Boxplot 1961-90 compared with 2018 for Belgium

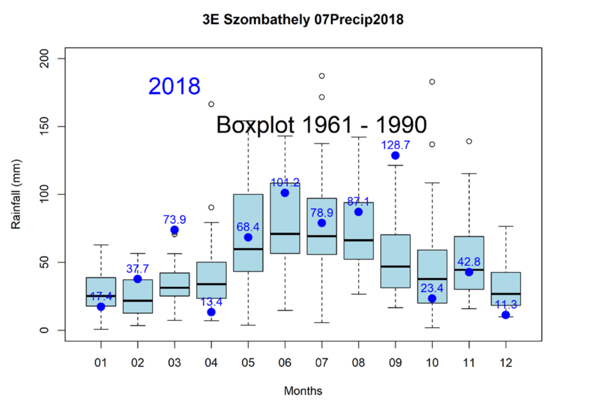


Figure 7: Boxplot 1961-90 compared with 2018 for Hungary

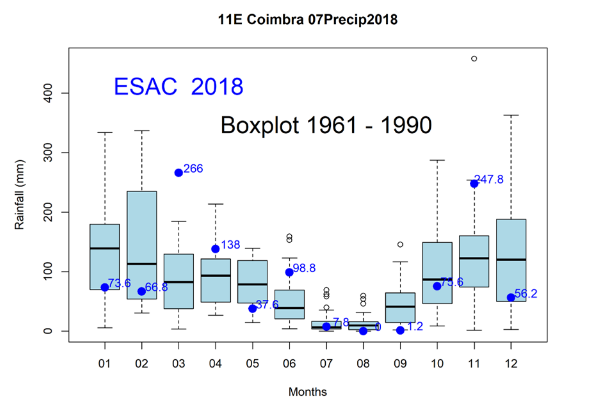


Figure 8: Boxplot 1961-90 compared with 2018 for Portugal

Meteorological analysis by R-scripts

Similar to the mixed-effects analysis R scripts were developed for the analysis of the meteorological data. The specific R- Packages for this analysis are:

- "*zoo*": a package for Regular and Irregular Time Series (so-called Z's Ordered Observations)
- "*hydroTSM*": a package for times series management for hydrological modelling
- "*lubridate*": a package for parsing date-time data

- "*lattice*": a package for Trellis graphics with a specific implementation of the "*xyplot*" functions and panels

The packages also automatically install several auxiliary packages, which are used by the specific package listed above.

The first step is the reading and exploration of the data.

The ECAD datasets are text-files and all identical in structure so the same script can be applied for data downloaded from ECAD. The datasets can be updated easily without any need for changing the script. For datasets delivered by the Study-Sites, minor adaptations are needed. One specific issue is the handling of missing data. For R "NA"-string is the default string indicating a missing value but can be changed easily.

The data are read into a "*data.frame*" and checked. The "*data.frame*" is then converted into a "*zoo*" time-series. The "*zoo*" time-series is one of the most flexible as it allows for irregular timesteps. All data are daily but some local datasets have missing dates in their text or CSV-files which make them irregular as the gap between two rows becomes larger than 1 day. Short interruptions during a few days are common for temperature, those were interpolated automatically. For rainfall, this is not appropriate.

After successful plotting, the zoo-series the exploratory "*hydroplot*"s are produced.

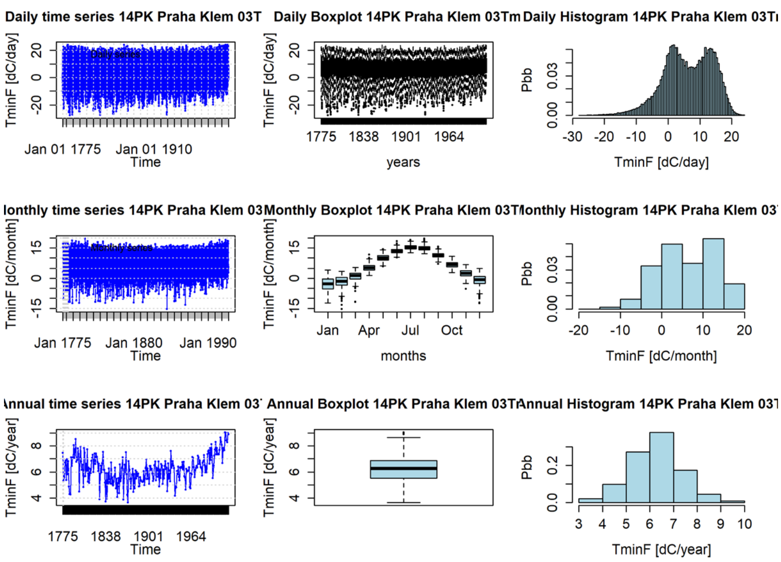


Figure 9: Hydroplot of the Tmin for Praha Klementinum, Czech republic, starting in 1775

A "*hydroplot*" shows 9 graphs. The three left are the time series for daily, monthly and yearly rainfall (or other variables, like Tmin, Tmax or ET0). The middle three give the boxplots of rainfall per year, monthly and yearly boxplots. The right ones show the histograms for daily, monthly and yearly sums.

As an example, Praha Klementium started measuring temperature in 1775 (Figure 9) and is the oldest station in the world. The ECAD stations, we selected in our analysis, had to cover from 1961 onwards until recent data. A substantial number started before 1900. The “*hydroplot*” is an efficient and convenient way of exploring the data, like seeing outliers, missing periods and possible trends.

In contrast, meteo-observations near the experiments (Figure 10) had shorter observation periods. This station VURZ belongs to the Czech Study Site.

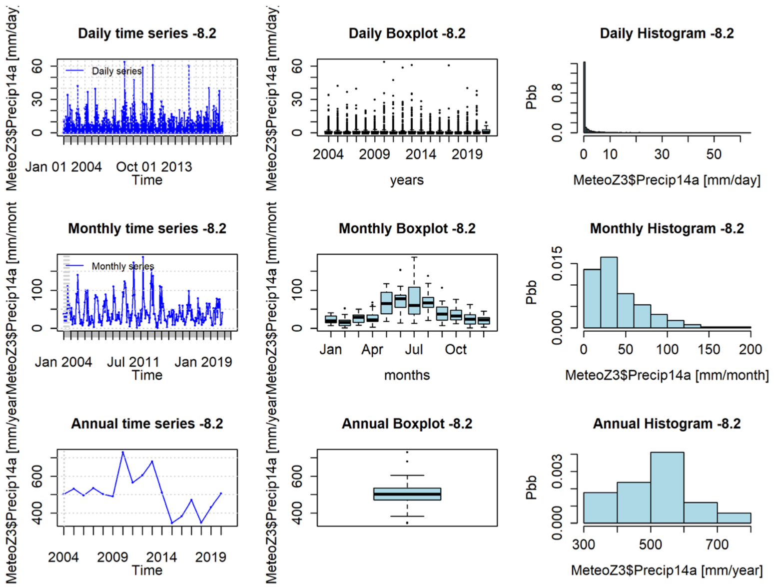


Figure 10: Hydroplot of rainfall for VURZ, research station in the Czech republic.

Subsequently, the ET0 was estimated by the Hargreaves-Samani equation and “*hydroplot*”s for ET0 were produced.

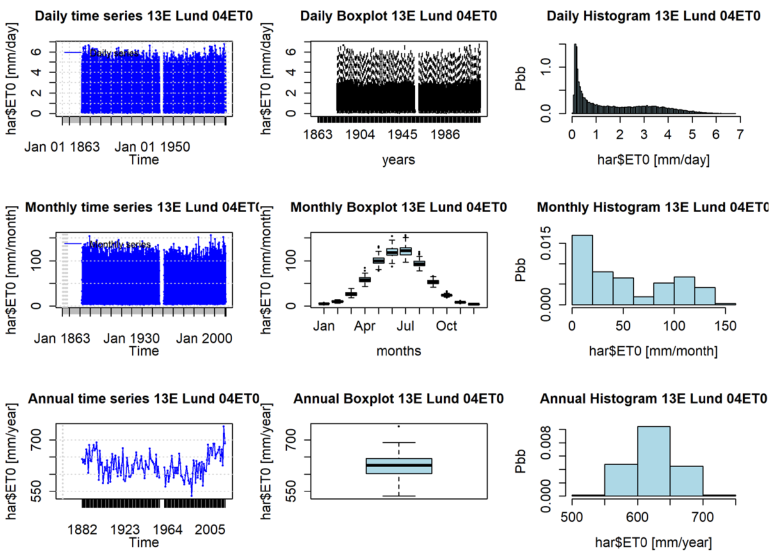


Figure 11: Hydroplot for ET0 for Lund in Sweden

Often like in the example for Sweden (Figure 11) a substantial increase in evapotranspiration demand was noticed over the recent years. That was the major reason for selecting the 1961-1990 period as a reference and not any later 30 year periods, which are not homogeneous due to global warming.

Finally in the script, the boxplots for 1961-1990 compared to the years 2018, 2019 and 2020 (see Figure 5, Figure 6, Figure 7 and Figure 8) and the summaries were produced. In most cases, those boxplots compared with years with experiments illustrate the effect of global warming.

Economic dimension-(contributed by WP4)

The economic dimension is assessed by the cost and benefit evaluation using structured questionnaires. These questionnaires in Excel format contain different sheets, each one evaluates a different cost type of the cropping system such as investment cost, maintenance cost, production cost, equipment cost, and benefits comparing control and SICS treatments. As a result, a summary of the cost and benefits provided at the end of the excel questionnaire which allows the economic comparison between the control and the SICS. More details about the method, required input and approach are given in D4.2.

Socio-cultural dimension -(contributed by WP4)

The sociocultural dimension is focusing on the acceptability of the SICS for farmers. Itis assessed by a qualitative approach using a short questionnaire developed to grasp the stakeholders' assessment of the tested SICS in terms of three key topics: changes in workload, perceived risks, and influence on farmers' reputation.

Study site researchers conducted the interviews at the end of the cropping season, with those farmers, who were involved in the field trials, or researchers or/and other stakeholders (e.g. advisors) involved in the trials if the trial was in a research station. In many Study-Sites, research teams had little or no previous experience with conducting interviews. Therefore, the questionnaire had to be kept as simple as possible. More details about the method, required input and approach are given in D4.2.

A short overview of the different experiments at the Study-Sites

Within SoilCare 16 different Study Sites covered a wide range of different pedo-climatic, socio-economic and political conditions across Europe. Within these Study Sites, different soil-improving cropping systems were selected, tested and evaluated.

Cropping systems refer to both crop type, crop rotation, and associated agronomic management techniques. As a cropping system under evaluation thus, we consider a unique combination of management operations and practices that are followed in a field with a specific treatment of the experiment that is tested. This means that within one experiment in each different Study Site we have several cropping systems to be evaluated that all have some identical characteristics (management practices of the field) and different treatments that are tested.

In the 16 Study sites, 27 experiments were selected for field trials and are presented in Table 1 analysed in this report. Within these 27 experiments, 135 different treatments (135 CS) were tested and evaluated for their effects on the soil and crop quality. A summary of the different treatments tested is presented in Table 2. The selected treatments were also evaluated for their economic, and sociocultural impacts.

The different experiments selected cover almost all common agro-management techniques. They include treatments that test crop-, nutrient -, irrigation-, tillage-, weed-, residue-, machine-management in different crop systems (permanent crops, crop rotations, monocultures).

As mentioned in the Biophysical dimension section depending on the experimental design and available data two different methods (Mixed models for replicated treatments, Averaged values if without replication) applied in each experiment for the analysis of the biophysical indicators. The method used in each experiment is presented in Table 3 together with information about the meteorological stations used for climate analysis.

Table 1: Summary and coding of experiments per Study Site

Study Site	Managing organisation	Experiment code in the database	Experiment name
1. Flanders, BE	Bodemkundige Dienst van België (12)	BDB_EX1	Organic soil amendments in wheat fields
		BDB_EX2	Soil cultivation in maize
		BDB_EX3	Soil cultivation and soil cover in maize
2. Akershus, NO	NIBIO (11)	NIBIO_EX1	Cover crops
		NIBIO_EX2	Biological compaction release
3. Keszthely, HU	University of Pannonia (22)	UP_EX1	Organic/inorganic N fertilization (IOSDV)
		UP_EX2	Tillage in maize-wheat biculture
4. Frauenfeld, CH	UBERN (9)	UNIBE_EX2	CULTAN
		UNIBE_EX3	Glyphosate
5. Viborg, DK	Aarhus University (13)	AU_EX1	CROPSYS

6. Loddington, GB	GWCT Allerton Project (14)	GWCT_EX1	Compaction alleviation
		GWCT_EX2	Grass leys
7. Tachenhausen, DE	University Hohenheim (5)	UH_EX1	Cover crops & Glyphosate
8. Draganesti Vlasca, RO	ICPA (18)	ICPA_EX1	Soil tillage effects on soil quality
9. Legnaro, IT	UNIPD (19)	UNIPD_EX1	Tillage and Cover Crop (TCC)
10. Szaniawy, PL	Institute of Agrophysics, Polish Academy of Sciences (20)	IA_EX1	Effect of crops (leguminous), liming and manure
11. Caldeirão, PT	IPC/ESAC (17)	ESAC_EX1	BB Rotation System
		ESAC_EX3	SS Organic Fertilisation
		ESAC_EX4	LT Succession System
12. Chania, Crete, GR	Technical University of Crete (7)	TUC_EX1	Soil erosion assessment
13. Orup, SE	SLU (23)	SLU_EX1	Subsoil loosening
14. Prague-Ruzyně, CZ	Crop Research Institute (25)	VURV_EX1	Tillage experiment and different N application
15. Almeria, ES	University of Almería (26)	UAL_EX1	Agua Amarga
		UAL_EX2	Tabernas – Continuous Deficit Irrigation
		UAL_EX3	Tabernas – Regulated Deficit Irrigation
16. Brittany, FR	FRAB (27)	FRAB_EX1	Wheat Early Sowing
		FRAB_EX2	Associated maize

Table 2:Summary of treatments per experiment in each Study SIte

	Code in the database	**Treatments names**
1. Flanders,	**BDB_EX1**	**Organic soil amendments in wheat fields**
	BDB_EX1_TR1	No fertilisation

	BDB_EX1_TR2	Mineral fertilization
	BDB_EX1_TR3	VFG compost
	BDB_EX1_TR4	Wood chips
	BDB_EX1_TR5	Solid pig manure
	BDB_EX1_TR6	Pig manure + lava grit
	BDB_EX2	**Soil cultivation**
	BDB_EX2_TR1	Conventional ploughing
	BDB_EX2_TR2	Non inversion tillage + herbicide
	BDB_EX2_TR3	Conventional ploughing + under sowing of grass
	BDB_EX2_TR4	Strip-tillage + herbicide
	BDB_EX2_TR5	Strip-tillage
	BDB_EX3	**Soil cultivation and soil cover in maize**
	BDB_EX3_TR1	Conventional ploughing
	BDB_EX3_TR2	Non inversion tillage + herbicide
	BDB_EX3_TR3	Conventional ploughing + under sowing of grass
	BDB_EX3_TR4	Strip-tillage
2. Akershus, NO	**NIBIO_EX1**	**Cover crop**
	NIBIO_EX1_TR1	No cover crop
	NIBIO_EX1_TR2	SN - Spring sown nitrogen fixating cover crop
	NIBIO_EX1_TR3	AN - Autumn sown nitrogen fixating cover crop
	NIBIO_EX1_TR4	SR - Spring sown cover crops root mix
	NIBIO_EX1_TR5	AR - Autumn sown cover crops root mix
	NIBIO_EX2	**Biological compaction release**
	NIBIO_EX2_TR1	Rotation barley- oilseed- barley
	NIBIO_EX2_TR2	Rotation oilseed- barley - oilseed
	NIBIO_EX2_TR3	Barley only
	NIBIO_EX2_TR4	Alfalfa in rotation with barley
3. Keszthely, HU	**UP_EX1**	**Organic/inorganic N fertilization (IOSDV)**
	UP_EX1_TR1	N0 + no organic
	UP_EX1_TR2	N0 + FYM (Farmyard Manure)
	UP_EX1_TR3	N0 + St + GM
	UP_EX1_TR4	N3 + no organic
	UP_EX1_TR5	N3 + FYM
	UP_EX1_TR6	N3 + St + GM
	UP_EX2	**Tillage in maize-wheat biculture**

	UP_EX2_TR1	Conventional + N0
	UP_EX2_TR2	Conventional + N2
	UP_EX2_TR3	Minimum+N0
	UP_EX2_TR4	Minimum+N2
4. Frauenfeld, CH	**UNIBE_EX1**	**Grass stripes**
	UNIBE_EX1_TR1	Green Verge
	UNIBE_EX1_TR2	Cropping area
	UNIBE_EX2	**CULTAN**
	UNIBE_EX2_TR1	CULTAN
	UNIBE_EX2_TR2	Mineral conventional (Lonza-Sol)
	UNIBE_EX2_TR3	Organic conventional (pig manure)
	UNIBE_EX3	**Glyphosate**
	UNIBE_EX3_TR1	No Glyphosate
	UNIBE_EX3_TR2	Glyphosate
5. Viborg, DK	**AU_EX1**	**CROPSYS**
	AU_EX1_TR1	O2/+M/-CC
	AU_EX1_TR2	O2/-M/+CC
	AU_EX1_TR3	O2/+M/+CC
	AU_EX1_TR4	O4/+M/-CC
	AU_EX1_TR5	O4/-M/+CC
	AU_EX1_TR6	O4/+M/+CC
	AU_EX1_TR7	C4/+F/-CC
	AU_EX1_TR8	C4/+F/+CC
6. Loddington, GB	**GWCT_EX1**	**Compaction alleviation**
	GWCT_EX1_TR1	Plough
	GWCT_EX1_TR2	Low disturbance subsoiler
	GWCT_EX1_TR3	AMF mycorrhizal inoculant
	GWCT_EX1_TR4	Control-no tillage
	GWCT_EX2	**Grass leys**
	GWCT_EX2_TR1	Cultivar - Aberniche
	GWCT_EX2_TR2	Cultivar - Perseus
	GWCT_EX2_TR3	Cultivar - Fojtan
	GWCT_EX2_TR4	Cultivar - Lofa
	GWCT_EX2_TR5	Cultivar - Donata

	GWCT_EX2_TR6	Control-Mixture of ryegrass and clover
7. Tachenhausen, DE	**UH_EX1**	**Cover crops & Glyphosate**
	UH_EX1_TR1	Glyphosate + cover crops
	UH_EX1_TR2	No Glyphosate + cover crops
	UH_EX1_TR3	Glyphosate + fallow
	UH_EX1_TR4	No Glyphosate + fallow
8. Draganesti Vlasca, RO	**ICPA_EX1**	**Soil tillage effects on soil quality**
	ICPA_EX1_TR1	Rotation 1 + Mouldboard ploughing
	ICPA_EX1_TR2	Rotation 2 + Mouldboard ploughing
	ICPA_EX1_TR3	Rotation 3 + Mouldboard ploughing
	ICPA_EX1_TR4	Rotation 1 + Subsoiling
	ICPA_EX1_TR5	Rotation 2 + Subsoiling
	ICPA_EX1_TR6	Rotation 3 + Subsoiling
	ICPA_EX1_TR7	Rotation 1 + Disk
	ICPA_EX1_TR8	Rotation 2+ Disk
	ICPA_EX1_TR9	Rotation 3 + Disk
	ICPA_EX1_TR10	Rotation 1 + Chisel
	ICPA_EX1_TR11	Rotation 2 + Chisel
	ICPA_EX1_TR12	Rotation 3 + Chisel
9. Legnaro, IT	**UNIPD_EX1**	**Tillage and Cover Crop (TCC)**
	UNIPD_EX1_TR1	Ploughed, no cover crop
	UNIPD_EX1_TR2	Ploughed, wheat cover crop
	UNIPD_EX1_TR3	Ploughed, radish cover crop
	UNIPD_EX1_TR4	No-Till, no cover crop
	UNIPD_EX1_TR5	No-Till, wheat cover crop
	UNIPD_EX1_TR6	No-Till, radish cover crop
10. Szaniawy, PL	**IA_EX1**	**Effect of crops (leguminous), liming and manure**
	IA_EX1_TR1	Control (only mineral fertilisation)
	IA_EX1_TR2	(L) Liming
	IA_EX1_TR3	(LU) Cover crops/ intercrops– lupines + serradella +phacelia
	IA_EX1_TR4	(M) Manure
	IA_EX1_TR5	(MLLU) Liming + lupines + serradella +phacelia + manure
11. Caldeirão,	**ESAC_EX1**	**BB Rotation System**
	ESAC_EX1_TR1	Organic Rice in rotation with organic lucerne
	ESAC_EX1_TR2	Conventional Rice monoculture

	ESAC_EX3	**SS Organic Fertilisation**
	ESAC_EX3_TR1	Conventional Maize with Urban Sludge amendment
	ESAC_EX3_TR2	Conventional Maize with Mineral amendment
	ESAC_EX4	**LT Succession System**
	ESAC_EX4_TR1	Maize in succession with pre-inoculated Pea
	ESAC_EX4_TR2	Maize in succession with pre-inoculated Red Clover
	ESAC_EX4_TR3	Maize in succession with pre-inoculated Yellow Lupin
	ESAC_EX4_TR4	Maize in succession with pre-inoculated Balansa Clover
	ESAC_EX4_TR5	Maize in succession with non-inoculated Yellow Lupin
	ESAC_EX4_TR6	Maize in succession with pre-inoculated Arrowleaf Clover
	ESAC_EX4_TR7	Maize in succession with Fallow
12. Chania, Crete, GR	**TUC_EX1**	**Soil erosion assessment**
	TUC_EX1_TR1	Bare soil in organic vineyards
	TUC_EX1_TR2	Cover crop (vetch) in organic vineyards
	TUC_EX1_TR3	Conventional orange orchard
	TUC_EX1_TR4	Conversion from orange orchard to avocado
	TUC_EX1_TR5	No-till in organic olive orchards
	TUC_EX1_TR6	Conventional tillage in organic olive orchards
13. Orup, SE	**SLU_EX1**	**Subsoil loosening**
	SLU_EX1_TR1	Normal mouldboard ploughing - control
	SLU_EX1_TR2	Sub soiling loosening
	SLU_EX1_TR3	Sub soiling loosening with straw pellets
14. Prague-Ruzyně, CZ	**VURV_EX1**	**Tillage experiment and different N application**
	VURV_EX1_TR1	Conventional ploughing + No N application
	VURV_EX1_TR2	Conventional ploughing +CAN
	VURV_EX1_TR3	Conventional ploughing +UREA
	VURV_EX1_TR4	Conventional ploughing +UREA^{stabil}
	VURV_EX1_TR5	Conventional ploughing+ CAN + UAN
	VURV_EX1_TR6	Minimum tillage + No N application
	VURV_EX1_TR7	Minimum tillage +CAN
	VURV_EX1_TR8	Minimum tillage +UREA
	VURV_EX1_TR9	Minimum tillage +UREA^{stabil}
	VURV_EX1_TR10	Minimum tillage + CAN + UAN
	VURV_EX1_TR11	Zero tillage + No N application
	VURV_EX1_TR12	Zero tillage +CAN

	VURV_EX1_TR13	Zero tillage +UREA
	VURV_EX1_TR14	Zero tillage +UREA^{stabil}
	VURV_EX1_TR15	Zero tillage + CAN + UAN
15. Almeria, ES	**UAL_EX1**	**Agua Amarga**
	UAL_EX1_TR1	Full Irrigation No-tillage
	UAL_EX1_TR2	Full Irrigation weeds
	UAL_EX1_TR3	Full Irrigation cover crops
	UAL_EX1_TR4	Regulated Deficit Irrigation- No-tillage
	UAL_EX1_TR5	Regulated Deficit Irrigation- weeds
	UAL_EX1_TR6	Regulated Deficit Irrigation- cover crops
	UAL_EX2	**Tabernas-Continuous Deficit Irrigation**
	UAL_EX2_TR1	Minimum Tillage
	UAL_EX2_TR2	Minimum Tillage plus pruning wood
	UAL_EX2_TR3	Minimum Tillage plus temporal cover crops
	UAL_EX3	**Tabernas-Regulated Deficit Irrigation**
	UAL_EX3_TR1	Minimum Tillage
	UAL_EX3_TR2	Minimum Tillage plus pruning wood
	UAL_EX3_TR3	Minimum Tillage plus temporal cover crops
16. Brittany, FR	**FRAB_EX1**	**Wheat Early Sowing**
	FRAB_EX1_TR1	Early sowing
	FRAB_EX1_TR2	Classic sowing
	FRAB_EX2	**Associated maize**
	FRAB_EX2_TR1	Maize- buckwheat
	FRAB_EX2_TR2	Pure maize

Table 3: Analysis method per experiment and Meteorological stations used

Study Site	Experiment code in the database	Biophysical Analysis Method	Meteorological Analysis (ECAD station) and local station
1. Flanders, BE	BDB_EX1	Mixed models	Ukkel (ECAD 17)
	BDB_EX2		
	BDB_EX3		
2. Akershus, NO	NIBIO_EX1	Mixed models	Long term Sarpsborg (ECAD 2590) Local: Osaker (ECAD 18010);
	NIBIO_EX2	Averaged values	

3. Keszthely, HU	UP_EX1 UP_EX2	Mixed models	Long term: Szombathely (ECAD 2042) Local: Keszthely
4. Frauenfeld, CH	UNIBE_EX2 UNIBE_EX3	Averaged values	Long term: Konstanz (ECAD 495) Local: Scalen-Reutenen & Aadorf-Tanikon
5. Viborg, DK	AU_EX1	Mixed models	Local: Foulum Rainfall only: Gronbaek (ECAD 113)
6. Loddington, GB	GWCT_EX1 GWCT_EX2	Mixed models	Long term: Nottingham (ECAD 1850)
7. Tachenhausen, DE	UH_EX1	Mixed models	Long term: Stuttgart (ECAD 2763) Local: Tachenhausen
8. Draganesti Vlasca, RO	ICPA_EX1	Mixed models	Long term: Bucuresti-Baneasa (ECAD: 219) Local: Draganesti Vlasca
9. Legnaro, IT	UNIPD_EX1	Mixed models	Local: Legnaro
10. Szaniawy, PL	IA_EX1	Mixed models	Long term + local: Siedlce (ECAD 333)
11. Caldeirão, PT	ESAC_EX1 ESAC_EX3 ESAC_EX4	Averaged values	Long term: Coimbra (ECAD 213) Local ESAC
12. Chania, Crete, GR	TUC_EX1	Averaged values	Long term: Chania (ECAD 327) Local: Alikianos; Vrysses & Kolumpari
13. Orup, SE	SLU_EX1	Mixed models	Long term: Lund (ECAD 463) Local: Horby_A (ECAD 5184)
14. Prague-Ruzyně, CZ	VURV_EX1	Mixed models	Long term: Praha_Klem (ECAD 27) Local: Vurz (near exp)

15. Almeria, ES	UAL_EX1	Mixed models	Long term: Almerica (ECAD3907) Local: Tabernas & Nijar
	UAL_EX2		
	UAL_EX3		
16. Brittany, FR	FRAB_EX1	Averaged values & Mixed models	Long term & local: Rennes-St Jacq. (ECAD 322)
	FRAB_EX2		

General comments on the monitoring and analysis

The tasks for WP5 at the interface between the work-packages and the Study-Sites was interesting and challenging leading to some recommendations.

Recommendations on planning a cropping system's monitoring and assessment

Planning, monitoring, and assessing a cropping system includes the consideration of the study area, the purpose of the assessment, conducting the measurements, storing of the data and analysis of the results. From our experience within SoilCare as responsible WP for several of the above requirements, the issues we faced as well as the interaction with the Study-Sites partners and other WPs we summarize some conclusions and recommendations for future projects and other CS assessments.

1. **Purpose of measurements and experiment setup**
   - The experimental design aims at answering scientific questions set at the start of the project and should allow a valid statistical analysis. Experimental designs that do not include replications of the experimental plots where the different treatments are allocated cannot be analysed and evaluated for their effectiveness with basic or advanced statistical methods and their results can only be used as approximations or trends. On-farm experiments require somewhat different designs as compared to research station plots but always randomisation and replications should be applied. A few less experienced Study-Sites would have benefited from support and guidance. As the large majority of Study-Sites have plenty of expertise, especially those running long term experiments, a "buddy" system by nearby experienced Study Sites would have helped. In general, the experiments were well designed.
   - The assessment must include a control or at least baseline measurements (before the implementation of the CS practices) of all the indicators to be analysed later with the same methods to allow comparison. For most experiments this baseline was available.

2. Proposed indicators for most common cropping systems

For assessing short term experiments of soil-improving systems that fall into a short-term period of running, indicators that present an early indication of effects should be used. On the other side, the changes should reflect the changes because of the treatments or the system and not vary through the year because of other factors. In the lifetime of the SoilCare project (2-3 years of monitoring), it is shown that several soil quality indicators used do not change or do not reflect changes because of the treatments.

Thus, for a short lifetime of a monitoring and assessment project, we propose the use of at least one indicator for each main soil quality category, measured annually or at the beginning and end of the monitoring depending on the assessment desired.

The indicators always provided in the template Study Site report are presented in the table below:

Category	Indicator (Unit)	Method
Soil productivity	Crop yield or crop biomass in dry matter (t $ha^{-1}year^{-1}$)	Yield measurement or quadrat sampling
Soil physical properties	Water stable aggregates (%)	Wet sieving (250 µm – 2mm)
Soil biological activity	Earthworm presence (number/m^2)	Mustard extraction method
Soil organic carbon	Total Organic Carbon (%)	Walkley- Black method

The Study Sites were invited to add other indicators if they felt that they were useful for their discussion and interpretation of the experiments.

3. Conducting the measurements

- It is important for comparison reasons the measurements to be conducting using the same methodology and sampling/analysis instruments or apparatus for the whole experiment. If the assessment includes several Study-Sites areas and a cross-Study-Sites analysis should be conducted, then is recommended the same protocols be used everywhere. The methods used, the site-specific adjustments to these methods and other details that may influence the results should be mentioned and shared with the results in any case.

- A timeline should be set before the sampling to allow correlations among indicators if this is part of the analysis selected.
- The baseline or control area samples must be taken during the same period and under the same conditions (crop-growth stage, soil condition) if not possible at the same time.

4. Storing of data

- Keeping a good and full record of the experiment's details including diary and details of the management practices, metadata of measurements, field and experimental design information instead of only measurements results, reduces analysis errors, allows comparisons and helps to draw conclusions based on a spherical approach.
- Storing the data in a uniform and detailed way as in the database scheme created by WP5 promotes usage of all the information from different disciplines with minimum excess interaction (if all the information are stored properly no need for back and forth emails and explanations), and reduces the risk of lost data and information when people change positions, computer malfunctions etc.

5. Analysis of the results

- The results for the different experiments were analysed by a common methodology. These analysis results were submitted to the Study Site's expert's knowledge and insight. In this way, a consistent and efficient approach for the assessment of the cropping systems was combined with the expertise from the Study-Sites.

A short synthesis of the reports on the experiments

This deliverable D5.3 describes the analysis and compiles all short term experiments into Study-Site specific reports. The Study-Sites pooled the objectives of the short term experiments into 4 thematic clusters. They are "*Soil cultivation", "Alleviation of compaction*", *"Fertilizer/Amendments" and "Soil improving crops".* In the experiments, Soil-Improving Cropping Systems (SICS) were compared with a standard practice serving as a control. Biophysical data from these agronomic trials were monitored and assessed in environmental, economic and socio-cultural dimensions for sustainability and acceptability.

A large number of Study-Sites also had long term experiments, which are officially not part of the SoilCare project. Some Study-Sites integrated their short term experiments within the long term ones. In general, the SoilCare short term experiments were too short to show a lot of significant effects on Soil Productivity (by Yield or Relative Yield), Organic Carbon, Structure Stability (by Water Stable Aggregates), Infiltration Rate (by Hydraulic Conductivity), Biological Activity (by Earthworm counting) and Bulk Density. Besides, hydraulic conductivity and bulk density have a large spatial and temporal variability in the field, which makes it more difficult to detect significant differences without increasing dramatically the number of measurements. The Study Site in Poland illustrated this spatial variability well.

For most experiments, reduced tillage and non-inversion tillage had a positive effect on the soil characteristics and did not in general lead to lower yields. The UK experiment showed that ploughing negatively affected the earthworm population, but major issues remain such as weed control as mentioned in the Italian experiment, which often requires herbicides. Also, a more shallow rooting depth might result in more risks under drought. The Italian experiment indicated a higher risk of crop-failure under No-Tillage. The Czech experiment, which started in 1995, points out that zero tillage is difficult for heavy soils and root crops, like beets and potatoes. Also, pest control as mentioned in the Belgian experiments was a challenge under non-inversion tillage.

Tillage and compaction alleviation are interlinked. Subsoiling might be needed from time to time to keep the soil layers in position while breaking up compaction. In the Romanian experiment, it was suggested to subsoil 60 cm deep every 3 to 4 years. The Swedish experiment on a naturally compacted soil illustrated that mechanical subsoiling, with or without the incorporation of organic materials, has a positive impact on root growth and rooting depths.

At several Study Sites, different fertilizers and amendments were compared. The Belgian Study Site compared adding woodchips, compost, pig manure with or without lava grit with a control. The C/N ratio helped to explain the availability of nutrients to the crops. The long term experiments in Hungary that started in 1983 showed, as expected, significant positive effects on yield and soil structure (via Water Stable Aggregates and Bulk Density). Also, the Cation Exchange Capacity as an indicator of nutrient retention was different for control and SICS. Surprisingly the soil organic matter content in the long term experiments in Hungary was not significantly different despite the very positive effects on yield and soil structure. It shows that the absolute value of organic matter is not as important as the healthy microbial life and building-up of water-stable aggregates. In the UK Study Site adding an inoculant had a modest effect on improving aggregate stability. In the Portuguese Study Site, urban sludge from urban wastewater treatment plants increased soil organic carbon and nutrients. In the Danish Study Site, higher yields were obtained by using the chemical as compared to organic fertilizer. However, in this experiment cover crops, legumes and animal manure reduced the yield gap.

Nowadays cover-crops in between growing seasons are commonly applied. Additionally, "under-crops" during the growing season have been tested. The benefits of cover-crops are generally well accepted and also illustrated by the experiments. Due to global warming, which is very well visible in the meteorological analysis for every Study Site, the lack of freezing during recent winters caused cover- crops not to die spontaneously and to survive the winter. In such case, herbicides or mechanical measures are required to kill them in spring. This is an important issue for further investigation as also mentioned for the Italian experiment. In the German experiment, the possible negative effect of Glyphosate on soil health was investigated and found to be minor. Banning herbicides for different reasons will require a high precision shallow tillage/mechanical weeding before seeding of the crops so as not to destroy the benefits of cover crops on soils again.

In Greece and Spain, the cropping systems were vineyards, fruit and olive orchards. In Crete, erosion reduction was the major challenge. Crete had a historical high rainfall in October 2017 and some more heavy rainfall events afterwards. Almería as the driest and hottest place in Europe focussed on water savings by deficit irrigation.

For most experiments yields of the control and the SICS were similar, and the socio-cultural analysis showed a modest impact on sustainability. However, the majority of soil-improving cropping systems incur extra costs, which are not always compensated by extra benefits, so that for several SICS the profitability suffers without financial support.

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I.1 Bodemkundige Dienst van België

Report 1: Monitoring and Analysis of the Application of organic soil amendments experiment

Study Site number: 1

Country: Belgium

Author(s): Mia Tits, Annemie Elsen

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Bodemkundige Dienst van België

Experiment: Application of organic soil amendments

Figure 1: Application of wood chips

Figure 2: Wood chips applied in the field trial

Version: Final

Date: 19-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate the effect of 4 organic amendments on soil quality compared with mineral fertilization. The experiment was established in November 2017 and was set up in a randomized complete block design with 4 blocks, containing 6 plots each, 4 for the SICS treatments and 2 for the control treatments.

Experimental field information

The experiment is conducted on an experimental field managed by the researchers and the farmer. The experimental field is located in Lovenjoel, Belgium at an altitude of about 50 m and covers an area of about 23760 m^2. The topsoil has a fine sandy texture according to the national classification system.

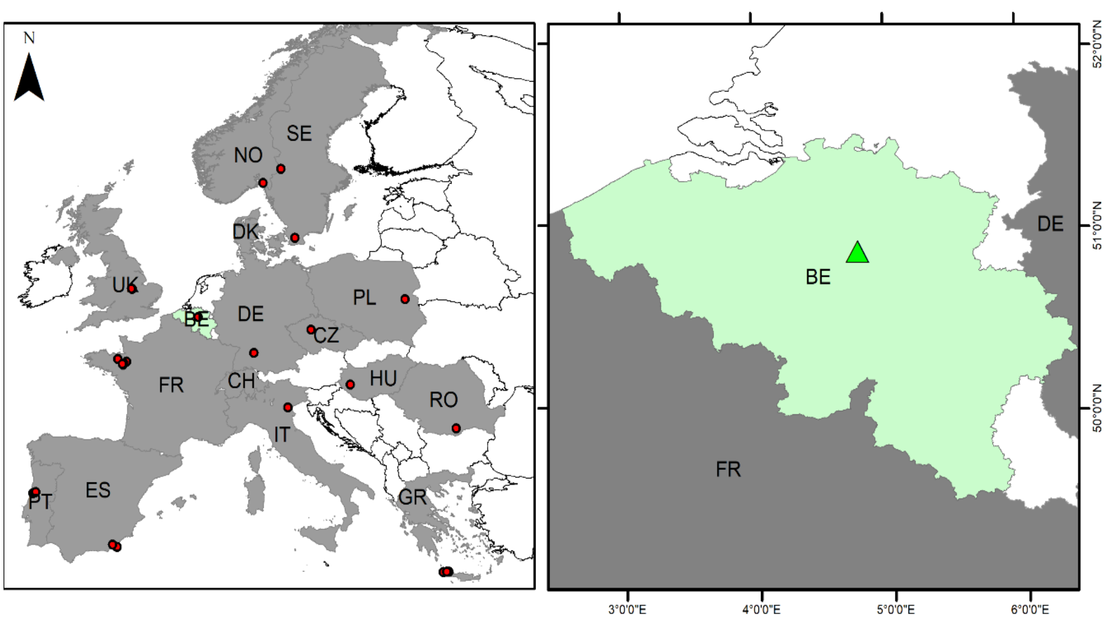


Figure 3: Location of the study site

SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

The soil profile of 1.5 m described by Marc Vanderveken on 2017 July 31, has 4 horizons.

Figure 4: Soil profile

Climate of the experimental field area

The major Belgian meteorological station is at Ukkel/Uccles. The station started in 1833.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Ukkel (ECAD00017)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	14.1	6.2	821.0	742.3
2018	16.4	8.1	650.2	801.3
2019	15.4	8.3	798.6	739.1

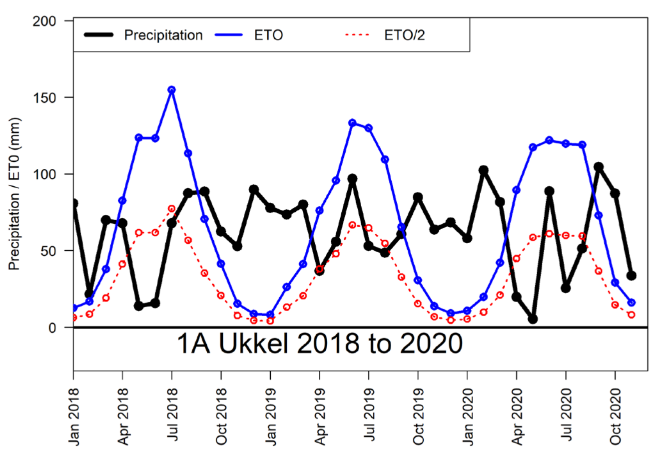
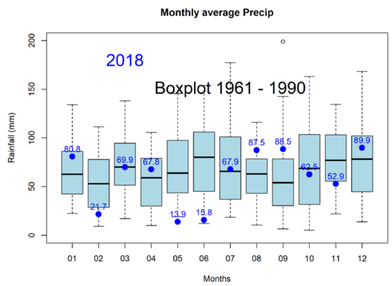
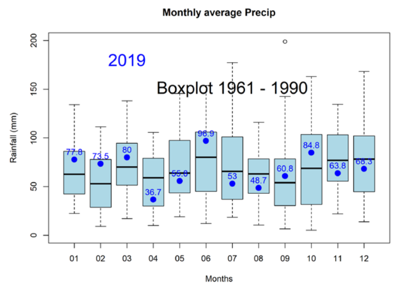


Figure 5: 1A Ukkel FAO growing season comparing monthly precipitation with 50% and 100% reference crop evapotranspiration ET0





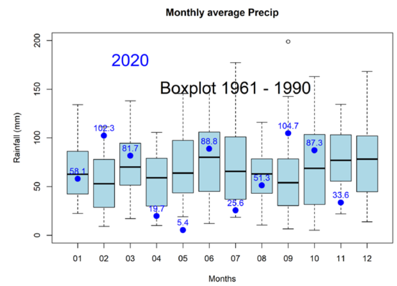


Figure 6: 1A Ukkel 07Precip2018box *Figure 7: 1A Ukkel 11Precip2019box* *Figure 8: 1A Ukkel 15Precip2020box*

In the figures the boxplots for 1961-90 are compared to the years of the experiments.

2018 was exceptionally warm, very abnormally sunny, very abnormally dry with an exceptionally low number of precipitation days. Specific characteristics/events:

- Very dry February with a poor replenishment of the soil water reserve
- Late cold spells at the end of February – beginning of March and mid-March,
- An intense heatwave from the end of July until the beginning of August,
- Persistent drought from the beginning of May until November.

2019 was warm, sunny and relatively dry. Specific characteristics/events:

- 3 heat waves (one in each summer month),
- Record high temperatures during the heatwave at the end of July, rising above 40°C for the first time in Belgian weather history.

2020 was sunny, quite dry and record warm. Specific characteristics/events:

- Sun-drenched and dry spring,
- Intense heatwave in early August,
- Very hot days in mid-September.

Cropping systems description

Treatments

The experiment consists of 6 treatments with the following codes in the SoilCare Database and the analysis following.

BDB_EX1_TR1: No fertilization (Control Treatment)

BDB_EX1_TR2= Mineral fertilization (Control Treatment)

BDB_EX1_TR3= Compost

BDB_EX1_TR4= Wood chips

BDB_EX1_TR5= Pig manure

BDB_EX1_TR6= "Pig manure + lava grit

16 t/ha of compost or solid pig manure was applied in the relevant plots at the beginning of the experiment (autumn 2017), whereas the wood chips amount applied was 150 m^3/ha. The treatment plots were laid out in large strips (9m x ±150m) allowing application of the organic materials with a common manure spreader.

Field operations

The applied organic amendments were incorporated superficially before sowing winter wheat in autumn 2017. In the following years, the experimental field was tilled at a depth of 25 cm before sowing the main crop. Nitrogen, phosphorus and potassium fertilizers, as well as different herbicides and fungicides, were applied according to the farmers' normal practice. Following crop rotation was applied during the trial period: winter wheat *(Triticum aestivum)* followed by a cover crop of yellow mustard, barley *(Hordeum vulgare) followed by turnips* and potato *(Solanum tuberosum)*. Liquid manure was injected into the field at the beginning of March 2020.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model. Variables with repeated measurements in time were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. For the variables measured only one time the Treatment factor was used alone. The blocking was introduced in all models as random effect, using the statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

For the yield and other crop related characteristics, the relative values of the treatments were compared to the control calculated in order to exclude the effect of the different crops in the rotation and analyse only the treatments and date effects.

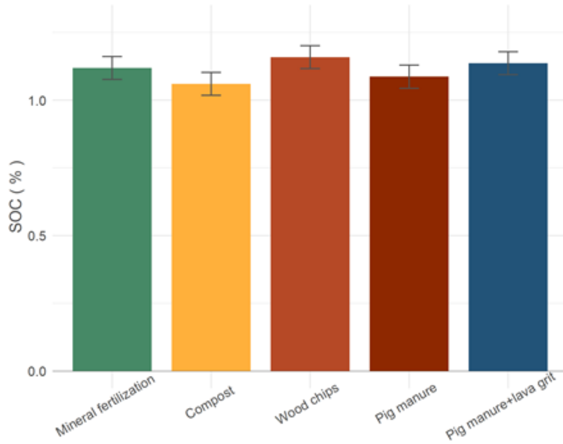
Data

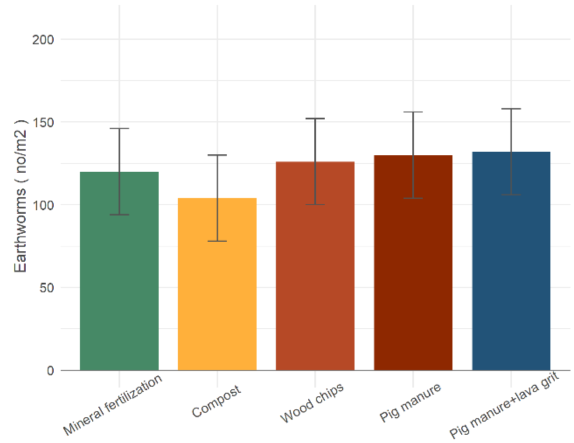
In the table below the variables measured and analysed for this experiment are listed. Results for all variables can be found in the ANNEXE II.

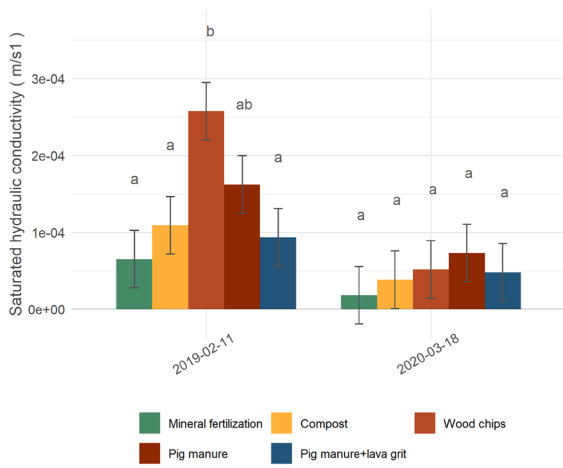
Table 2: Indicators measured in the SS (all Figures in annex II)

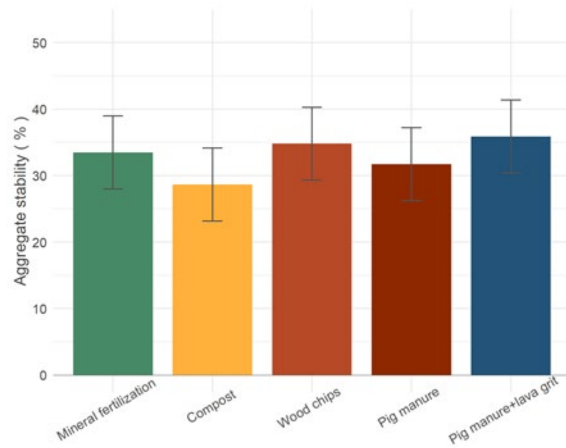
Observation code	Unit	Description
Ksat	m/s[1]	Saturated hydraulic conductivity
Was	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
Soc	%	SOC
ph_kcl	_	pH (KCl)
earthworm_no	no/m^2	Earthworms
Nmin1	kg N/ha	Mineral N in 0-30 cm layer
Nmin2	kg N/ha	Mineral N in 30-60 cm layer
Nmin3	kg N/ha	Mineral N in 60-60 cm layer
crop_yield_ha	kg/ha	Crop yield
byproduct_yield_ha	kg/ha	Yield of by-product
totalbiomass_production_ha	kg DM/ha	Total biomass production
grain_proteincontent	%	Grain protein content
yield_DMcontent	%	DM content of the yield
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
byproduct_DMcontent	%	DM content of by-product
plant_number	% of DM	N-content of by-product

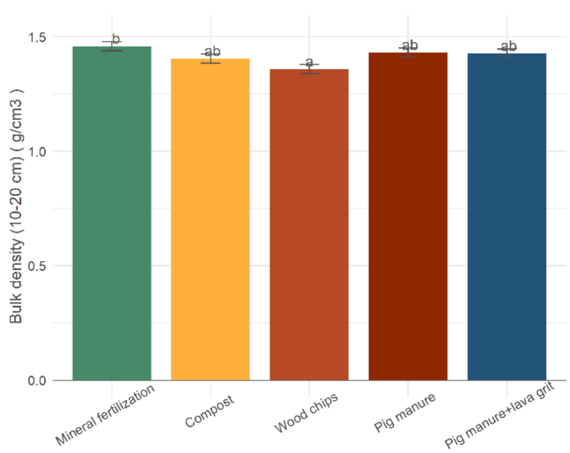
Results

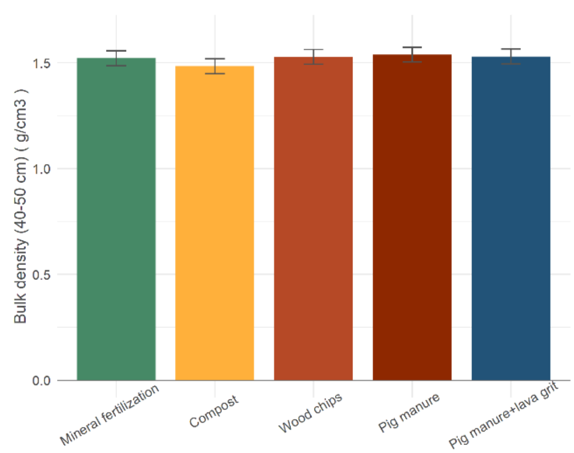

SOC (%)
0.0
0.5
1.0
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit


Earthworms (no/m2)
0
50
100
150
200
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit


Saturated hydraulic conductivity (m/s1)
0e+00
1e-04
2e-04
3e-04
a
a
b
ab
a
a
a
a
a
a
2019-02-11
2020-03-18
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit


Aggregate stability (%)
0
10
20
30
40
50
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit


Bulk density (10-20 cm) (g/cm3)
0.0
0.5
1.0
1.5
b
ab
a
ab
ab
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit


Bulk density (40-50 cm) (g/cm3)
0.0
0.5
1.0
1.5
Mineral fertilization
Compost
Wood chips
Pig manure
Pig manure+lava grit

Analysis (focus on wood chips)

SOC: total organic carbon (TOC) in the topsoil layer (0-23 cm) was determined by dry combustion. No significant differences between the treatments were observed. The decomposition of the wood chips in the soil and the build-up of organic matter is a long-term process, the results of which will probably only be measurable after a longer period than 4 years. Moreover, the in situ observation of the OC evolution is complicated by the large inherent variability in the OC measurements themselves (sampling, ...), which makes any measured differences difficult to demonstrate statistically.

Ksat: Ksat was determined by measuring the infiltration rate (double-ring infiltrometer). To obtain representative results, this measurement requires several repetitions per strip, which makes it rather labour-intensive. The quality of the measurement also depends on the weather and soil conditions: it should not be extremely dry nor extremely wet. The large spread in the results shows the difficulty of performing representative measurements of the infiltration rate. Significant differences between the treatments were only observed at the first measurement time (2019), with a significant higher infiltration rate in the wood chips treatment. Nevertheless, the trend towards a positive effect of the application of organic materials in general and more specifically of wood chips on the water infiltration into the soil was visible throughout the experiment.

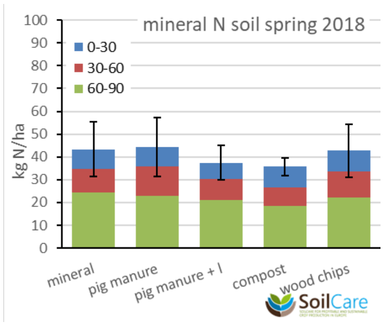
Water stable aggregates: The percentage of water-stable aggregates was measured by wet sieving. The effect of organic amendments on the formation and the stability of soil aggregates is linked to their conversion into stable organic matter (humus) in the soil. It can therefore be expected that this effect will only be measurable after several years. Moreover, the history of the plot also plays a role, because, in addition to humus, tillage, fertilization and rooting have a strong influence on the formation of stable aggregates. In the trial, no significant differences were observed between the treatments.

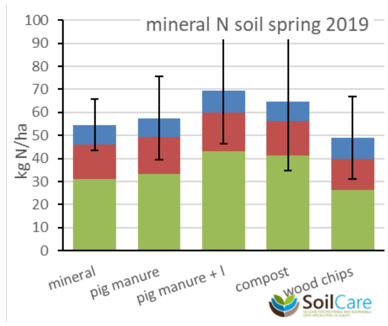
Bulk density: Bulk density was measured with the core method. As expected, the lowest bulk density in the topsoil layer (10-20 cm) was measured in the wood chips treatment, significantly lower than the bulk density of the plots with only mineral fertilization.

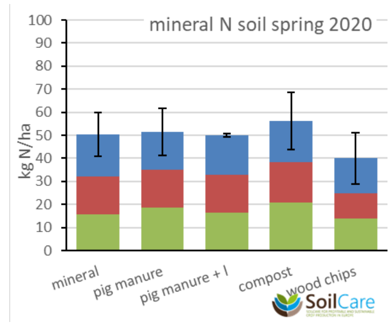
pH (KCl): The applied organic amendments had no significant effect on the soil pH.

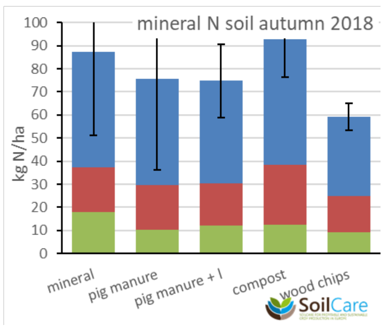
Earthworms: Earthworm counting was performed with the mustard method. Probably due to the specific climatic conditions during the trial period (extremely dry and hot), earthworms could only be counted at one moment. No significant differences were observed among the treatments.

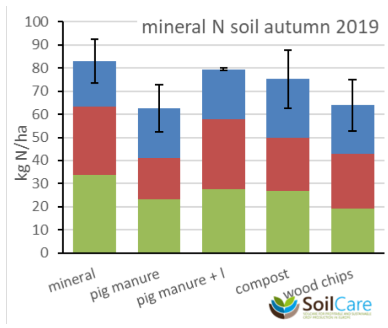
Study site analysis

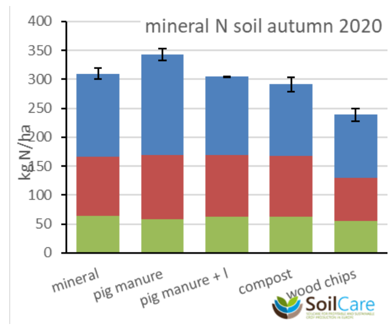


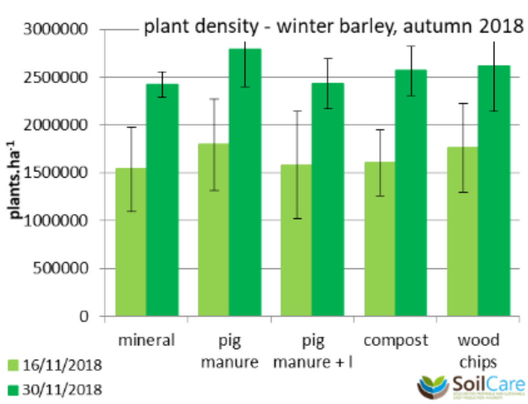












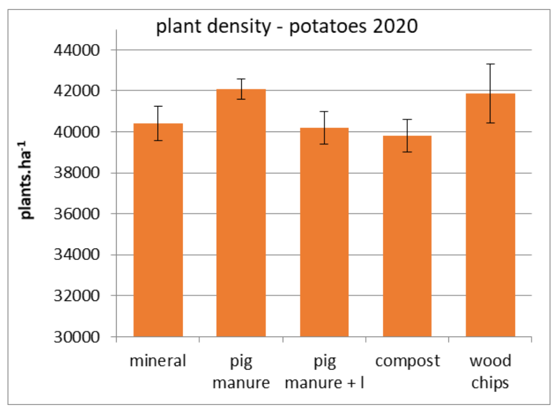


Figure 9: The lighter strips on the satellite image (5/5/2018) correspond to the plots with wood chips application, where the initial growth of the wheat was inhibited

Mineral N in the soil profile: mineral N was measured in the soil profile (0-90 cm, per layer of 30 cm) with the continuous flow after extraction in KCl. Due to the relatively high C/N ratio of wood chips, it is expected that temporary nitrogen immobilization will occur after their application. Depending on weather and soil conditions, this immobilization will occur in a shorter or longer term. This means that the effects can be both positive (nitrogen immobilization in autumn and thus a decrease in the nitrate residue and nitrate leaching during winter) and negative (less nitrogen available for the crop in the spring). In the experiment, no lower mineral N content was measured in the first spring following the autumn application of the wood chips. The decomposition of the wood chips had not yet fully started at this time. In the following autumn and later on, however, a lower mineral N content was measured in the wood chips treatment.

Plant population: At the end of 2017 – the beginning of 2018, when winter wheat was sown immediately after incorporation of the wood chips, reduced crop emergence and early development was visually observed in the wood chips treatment compared to the rest of the field. In the following years, plant counts of winter barley (2019) and potatoes (2020) were performed. Neither for winter barley nor potatoes, differences in emergence were observed.

Crop yield and total biomass production: Temporary N immobilization and possible effects of wood chips application on crop emergence and crop growth could ultimately harm the yield of the next crop grown after the wood chip application. On the other hand, it can be expected that the increase of the organic matter content, the improvement of the soil water balance and the general improvement of the soil quality would have a positive effect on crop yield in the longer term. In the experiment field, measurements were performed to determine crop yields of winter wheat, winter barley and potatoes. No significant differences in crop yield or total biomass production were found for any of the measured crops.

Socio-cultural dimension

SICS treatment: BDB_EX1_TR4 (wood chips)

Control: BDB_EX1_TR5 (Pig manure)

Table 3: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.33	1.00	Complete
Workload	-0.33	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	0.00	1.00	Complete

Economic dimension

SICS treatment: BDB_EX1_TR4 (wood chips)

Control: BDB_EX1_TR5 (Pig manure)

Table 4: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	**AMP SICS**
Agricultural management technique	Incorporation of solid manure	Incorporation of wood chips
Investment costs	77	2078
Maintenance costs	0	0
Production costs	0	0
Benefits	2964	2806
Summary = benefits -— costs	2887	728
Percentage change	296.5	

Overall analysis and main findings

SICS treatment: BDB_EX1_TR4 (wood chips)

Control: BDB_EX1_TR5 (Pig manure)

Table 5: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.38	0.86	High
Environmental dimension	0.00	0.66	Medium
Economic dimension	-0.93	1.00	Complete
Socio-cultural dimension	-0.33	1.00	Complete
Physical properties	0.00	0.60	medium
Chemical properties	0.00	0.80	High
Biological properties	0.00	0.55	Medium

Table 6: Benefits and drawbacks of the SICS "wood chips application" as compared to the control group

Benefits:	Improvement of soil quality Better soil resilience Better crop yields at the longer term Valorisation of residual waste Erosion prevention
Drawback:	Uncertainty about N fertilization (due to temporary N immobilization The potential risk of bad crop emergence – crop failure in case of improper application Risks of plant diseases or weed infestation in case of use of non-sustainable produced wood chips (e.g. waste container depots) Increase of workload Increased costs (machinery, purchase of wood chips)

Summary of the field trial results

The build-up of organic matter in the soil is a long-term process, the positive effects of the application of organic amendments were not yet measurable in the field, during the short term of this project. Nevertheless, positive effects of wood chips application could already be observed in terms of a better water infiltration in the soil (leading to a lower erosion risk) and a lower bulk density of the topsoil layer (leading to a better soil structure for plant growth).

Because of their high C/N ratio, the application of wood chips in the soil induces temporary N immobilization. This N immobilization effect can be both positive (N immobilization in autumn and thus a decrease in the nitrate residue and nitrate leaching during winter) and negative (less available N for the crop in spring). In the latter case, N availability for the next crop will have to be monitored and if necessary N fertilization will have to be adapted. In the experiment, no lower mineral N content was measured in the first spring following the autumn application of the wood chips, but in the next autumn and later on, a lower mineral N content was measured.

In 2017, when winter wheat was sown a few days after the wood chips application, poorer crop emergence and initial development were observed. However, the effect was hardly noticeable on crop yield. No negative effects were observed for the following crops (winter barley, potatoes) anymore. Although N fertilization in the years after the application of the soil amendments was the same for all the treatments, no negative effect of lower N availability in the wood chips treatment, due to N immobilization, on the yields was observed.

Drawbacks and benefits, barriers and enablers for the application of wood chips in arable fields

Although most of the people we interviewed (farmers, advisors, researchers, policymakers) were well aware of the possible benefits of the application of wood chips on arable fields, the main barriers for applying the technique concern the expected costs and workload as well as the limited availability of wood chips and the current legislation making the use of “waste” products on the field very cumbersome. Following barriers and possible enablers were highlighted:

Table 7: Drawbacks and enablers for wood chips application

Barriers	**Enablers**
insufficient availability of wood chips	encourage plantation and maintenance of hedges and wood edges
lack of information	support research, demonstration and dissemination
inconsistencies in legislation regarding organic fertilization and use of organic amendments	adapt and align legislations
high costs in general	introduce stimulating measures, such as management agreements

	compensate ecosystem services e.g. carbon credits
high machinery costs	cooperative purchase of machines

Overall general conclusions (focus on wood chips)

Valorisation of residual biomass – closing carbon cycles

The use of wood chips as an organic soil amendment in arable land contributes to closing cycles and maximizing the valorisation of (residual) biomass flows from the landscape. Applying shredded, locally harvested wood from ecologically oriented landscape management to arable fields is a high-quality application according to the cascade principle for residual biomass flows (cfr. waste management hierarchy and life cycle thinking).

Carbon sequestration and soil quality in the long term

Wood chips are an interesting raw material for the build-up of soil organic matter due to their high C/N ratio. Simulations with RothC-model and incubation tests (performed in the context of other demonstration projects in Flanders) show that wood chips introduce a slowly decomposing carbon source into the soil with the potential to increase soil carbon stocks sustainably in the longer term and thus improve soil quality. In the context of global warming, besides carbon sequestration, a higher organic matter content can increase the resilience of the soil against drought, among other things. At the same time, the experiments and simulations show that this positive effect should not be expected in the short term, but rather as an investment in the longer term.

Soil nitrogen balance

A soil parameter that can be strongly influenced in the short term by the use of wood chips is the amount of available nitrogen. The temporary immobilization of mineral nitrogen after application of wood chips can be a desirable effect (less nitrogen leaching in the autumn and winter), but can also temporarily lead to nitrogen shortages in the crops and thus yield loss. It is therefore very important, after application, to monitor closely the mineral nitrogen content in the soil for the next crop.

Nitrogen and phosphorus content in the context of Flemish manure legislation

Concerning the chemical composition of the chips, the C/N and C/P ratio are very important agricultural parameters. These ratios are much higher for wood chips than for other more common organic soil amendments such as animal manure and compost. This makes it possible, within the framework of the

Flemish manure decree, to apply larger quantities to arable fields and thus to give a boost to the organic matter content of the soil without the risk of excessive P or N applications.

Costs and benefits

An important practical note is the limited availability of good quality wood chips in Flanders and the economic aspect of using them in soil management. The costly logistics side of wood edge management makes wood chips expensive. Also, any yield loss linked to poorer crop emergence and/or nitrogen immobilization after the wood chips application can increase the (cultivation) costs in the short term, without there being a direct return. This constitutes a significant barrier to fully integrate the technology into landscape management.

Support and Flemish policy

Therefore, carbon sequestration in arable soils by reusing biomass from sustainable wood edge management must be stimulated as a measure and supported by the Flemish agricultural policy.

Report 2: Monitoring and Analysis of the Soil Cultivation and soil cover in maize experiments

Study Site number: 1

Country: Belgium

Author(s): Mia Tits, Annemie Elsen

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Bodemkundige Dienst van België

Experiment 2: Soil cultivation and soil cover in maize I

Experiment 3: Soil cultivation and soil cover in maize II

Version: Final

Date: 19-02-2021

Experiment 2

Experiment 2 description

The main objective of the experiment is to evaluate the effect of 4 alternative cultivation types in maize. The experiment was established in May 2018 and was set up in a randomized complete block design with 4 blocks, containing 5 plots each, 4 for the SICS treatments and 1 for the control treatment

Figure 10: Strip-till in grass cover crop

Figure 11 Wireworm infestation in a strip-tilled plot

Experimental field information

Experiment 2 was conducted on an experimental field managed by the researchers and the farmer. The experimental field is located in Lovenjoel, Belgium at an altitude of about 40 m and covers an area of about 6930 m^2. The topsoil texture belongs to the sandy textural class according to the national classification system.

The soil profile of 1.5 m described by Marc Vanderveken, has 3 horizons.

The climate of the experimental field area

See Report 1 for Belgium. Identical conditions for the weather.

Cropping systems description

Treatments

The experiment consists of 5 treatments with the following codes in the SoilCare Database and the analysis following.

BDB_EX2_TR1= Conventional ploughing (Control Treatment)

BDB_EX2_TR2= Destruction of the cover crop (herbicide) + Non-inversion tillage

BDB_EX2_TR3= Conventional ploughing + under sowing grass (sown simultaneously with the maize)

BDB_EX2_TR4= Destruction of the cover crop (herbicide) + Strip-tillage

BDB_EX2_TR5= Flailing of the cover crop + Strip-tillage

The conventional ploughing in the first (control treatment) and third treatments is moldboard ploughing at 25 cm depth.

The grass used in the third treatment was *Festuca arundinacea*, commonly known as tall fescue. The grass was sown simultaneously with the maize, between the maize rows, with an adapted Pöttinger Aerosem sowing machine. The used grass species (*Festuca arundinacea)*, has normally a slower emergence and initial growth and was chosen to allow a good emergence and initial growth of the maize.

The strip tillage in treatment 5 was done in a living grass cover (rye, flailed) while in the fourth treatment the rye cover was killed with a herbicide.

Field operations

The main crop in the field was *Zea mays, known as maize,* which was sown in May and harvested at the beginning of September (2018) and mid-September (2019). Every winter, rye *(Secale cereale)* was planted as a cover crop. Mineral fertilization (nitrogen, phosphorus, potassium), as well as herbicides, were applied according to the farmers' normal practice, adapting herbicide doses and products to the presence of the grass undersown in the maize.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model. Variables with repeated measurements in time were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. For the variables measured only one time, the Treatment factor was used alone. The blocking was introduced in all models as a random effect, using statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

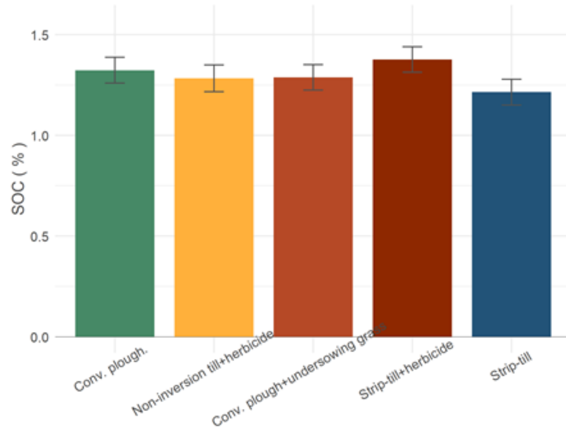
In the table below, the variables measured and analysed for this experiment are listed.

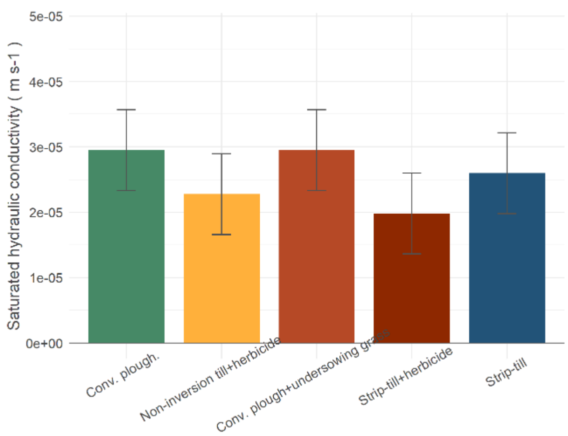
Table 8: Indicators measured in the SS (all Figures in annex II)

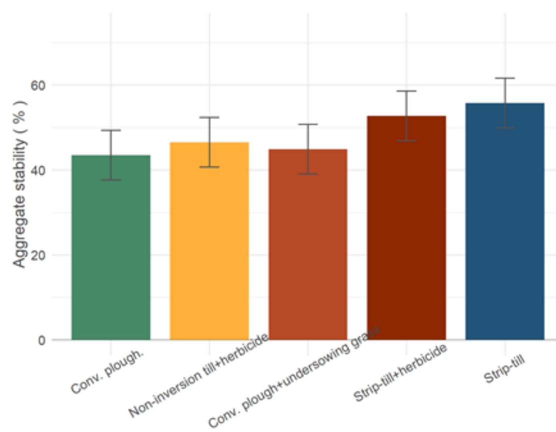
Observation code	Unit	Description
ksat	m s^{-1}	Saturated hydraulic conductivity
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
soc	%	SOC
ph_kcl	_	pH (KCl)
crop_yield_ha	kg/ha	Crop yield
totalbiomass_production_ha	kg DM/ha	Total biomass production
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
plant_number	no/ha	Plant number
crop_height	cm	Crop height
Nmin1	kg N/ha	Mineral N in 0-30 cm layer
Nmin2	kg N/ha	Mineral N in 30-60 cm layer
Nmin3	kg N/ha	Mineral N in 60-90 cm layer

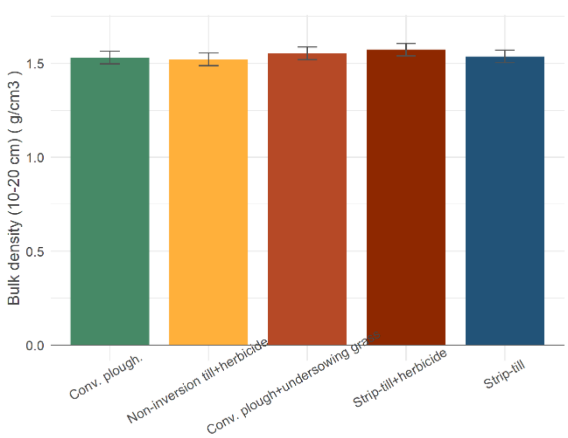
pest_infestation	%	Infected plants

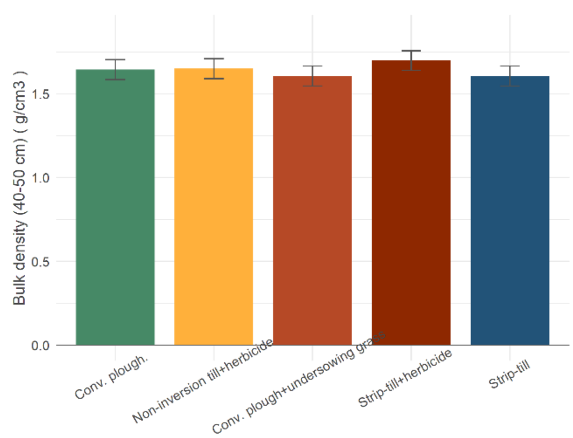
Results

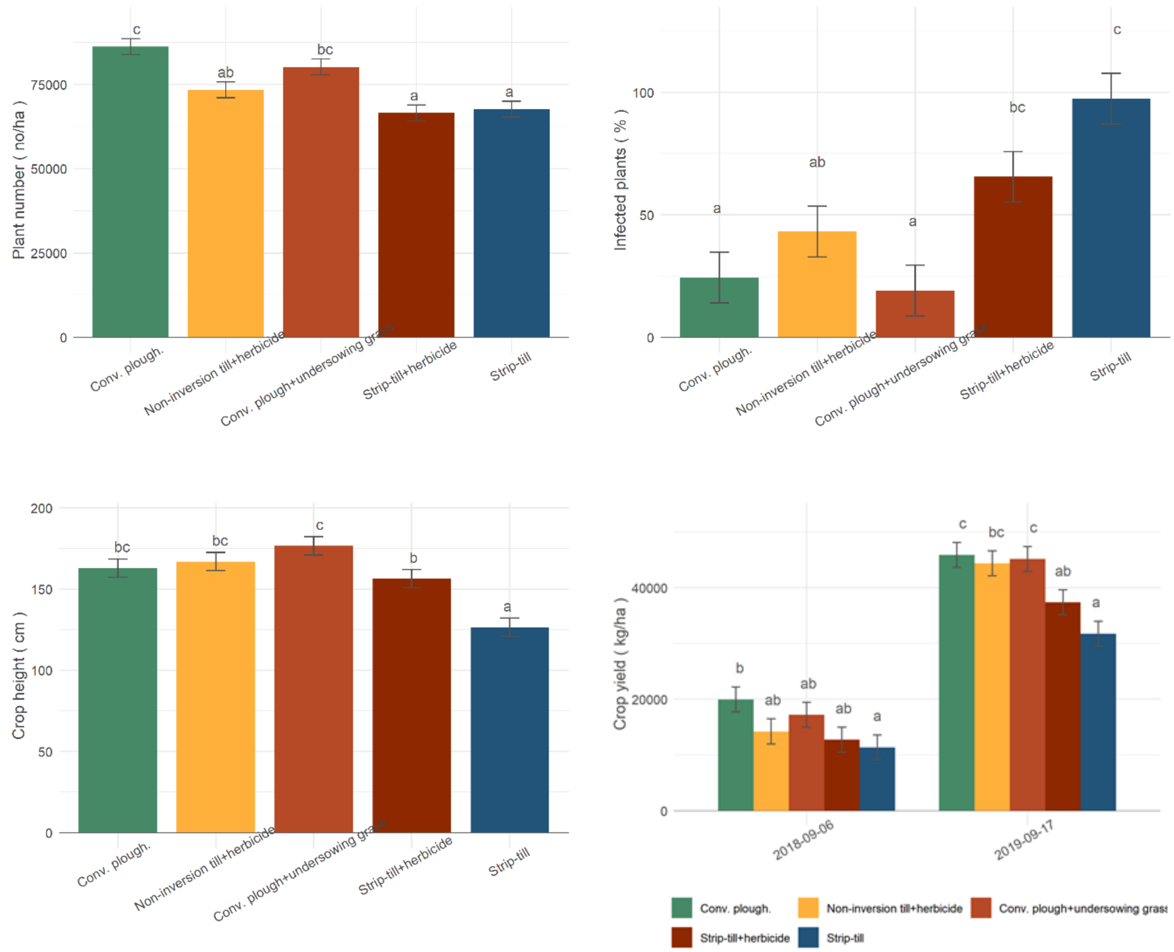




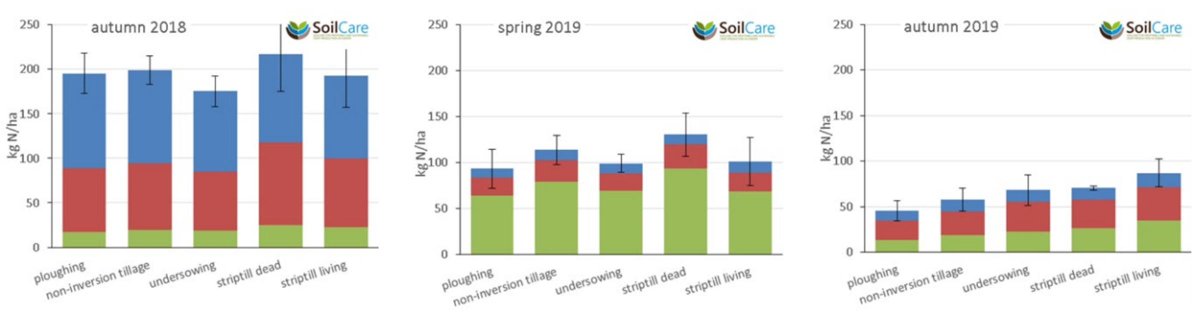








Study site analysis



Analysis

In this trial, no significant differences were found among the treatments regarding soil organic carbon content or soil physical characteristics (ksat, bulk density, infiltration rate).

However, important significant differences were noted regarding plant growth and crop yield. Significantly lower maize growth and yields were found in the strip-till treatments, caused by important infestations by wireworms, probably linked to a field history of converted grassland and further stimulated by the grass residues left on the soil in these plots. Consequently, N uptake of the maize was also significantly lower, resulting in significantly higher mineral N residues in the autumn of 2019.

Regarding the treatment with grass undersowing, it must be noted that, due to weather conditions and presumably an insufficiently adapted herbicide application (not confirmed by the farmer), the grass emergence was strongly suppressed by the quick emergence and initial growth of the maize. As a result, grass growth in these plots was minimal/negligible and no further conclusions can be drawn regarding this treatment.

Experiment 3

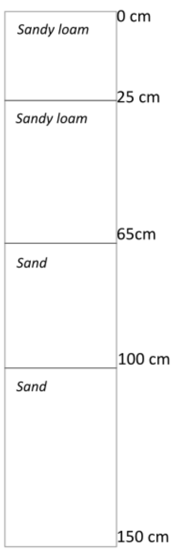
Experiment 3 description

The main objective of the experiment is to evaluate the effects of 4 alternative cultivation types in maize. Because of the disappointing results of experiment 2 due to severe wireworm infestations and extremely poor establishment of the undersown grass, a new experimental field without grass history was selected in 2020. In this field, the treatments were adapted according to the field conditions and the farmers' normal practice and to improve both the maize and grass development: mustard-phacelia cover crop instead of rye, different grass mixture, different grass sowing date and grass sowing technique. The experiment was established in April 2020 and was set up in a randomized complete block design with 4 blocks, containing 4 plots each, 3 for the SICS treatments and one with the control treatment.

Figure 12: Grass is undersown in maize

Figure 13: Undersown grass, situation after the maize harvest

Experimental field information



Experiment 3 was conducted on an experimental field managed by the researchers and the farmer. The experimental field is located in Tielt-Winge, Belgium at an altitude of about 65 m and covers an area of about 9600 m^2. The topsoil has a sandy loam texture according to the national classification system.

The soil profile of 1.5 m, described by Marc Vanderveken, has 4 horizons.

The climate of the experimental field area

Check Report 1.

Cropping systems description

Treatments

The experiment consists of 4 treatments with the following codes in the SoilCare Database and the analysis following.

BDB_EX3_TR1= Conventional ploughing (Control Treatment)

BDB_EX3_TR2= Non-inversion tillage

BDB_EX3_TR3= Conventional ploughing + undersowing of grass (± 5 weeks after the maize sowing)

BDB_EX3_TR4= Strip-tillage

The conventional ploughing in the first (control treatment) and third treatments is moldboard ploughing at 25 cm depth.

The used grass species for the undersowing treatment was adapted to its sowing date: a more vigorous grass mixture of *Lolium perenne* and *Dactylis glomerate* was used to ensure better grass emergence at a later maize development stage (± 6 weeks after maize sowing). The grass was sown between the maize rows with a pneumatic seeder mounted on a hoeing machine.

Field operations

The main crop in the field was *Zea mays, known as maize,* which was planted in April and harvested at the beginning of September. Before the maize crop, a mixture of mustard (*Sinapis alba*) and phacelia (*Phacelia tanacetifolia*) was planted as a cover crop. Mineral fertilization (nitrogen, phosphorus, potassium), as well as herbicides, were applied according to the farmers' normal practice, adapting herbicide doses and products to the presence of the grass undersown in the maize. Liquid manure was injected into the field at the end of March 2020.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model. Variables with repeated measurements in time were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. For the variables measured only one time, the Treatment factor was used alone. The blocking was introduced in all models as a random effect, using statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

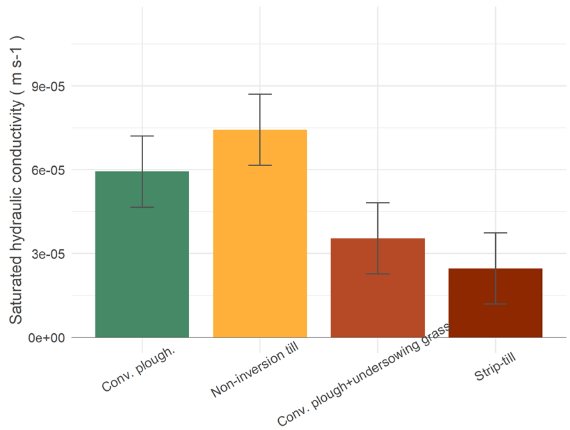
In the table below the variables measured and analysed for this experiment are listed.

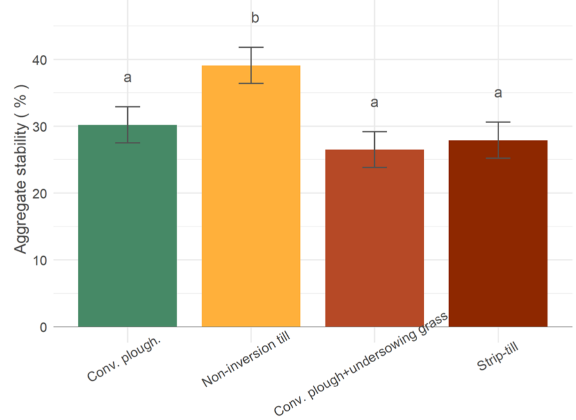
Table 9: Indicators measured in the SS (all Figures in annex II)

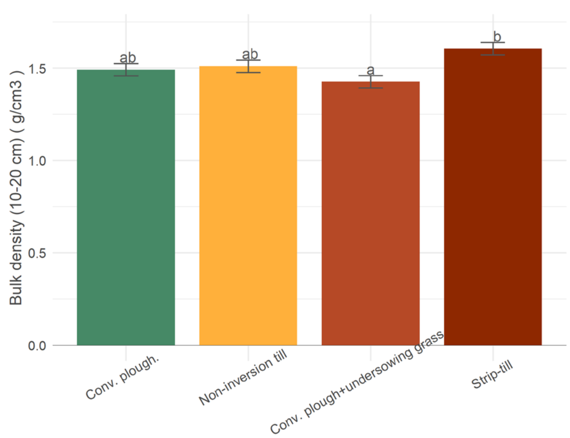
Observation code	Unit	Description
ksat	m s^{-1}	Saturated hydraulic conductivity
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)

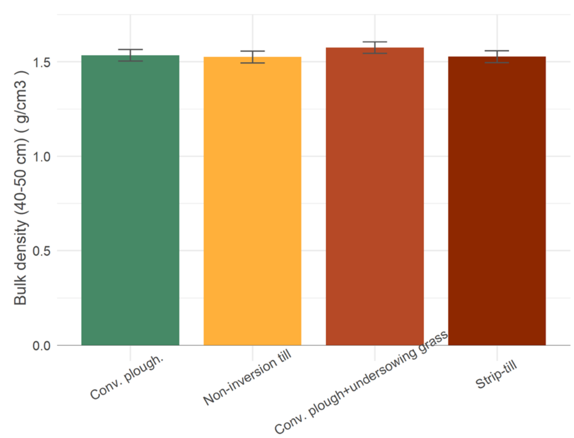
crop_yield_ha	kg/ha	Crop yield
totalbiomass_production_ha	kg DM/ha	Total biomass production
yield_DMcontent	%	DM content of the yield
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
plant_number	number/ha	Plant number
crop_height	cm	Crop height

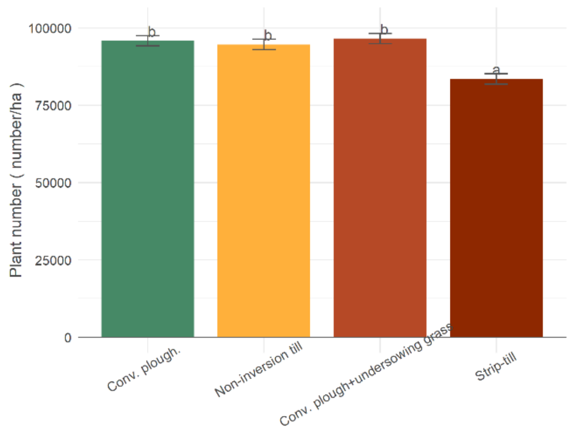
Results

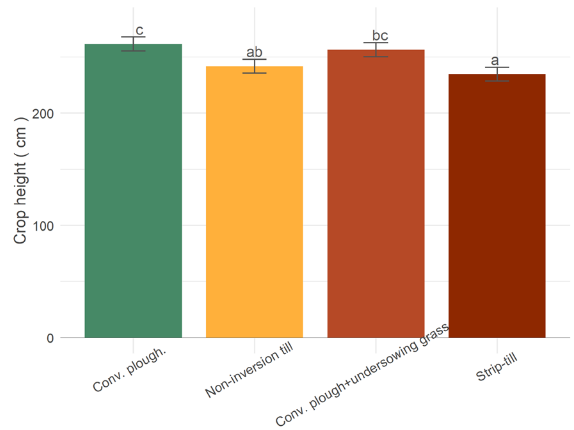


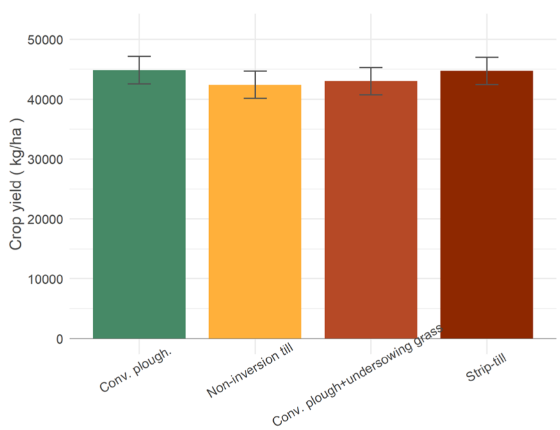


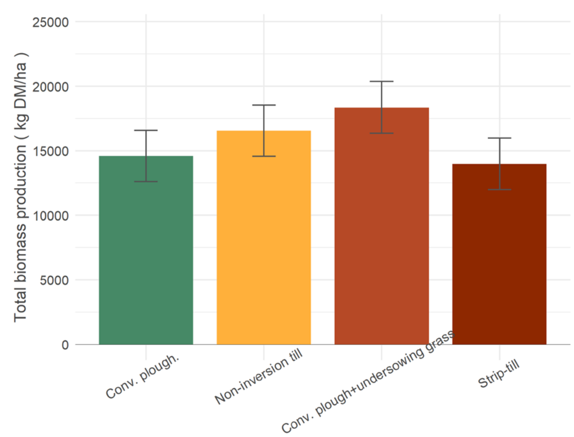












Analysis

In this trial, the non-inversion tillage treatment had significantly better soil physical characteristics: higher aggregate stability and infiltration rate. The strip-till treatment scored in general a lower physical soil quality, with a significantly higher bulk density in the top layer compared to the undersown treatment.

Although no wireworm (or other) infestations were present in this field, the strip-till treatment still had a lower crop establishment (significantly lower plant population and lower crop height) than the other treatments. Field observations indicated that the strip-till was not carried out accurately in all the plots: sometimes the maize was sown beside the tilled strip instead of in the middle of it. This was probably the cause of the lower plant emergence and growth in this treatment. Nevertheless, the maize succeeded at least partially in compensating for this lower plant population, since no significant differences in crop yield and total biomass production were observed between the treatments.

Regarding the treatment with grass undersowing it must be noted that due to the extremely dry weather conditions after the grass undersowing, the grass emergence and growth was poor (but better than in experiment 2). After the maize harvest, the remaining grass was partially damaged, leaving a poorer grass cover at the beginning of the winter, compared to e.g. grass sown after the harvest of maize (October) in a neighbour maize field. However, the underground biomass (roots) was more developed in the undersown grass and later on the grass recovered quickly.

Figure 14: undersown grass after the maize harvest

Figure 15: the grass was sown after the maize harvest in a neighbouring field

Socio-cultural dimension

SICS treatment: BDB_EX2_TR4 (herbicide destroyed rye cover crop + strip till)

Control: BDB_EX2_TR1 (conventional ploughing)

Table 10: Impact of SICS (herbicide+ strip-till) on the socio-cultural dimension as compared to the control group

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.56	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.75	1.00	Complete
Farmer reputation	0.00	1.00	Complete

SICS treatment: BDB_EX3_TR4 (flailed mustard & phacelia + strip till)

Control: BDB_EX2_TR1 (conventional ploughing)

Table 11: Impact of SICS (strip-till) on the socio-cultural dimension as compared to the control group

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.36	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	0.00	1.00	Complete

SICS treatment: BDB_EX2_TR3 (conventional ploughing + simultaneous undersowing of grass)

Control: BDB_EX2_TR1 (conventional ploughing)

*Table 12:Impact of SICS (**simultaneous** grass undersowing) on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)*

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.10	1.00	Complete
Workload	0.50	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	0.00	1.00	Complete

SICS treatment: BDB_EX3_TR3 (conventional ploughing + **later** undersowing of grass)

Control: BDB_EX2_TR1 (conventional ploughing)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.10	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	0.00	1.00	Complete

Economic dimension

SICS treatment: BDB_EX2_TR4 (herbicide destroyed rye cover crop + strip-till)

Control: BDB_EX2_TR1 (conventional ploughing)

Table 13: Summary of the benefits of SICS (herbicide + strip-till vs. control), this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	AMP SICS
Agricultural management technique	Conventional ploughing	Strip-till
Investment costs	353	305
Maintenance costs	0	0
Production costs	0	0
Benefits	4506	3395
Summary = benefits - costs	4153	3090
Percentage change	34.4	

SICS treatment: BDB_EX2_TR3 (conventional ploughing + simultaneous undersowing of grass)

Control: BDB_EX2_TR1 (conventional ploughing)

Table 15: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	AMP SICS
Agricultural management technique	Grass cover sowing after the maize harvest	Grass undersowing
Investment costs	507	463
Maintenance costs	0	0
Production costs	0	0
Benefits	150	150
Summary = benefits - costs	-357	-313
Percentage change	-12.1	

SICS treatment: BDB_EX2_TR3 (conventional ploughing + later undersowing of grass)

Control: BDB_EX2_TR1 (conventional ploughing)

	Impact index	Data completeness index (DCI)	Data completeness rating
	-1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	1 = All input variables have been considered 0 = No input variables have been considered	DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Economic dimension	0.00	1.00	Complete

Overall analysis and main findings

Summary of the field trial results

Non-inversion tillage

In the context of erosion control, non-inversion tillage is a cultivation technique that is booming worldwide. Extensive attention has also been paid to this technique in Flanders in recent decades, also in terms of policy regarding erosion control. However, despite the various research and demonstration projects that have taken place in recent years, farmers who are not yet familiar with this technique often still have questions about the consequences of non-inversion tillage for crop production (yields from different crops, crop quality, ...) and soil quality (soil density, carbon content, ...).

In soils with non-inversion tillage, the organic carbon of the topsoil layer is redistributed in the longer term, with an increase in the layer of 0-10 cm and a decrease in the layer of 20-30 cm. This redistribution is because that crop residues remain on the soil surface and are not mixed with the 0-30 cm layer, as is the case with ploughing. The redistribution of the carbon is less pronounced in fields with low organic matter inputs as well as fields having regularly potatoes and beets in their rotation (soil disturbance and mixing during harvest).

In the first maize experiment (Experiment 2), the plots with non-inversion tillage were more infested by wireworms than the control plots (conventional ploughing), but less than the strip-tilled plots, with analogous effects on plant number and yield. Regarding soil physical characteristics (bulk density, aggregate stability, infiltration rate) as well as mineral nitrogen content in the soil, no significant differences with the control treatment were observed.

In the second maize experiment (Experiment 3), the plots with non-inversion tillage had significantly better aggregate stability and a better infiltration rate than the control plots.

Strip-till

Strip-till is a form of non-inversion tillage where only the soil strip where the crop is sown is cultivated. Sowing should be done exactly in the middle of the cultivated strip. If not, seed germination and plant development will be inhibited. In the Flemish legislation regarding erosion control, strip-till is one of the possible measures to be applied to meet cross-compliance (CAP) in highly erosion-sensitive fields.

A good soil structure is important for strip-till. If the soil is too compacted, the water does not penetrate sufficiently into the uncultivated soil and concentrates in the cultivated strips. In wet spring conditions, there is a risk that too much water will accumulate in the cultivated strip and the young plants will suffer.

As with other forms of non-inversion tillage, the choice of cover crop is also important. With a frost-sensitive cover plant such as white mustard, fieldwork can be started immediately in the spring without much extra work. Frost resistant cover crops such as grass or rye have to be (chemically) destructed first.

In the first maize experiment (Experiment 2), a strip-till was applied in a maize field with a cover crop of rye. Since rye is a frost-resistant crop, it had to be destroyed before the strip-till could be carried out. This was done in two ways: chemically, with a herbicide spraying, and mechanically, by flailing the rye crop. In the latter case, however, the cover crop was not dead and showed an important regrowth after the maize sowing. After the maize germination, important infestations by wireworms were observed in the experimental field, most probably linked to the field history of converted grassland. In the strip-tilled plots, these infestations were further stimulated by the (dead or living) grass residues left on the soil, inducing important significant reductions of plant number, plant growth and crop yield. In this experiment, no significant differences were found between the treatments regarding soil organic carbon content or soil physical characteristics.

In the second maize experiment (Experiment 3), the cover crop used was a mixture of yellow mustard and phacelia. The cover crop was destroyed by frost during winter and the residues were flailed before carrying out the strip-till. However, this experiment showed how important it is to perform the strip-till accurately. In some plots, the maize was not sown exactly in the middle of the tilled strip, causing lower plant emergence and growth (but without significant effect on crop yield and total biomass production). Regarding physical soil quality, the strip-till treatment in this experiment scored generally lower, with a significantly higher bulk density in the top layer compared to the undersown treatment.

Grass undersowing

The rules for cover crops in the context of meeting the greening requirements for the CAP stipulate that cover crops must be sown before October 1. If the cover crop is sown after the maize harvest, this implies that the maize must be harvested before October 1. Depending on the climatic conditions of the year and the used varieties, the maize could not have reached a sufficiently high dry matter content at that time. With grass undersowing, the cover crop is sown while the maize is still on the field. It is then no longer necessary to harvest the maize before October 1. After the maize harvest, the grass cover crop can develop immediately. Compared to the sowing of cover crops after harvest, this should yield several benefits. The undersown grass no longer needs to germinate and start under sometimes less favourable autumn conditions. If the undersowing is successful, the grass cover is already well developed in winter and thus protects the soil against erosion and compaction. A well-developed cover crop also produces more organic matter and thus contributes more to soil structure and soil fertility in general. The grass will also continue to grow in autumn, absorbing mineral nitrogen with a positive effect on nitrate residue and water quality.

Undersowing grass can be done in two ways: simultaneously with the maize, or in a later maize stage, in the 4-5 or even the 8-10 leaf stage. The choice of the grass variety has to be adapted at the sowing time. Fescue is the best choice for simultaneous undersowing, since it develops more slowly in the early stages, resulting in less competition with the maize crop. For under-sowing at a later stage of the maize, it is better to choose more vigorous grasses such as Italian ryegrass and/or *Dactylis glomerata*, since the maize is then already sufficiently developed to be able to compete with the grass.

Weed control is a bottleneck when undersowing grass in maize. On the one hand, the present weeds should be sufficiently controlled, especially on fields with high grass weed infestations. On the other hand, undersown grass should not be affected or killed.

Apart from the right grass variety, the weather conditions after sowing will also determine the success. A dry period shortly before or after sowing will significantly slow down the germination of the grass seed.

In Experiment 1 (2018-2019), Fescue grass was undersown simultaneously with the maize. However, due to weather conditions and presumably an insufficiently adapted herbicide application (not confirmed by the farmer), the grass emergence was strongly suppressed by the quick emergence and initial growth of the maize. So, no conclusions could be drawn regarding this undersowing technique from this experiment.

In Experiment 2 (2020), a mixture of Italian ryegrass and *Dactylis glomerata* was undersown ± 5 weeks after the maize sowing. Again, due to the extremely dry weather conditions after the grass undersowing, the grass emergence and growth was poor but better than in experiment 2. After the maize harvest, the remaining grass was partially damaged by the harvesting machines, leaving a poorer grass cover at the beginning of the winter.

In both experiments, no significant effect of the grass undersowing was observed, neither on maize development and yield nor on soil parameters.

Drawbacks and benefits

From the results of the experiments as well as from farmers' and advisors' interviews, the following benefits and drawbacks can be listed:

For strip-till:

Benefits	Drawbacks
requires less labour: soil cultivation and sowing is done in one passage. Certain strip-till machines even allow injecting liquid manure at the same time.	higher crop protection costs (with frost-resistant cover crops).
less fuel required in sandy soils.	higher machinery costs (strip-till machine).
reduction of erosion.	a higher level of expertise required.
better drought resistance.	higher risk of crop failure (due to pests, weeds or poor quality of the work)

For grass undersowing:

Benefits	Drawbacks
possible reduction of nitrate leaching	high level of expertise required.
increase of soil organic matter (in the long term)	results depend highly on weather conditions after sowing.
reduction of erosion	increased risk of crop failure if not well carried out (competition of the grass or weed infestation of grass weeds).
	requires more labour because of the lower working capacity of the used machines.

Overall general conclusions

- Strip-till: possible benefits regarding erosion reduction and soil quality, but requires high levels of skill and expertise. If done in a frost-resistant cover crop, herbicide sprayings with Round-Up are required to destroy the cover crop sufficiently. The technique induces higher risks of crop failure, due to pests, weeds or poor quality of the work.

- Grass undersowing: possible benefits regarding erosion reduction, soil quality (soil organic matter) and reduction of nitrate leaching during winter (the cover crop being further developed at the start of the winter), but the technique requires a high level of skill and expertise. The results depend on (unpredictable) climatic conditions after the maize and grass sowing. Nevertheless, in the end, grass undersowing is considered a more promising technique to prevent erosion and nitrate leaching during winter and improve soil organic matter content at the same time.

General conclusions based on all the experiments by BDB

Application of wood chips in arable soils:

- Valorisation of residual biomass – closing carbon cycles.
- Carbon sequestration and improved soil quality in the long term.
- Soil nitrogen balance: take into account temporary N immobilization.
- Low N and P content make it possible, in the context of Flemish manure legislation, to apply larger quantities to arable fields (e.g. solid manure or compost).
- Costs and benefits: expensive! The availability of wood chips is a possible barrier.
- Support and Flemish policy: (financial) support and incentives from the policy is needed.

Strip-till in maize:

- Introduced in Flanders in the context of the cross-compliance regarding erosion.
- Several bottlenecks regarding practical implementation, ecological impact (Roundup), and pest control.

Grass undersowing in maize:

- (Again) in the spotlight in Flanders in the context of the greening measures (CAP) and the new derogation rules regarding cover crops.
- Knowledge and expertise required regarding practical implementation: date of undersowing, choice of grass species, adapted weed control products.
- The result depends on weather conditions.
- A promising technique in the context of erosion prevention, reduction of nitrate leaching during winter and increasing soil organic carbon content.

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I.2 NIBIO (Norway)

Report 1 on Monitoring and Analysis

Study Site number: 2

Country: Norway

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Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): NIBIO

Experiment: Cover crops

Version: C

Date: 11-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to investigate cover crops and their multi-beneficial roles on chemical, physical and biological properties. Two sowing times (spring and autumn), as well as different mixtures of cover crops, were investigated. The experiment was established in June 2018 and was set up in a randomized complete block design with 3 blocks, containing 5 plots each, 4 for the SICS treatments and 1 for the control treatment.

Experimental field information

The experiment is conducted on an experimental field where the researchers and representative from the agriculture extensive service jointly manage it. The experimental field is located in Østfold County, southeast Norway at an altitude of about 45 m a.s.l. and covers an area of about 360 m^2. The topsoil has a clay loam texture according to the USDA classification system.

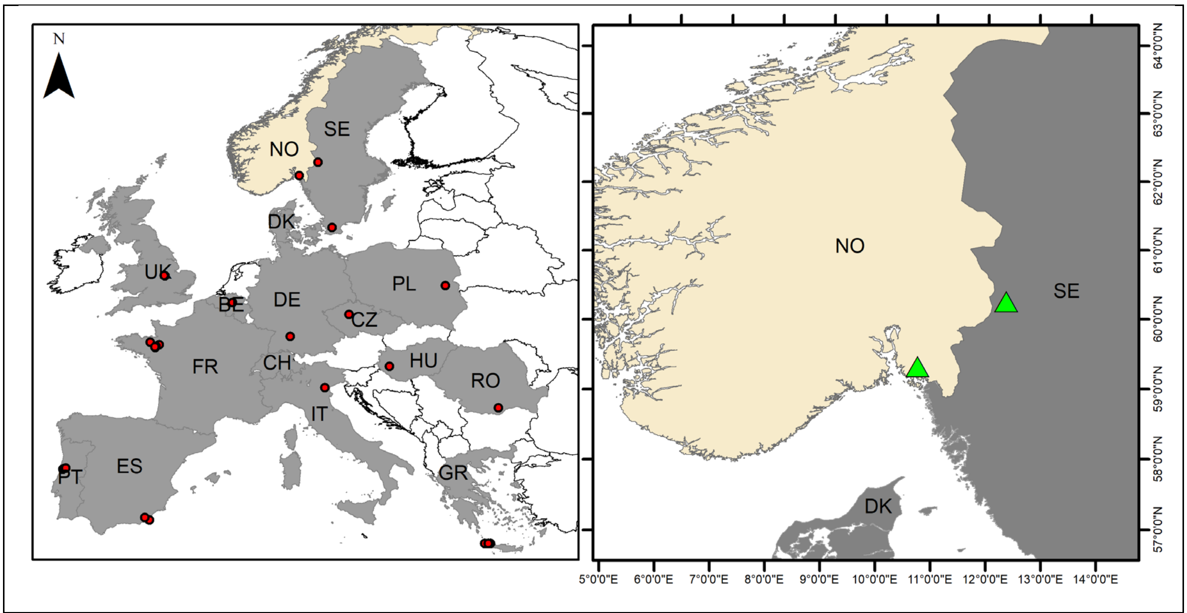


Figure 1: Location of the study site

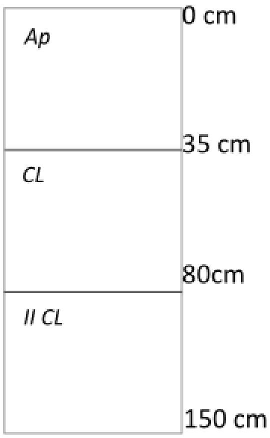


Figure 2:Soil profile horizons

The soil profile (Øsaker) of 1.5 m depth which was described in 2011, consists of 3 horizons and is characterized as Stagnosol according to the USDA classification system.

The climate of the experimental field area

The measurement station nearby the experiments is Øsaker (written in the R-scripts as Osaker) belonging to the Agrometeorology Service of Norway.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Osaker (ECAD 2763)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	9.5	2.3	849.5	556.8A
2018	11.4	3.4	655.5	667.3
2019	12.0	3.3	1282.1	658.4
2020*	13.2	4.7	982.6	667.0

Unfortunately, Osaker has several missing temperature observations during the nineties, so that the "normal" 1961-90 for Tmin, Tmax and ET0 rather representative for 1961-80.

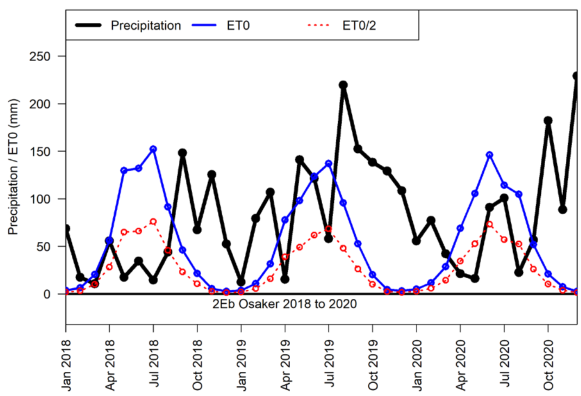
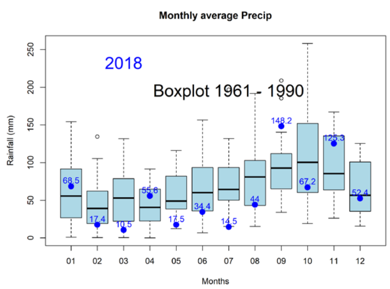
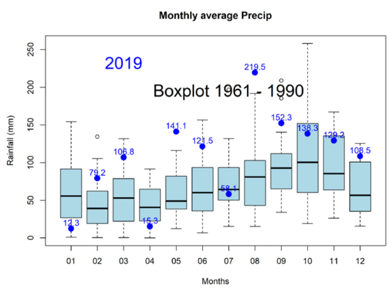


Figure 3: 2Eb Osaker 00aFAOgrow





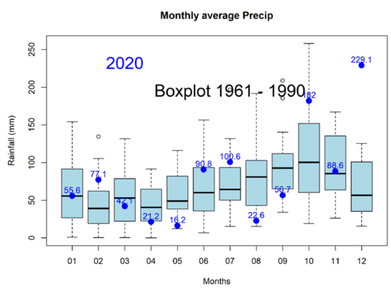


Figure 4: 2Eb Osaker 07Precip2018box *Figure 5: 2Eb Osaker 11Precip2019box* *Figure 6: 2Eb Osaker 15Precip2020b*

In 2018 Southern Norway experienced its driest summer since 1947. Nationally, the crop yield was reduced by 50 %. Accordingly, the experiment's cover crops suffered, resulting in the growth of only a few cover crop species. As illustrated in the comparison between 1961-90 shown by boxplots and the monthly rainfall for 2018 several months during the spring and the summer were exceptionally dry.

The growing season of 2019 was characterized by being wetter than the previous year and the period 1961-1990. Except for July, there was an increase in precipitation from May to October compared to 1961-1990. High precipitation during autumn complicated and delayed the harvest.

In 2020, precipitation in the growing season was more similar to the monthly average between 1961-1990 than in previous years.

Cropping systems description

Treatments

The experiment consists of 5 treatments with the following codes in the SoilCare Database and the following analysis.

NIBIO_EX1_TR1: Control - No cover crop

NIBIO_EX1_TR2: SN - Spring sown nitrogen fixating cover crop

NIBIO_EX1_TR3: AN - Autumn sown nitrogen fixating cover crop

NIBIO_EX1_TR4: SR - Spring sown cover crops root mix

NIBIO_EX1_TR5: AR - Autumn sown cover crops root mix

- The cover crop of the second treatment (SN) is a mixture of white clover, birdsfoot trefoil and crimson clover sown in spring with the main crop or shortly after. The mixture contains legumes that fixate nitrogen from the air.
- The third treatment (AN) includes vetch, hairy vetch and Pisum sown in autumn. The mixture contains legumes that fixate nitrogen from the air.
- The SR treatment’s mixture includes chicory, perennial ryegrass and alfalfa sown in spring with the main crop or shortly after. The mixture of cover crops is combined to prevent leaching of nitrogen through uptake.
- The AR treatment evaluates the mixture of forage radish and westerwold ryegrass (annual) sown in autumn. The mixture of cover crops is combined to prevent leaching of nitrogen through uptake.

Field operations

Crop rotation is taking place in the field. The main crop planted in May 2019 and harvested in August 2019 was barley *(Hordeum vulgare)*, and in May 2020 with harvesting at the beginning of September oat *(Avena Sativa)*. 22-3-10 fertilizer was applied between 2018 to 2020, and harrowing occurred for weed management. Autumn sown cover crops were sown after harvest in 2018. However, in 2019 and 2020 the cover crops were sown 2.5 weeks earlier than harvest.

Bio-physical data analysis – WP5

Method

Differences between treatments for all variables were analysed with a Mixed-Effects Model. Variables, where measurements were repeated over time, were analysed either the full model fixed structure “Treatment*Date” or the “Treatment+Date” depending on which model presented lower AIC. The variables measured only one time, the Treatment factor was used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models’ standard error.

For the yield and other crop-related characteristics, the changes in the relative values of the treatments in comparison with the control were calculated. This was done to exclude the effect of different crops in the rotation and analyse only the treatments and date effects

Data

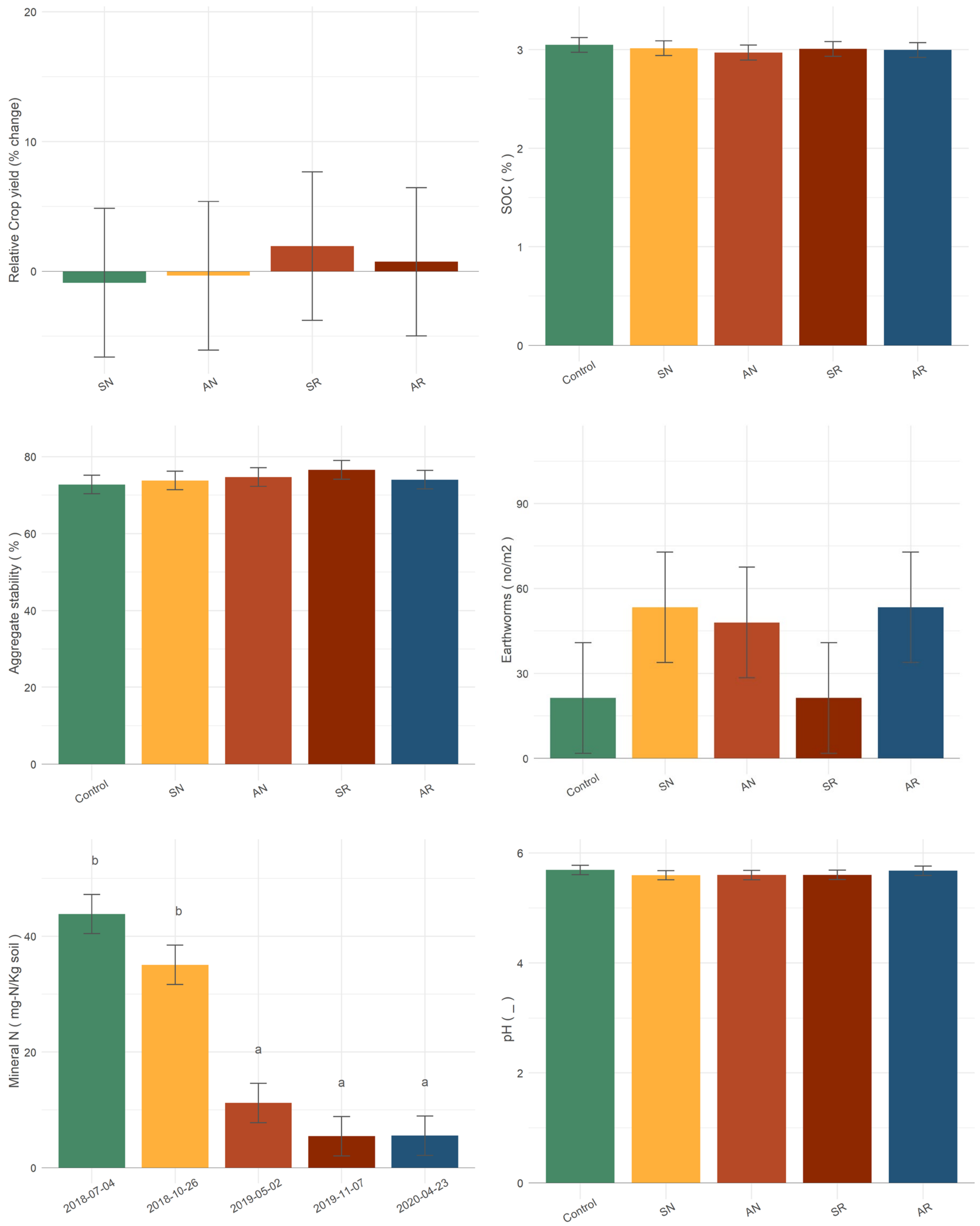
In Table 2. you can find the variables measured and analysed for this experiment. Results for all variables can be found in ANNEXE II.

Table 2: Indicators measured and analysed for the SS

Observation code	**Unit**	**Description**
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density
nmin_top	mg-N/Kg soil	Mineral N
k_plus	cmol+/kg	Exchangeble K
ca2_plus	cmol+/kg	Exchangeble Ca
na_plus	cmol+/kg	Exchangeble Na
mg2plus	cmol+/kg	Exchangeble Mg
soc	%	SOC
ph_kcl	_	pH
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
pavail2	P mg PO4/kg	Olsen P

crop_protein	%	Crop protein
crop_fat	%	Crop fat

Results



Analysis

High temperatures in 2018 resulted in poor plant growth and consequently an excess in mineral nitrogen in the soil, as illustrated by the high levels of mineral N in 2018 compared to 2019 and 2020

(Fig.?). The plant species most often observed through field observations was vetch in the SN mixture and ryegrass in the SR and AR treatments. Crimson clover in the SN treatment and radish in AR treatment was observed occasionally. The results show a decrease in mean relative crop yield for treatments where legume cover crop species were included (Treatment SN and AN). Increased mean relative crop yield was observed for treatments with ‘root mix’. However, the variance between plots is large. Only small changes can be observed for aggregate stability. Compared to the control, mean aggregate stability was the highest in treatments with SR. However, the mean earthworm count (in 2020), were equally low for the SR treatment as the control. The pH measured in spring 2020 varied between 5.4 and 5.8. This level is considered low and could be an effect of the weather in 2018 an 2019 and/ or fertilising. While the main crop oats are robust, low pH might have affected the growth of the cover crops negatively. Three years is not enough to measure any changes in soil organic carbon (SOC).

Study site analysis

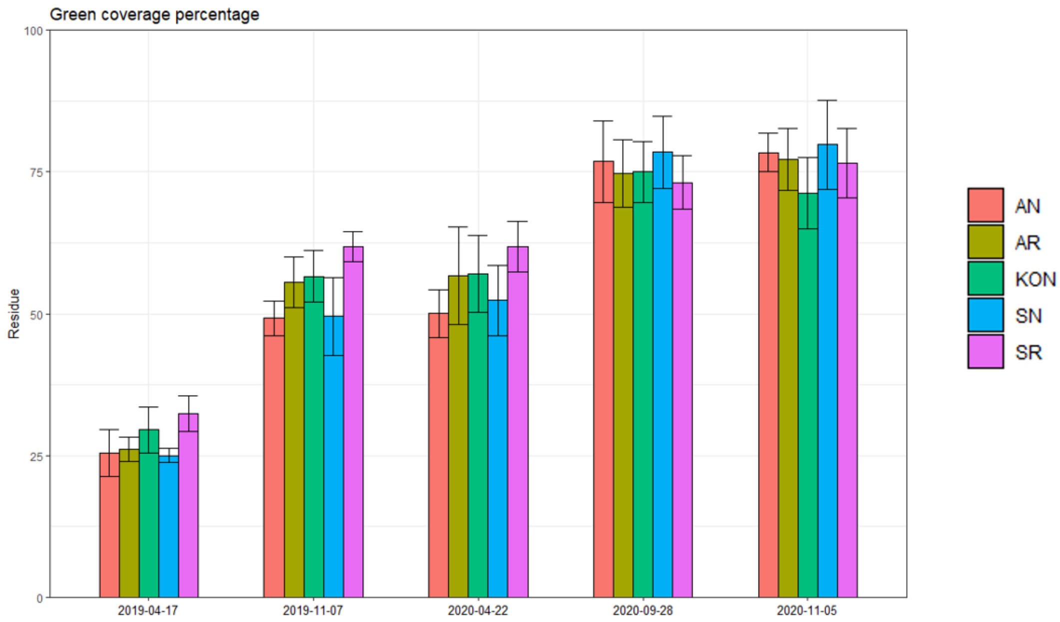


Figure 7:Green coverage percentage (without distinguishing weeds and cover crops)

Socio-cultural dimension

The use of cover crops increases the workload and using cover crops might compete with the main crop for nutrients, possibly decreasing the yield. However, this might be a short-term effect. Investigations into the long-term effect of cover crop on soil health and consequently on crop yield is needed.

SICS: NIBIO_EX1_TR4 (SR – Spring sown cover crops root mix

Control: Nibio_EX1_TR1 (no cover crop)

Table 3: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.26	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Economical dimension

The additional cost of planting cover crops in spring has been calculated based on calculations in Bøe et. al. (2020). Seed costs were gathered from a national seed distributor and were not identical to the one chosen in the experiment. However, it is considered representative. Results show a positive economic impact of using cover crops compared to not using cover crops. The main reason for this outcome is the subsidisation of cover crops through the regional environmental programme. As the calculation is based on the cost of ryegrass and clover, seed cost might increase if other plant species are chosen and consequently the overall cost. Although cover crops might reduce crop yield, equal crop yield of control and treatment was assumed.

SICS: NIBIO_EX1_TR4 (SR – Spring sown cover crops root mix

Control: Nibio_EX1_TR1 (no cover crop)

Table 4: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	AMP SICS
Agricultural management technique	No cover crop	Cover crop
Investment costs	0	7.6
Maintenance costs	0	68.3
Production costs	0	0
Benefits	208	338
Summary = benefits - costs	208	262.2
Percentage change	26	

Overall analysis and main findings

Control: NIBIO_EX1_TR1 (no cover crop)

The overall sustainability was assessed for the spring-sown cover crop root mix. Cover crops had, according to this analysis, a positive impact on overall sustainability. The main contributor was the economic dimension, while the socio-cultural dimension had a slightly negative impact. In Norway, cover crops are subsidised, and the choice of plant species is crucial to the profitability of using cover crops. There was no significant impact of cover crops on measured soil properties (Table 5). Increased mean relative crop yield was observed for the treatment. Mean aggregate stability was the highest in treatments with SR. However, the mean earthworm count was equally low as the control. The low pH measured in spring 2020 could have affected the growth of the cover crops negatively. Furthermore, dry and wet weather and occasionally high amounts of weeds might have affected the growth of cover crops.

Table 6: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.07	0.83	High
Environmental dimension	0.00	0.58	medium
Economic dimension	0.03	1.00	Complete
Socio-cultural dimension	-0.26	1.00	Complete
Physical properties	0.00	0.55	medium
Chemical properties	0.00	0.79	medium
Biological properties	0.00	0.50	medium

Table 7: Benefits and drawbacks of the SICS as compared to the control group

Benefits:	Farmer reputation improved; Cost-benefit;
Drawback:	Increase of workload; Potential risk of crop failure; Potential other risks

General conclusions based on all the treatments

It has been proven difficult to establish and achieve sufficient density of cover crop plants in the small plot scale experiment in Øsaker, especially in years that are dry (2018) and in years with high precipitation (2019). Results must be interpreted with these considerations in mind. High temperatures in 2018 resulted in poor plant growth and consequently reduced uptake of fertiliser N. This resulted in excess mineral nitrogen in the soil. The high-level soil mineral N was reduced in later years. Moreover, occasionally high amounts of weeds (chickweed), as well as practical challenges such as sowing methods (etc. broadcasting of seeds), might have affected the growth of the cover crop species and the main crop in later years. Low pH was measured in 2020. This could be an effect of e.g. the accumulation of cations from fertiliser in 2018. Investigations into the effect of low pH on the growth of plant species included in this experiment could be relevant for future work. Cover crop species that were most frequently observed was ryegrass, vetch and occasionally crimson clover and radish. Plant species used for autumn-sown cover crops should grow quickly to ensure a sufficient plant cover before frost. The vetch is a promising species suitable for this purpose. However, investigations into optimal seed amount should be carried out. In Norway, subsidies are an important measure to motivate farmers to implement cover crops. Dependent on the choice of plant species to cover crops, subsidies can compensate for the cost.

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Report 2 on Monitoring and Analysis of the compaction release experiment

Study Site number: 2

Country: Norway

Author(s): Till Seehusen

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Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): NIBIO

Experiment: Compaction released by plant roots

Version: C

Date: 19-02-2021

Experiment description

The main objective of the experiment is to investigate the role of different crop rotations schemes on soil properties and to release soil compaction in a field with 3 different degrees of former (2015) compaction. The experiment established in June 2017 and was set up in a split-plot design. It has 4 main plots for each soil compaction degree (3 compaction levels + control). 4 different rotation treatments are tests in these main plots. Each treatment is replicated twice in each main plot. The main plots have not been replicated.

Experimental field information

The experiment is conducted on an experimental field where the researchers and representative from the agriculture extensive service jointly manage it. The experimental field is located in Solør Odal, near Kongsvinger (60.25°N, 12.08°E) in South-East Norway (IUSS southeast Norway and covers an area of about 588 m^2. The topsoil has a silty texture according to the USDA classification system.

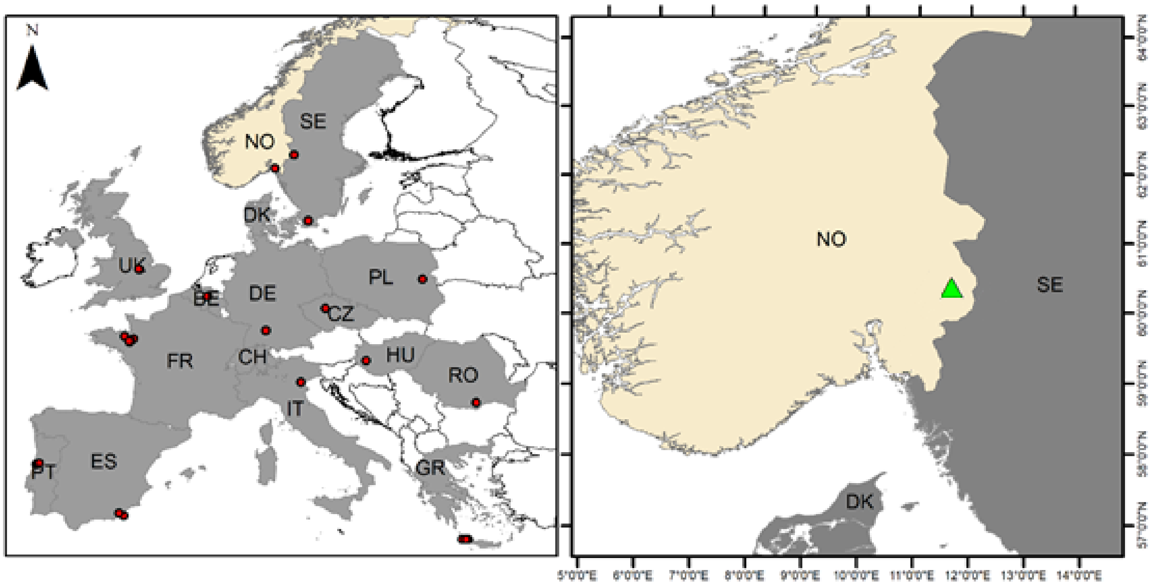
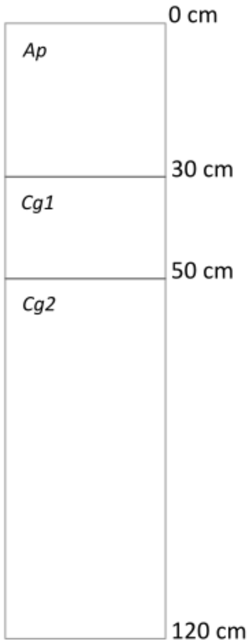


Figure 8: Location of the study site

Table 8: Particle size distribution and organic carbon content of the soil (Haplic Stagnosol) Soil horizons and texture according to FAO (2006)

Depth	Horizon[1]	Sand	Silt	Clay	Texture[1]	Corg
cm		------- % -------				
20	Ap	8	83	9	Si	2.4
40	Cg1	6	84	10	Si	
60	Cg2	5	84	11	Si	



The soil profile (Solør) of 1.2 m which described in 2015, has 3 horizons and is characterized as Stagnosol according to the USDA classification system.

The climate of the experimental field area

The area is characterized by a continental climate with cold winters and warm summers. The average temperature is 4.8°C and the average precipitation is 700 mm with the highest peak in the summer season. Temperatures increase from January (minimum temperature 1961- 1990 – 30.9 °C) to July (maximum 34.4°C).

Table 9: Average Tmax, Tmin, Precipitation and ET0 for Roverud (ECAD 18033)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	8.3	-0.6	655.9	597.7
2018	10.7	1.0	515.5	716.0
2019	10.6	1.5	704	666.3

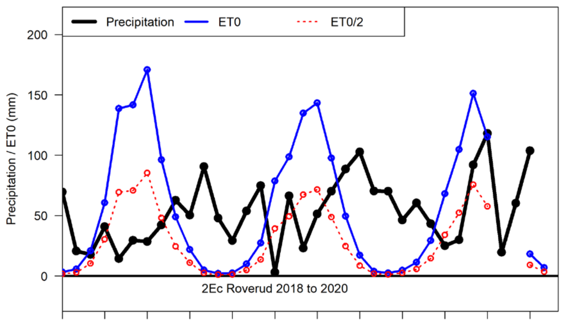


Figure 9: 2Ec Roverud 00aFAOgrow

The temperature during the trial period was on average warmer than average with 2018 being the warmest year (Table 10). Precipitation was on average higher than average during the research period with 2016 being the wettest growing season and 2018 the driest. There were not registered soil temperatures below 0°C in 20cm depth during the research period (Data not shown).

Table 10: Deviations in mean air temperature (2m height) and precipitation (mm) for the weather station at Roverud during the research period (www.lmt.nibio.no) relative to the long-term average of temperature and precipitation (1961-1990) (Aune 1993, Førland 1993). Italic values for precipitation taken from Årnes climate station.

Temperature	**Normal**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
January	-6.4	+4.2	-3.6	+2.6	+2.3	-0.9	+8.5
February	-5.9	+4.4	+3.0	+3.0	-0.4	+4.7	+6.1
Mars	-1.5	+3.3	+3.2	+2.7	-3.6	+1.8	+3.2
April	3.4	+1.9	+0.8	-0.1	+0.8	+3.4	+1.9
May	10	-2.4	+1.0	+0.4	+5.1	-1.2	-1.7
June	14.4	-1.8	+0.7	-0.6	+1.5	+0.5	+2.9
July	15.3	-0.4	0.6	-0.6	+5.0	+1.1	-2.1
August	14.5	+0.2	-0.6	-0.8	+0.1	+1.0	+1.3
September	9.7	+1.0	+4.0	+0.9	+1.6	+0.6	+1.5
October	5.3	+0.0	-1	+0.1	+0.3	-1.2	+1.1
November	-0.7	+2.9	+0.2	+0.6	+2.1	-0.4	+0.7
December	-5.2	+5.7	+4.4	+0.7	+0.8	+3.1	+5.2

Precipitation	**Normal**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
January	40	+43.1	+9.6	-22.8	+23.8	-15.8	+26.8
February	33	-8.8	+1.8	+7.6	-10.4	+28.8	+33.2
Mars	36	+1.1	+6.6	-5.7	-19.9	+20.3	/
April	39	-22.2	+27.0	-16	+2.4	-22	/
May	51	+62.0	-10.2	+0.9	-30.6	+21.8	/
June	71	-10.4	-+57.0	-19.6	-41.4	+19.8	/
July	74	-6.4	-15.6	-29	-45.4	-31.1	+33.2
August	78	-12.8	+36.2	+49.0	-35.6	-9.8	-52.9
September	82	+53.0	-60.2	/	-19.2	+46.5	-8.3
October	79	-72	-55.2	+5.0	-28.6	+25.5	+89.4
November	69	-3.1	-9.5	+5.5	+4.7	+44.5	
December	48	-1.9	-23	-1.8	+8.5	+21.9	

Cropping systems description

Treatments

The experiment consists of 4 treatments with the following codes in the SoilCare Database and the analysis following.

NIBIO_EX2_TR1 = ROT1

NIBIO_EX2_TR2 = ROT2

NIBIO_EX2_TR3 = ROT3

NIBIO_EX2_TR4 = ROT4

The rotation scheme for each treatment is presented below:

	ROT1	ROT2	ROT3	ROT4
2017	barley	oilseed	barley	alfalfa
2018	oilseed	barley	barley	alfalfa
2019	barley	oilseed	barley	alfalfa
2020	oilseed	barley	barley	alfalfa
2021	barley	barley	barley	barley

The different treatments are allocated in main plots with 3 different degrees of former (2015) compaction and a reference main plot without former compaction. For detail about the former compaction please check Seehusen et, al. 2019.

The three different levels are:

Ref: no previous compaction

10*1.7 Mg wheel load: 10x wheeling with 13 t total weight

10*2.8 Mg wheel load: 10x wheeling with 17 t total weight

10*2.8 Mg red: 10x wheeling with 17 t total weight + reduced tire inflation pressure

Field operations

The experimental field gets 500 kg/ha 20-4-11 NPK fertilization annually, and all plots apart from the alfalfa were ploughed during spring and harrowed each year.

Bio-physical data analysis – WP5

Method

For analysing the indicators, the raw values averaged per date and treatment and are presented. The standard deviation is presented with **dashed lines** and represent the variation in the two replications of each treatment within each main plots.

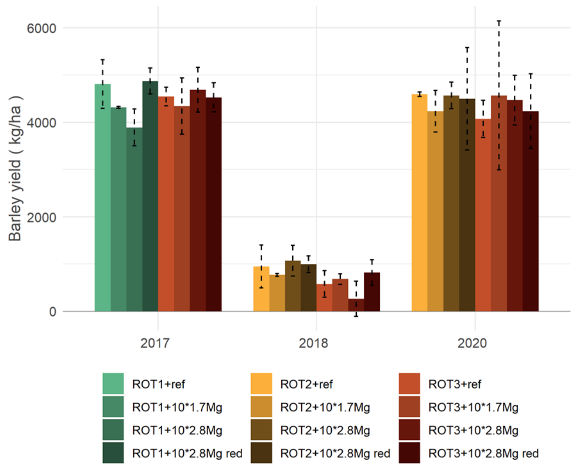
Data

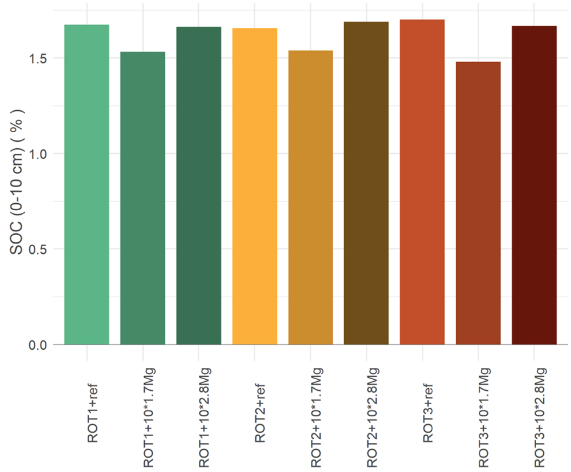
In Table 11. you can find the variables measured and analysed for this experiment.

Table 11:Indicators measured and analysed for the SS

Observation code	Unit	Description
nmin_top	mg-N/Kg soil	Mineral N (0-10 cm)
nmin_10_20	mg-N/Kg soil	Mineral N (10-20 cm)
nmin_20_30	mg-N/Kg soil	Mineral N (20-30 cm)
soc_top	%	SOC (0-10 cm)
soc_10_20	%	SOC (10-20 cm)
soc_20_30	%	SOC (20-30 cm)
crop_yield_ha	kg/ha	Barley yield

Results





Analysis

Crop yield: In 2018 Southern Norway experienced its driest summer since 1947, see Table 10. Nationally, the crop yield was reduced by up to 50 %. Accordingly, the yields on the research field were low that year which fits the yields from the surrounding fields (data not shown).

In 2019, the spring was very wet and the soil not workable which led to a delay in fieldwork. The field was not sown before mid of June which was too late to obtain maturity of the barley. The field was therefore not harvested in 2019.

There were not found any significant effects of neither former compaction treatment nor crop rotation on yields. The yields in the research field were lower than on the surrounding fields but the general trend is reflected in the yields of the area around.

SOC: The former compaction treatment with multiple wheeling with 1.7 Mg wheel load gave a lower SOC content in the upper soil layer independent of crop rotation. There were not found effects of crop rotation on SOC content

Study site analysis

Figure 10: Deep ruts due to soil compaction, picture from 2015. Picture: T. Seehusen

Figure 11 Roots of turnip rape, barley and alfalfa in growing season 2018. Picture: T. Seehusen:

Figure 12: Roots of alfalfa in the soil during growing season 2020. Picture T. Seehusen

Socio-cultural dimension

SICS: NIBIO_EX2_TR4 (Alfalfa)

Control: NIBIO_EX2_TR3 (Barley only)

Table 12: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.30	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.75	1.00	Complete
Farmer reputation	0.00	1.00	Complete

Economical dimension

Oilseed (turnip rape cv Petita) would be a good choice in terms of financial income but the growing season is too short in this part of Norway. Alfalfa (*Medicago sativa L.*) copes good with the climatic conditions but leads to additional costs and higher effort under production. Since alfalfa is grown over several years (at least 2) it reduces the flexibility of the farmer. As it is today, alfalfa yield cannot be sold which leads to reduce income and is a drawback.

Table 13: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMT control	**AMT SICS**
Agricultural management technique	Barley	Alfalfa
Investment costs	10	0
Maintenance costs	492	38.2
Production costs	0	0
Benefits	208	208
Summary = benefits - costs	-294	169.8
Percentage change	-154.7	

AMT means agricultural management practice

Overall analysis and main findings

This field is based on a former compaction trial that was established in 2015 (Seehusen, Riggert et al. 2019).

The objective of that study was to evaluate the effect of wheeling with two different wheel loads (1.7 and 2.8 Mg) and contrasting wheeling intensities (1x and 10x) on the bearing capacity of a Stagnosol derived from silty alluvial deposits. The results from that study showed that, although the wheel loads used were comparatively small, typical for the machinery used in Norway, the results show that both increased wheel load and wheeling intensity had negative effects on soil physical parameters (bulk density, air capacity, saturated hydraulic conductivity) especially in the topsoil but with similar tendencies also in the subsoil. Stress propagation was detected down to 60 cm depth. The first wheeling was most harmful, but all wheeling's led to accumulative plastic soil deformation. Under the workable conditions in this trial, increased wheeling with a small machine was more harmful to soil structure than a single wheeling with a heavier machine. However, the yields in the first two years after the compaction did not show any negative effect of the compaction.

The main aim of this part of the study (from 2017) is to determine the effect of crop rotation and different plant roots on soil structure and to which degree plant roots may be able to alleviate compaction under Norwegian climate conditions. The first results show that the roots of alfalfa grown over several years have a great ability to establish a comprehensive root system also below the ploughed layer. The root system of alfalfa has earlier been shown to be effective to loosen up and improve the soil structure of compacted soils (Löfkvist 2005).

The **yields** for all three seasons showed no significant effect of treatments on yields. There may be several reasons for that: (a) The research plots were quite small which made mechanisation challenging, (b) animals (moose) which led to considerable damage on the small plots. Due to this, the yield data presented in this study are not representative of yields that would have been possible to obtain in a larger field.

Also, all four seasons were characterized by challenging growing seasons. The year 2017 was wetter than average (Table 10), the year 2018 was all too dry while 2019 was characterized by a wet spring and autumn period. 2020 was wetter than average in July and drier than average in August and September. None of these seasons was representative.

In this trial it had therefore been difficult to establish and achieve sufficient density of oilseed in the small plot scale experiment and results must be interpreted with these considerations in mind.

Although it was chosen a variety that was considered to be robust and adapted to a short growing season, oilseed is not the right choice in this part of Norway.

Alfalfa seems to be more promising in terms of alleviation of compaction but leads to considerably more effort for the farmer. Since the harvested plant material is difficult (or even impossible) for farmers to sell, the production of alfalfa is quite costly. If the analyses from the soil sampling (still missing) confirm earlier studies (Löfkvist 2005) that alfalfa is efficient to alleviate compaction also under Norwegian condition, subsidies could be an important measure to motivate farmers to implement alfalfa in crop rotation.

The results for the **SOC** (10cm) measured in 2019 show no clear effect of crop rotation. The data indicate that the former compaction treatment with 10x 1.7Mg wheel load, which had a more distinctive compaction effect on several soil parameters (e.g. Precompression, bulk density and air capacity) than wheeling with the higher wheel load in 20 cm depth (Seehusen, Riggert et al. 2019) had the lower SOC content independent on crop rotation.

It is expected that crop rotation as practised in this trial has a positive effect on yields in the long term (Lal et al., 1994) this could not be shown in the results of this trial so far.

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•Seehusen, T., R. Riggert, H. Fleige, R. Horn and H. Riley (2019). "Soil compaction and stress propagation after different wheeling intensities on a silt soil in South-East Norway." Acta Agric. Scand., Sect. B, 69(4): 343-355.

General conclusions based on both experiments

The cropping seasons were characterized by challenging growing seasons. None of these seasons was representative. The year 2017 was wetter than average, the year 2018 was all too dry while 2019 was characterized by a wet spring and autumn period. 2020 was wetter than average in July and drier than average in August and September.

In both trials, it has been difficult to establish and achieve sufficient density of the cover crops or oilseed in the small plot scale experiments and results must be interpreted with these considerations in mind.

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I.3 University of Pannonia (Hungary)

Report 1 on Monitoring and Analysis of Organic / inorganic N fertilization (IOSDV)

Study Site number: 3

Country: Hungary

Author(s): Zoltan Toth & Attila Dunai

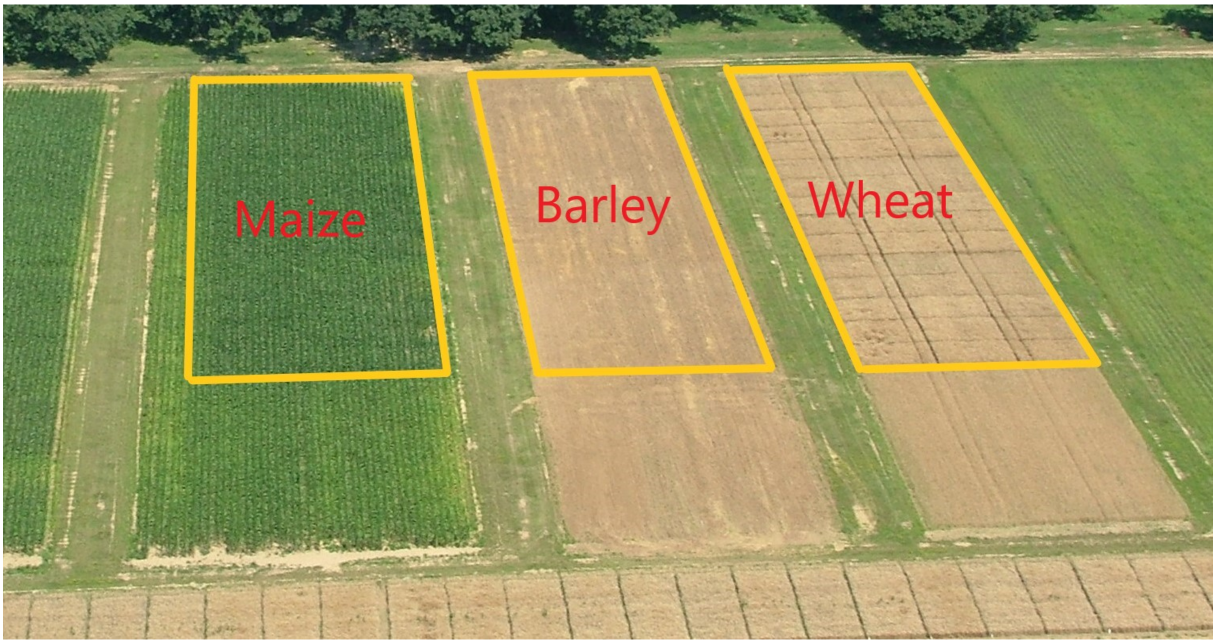
Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): University of Pannonia

Experiment: Organic/inorganic N fertilization (IOSDV)



Version: 2

Date: 22-02-2021

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Experiment description

The main objective of the IOSDV (ILTE) long-term field experiment is to evaluate the effect of mineral and organic fertilization on soil organic carbon content as well as on grain production of cereals. The experiment established in 1983 and was set up in strip-plot -randomized complete block design with three replications, and with 3 main plots, one for each application of different forms of organic fertilizers. The factors of the experiment are the increasing rate of mineral N fertilization and the complementary application of the organic fertilizers in a three-course crop rotation (maize, winter wheat and winter barley).

Experimental field information

The experiment is conducted on an experimental field managed by the researchers jointly with farmers. The experimental field is located in Keszthely in the western part of Hungary at an altitude of about 118 m and covers an area of about 10000 m^2. The topsoil has a Sandy Loam texture according to the USDA classification system.

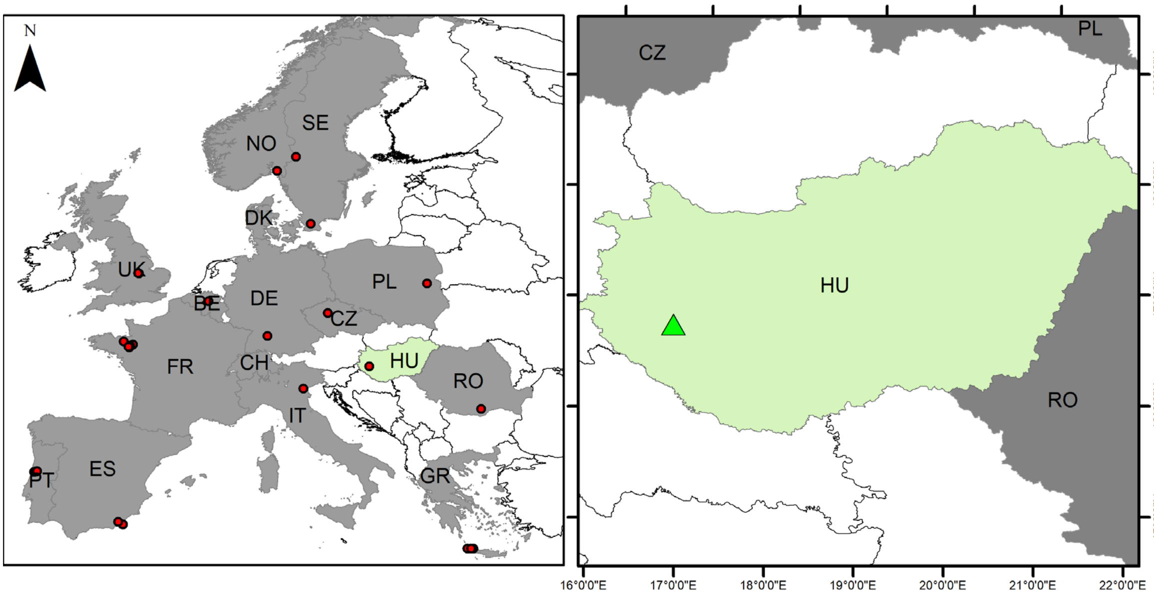


Figure 1: Location of the study site

The soil profile of 1.5 m which described in April 2018, has 4 horizons and is characterized as a Ramann-type brown forest soil (Eutric Cambisol) according to the national soil classification system. The maximum rooting depth is deeper than 200 cm and there is a ploughing pan at 25 cm depth. Average Soil Organic Carbon (SOC) content in the topsoil is 1.2-1.3 %, $pH_{(KCl)}$ value is 7.3-7.5. $CaCO_3$ content in topsoil is low, but with a rise in depth it increases and at 1 m of depth $CaCO_3$ content is as high as 20% or higher and lime concretions can be observed.

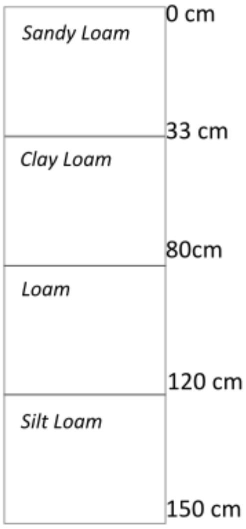


Figure 2: Soil profile of the study site

The climate of the experimental field area

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Szombathely. (ECAD 2042)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	14.4	4.7	610.8	870.1
2018	16.8	7.1	684.2	954.2
2019	17.0	7.1	587.7	928.6
2020*	NA	NA	599.3	NA

2020*: the temperature data in ECAD for 2020 appear to be erroneous

Table 2: Average Tmax, Tmin, Precipitation and ET0 for Keszthely

Year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
2018	17.0	7.3	717.0	960.9
2019	17.7	7.3	663.1	961.5
2020	17.1	6.6	656.1	960.6

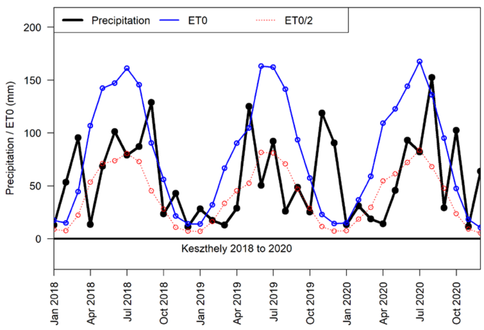


Figure 3: 3aKeszthely 00aFAOgrow

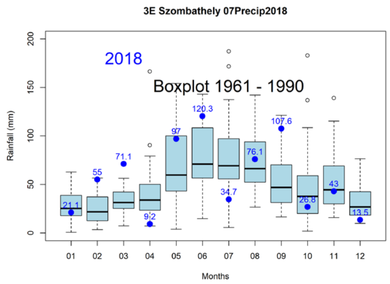


Figure 4: 3E Szombathely 07Precip2018box

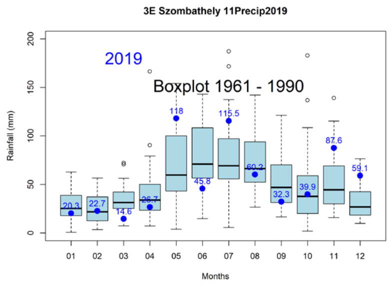


Figure 5: 3E Szombathely 11Precip2019box

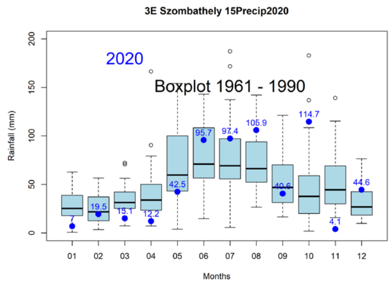


Figure 6: 3E Szombathely 15Precip2020box

The climate is semi-continental, moderately wet, Atlantic and Mediterranean effects can succeed. The area belongs to the Pannonian climatic zone (Metzger et al. 2005). Long-term annual average precipitation is 683 mm (1901-2000) but its distribution is often anomalistic. The highest precipitation occurs in June, the lowest in January, while the highest mean temperature was recorded in July, the lowest in January. The long-term mean annual temperature is 10.5 ^{o}C.

During the years of the study annual mean temperature values were much higher, than the long-term average (12.0, 12.4., and 12.3 ^{0}C in 2018, 2019 and 2020), while the annual precipitation values were close to the long-term average (Table 1 and Table 2). Evapotranspiration (ETO) values were much higher in each experimental year than precipitation even in the vegetation period. In the years 2019 and 2020 March and April were seriously drier and warmer than the long-term average influencing the growth of winter cereals as winter wheat and winter barley grown in the experiment in tillering growth stage negatively resulting in less crop density.

Future climate challenges in the Pannonian Region

According to the projected temperature and precipitation changes higher temperature values are likely to occur in the future, and warmer conditions tend to occur if greater radiative forcing change is assumed. In the case of precipitation, larger variability emerges, but for July, a clear decreasing trend is projected. The rainfall variability index shows that the number of dry years will be 5–20 from the 30-year time series in the mid-century and extremely dry conditions will tend to occur in 2–12 years (Kis, et al. 2020).

The estimated changes in climatic conditions including increasing temperature, with particular attention to the summer means, together with the expected changes in the temporal precipitation distribution pose an enormous challenge to agriculture. Climate change will most likely expose a significant negative impact on the spring-sown crops in Hungary. Although the yield losses could be avoided with irrigation or could be mitigated with earlier sowing, the role of winter crops is likely to become more significant in Hungary in the future (Pokovai, et al., 2020).

In the site of Hungarian LTE-s (Keszthely, Western Hungary, Central Europe, Pannonian Region) a significant decreasing trend of 0.2–0.7 mm/year precipitation was highlighted statistically (Kocsis et al., 2020).

Cropping systems description

Treatments

The part of the experiment that analysed within the SoilCare project consists of 6 treatments with the following codes in the SoilCare Database and the analysis following and only the one field (replication) selected.

UP_EX1_TR1= N0 + no organic

UP_EX1_TR2= N0 + FYM

UP_EX1_TR3= N0 + St + GM

UP_EX1_TR4= N3 + no organic

UP_EX1_TR5= N3 + FYM

UP_EX1_TR6= N3 + St + GM

The treatments above are combinations of level from two factors, mineral N fertilization and three variants of organic fertilizers.

- The mineral N fertilizer rates are 0 and 210 kg/ha N in case of maize, 0 and 150 kg/ha N for winter wheat and 0 and 120 kg/ha N for winter barley in the N0 and N3 abbreviation respectively and is applied in the form of solid Calcium Ammonium Nitrate.
- The organic fertilizer treatments were applied as complementary fertilization with mineral NPK fertilizers having three different variants: no organic fertilizer application (no organic), organic farmyard manure (FYM) application (35 t/ha, in every third year before maize), and straw/stalk (St) incorporation (completed with 10 kg mineral N for each t straw/ha). The total amount of residue yield of all the three crops that were produced on each plot was measured and incorporated into the soil. Also, after winter barley on the 'St' plots, extra green manure (GM) was applied (Raphanus sativus var. Oleiformis) as a second crop sowing on the barley stubble.

Field operations

As mentioned, the treatments were applied in a field with a 3-year cereal crop rotation (maize, winter wheat, winter barley) system. Maize is planted in April and harvested in October, whereas winter wheat and winter barley are normally seeded in October and harvested in July. Mouldboard ploughing at 25 cm and all soil and pest managements were applied as usual in conventional farming systems. Supplemental P and K fertilizers at rates of 100 kg/ ha, P_2O_5 and 100 kg/ ha, K_2O was applied on all the experimental plots (even on the N0 plots). In the field analysed in 2018 maize sown and followed by winter wheat that harvested in July 2019 and then winter barley sown in October 2019 and harvested in July 2020.

Bio-physical data analysis – WP5

Method

Differences between treatments for all variables analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

For the yield and other crop-related characteristics change also the relative values of the SICS treatments compared to the control, calculated to exclude the effect of the different crops in the rotation and analyse only the treatments and date effects.

Data

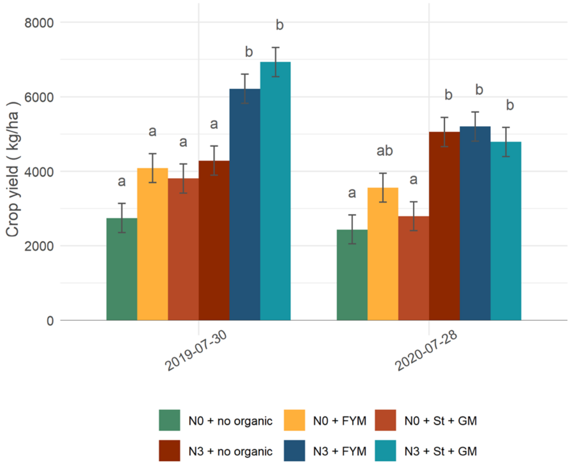
In the table. you can find the variables measured and analysed for this experiment.

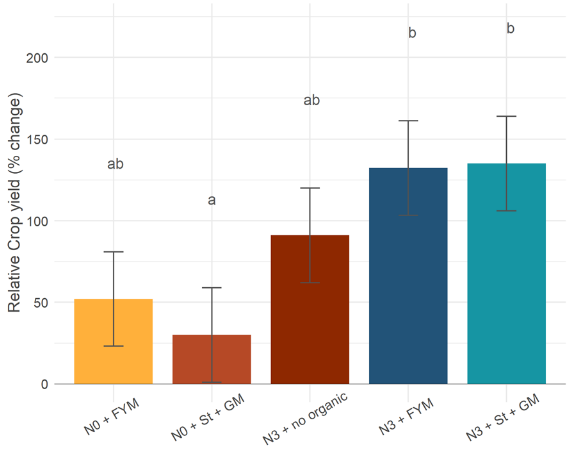
Table 3:Indicators measured and analysed

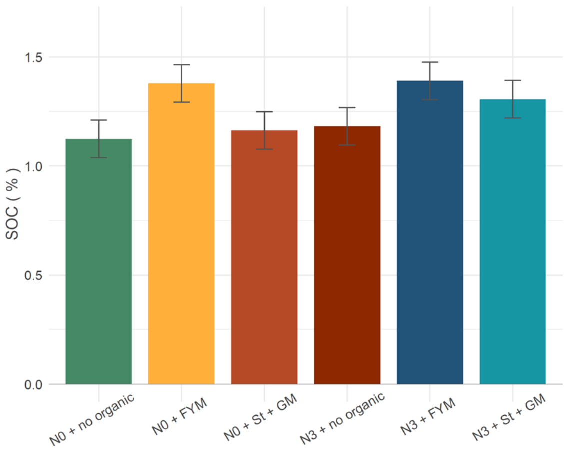
Observation code	Unit	Description
ksat	cm/h	Saturated hydraulic conductivity
wsa		Water stable aggregates
bd_top	g/cm^3	Bulk density top
bd_bot	g/cm^3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorus
soc	%	SOC

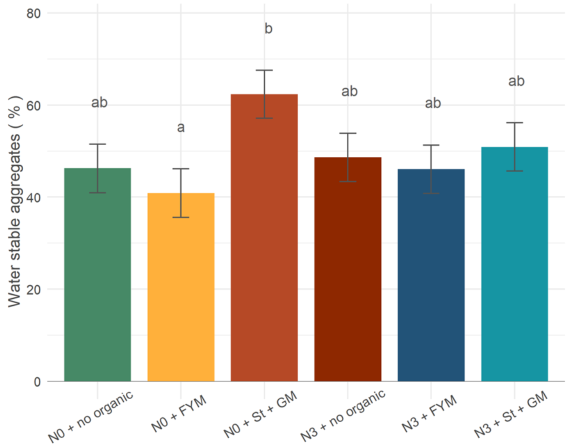
ph_kcl	_	pH in KCl
ph_h2o	_	pH in water
earthworm_no	no/m^2	Earthworm number
microb_biom_c	µgC_micg^{-1}DM	Microbial biomass carbon
crop_yield_ha	kg/ha	Crop yield
CEC	cmol+/kg	Cation Exchange Capacity

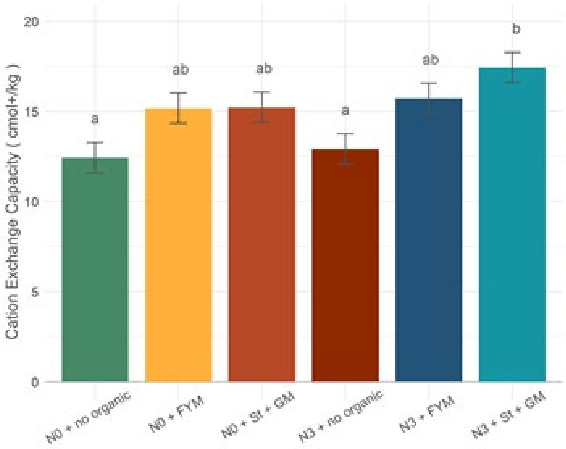
Results

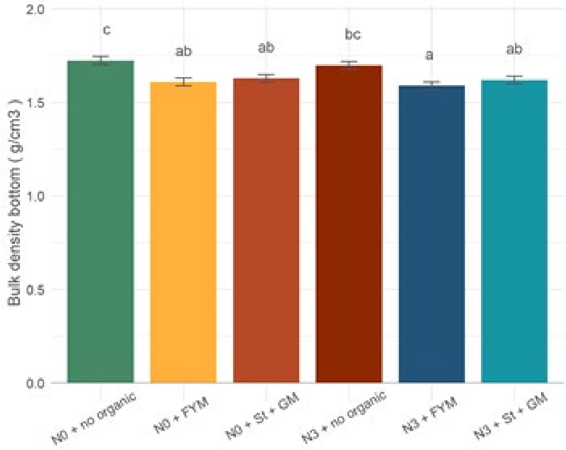












Analysis

Yield

Organic amendments either FYM or St+GM influenced yield values positively even in 2019 when winter wheat was grown in the 2nd year after FYM application. The yield increase was significant when organic amendments were applied in combination with mineral N fertilizer. In 2020 when winter barley was grown, no significant effect of organic amendments was detected, only FYM resulted in higher (but not significant) yield on the N0 plots in the 3rd year after FYM application.

Soil Organic Carbon (SOC)

FYM increased SOC but not statistically significant as an effect of long-term application (since 1983) both in the case of N0 or N3 variants. St+GM amendment resulted in moderate SOM increase, only when the N3 rate was applied, presumably due to the larger amount of crop biomass produced in the N fertilized variant. SOM increasing effect of FYM was higher than that of St+GM. This can be explained by better availability of fresh straw - as a labile form of organic C - for decomposition processes, than a more stable form of organic substances after a fermentation process during maturation of FYM (Hannula et al. 2021).

Water stable aggregates (WSA)

St+GM addition resulted in significantly higher WSA values compared to FYM application. WSA results are consistent with SOM results, since not SOC is responsible for soil structural stability itself, but other forces and effects play a role also. Such an effect has resulted from microbiological processes since during Soil Organic Matter decomposition adhesive materials are created (eg.

polysaccharides) resulting in higher aggregate stability. This positive effect on WSA lasts as long as the microbiological activity is high.

Cation Exchange Capacity (CEC)

CEC is an important soil characteristic providing nutrient holding, retention and buffering capacity of the soil, influencing soil structure stability. As an effect of organic amendments, CEC values of soil increased either in N0 or N3 plots. CEC increasing effect was significant when St+GM was applied in combination with mineral N fertilization (N3+St+GM) compared to the "no organic" variants.

Bulk Density (BD)

The measurement of BD gives the level of soil porosity. Soil porosity determines the water and air management characteristics of the soil. Either total porosity or functional distribution of pore sizes important. The lower the BD the higher the total porosity. On the other hand, the higher the BD the lower the total porosity. BD of compacted soils are also higher, so BD is often used as a measure of soil compaction. In the cultivated soil layer, BD can easily be changed by soil tillage. In the layers below the depth of tillage total porosity cannot be increased by soil cultivation, even as an effect of soil compaction it can be decreased resulting in higher BD values. That is why the role of other soil and crop management technologies is very important in sustaining high soil porosity level (low BD) to provide high water infiltration capacity and good aeration. As an effect of organic amendments, BD values were significantly lower in most of the combinations than in "no organic" variants providing better infiltration and aeration of the soil. Besides, lower BD values mean less compacted status, so root development can be also better in these plots.

Study site analysis

Both variants of organic amendment resulted in positive influences on soil properties as well as on productivity. Less risk for soil degradation (compaction induced by traffic while spreading) and weed infestation as well as higher economic sustainability occurred, when Straw was left on-field and recycled back into the soil.

The positive effect of St+GM on WSA is very important and it is following the findings reported by Hannula et al. (2021) from the same experiment. In this research functional diversity of fungi was evaluated including UP_EX1 experiment. According to this as an effect of stalk/straw addition, there was a consistent increase in fungal saprotrophs (effect sizes of 0.244 for HUN1 and 0.054 for DEN1, respectively) in straw treatments. While manure addition seemed to have negative effects on the relative abundance of saprotrophs (effect sizes of -0.120 for HUN1, -0.218 for HUN3 and -0.186 for

BEL2). These tendencies can also be explained by better availability of fresh straw - as a labile form of organic Carbon - for decomposition processes, than a more stable form of organic substances after a fermentation process during maturation of farmyard manure (FYM).

Socio-cultural dimension

Table 4: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

a)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.13	1.00	Complete
Workload	-0.33	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	1.00	1.00	Complete

b)

SICS: UP_EX1_TR6 (St+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.60	1.00	Complete
Workload	1.00	1.00	Complete
Perceived risks	0.00	1.00	Complete
Farmer reputation	1.00	1.00	Complete

c)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR6 (St+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.16	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Amongst organic amendments Straw incorporation proved to be the best regarding the socio-cultural analysis. The main reason for this is despite the yield increasing effect of FYM, it is compensated by the higher benefit (income) value of selling straw in no organic control plots. FYM application has many positive effects on soil properties, but it can also be a potential risk to promote weed infestation and soil compaction during spreading. Better soil quality and lower use of external inputs resulted in an effect of FYM are granted by the farmer reputation.

Economical dimension

Table 5: Summary of the benefits of SICS (SICS vs. control).

a) this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	AMT control	**AMT SICS**
Agricultural management technique	Straw is harvested and sold	FYM applied in each 3rd year
Investment costs	0	0
Maintenance costs	25	31
Production costs	89,6	109,2
Benefits	1194,2	1079
Summary = benefits - costs	1080	939
Percentage change	15%	

AMT means agricultural management practice

b) this case shows a neutral impact of SICS in comparison to the control, the numbers are in euro/ha

SICS: UP_EX1_TR6 (St+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	AMT control	AMT SICS
Agricultural management technique	Straw is harvested and sold	Straw left on-field and incorporated
Investment costs	0	0
Maintenance costs	25	0
Production costs	89,6	0
Benefits	1197,5	1054,1
Summary = benefits - costs	1083	1054
Percentage change	3%	

AMT means agricultural management practice

c) this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR6 (St+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	AMT control	AMT SICS
Agricultural management technique	Straw left on-field and incorporated	FYM applied in each 3rd year
Investment costs	0	0
Maintenance costs	0	31
Production costs	0	109,2
Benefits	1054	1079
Summary = benefits - costs	1054	939
Percentage change	12%	

AMT means agricultural management practice

The costs of straw harvesting, manipulation and transport, as well as FYM spreading are not compensated totally by the higher income (benefits) of higher yield. On the other hand, in no organic (control) variant extra income by straw selling compensate either the cost of straw harvest, manipulation and transport or lower income.

There were no significant differences between the summaries of no organic and St variants.

Overall analysis and main findings

Table 6: Impact of SICS on the overall sustainability

a)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.06	1.00	Complete
Environmental dimension	0.34	1.00	Complete
Economic dimension	-0.12	1.00	Complete
Socio-cultural dimension	-0.13	1.00	Complete
Physical properties	0.43	1.00	complete
Chemical properties	0.24	1.00	complete
Biological properties	0.25	1.00	complete

b)

SICS: UP_EX1_TR6 (St+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.44	1.00	Complete
Environmental dimension	0.37	1.00	Complete
Economic dimension	0.38	1.00	Complete
Socio-cultural dimension	0.60	1.00	Complete
Physical properties	0.27	1.00	complete
Chemical properties	0.66	1.00	complete
Biological properties	0.25	1.00	complete

c)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR6 (St+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.15	1.00	Complete
Environmental dimension	0.22	1.00	Complete
Economic dimension	0.38	1.00	Complete
Socio-cultural dimension	-0.16	1.00	Complete
Physical properties	0.33	1.00	complete
Chemical properties	0.22	1.00	complete
Biological properties	0.15	1.00	complete

Overall sustainability was the best when straw was left on the field summarizing all aspects. FYM application also resulted in good sustainability regarding biophysical parameters, but economically it was the least effective comparing to the no organic (control) and St variants. This statement is correct when the market price of straw is high. As soon as the price of straw decreases economic evaluation of FYM application can be better.

Table 7: Benefits and drawbacks of the SICS as compared to the control group

a)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Benefits:	generally higher yield and better biophysical parameters;
Drawback:	higher costs are not compensated by the higher-income risk of weed infestation and soil compaction during spreading;

b)

SICS: UP_EX1_TR6 (St+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR4 (no org.+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Benefits:	generally higher yield and better biophysical parameters;
Drawback:	higher risk of maintenance of pests and diseases;

c)

SICS: UP_EX1_TR5 (FYM+N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Control: UP_EX1_TR6 (St+ N3 (N3: 210 (maize), 150 (wheat), 120 (barley) kg/ha N)

Benefits:	good biophysical condition, higher level of nutrient recircling in farm; less external nutrient
Drawback:	poorer aggregate stability and profitability;

Organic Amendments generally increased yield even in combination with mineral N fertilizer. Soil properties generally were also improved by their application. FYM especially increased SOC, while St+GM increased WSA values. Both amendments increased CEC and decreased BD values providing higher nutrient holding and buffering capacity, increasing soil structure stability, as well as better infiltration and aeration of the soil, enhancing better root growth.

These amendments are the by-products of farming. FYM is produced in mixed farms dealing with crop production and animal husbandry as well. Extra costs of production and value of FYM are compensated by the incomes of animal husbandry. The extra expenditures – as high as 140 EUR/ha - occurs by harvesting straw and loading spreaders and broadcasting on the field are recovered by the extra yield in the next 2 years, and other extra benefits can be detected in soil properties. When FYM application is compared to St addition both economic efficiency and environmental impact is better in the case of St recycling.

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Report 2 on Monitoring and Analysis of Soil Cultivation experiment

Study Site number: 3

Country: Hungary

Author(s): Zoltan Toth & Attila Dunai

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): University of Pannonia

Experiment: Soil Cultivation

Version: 2

Date: 22-02-2021

Experiment description

The main objective of the soil cultivation long-term field experiment is to evaluate the effect of crop rotation, levels of nitrogen fertilization and soil cultivation on soil properties and system sustainability. The experiment established in 1972 and was set up in strip-plot -randomized complete block design with four replications. The factors of the experiment are the increasing rate of mineral N fertilization and the different soil cultivation methods in maize wheat biculture. (maize-maize-wheat-wheat).

Experimental field information

The experiment is conducted on an experimental field managed by the researchers jointly with farmers. The experimental field is located in Keszthely in the western part of Hungary at an altitude of about 119 m and covers an area of about 16000 m^2. The topsoil has a sandy loam texture according to the USDA classification system.

Details about the soil profile and the location can be found in Report 1.

The climate of the experimental field area

The Soil Cultivation experiment is located within 100m distance from UP_EX1, so climatic conditions are considered the same.

Details about the climatic conditions can be found in Report 1.

Cropping systems description

Treatments

The part of the experiment that analysed within the SoilCare project consists of 4 treatments with the following codes in the SoilCare Database and the analysis following:

UP_EX2_TR1 = Conventional + N0

UP_EX2_TR2 = Conventional + N2

UP_EX2_TR3 = Minimum+N0

UP_EX2_TR4 = Minimum+N2

The treatments above are combinations of level from two factors, mineral N fertilization and two different soil cultivation methods.

- The mineral N fertilizer rates are 0 and 180 kg/ha N in the case of maize, 0 and 160 kg/ha N for winter wheat in the N0 and N2 abbreviation respectively.

- The conventional tillage method is based on deep winter ploughing of 25 cm whereas the minimum tillage refers to disking just before sowing at 15 cm depth.

Field operations

The treatments are applied in a field with maize, winter biculture (maize-maize-wheat-wheat). The years monitored and documented in this report, maize planted in 2018 and followed by 2 years of wheat (2019,2020). Maize is planted in April and harvested in October, whereas winter wheat is normally seeded in October and harvested in July. Supplemental P and K fertilizers at rates of 100 kg/ha, P_2O_5 and 100 kg/ha, K_2O was applied on all the experimental plots (except the N0 plots)

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model

Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

For the yield and other crop-related characteristics change also the relative values of the SICS treatments compared to the control, calculated to exclude the effect of the different crops in the rotation and analyse only the treatments and date effects.

Data

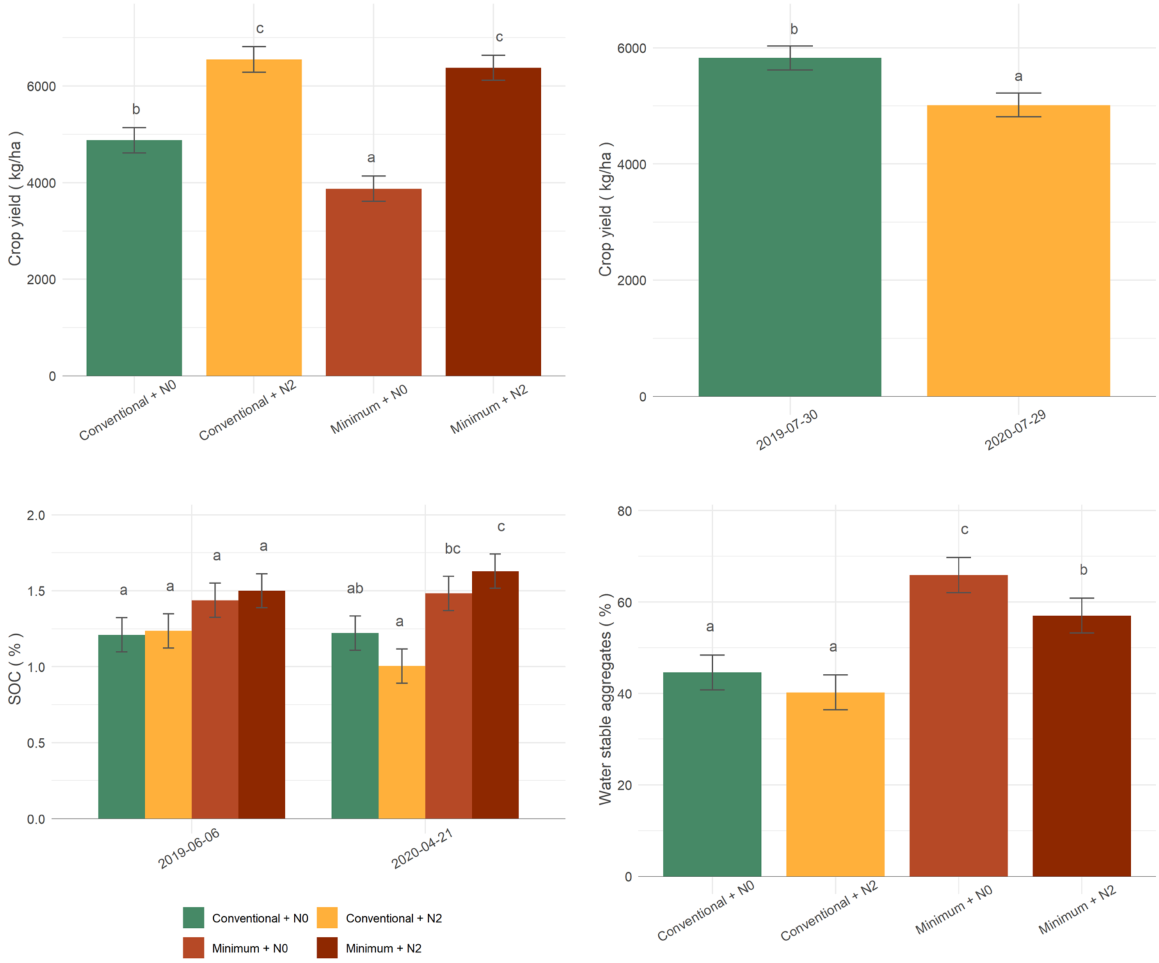
In the table. you can find the variables measured and analysed for this experiment.

Table 8:Indicators measured ana analysed

Observation code	Unit	Description
ksat	cm/h	Saturated hydraulic conductivity
wsa		Water stable aggregates
bd_top	g/cm^3	Bulk density top
bd_bot	g/cm^3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorus
soc	%	SOC
ph_kcl	_	pH in KCl

ph_h2o	_	pH in water
earthworm_no	no/m^2	Earthworm number
microb_biom_c	µgC_micg^{-1}DM	Microbial biomass carbon
crop_yield_ha	kg/ha	Crop yield
CEC	cmol+/kg	Cation Exchange Capacity

Results



Analysis

<u>*Crop Yield*</u>

The yield of cereals was significantly lower in the minimum tillage variant on N0 plots. When mineral N fertilizer was applied, yield level increased significantly in both tillage variants and there was no significant difference between conventional and reduced tillage. In 2020 wheat yielded less than in 2019. In the previous year of the rotation, Maize yield was higher in the minimum tillage variant. When averaged over the rotation period, minimum tillage resulted in slightly higher yields than conventional tillage.

Soil Organic Carbon (SOC)

Minimum tillage resulted in higher SOC values, due to less soil disturbance and consequently less intensive mineralisation both in N0 and N2 variants. SOC increasing effect was significant in 2020 on N2 plots.

Water Stable Aggregates (WSA)

Aggregate stability was significantly increased by minimum tillage. The highest values of WSA were measured in the minimum tillage variant when no mineral N fertilizer was applied (N0). Application of mineral N fertilizer (Calcium Ammonium-Nitrate) resulted in a significant WSA decrease.

Study site analysis

Minimum tillage is proved to be an effective alternative to soil management providing similar or even higher level of yield through better water conservation, positively influencing other soil properties as microbial biomass carbon, SOC and WSA, providing better conditions for conserving soil against degradation.

Socio-cultural dimension

Table 9: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

SICS: UP_EX2_TR4 (Minimum tillage +N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

Control: UP_EX2_TR2 (Conventional tillage + N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.20	1.00	Complete
Workload	0.50	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Reduced tillage proved to be advantageous, since performed better results than conventional tillage except for perceived risk due to the higher probability of weed infestation.

Economical dimension

Table 10: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha.

SICS: UP_EX2_TR4 (Minimum tillage+N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

Control: UP_EX2_TR2 (Conventional tillage + N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

	AMT control	AMT SICS
Agricultural management technique	Conventional tillage	Reduced tillage
Investment costs	0	0
Maintenance costs	14	9
Production costs	178.5	220.3
Benefits	1050	1170
Summary = benefits - costs	858	941
Percentage change	-9%	

AMT means agricultural management practice

Reduced tillage resulted in a similar yield in the case of wheat, but a higher yield in the case of maize. The economic analysis was done on yield values averaged over maize and wheat as rotated in the experiment. The economical benefit of AMT SICS (reduced tillage) was 9 % higher than AMT control.

Overall analysis and main findings

Table 11:Impact of SICS on the overall sustainability.

SICS: UP_EX2_TR4 (Minimum tillage +N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

Control: UP_EX2_TR2 (Conventional tillage + N2 (N2: 180 (maize), 160 (wheat) kg/ha N)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.07	1.00	Complete
Environmental dimension	0.00	1.00	Complete
Economic dimension	0.04	1.00	Complete
Socio-cultural dimension	0.20	1.00	Complete
Physical properties	0.03	1.00	complete

Chemical properties	0.13	1.00	complete
Biological properties	0.05	1.00	complete

Socio-cultural acceptance and economical sustainability of reduced tillage are better than conventional tillage, however, more pesticides might be used and some of the soil physical properties are poorer than in conventional tillage (eg. water infiltration and penetration resistance).

Table 12: Benefits and drawbacks of the SICS as compared to the control group

Benefits:	Aggregate stability; SOC; Earthworm density; Yield quality; Reduction of workload; Farmer reputation improved; Cost-benefit;
Drawback:	Infiltration; Penetration resistance; Mineral nitrogen; pH; Weed diseases; Potential economic risk; Potential risk of crop failure;

As an effect of minimum tillage yield level of cereals decreased, but it was compensated by mineral N fertilizer application. When mineral N was applied there was no significant difference in yield. When maize yield is also involved in the analysis and yield data is averaged over the rotation, SICS (reduced tillage) performed slightly better.

Reduced tillage had a positive effect on soil properties as SOC, WSA, CEC and Microbial Biomass Carbon.

Minimum tillage also results in lower labour hour as well. On the other hand, due to less mechanical weed control, weed infestation is more serious than in conventional tillage. Consequently, minimum tillage may require more chemical weed control.

Summarizing the advantages and disadvantages of minimum tillage it can be concluded that the production level of AMT Control and SICS are close to each other. Besides, reduced tillage applications have many positive effects on soil properties, providing better soil physical and biological status. These advantages compensate for the negative impacts of more intensive chemical weed control needed.

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I.4 Centre for Development and Environment, University of Bern (Switzerland)

Report 1 on Monitoring and Analysis of the CULTAN experiment

Study Site number: 4

Country: Switzerland

Author(s): Abdallah Alaoui, Roger Bär, Felicitas Bachmann

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): CDE, University of Bern

Experiment: CULTAN

Figure 1: Injection of the fertilizer (CULTAN)

Version: Complete

Date: 19-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to compare the effects of different fertilization methods and materials. Different fertilization techniques are applied next to each other to compare their impact on nitrogen losses (emission in the atmosphere or leaching in the groundwater), the accessibility of nutrients for crops, the nutrients uptakes by the plants, the diversity of the microbial community, and the crop quality and yield: The experiment was established in May 2018 and was set up in control versus treatment (elementary) experimental design. The treatments are replicated three times in two different experimental fields.

Experimental field information

The experiment is conducted on two farm fields which are managed by farmers in Frauenfeld, Switzerland. The first field (UNIBE_FD3 in the database) is located at an altitude of about 389 m and covers an area of about 4500 m^2. The topsoil has a silty loam texture according to the USDA classification system. The second field (UNIBE_FD4 in the database) is located at an altitude of about 392 m and covers an area of about 8740 m^2. The topsoil has a silty loam texture according to the USDA classification system.

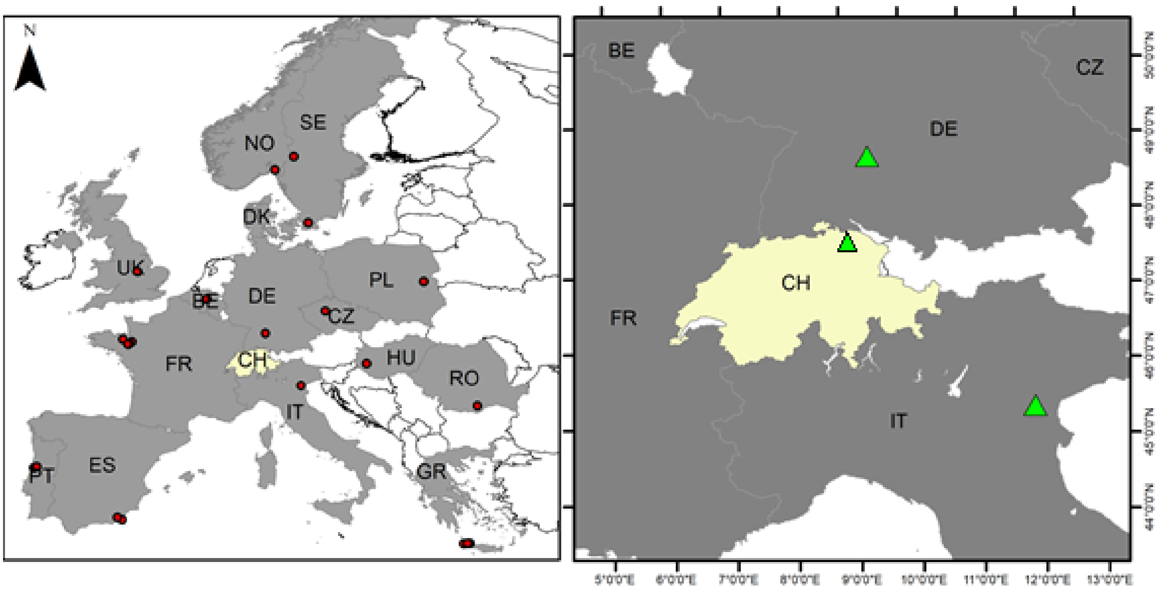


Figure 2: Location of the study site

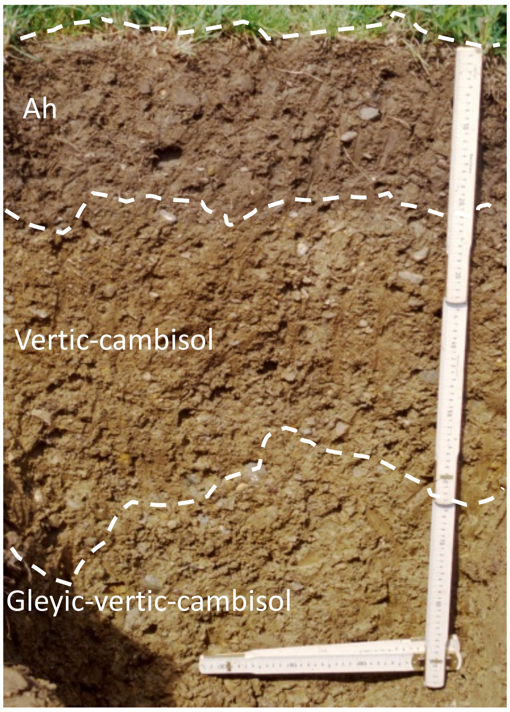


Figure 3: Soil profile of the region of Frauenfeld

In the region of Frauenfeld, the soil is classified as a Cambisol according to the WRB taxonomy. The horizon differentiation is weak. Soil is about 1 m in depth and is composed by the horizon Ah of 10-15 cm of about 3.2 % humus. Below, a vertic cambisol is often found between 15 and 40 cm. Below 40 cm depth, the soil horizon is classified as gleyic vertic cambisol. In the arable land of the region of Frauenfeld, tillage causes the organic material (litter layer) to decompose, humify and mineralise more quickly. Therefore, some farmers introduce an artificial meadow as an intermediate stage that has a structure-regenerating effect.

The climate of the experimental field area

For the experiments around Frauenfeld, a longstanding station is in Konstanz, Germany at the Boden See. In ECAD (number 495) the data started in 1947 up to November 2020 (including). The station is at 443m ASL. Frauenfeld itself has a station at 393m ASL, but no recent data are available on temperature. Aadorf Tanikon at 539m ASL and Salen-Reutenen at 718 m ASL cover from 1970 to 2020. Please note that in general, a temperature lapse is in the order of magnitude of 0.6 °C/100 m. Also, the rainfall varies depending on the altitude.

Table 1: Yearly values for Tmin, Tmax, Precipitation and ET0

Station	Period/year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
Konstanz (ECAD495)	1961-90	13.2	5.6	849.0	764.0
Aadorf Tanikon	2018	15.5	5.6	912.1	916.1
Salen Reutenen	2018	13.7	6.6	659.2	771.6
Aadorf Tanikon	2019	14.8	4.9	1196.3	865.1
Salen Reutenen	2019	12.8	6.2	811.8	707.0
Aadorf Tanikon	2020	15.2	5.2	1106.4	876.0
Salen Reutenen	2020	13.2	6.4	748.7	719.8

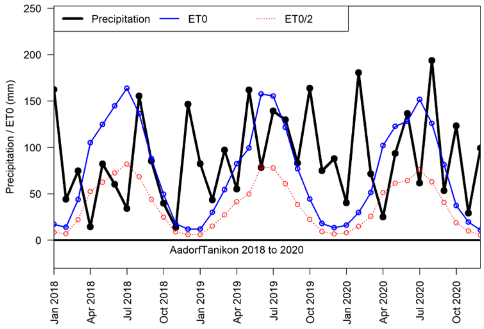


Figure 4: 4bAadorfTanikon 00aFAOgrow

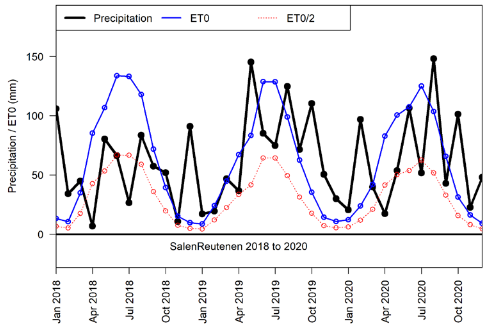


Figure 5: 4cSalenReutenen 00aFAOgrow

Both in 2018 and 2020 a dry April was experienced. The longer-term 1961-90 period shows relatively higher rainfall during the summer.

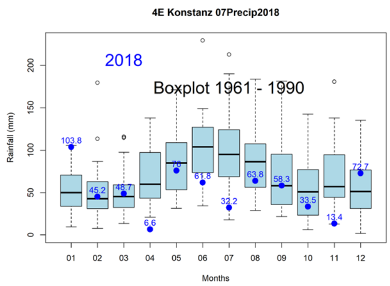


Figure 6: 4E Konstanz 07Precip2018box

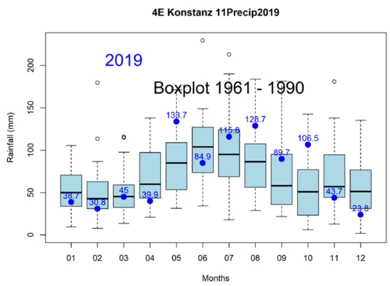


Figure 7: 4E Konstanz 11Precip2019box

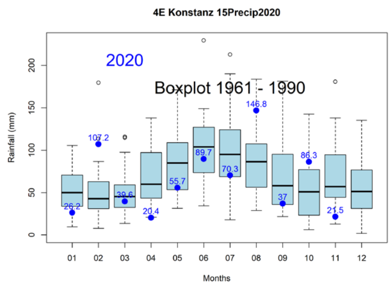


Figure 8: 4E Konstanz 15Precip2020box

Cropping systems description

Treatments

The experiment analysed within the SoilCare project consists of 3 treatments with the following codes in the SoilCare Database and the analysis following.

UNIBE_EX2_TR1 = CULTAN

UNIBE_EX2_TR2 = Mineral

UNIBE_EX2_TR3 = Organic

The amount of fertilizer was calculated to reach a total of 145 kg N per ha as a target, including initial fertilizer and farmyard manure.

CULTAN: Manuring, Nitrogen fertilization is applied directly into the soil. Punctual fertilization and not spreading the fertilizer all over the soil (Ammonium nitrate sulphate, liquid) AMS liquid fertilization; AMS: ammonium sulphate (NH4)2SO4; 21% as NH4-N; 24% as SO4-S applied with CULTAN. The NH4-fertilizer is placed in highly concentrated depositions into the soil

Mineral: Mineral conventional manure (Lonza Sol N); Nitrogen fertilization with spreader; 80% pig manure and 20% Lonza-Sol N (Lonza-Sol N: 9.8% as ammonium-N; 9.8% as nitrate-N; 19.5% as urea-N N applied with centrifugal spreader (surface application).)

Organic: Conventional organic manure (2/3 pig manure and 1/3 cattle manure: 1.9kg N/m^3, 1.9kg P/m^3;2.4 kg K/m3, applied with drag hose technique.)

Field operations

Ecological performance record (PER)-cropping farm with livestock and pig farming. The farm manager and contractor apply minimal tillage (disk harrow at 12 cm) and produce fodder cereals, grain maize, and sugar beet. There is not ploughing since 1997 and no use of glyphosate since 2011. The land consists of 67 ha totally, 53 ha as arable land and 11 ha as permanent pasture with green manure.

The management operation in the fields includes minimum tillage crop rotation and incorporation in the soil of the crops planted as green manure before the sowing. In the FD3 the main crops were: 2018 Silage maize, 2019: winter wheat followed by green manure (phacelia, sunflower, *Avena sativa Lr*), 2020 maize. For FD4 the main crops are 2018: *Sinapis alba*, 2019 Winter wheat, 2020: Rapeseed.

Bio-physical data analysis – WP5

Methods

- For analysing the indicators, the raw values averaged per date and treatment for each field separately and are presented. The standard deviation is presented with dashed lines and represent the variation in the thee replicate plots per field (when measurements existed in all plots on the same days).
- The analysis was done by field as the dates of sampling and the response variable did not coincide to group the results.

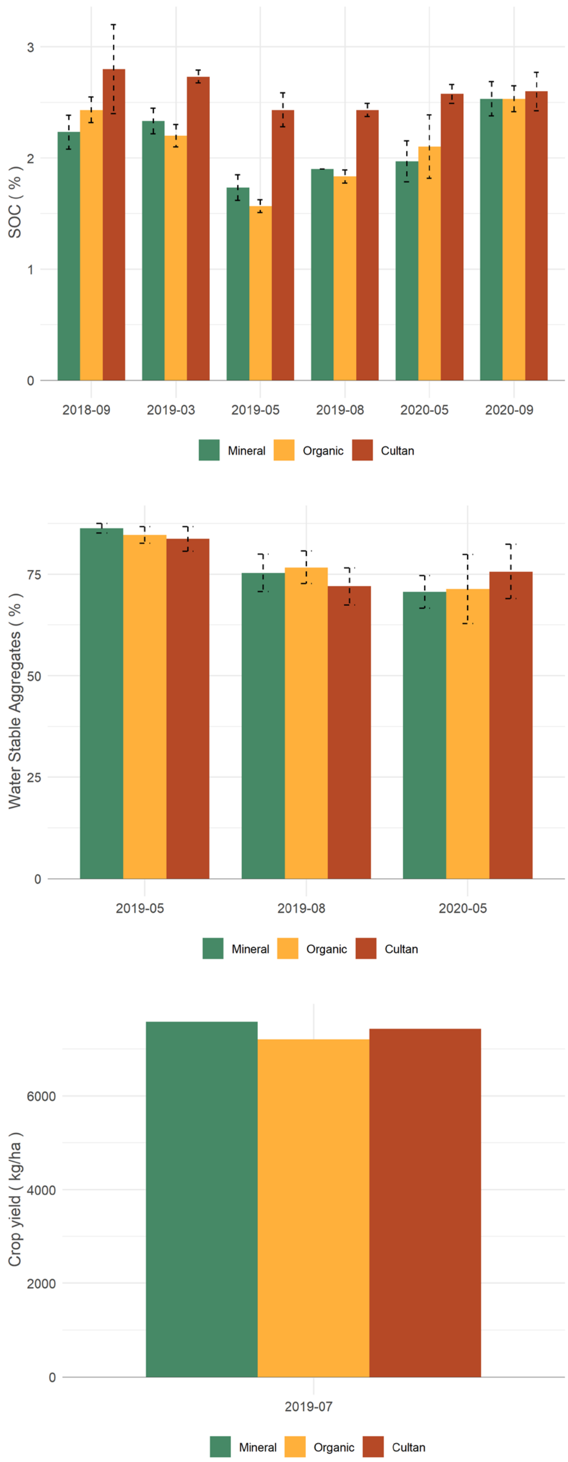
Data

In the table, you can find the variables measured and analysed for this experiment in all treatments. Results for all variables can be found in ANNEXE II.

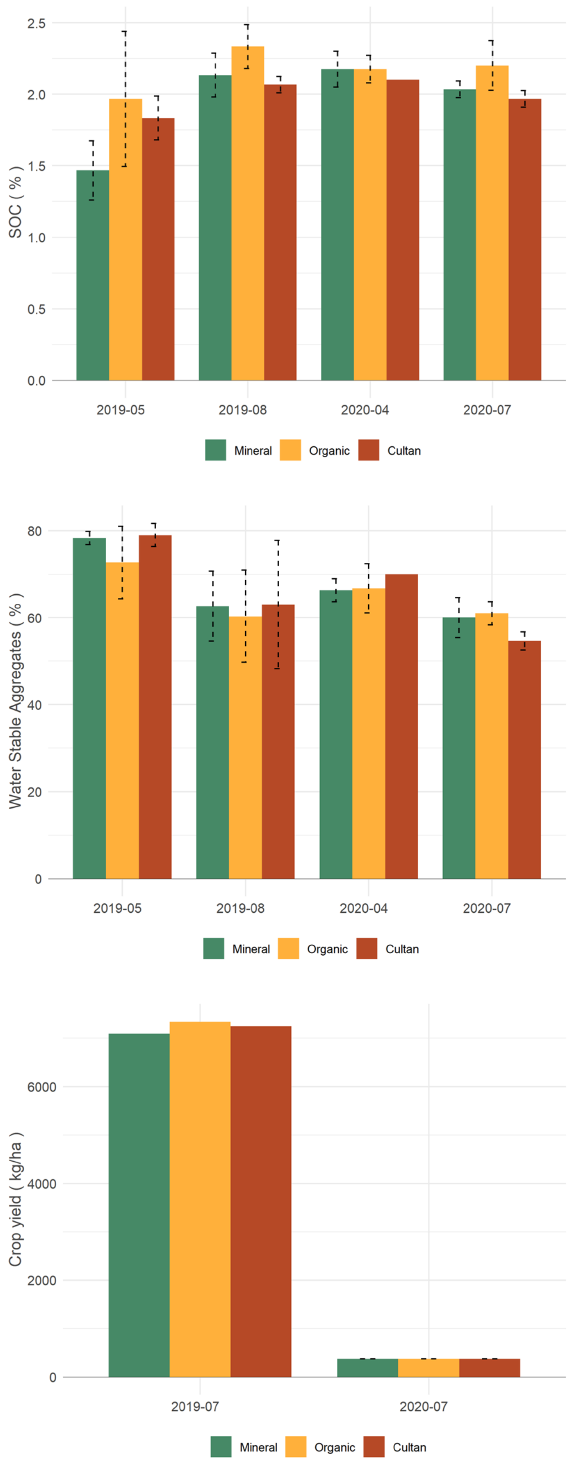
Observation code	Unit	Description
ksat	cm s^{-1}	Ksat
top_wc_pf2_0	m3m-3	Water content-FC
top_wc_pf4_2	m3m-3	Water content-PWP
top_wc_pf2_7	m3m-3	Water content-pF2.7
top_wc_pf_1_8	m3m-3	Water content-pF1.8
top_satur_wc	m3m-3	Water content-Saturation
wsa	%	Water Stable Aggregates
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
weed_infestation	%	Weed infestation
crop_yield_ha	kg/ha	Crop yield

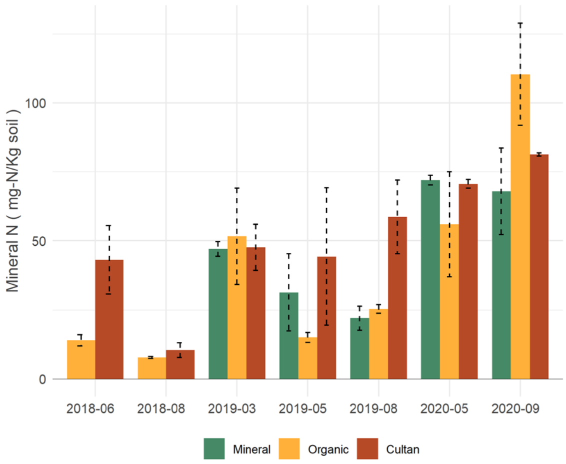
Results

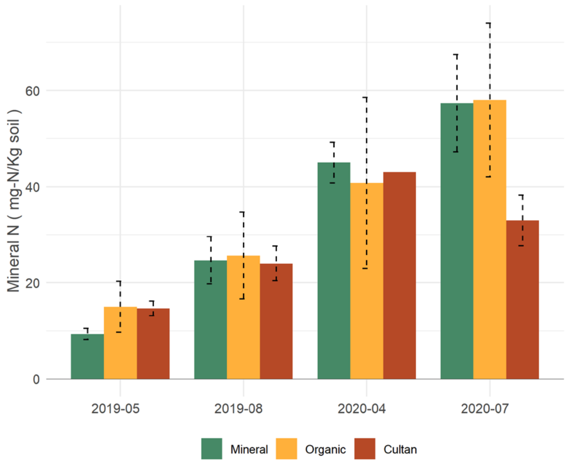
A) FD3



B) FD4







Analysis

Traditionally, fertilizers are applied on the soil surface, and the nitrogen is left to leach to the root level with precipitation or irrigation. The Controlled Uptake Long-Term Ammonium Nutrition method (CULTAN) designed and popularized by K. Sommer (Sommer, 2003). CULTAN is one of the promising methods to deposit a highly concentrated solution of ammonium sulphate in the rooting zone to avoid excessive losses of reactive nitrogen, such as a nitrogen amendment corresponding to the crops' needs, chemical speciation of the nitrogen fertilizer, and improved timing and method of fertilizer application (Cameron et al., 2013). According to the literature, it is hypothesized that CULTAN has the following benefits:

Frame Ammonium ions are tightly bound to the soil resulting in reduced leaching into the groundwater and long-term nutrition of plants.

Leaching of mobile nitrates into the groundwater is reduced, as the inhibition of nitrifying bacteria diminishes the conversion of Ammonium ions to Nitrites, then nitrates, and injection confines it to the proximity of the root tips. The formation of detrimental nitrogen oxides NO_x, mainly produced during the denitrification process, is assumed likewise to be diminished.

More efficient nitrogen assimilation by the plants results in an increased crop yield.

Thus, CULTAN could temporarily induce immobilization of mineral nitrogen and thus reduce the risk of nitrate leaching to groundwater during winter. It could promote nutrient uptake by the plant (N, P, K, C, micronutrients).

CULTAN was used two times on the field, 6.06.2018 and 20.04.2019, while sampling campaigns took place during different periods after the application (20.09.2018; 26.03.2019; 20.05.2019, and 6.08.2019), the relatively high mineral nitrogen measured in SICS as compared to the control, can attest to relative nitrogen assimilation by the plants (Mineral N, FD3). However, this observation cannot be generalized for all observation periods, nor Field FD4.

While SOC values relatively improved if FD3 for some periods, it remains comparable to the SOC value of the control treatment in FD4. The comparison between the values of the remaining properties of SICS and control (1 and 2) do not show a difference (e.g. soil properties and crop yield). Continuous measurements should shed light on the benefits of CULTAN from a long-term perspective.

Socio-cultural dimension

SICS: UNIBE_EX2_TR1 (UDE-CULTAN)

Control 1: UNIBE_EX2_TR3 (UDK1-org. conventional (pig manure))

Control 2: UNIBE_EX2_TR2 (UDK2-min. conventional (Lonza-Sol))

CULTAN fertilization shows a slightly positive result in terms of socio-cultural sustainability. CULTAN fertilization slightly reduces the farmer’s workload, because, in contrast to the control treatments, no labour input is needed for preparing manure. Practising CULTAN fertilization is not perceived to involve any risk nor to impact the farmer’s reputation. However, an inconvenience is that CULTAN fertilization requires special machinery, to which not every farmer currently has access.

Table 2: Impact of SICS on the socio-cultural dimension as compared to both control groups (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.20	1.00	Complete
Workload	0.50	1.00	Complete
Perceived risks	0.00	1.00	Complete
Farmer reputation	0.00	1.00	Complete

Economical dimension

While the other costs remain the same, the adoption of CULTAN implies significant additional costs related to the production (Table 3). It consists mainly of supplementary machinery and products.

Table 3: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to both control groups, the numbers are in euro/ha.

	AMT control 1	**AMT control 2**	**AMT SICS**
Agricultural management technique	Organic–Conventional (Pig manure)	Mineral–conventional (Lonza-Sol)	CULTAN
Investment costs	0	0	0
Maintenance costs	0	0	0
Production costs	164.2	137.2	270.2
Benefits	1080	1137	1087.5
Summary = benefits - costs	915.8	999.8	817.3
Percentage change	12.0	22.3	

AMT means agricultural management technique; the costs of investment and maintenance are the same for all treatments and are not detailed in the assessment

Overall analysis and main findings

The assessment of the overall sustainability of the SICS (CULTAN) is negative, which is due to a) the increase in production costs resulting from the fact that special machinery is required and b) that the expected benefit of more efficient nitrogen assimilation by plants resulting in higher yields could not be demonstrated. Nevertheless, a positive effect is that the SICS slightly reduces the farmer's workload (Table 3).

Table 4: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.16	0.91	High
Environmental dimension	-0.10	0.78	Medium
Economic dimension	-0.60	1.00	Complete
Socio-cultural dimension	0.20	1.00	Complete
Physical properties	-0.05	0.85	High
Chemical properties	-0.22	0.85	High
Biological properties	-0.05	0.65	Medium

The high cost of SICS implementation was due to the costs related to the equipment necessary for the CULTAN injection (Table 4). A more generalized adoption of this technique by a large community of farmers would decrease the costs related to the equipment necessary for this technique.

Table 5: Benefits and drawback of the SICS

Benefits:	Reduction of workload;
Drawback:	Mineral nitrogen; Cost-benefit;

References

- Cameron K.C., Di H.J., Moir J.L. (2013). Nitrogen losses from the soil/plant system: a review. Ann. Appl. Biol., 162, 145–173. (doi:10.1111/aab.12014).
- Jérémie L. (2019). SoilCare for Profitable and Sustainable Crop Production in Europe. Interim report; Centre for Development and Environment, CDE, University of Bern, Switzerland, pp 95.
- Sommer, K. 2003. Grundlagen des CULTAN- Verfahrens, In: Kücke, M., (Ed.) Anbauverfahren mit N-injektion (CULTAN), Ergebnisse, Perspektiven, Erfahrungen (Beiträge des Workshops am 29. November 2001 in Braunschweig). Bundesforschungsantalt für Landwirthschaft (FAL), Landbauforschung Völkenrode, Sonderheft 245 (FAL Agricultural Research, Special issue 245), 1–22.

Report 2 on Monitoring and Analysis of the Glyphosate experiment

Study Site number: 4

Country: Switzerland

Author(s): Abdallah Alaoui, Roger Bär, Felicitas Bachmann

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): CDE, University of Bern

Experiment: Glyphosate

Version: Complete

Date: 19-02-2021

Experiment description

The main objective of the experiment is to compare the effects of glyphosate use to destroy the green manure applied in the field resulting in bare soil in comparison with green manure staying in the field. The experiment was established in June 2018 and was set up in a control versus treatment (elementary) experimental design. The treatments are replicated three times in two different experimental fields.

Experimental field information

The experiment is conducted on two farm fields that are managed by farmers. The first field close to "*Ellikon an der Thur*", Switzerland (UNIBE_FD5 in the database) is located at an altitude of about 403m and covers an area of about 16400 m^2. The topsoil has a silty loam texture according to the USDA classification system. The second field (UNIBE_FD6 in the database) is located in Trüllikon, Switzerland at an altitude of about 479 m and covers an area of about 18900 m^2. The topsoil has a silty loam texture according to the USDA classification system.

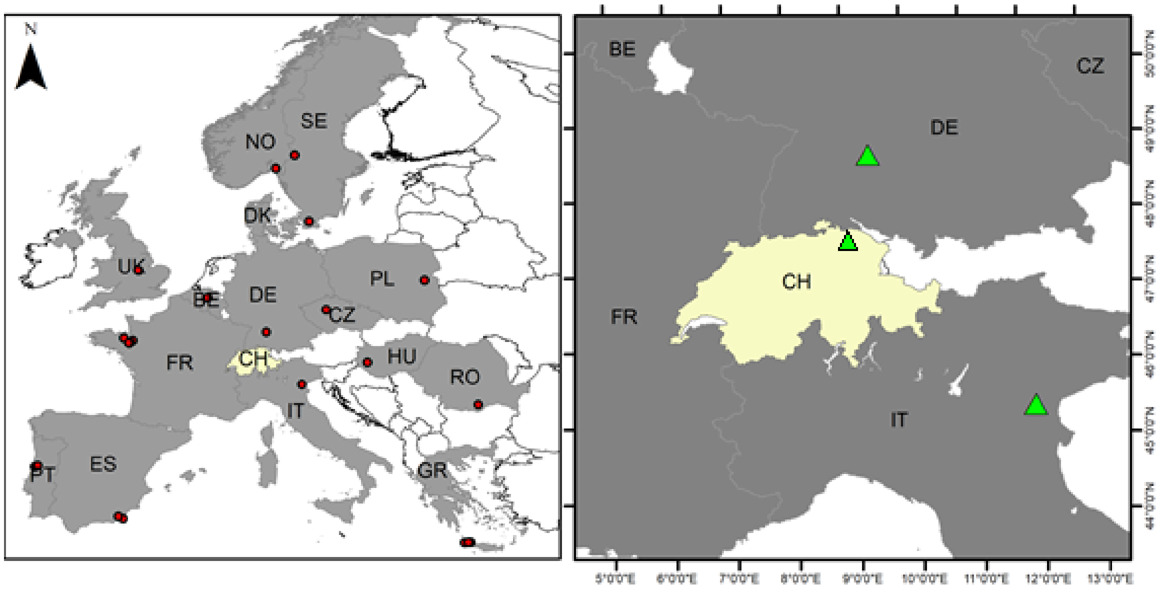


Figure 9: Location of the study site

The climate of the experimental field area

See the first report for the meteorological information.

Cropping systems description

Treatments

The experiment that analysed within the SoilCare project consists of 2 treatments with the following codes in the SoilCare Database and the analysis following.

UNIBE_EX3_TR1 = No glyphosate

UNIBE_EX3_TR2 = Glyphosate

- No glyphosate: Green manure (intercropping), is applied in the field and stays on the plots.
- Glyphosate: Green manure is applied in the field and gets destroyed with glyphosate resulting in bare soil.

Field operations

The management operation in the fields includes minimum tillage (disk harrow at 5 cm), and crop rotation. In the FD5 the main crops were: 2019: sugar beet, 2020: onions and the green manure was yellow mustard. For FD6 the main crops are 2019: sugar beet, 2020: potatoes. The green manure included the following crops: Large grain legumes, sunflower, phacelia and oat. Different fertilizers are applied to both fields as well as several chemicals (pesticides, insecticides etc.) according to the needs.

Bio-physical data analysis – WP5

Methods

- For analysing the indicators, the raw values averaged per date and treatment for each field separately and are presented. The standard deviation is presented with dashed lines and represent the variation in the three replicate plots per field (when measurements existed in all plots on the same days).
- The analysis was done by field as the dates of sampling and the response variable did not coincide to group the results.

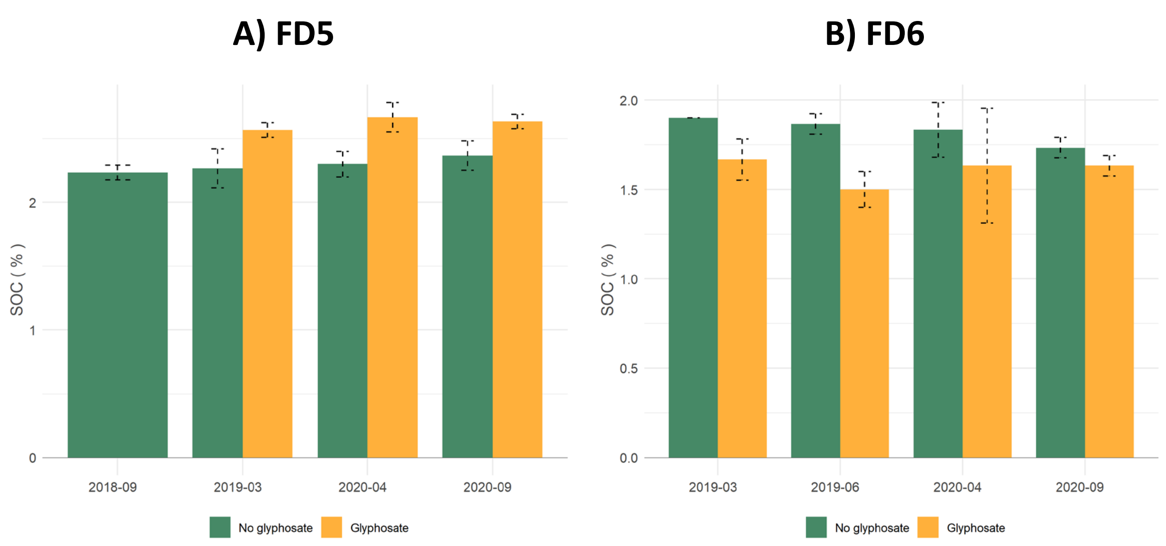
Data

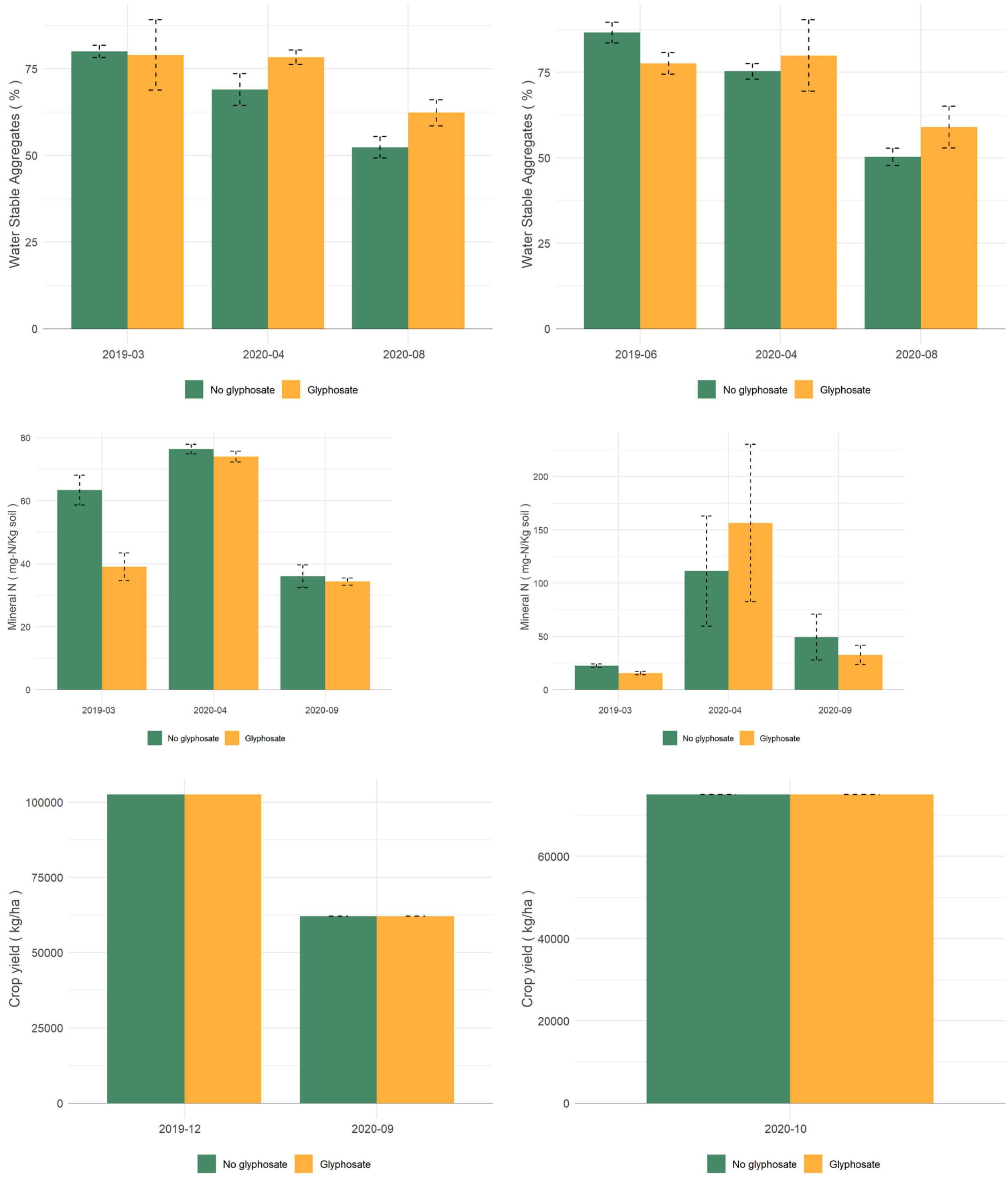
In the table, you can find the variables measured and analysed for this experiment in all treatments. Results for all variables can be found in the ANNEXE II.

Observation code	Unit	Description
ksat	cm s^{-1}	Ksat
top_wc_pf2_0	m3m-3	Water content-FC
top_wc_pf4_2	m3m-3	Water content-PWP
top_wc_pf2_7	m3m-3	Water content-pF2.7

top_wc_pf_1_8	m3m-3	Water content-pF1.8
top_satur_wc	m3m-3	Water content-Saturation
wsa	%	Water Stable Aggregates
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
weed_infestation	%	Weed infestation
crop_yield_ha	kg/ha	Crop yield

Results





Analysis

Results show no difference between most properties of SICS and the control, e.g. K_{sat}, bulk density, mineral nitrogen, pH, crop yield, crop cover characteristics and weed infestation. For the aggregate stability (in FD5 and FD6) and SOC (in FD5), there was a slight deterioration due to the SICS implementation. These results should be seen in the context of a transition phase between the extensive use of glyphosate and the no glyphosate use and should be considered as encouraging. However, there are two main challenging issues to address to adopt sustainable management practices: (i) inform the farmer about the impact of using pesticides on environmental, animal, and human health, and (i) support financially the farmer for the complete transition.

Study site analysis

The major soil threats existing at this site are: compaction, erosion, a decline in SOM, decline in soil biodiversity, and soil contamination (excess of nutrients, persistent organic pollutant)
The target objectives of SICS implementation are the increase of biodiversity, increase in SOM, alleviate soil erosion by a permanent cover crop, reduced need for pesticides (mustard green manure suppress weeds), alleviate soilborne diseases and nematodes, and improvement of water infiltration rate. The effect on biodiversity, yield and quality would be important properties to investigate.

Socio-cultural dimension

SICS: UNIBE_EX3_TR1 (USE-Green Manure, no pesticide)
Control: UNIBE_EX3_TR2 (USK-naked soil, glyphosate)

The SICS rates slightly positive in terms of socio-cultural aspects, because the benefits of the SICS are widely recognized and it has no negative effect on workload. The main drawback perceived is the risk that some plants or weeds might survive winter, which would negatively affect the quality and quantity of the following sugar beet crop.

Table 6: Impact of SICS on the socio-cultural dimension as compared to the control group

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.10	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Economical dimension

SICS: UNIBE_EX3_TR1 (USE-Green Manure, no pesticide)

Control: UNIBE_EX3_TR2 (USK-naked soil, glyphosate)

The assessment of the economical dimension shows a slight decrease in cost-benefit resulting mainly from the production costs. However, the percentage change is negligible. It is worse to highlight the fact that the cost-benefit was reported to the same surface area, while in reality the SICS was implemented in 0.144 ha and the control in an area of 1.5 ha. This means that increasing the surface area of SICS will probably increase workload and perceived risk while the increase of the surface area of the control will increase the production costs.

Table 7: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to both control groups, the numbers are in euro/ha.

	AMT control	AMT SICS
Agricultural management technique	Naked soil, glyphosate	Green Manure, no pesticide
Investment costs	0	0
Maintenance costs	0	0
Production costs	548.7	528.5
Benefits	1147.4	1104.5
Summary = benefits - costs	598.7	576
Percentage change	3.9	

Overall analysis and main findings

The overall sustainability deteriorated slightly with the implementation of the SICS (Table 7). The deterioration of the environmental dimension results from the negative changes in aggregate stability and SOC. However, these changes were relatively small when comparing qualitatively the values of the control and the ones of the SICS. Besides, the potential risk of crop failure increases (Table 8).

Table 8: Impact of SICS on overall sustainability.

SICS: **UNIBE_EX3_TR1** (USE-Green Manure, no pesticide)

Control: UNIBE_EX3_TR2 (USK-naked soil, glyphosate

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.03	0.86	High
Environmental dimension	-0.15	0.64	Medium
Economic dimension	-0.01	1.00	Complete
Socio-cultural dimension	0.10	1.00	Complete
Physical properties	-0.05	0.75	Medium
Chemical properties	-0.31	0.75	Medium
Biological properties	-0.10	0.55	Medium

Table 9: Benefits and drawback of the SICS

Benefits:	Farmer reputation improved;
Drawback:	Aggregate stability; SOC; Potential risk of crop failure; Cost-benefit;

References

Den Herder G, Parniske M. 2009. The unbearable naivety of legumes in symbiosis. Curr. Opin. Plant Biol. 12:491–99

General conclusions based on all the experiments

Experiment 2:

The benefits of CULTAN can be summarized as follows:

Frame Ammonium ions are tightly bound to the soil resulting in reduced leaching into the groundwater and long-term nutrition of plants.

Leaching of mobile nitrates into the groundwater is reduced, as the inhibition of nitrifying bacteria diminishes the conversion of Ammonium ions to Nitrites, then nitrates, and injection confines it to the proximity of the root tips. The formation of detrimental NOx, mainly produced during the denitrification process, is assumed likewise to be diminished.

More efficient nitrogen assimilation by the plants results in an increased crop yield. Thus, CULTAN could temporarily induce immobilization of mineral nitrogen and thus reduce the risk of nitrate leaching to groundwater during winter.

Based on the results obtained in this report, the following highlights of using CULTAN can be summarized as follows:

There is a need to adapt the manuring balance to the needs of the crop to avoid losses of reactive nitrogen. Considering nitrogen inputs from the atmosphere and the soil. The relatively high mineral nitrogen measured in SICS as compared to the control can attest to relative nitrogen assimilation by the plants although this observation cannot be generalized for all observation periods.

While SOC values relatively improved if one field for some periods, it remains comparable to the SOC value of the control treatment in the other field.

Adopting CULTAN could result in high soil biodiversity and could help to reduce N_2O emissions and increase plant access to nutrients. However, it requires an extra effort to adjust its dosage to the needs of the crops under consideration.

Experiment 3

The modest results obtained while comparing the performance of SICS with one of the controls consisting of the no change in the major measured properties attest to the promising use of an alternative to pesticides (green manure).

The main drawback perceived due to the SICS implementation is the risk that some plants or weeds might survive winter, which would negatively affect the quality and quantity of the following sugar beet crop.

Farmer's practices are far removed from sustainable farming. There is a need to continue encouraging and supporting him to proceed without pesticides for his practices. To his credit, sustainable beet cultivation is not yet well established. Pests can lead to a significant loss in yield. These considerations show that without concrete support such as subsidies, this task will be challenging.

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I.5 Aarhus University (Denmark)

Report 1 on Monitoring and Analysis

Study Site number: 5

Country: Denmark

Author(s): Chiara De Notaris, Gitte Holton Rubaek, Tommy Dalgaard

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Aarhus University

Experiment: CROPSYS

Version: Complete

Date: 15-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate how soil health would be affected in the long-term by the inclusion of grass/clover or grain legumes in the rotation, the use of cover crops and fertilization with animal manure, and to compare organic and conventional cropping. The experiment was established in 1997 and was set up in a factorial design with 2 blocks, containing 32 plots each as there is a combination of 8 treatments and 4 crops.

Experimental field information

The experiment is conducted on an experimental station managed by researchers. The experimental field is located in Viborg, Denmark at an altitude of 4m. The topsoil has a sandy loam texture according to the USDA classification system.

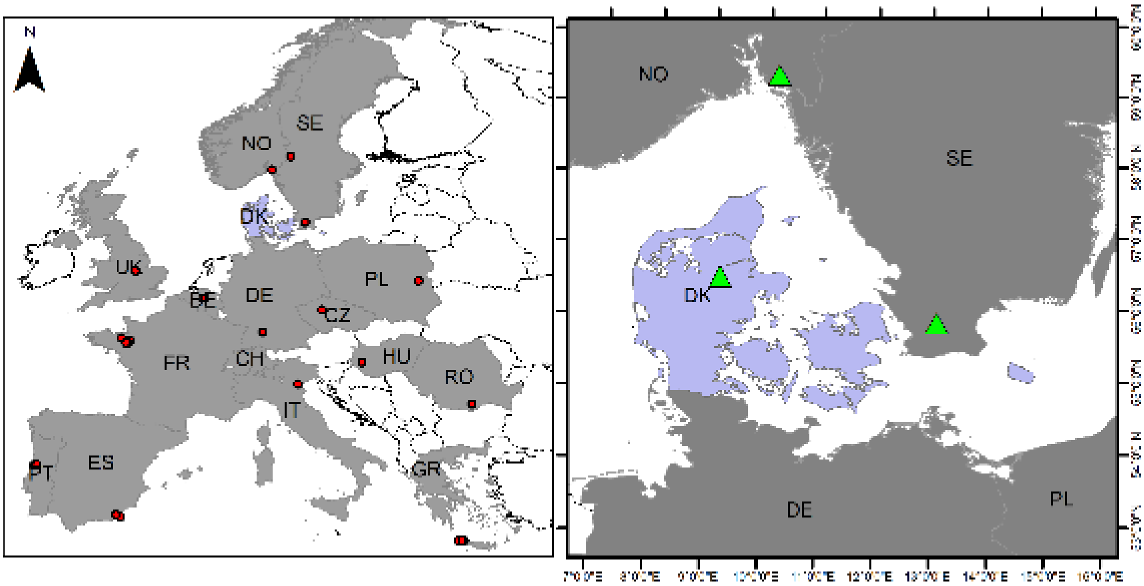


Figure 1: Location of the study site

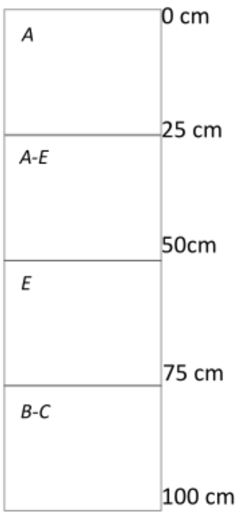


Figure 2: Soil profile horizons

According to the soil profile of 1 m described in 1996, there are 4 horizons (Djurhuus and Olesen, 2000), with a maximum rooting depth to be more than 2 m as observed in October 2006 and 2007 (Sapkota et al., 2012).

The climate of the experimental field area

The experimental farm Foulum near the experiments has a meteorological station with data available from 01/01/2014 till now. Unfortunately, Denmark provides a very limited amount of stations to ECAD and very little on the mainland. The station Gronbaek-Allingskovgard only contains Precipitation and does not include 2020. This series started in 1872 with precipitation and, strangely, no temperature is available in ECAD for this station. Therefore this station was used for the Precipitation normal 1961-90 only and compared to that of Foulum. The nearest temperature data in ECAD are at 80 km from Foulum, and rather along the coast and quite different.

Table 1:Average yearly Tmax, Tmin, Precipitation and ET0 for the normal 1961-90 and 2018, 2019 and 2020

Station	Period/year	Tmax	Tmin	Precip	ET0
		°C	°C	mm	mm
Gronbaek	1961-90	NA	NA	703.6	NA
Foulum	2018	12.5	5.8	539.0	802.7
Foulum	2019	12.3	5.7	893.0	751.8
Foulum	2020	12.8	6.0	703.5	765.1

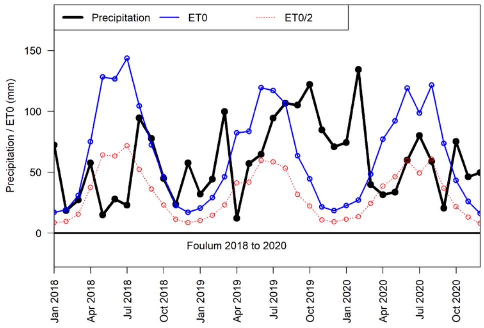
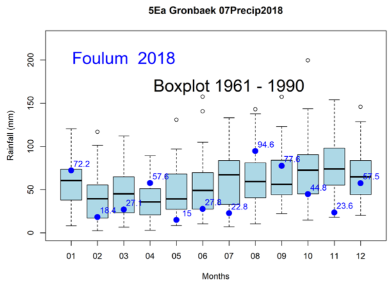
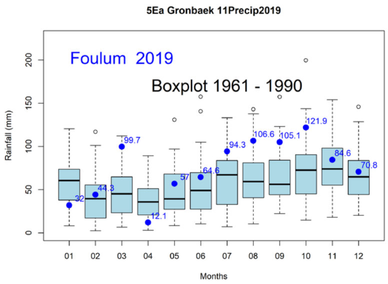


Figure 3: 5aFoulum 00aFAOgrow





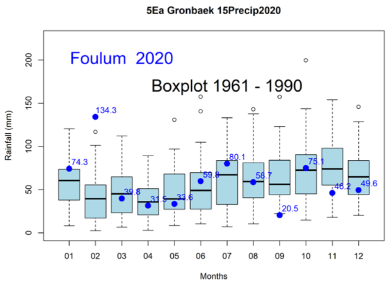


Figure 4: 5Ea Gronbaek 07Precip2018box *Figure 5: 5Ea Gronbaek 11Precip2019box* *Figure 6: 5Ea Gronbaek 15Precip2020bo*

The year 2018 was characterized by an unusually dry summer, thus four irrigation events were performed (145 mm in total).

Cropping systems description

Treatments

The experiment consists of 8 treatments with the following codes in the SoilCare Database and the analysis following.

AU_EX1_TR1= O2/+M/-CC

AU_EX1_TR2= O2/-M/+CC

AU_EX1_TR3= O2/+M/+CC

AU_EX1_TR4= O4/+M/-CC

AU_EX1_TR5= O4/-M/+CC

AU_EX1_TR6= O4/+M/+CC

AU_EX1_TR7= C4/+F/-CC

AU_EX1_TR8= C4/+F/+CC

where:

O2: Organic rotation with one-year green manure

O4: Organic rotation with one-year grain legume

C4: Conventional rotation with one-year grain legume

-CC: Without cover crop

+CC: With cover crop

-M: Without animal manure

+M: With animal manure

+F: With mineral fertilizer

A four-course rotation with all crops presents every year is used. The O2 rotation included spring barley *(Hordeum vulgare L.),* oats *(Avena sativa)* and spring wheat *(Triticum aestivum),* whereas C4 and O4 included spring barley *(Hordeum vulgare L.),* faba beans *(Vicia faba L.)*, oats *(Avena sativa)* and spring wheat (*Triticum aestivum*). The planting of the main crops is happening between April and May and harvesting in August. The cover crop was grass vegetation in C4 and a legume-grass mixture in O2 and O4.

The plots of the treatments that get mineral fertilizer receive an NPK (21-3-10 or 0-4-21) mineral fertilizer. The animal manure which is injected in the relevant treatments has a CN ration of 7.35 and about 40% C and the average amount that is applied per plot is 1607 kg/ha.

Field operations

Different tillage operations are performed depending on the crop and rotation. These include harrowing, rolling, ploughing, and inter-row hoeing, in all plots except those with green manure (O2-grass vegetations) and blind harrowing (not in all the plots -just Vicia faba in C4, not in grass vegetations in O2). Irrigation was applied according to the needs.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model

Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

For the yield change, the relative values of the treatments compared to the control (Treatment 7) were calculated to exclude the effect of the different crops and analyse only the treatments effect. For each block, the yield values for the 4 different crops for the control treatment 7 (C4+F-CC) were found, and the relative yield change for the other treatments compared to this one was calculated.

Data

In the table, you can find the variables measured and analysed for this experiment. Results for all variables can be found in the ANNEXE II.

Table 2:Indicators measures and analysed

Observation code	**Unit**	**Description**
top_wc_pf2_0	m3m-3	Water content at FC
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
p_avail	mg-P/100gr Soil	Available P
soc	%	SOC
ph_kcl	_	pH
earthworm_no	no/m2	Earthworms
tot_N	%	Total N
air_perm	um2	Air permeability
pore_org	um2	Specific permeability
k_avail	mg K/100 gr soil	Available K
mg_avail	mg Mg/100 gr soil	Available Mg

extr_c	g C/kg soil	Extractable C
crop_yield_ha	kg/ha	Crop yield
crop_N	%	N content-harvest material
covercrop_DM	kg/ha	Cover crop aboveground biomass
covercrop_N	%	N content-aboveground biomass

Results

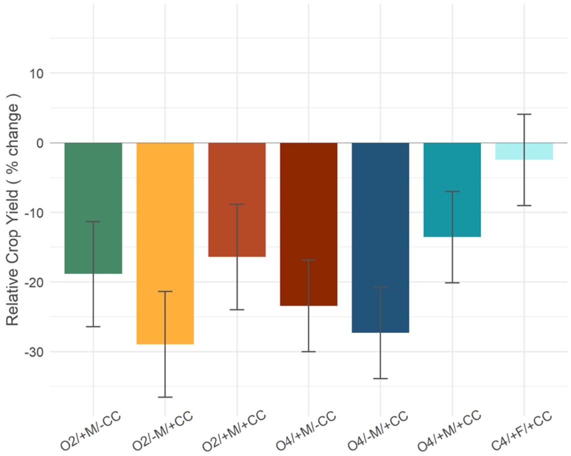


Figure 7: Relative yield change for the cash crops compared to the control treatment.

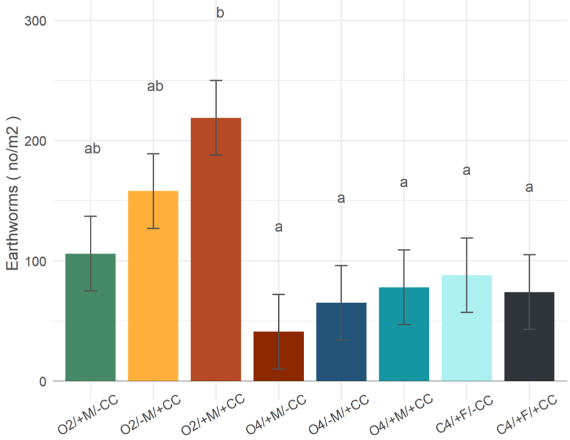


Figure 8: Earthworm abundance in different treatments

Analysis

In this field experiment, organic treatments had lower yields compared to the control (conventional without cover crops), but the yield gap was alleviated by the use of cover crops and animal manure. Earthworm abundance was the greatest in O2, thanks to the inclusion of one year of legume-based ley. Also, earthworms were particularly abundant in treatments with cover crops. This points to a joint effect of good quality litter availability and reduced soil disturbance by cultivation, which was less frequent in treatments with cover crops. Soil physical properties had only small variations between treatments, with no treatment being in critical conditions. Bulk density was the greatest in the control treatment (C4+F-CC) and the lowest in O4+M-CC, which was the treatment with the most frequent harrowing. The latter treatment was also the one with the greatest air permeability, even though no significant differences could be determined. Nutrient availability at the time of sampling varied between treatments, in response to the use of cover crops and animal manure and due to differences in the export of nutrients with crops between treatments. This was due to both short and long-term processes, such as the temporary immobilization of P in cover crop biomass and the depletion of P in organic treatments without animal manure, where no P was added for more than 20 years.

Study site analysis

The small differences in soil organic carbon (SOC) observed between treatments in 2019 reflected the same variation as observed at the start of the experiment, with the current treatment setup starting in 2005. Thus, the change in SOC was small and similar for all treatments, with no clear difference between organic and conventional.

Table 3: Soil organic carbon (SOC) in the different treatments in 2005 and 2019

Rotation	Fertilizer	Cover crop	SOC (%) 2005	SOC (%) 2019
O2	+M	+CC	2.3	2.4
		-CC	2.0	2.1
	-M	+CC	2.0	2.1
O4	+M	+CC	1.9	2.1
		-CC	2.2	2.3
	-M	+CC	2.1	2.3
C4	+F	+CC	2.2	2.2
		-CC	1.9	2.0

Socio-cultural dimension

The socio-cultural setting for farmer's implementation of the identified SICS in form of cover crops in systems with (and without) use of manure, has been favourable.

Since the cooperative dairy and slaughterhouse movement, and driven by lucrative export markets to The UK and other early industrial nations, Danish agriculture and production have been dominated by livestock farming, and the use of livestock manure resources to nourish both plants and soils have been an important agenda for farmers. Moreover, since the mid-1980'es legislation has ensured policy measures to support farm implementation, and therefore in general the SICS implementation has been effective, however with some farmers complaining of the needs to plant cover crops all over, also in fields where perceived not needed. Therefore, the SoilCare demonstration of SICS effectiveness has been timely and well-received, in particular also in the later years, where carbon sequestration and thereby greenhouse gas mitigation has furthermore been high on the agenda.

Economical dimension

The main function of the cover crop is to reduce N leaching at an estimated rate of 12 kg/ha N-leaching reduced per treatment year. The cost is very low, as the ryegrass is under-sown together with the cereal seeds, and 6 kg/ha of 50 DKK/kg (approx. 300 DKK/ha).

According to Eriksen et al. (2014*) the partial budget economic cost of reducing N leaching with the SICS is 5 DKK/kg N, if annually N the leaching is reduced to 12 kg N. However, as also the case in the study site, the whole crop rotation is changed when implementing spring cereal crops with cover crops (catch crops), and the total production economic cost of these changes is in line with Eriksen et al. (2014*) estimated to 157 DKK/kg N if the annually N leaching is reduced to 12 kg N. *) http://dnmark.org/wp-content/uploads/2015/01/Virkemiddelkatalog.pdf.

Overall analysis and main findings

A negative yield change was observed in all organic treatments compared to the control (conventional without cover crops), but the gap was reduced by the use of cover crops and animal manure, as also reported by Shah et al. (2017) in a previous study on the same long-term crop rotation experiment. Nutrient and especially nitrogen (N) availability is an important limiting factor for crop yield in organic systems, thus SICS that can improve the availability and recirculation of N in the system can increase the yield. In O4 and O2, cover crops were a mixture of legume and non-legume species, serving the double function of reducing N losses via leaching and adding N through biological N_2 fixation (De Notaris et al., 2021). In C4, no positive effect of cover crops on crop yield was observed, indicating that no N limitation was present. On the other hand, cover crops in C4 did not include legumes, thus a limited N residual effect of cover crops in C4 could be part of the reason.

The inclusion of one year of legume-based ley had a positive effect on earthworms, which were more abundant in O2 compared to O4 and C4. Cover crops had a positive effect on earthworms as well. The availability of good quality litter and reduced soil disturbance is known to be beneficial for earthworms, and the results from this study can confirm it.

At the start of the experiment, the clay/SOC ratio was 4, indicating good soil structural stability (Dexter et al., 2008). In 2019, soil physical properties and SOC content were similar across treatments, with only small variations which did not result in any treatment being in critical conditions. Given the high initial structural stability of the soil, all the treatments tested in this experiment managed to maintain good soil physical properties. It should be noted that no “extreme” treatments were included, as even the control conventional treatment had a four-year crop rotation and limited soil disturbance.

Inorganic treatments, cover crops and animal manure affected the availability of nutrients in the soil at the time of sampling, due to both short and long-term processes (e.g., temporary immobilization of P in cover crop biomass and depletion of P in organic treatments without animal manure). Overall, no treatment had critically low contents of any nutrient, also due to the supply of potassium sulfate to all organic treatments.

References

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General conclusions based on the experiment

The use of cover crops, animal manure and legume-based leys can maintain or improve soil physical, chemical and biological properties while reducing the yield gap between organic and conventional production. This is particularly relevant in organic arable systems, where the availability of nutrients may be limited.

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I.6 GWCT Allerton Project (UK)

Report 1 on Monitoring and Analysis of Compaction Alleviation Experiment

Study Site number: 6

Country: United Kingdom

Author(s): Jenny Bussell, Chris Stoate

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): GWCT Allerton Project

Experiment: Compaction alleviation

Version: 2

Date: 18-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate the effect of different physical and biological ways to alleviate or minimise the impacts of soil compaction in a direct drilling system. The experiment established in 2017 and was set up in randomized complete block design with three replication blocks, containing 4 plots each, 3 for the SICS treatments and 1 for the control treatment.

Experimental field information

The experiment is conducted on a farm field managed by the researchers in collaboration with the farm manager. The experimental field is located in Loddington, Leicester, UK, at an altitude of about 140 m and covers an area of about 3400 m^2. The topsoil has a clay texture.

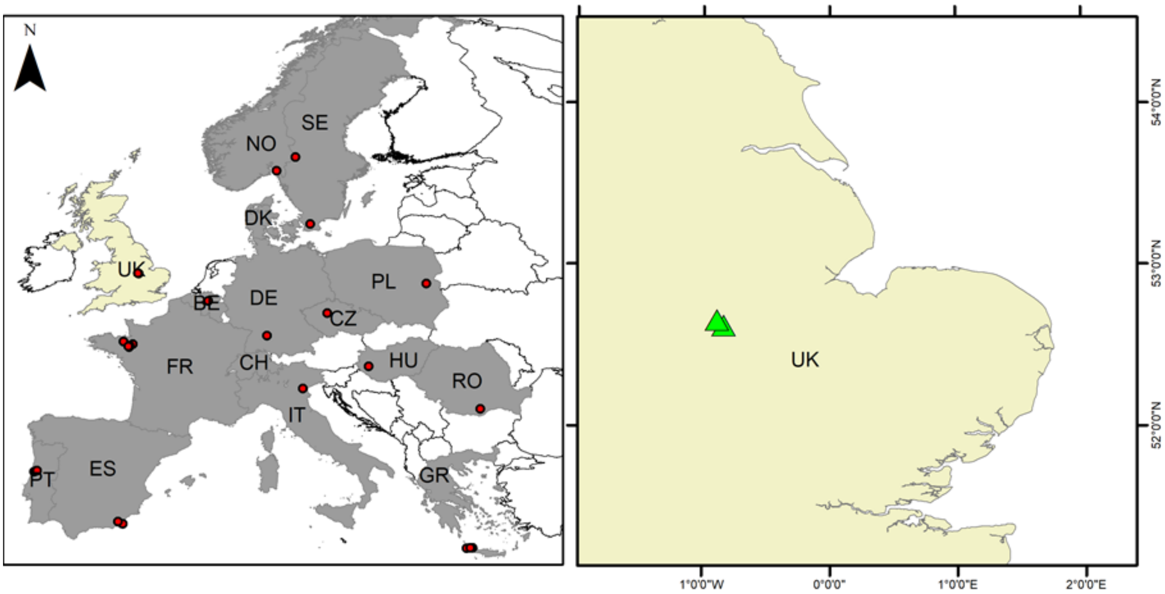


Figure 1: Location of the study site

The soil profile of 0.9 m which was described in April 2019 by I.S Panagea, has 3 horizons.

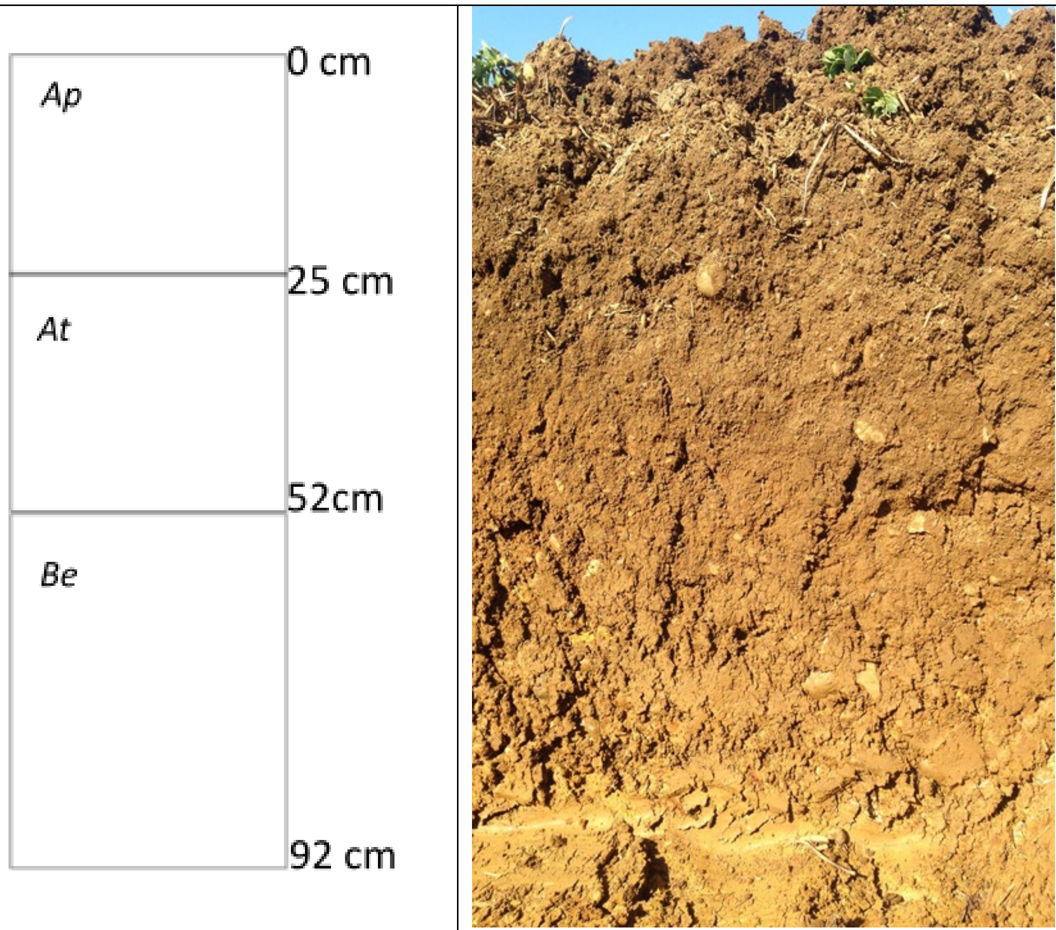


Figure 2: Soil Profile of the SS

The climate of the experimental field area

The long-standing weather station for Nottingham was selected. Data are available as Nottingham (ECAD 1850) and starts in 1960 up to recent.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Nottingham (ECAD001850)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	12.8	5.5	707	650.4
2018	14.4	6.9	700.2	714.8
2019	14.1	7.1	994.8	671.2

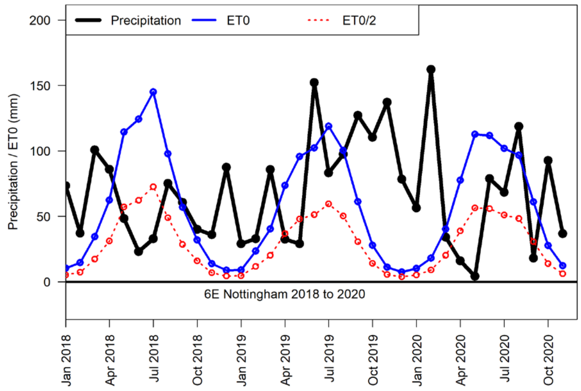


Figure 3: 6E Nottingham 00aFAOgrow

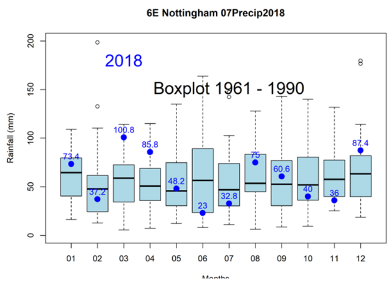


Figure 4: 6E Nottingham Precip2018box 07Precip2018box

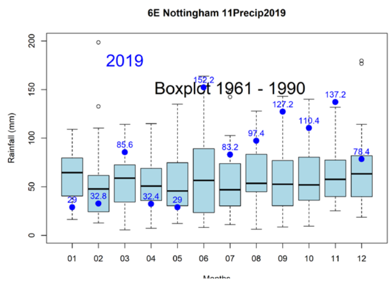


Figure 5: 6E Nottingham Precip2019box 11Precip2019box

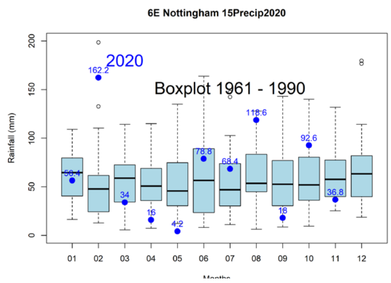


Figure 6: 6E Nottingham Precip2020box 15Precip2020box

During the years of the experiment, the mean annual temperature was 9.7 ^{o}C and 15.3^{o}C in October to March and April to September respectively, and the mean yearly precipitation is 686 mm.

Cropping systems description

Treatments

The experiment that analysed consists of one control and three treatments to remove compaction across the experimental area with the following codes in the SoilCare Database and the analysis following.

GWCT_EX1_TR1= Ploughing

GWCT_EX1_TR2= LDS- Low disturbance subsoiler

GWCT_EX1_TR3= AMF Mycorrhizal inoculant

GWCT_EX1_TR4= No tillage (Control)

The ploughing in the first treatment refers to moldboard ploughing at 25 cm and the use of the low disturbance subsoiler in the second treatment took place every year mid-autumn. The AMF treatment was a granular mycorrhizal fungi inoculant which was added to seed at drilling to form associations with crop roots and enhance plant nutrient acquisition. In the no-tillage, control treatment the only operation is the direct drilling of the main crop.

Field operations

The treatments were applied to a field that undergoes yearly crop rotation. In November 2017 winter barley *(Hordeum vulgare*) and in November 2019 *Vicia faba* were planted as main crops by direct drilling. Winter wheat and winter barley are normally planted in October and harvested in July. Supplemental N and Mg and Mn fertilizers were applied across all the experimental plots. Also different herbicides, insecticides, fungicides and growth regulators are applied depending on the conditions but were common to all plots.

Bio-physical data analysis – WP5

Method

Differences between treatments were analysed with a Mixed-Effects Model

Variables with repeated in time measurements were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. For variables measured only once the Treatment factor was used alone. The blocking was introduced in all models as a random effect, using statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

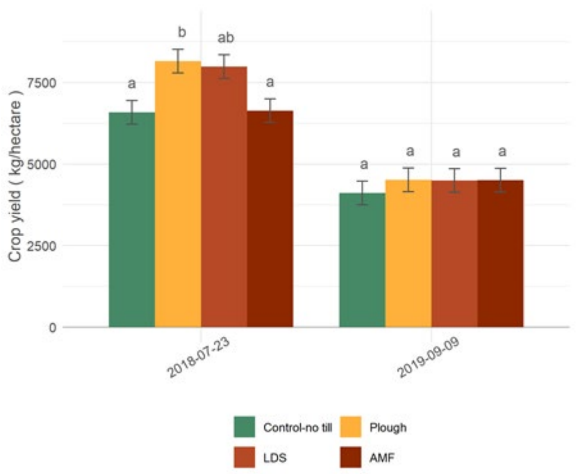
In the table. you can find the variables measured and analysed for this experiment. Results for all variables can be found in the ANNEXE II.

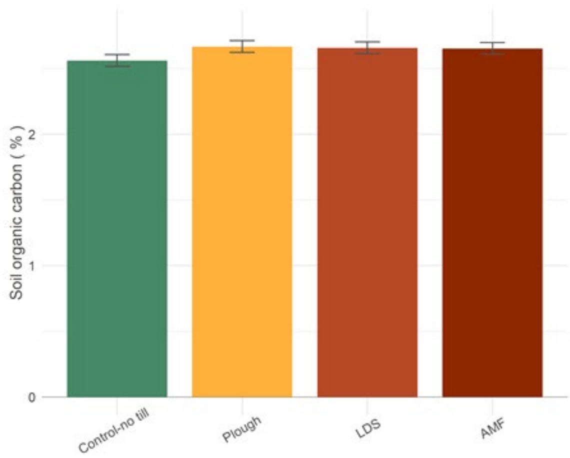
Table 2: Indicators measured and analysed

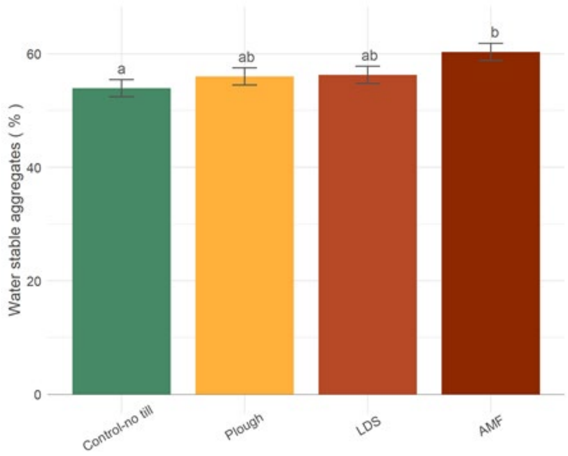
Observation code	Unit	Description
top_wc_pf2_0	m^3 water/m^3soil	Water content-Field capacity
top_wc_pf4_2	m^3 water/m^3soil	Water content-PWP
top_wc_pf2_7	m^3 water/m^3soil	Water content-Stress point
top_wc_pf_1_8	m^3 water/m^3soil	Water content at pF1.8
top_satur_wc	m^3 water/m^3soil	Water content at Saturation
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density in topsoil

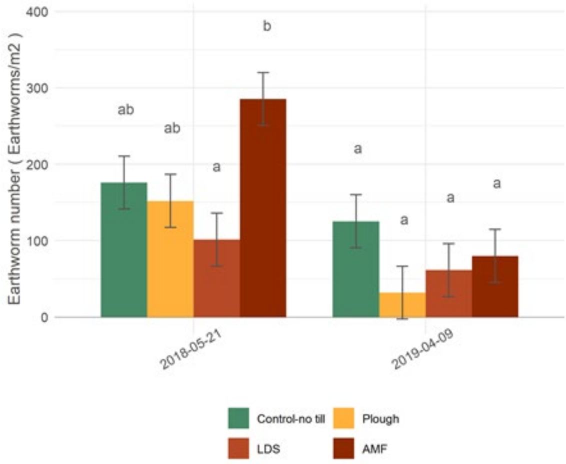
penetration_score	kPa	Penetration resistance
top_clay	%	Clay content
top_silt	%	Silt content
top_sand	%	Sand content
nmin_top	mg N/kg soil	Mineral nitrogen
p_avail	mg P/100 g Soil	Phosphorus
k_plus	cmol+/kg	Potassium
ca2_plus	cmol+/kg	Calcium
mg2plus	cmol+/kg	Magnesium
soc	%	Soil organic carbon
ph_kcl	_	pH
ph_h2o	_	pH
earthworm_no	Earthworms/m^2	Earthworm number
crop_yield	kg/m^2	Crop yield of the plot
crop_yield_ha	kg/hectare	Crop yield
vess	_	Visual evaluation of soil structure
greenhouse_gas	gCO^2/m^2/h	Carbon dioxide flux
water_infiltration	m^3 water/m^{3}soil	Water infiltration

Results







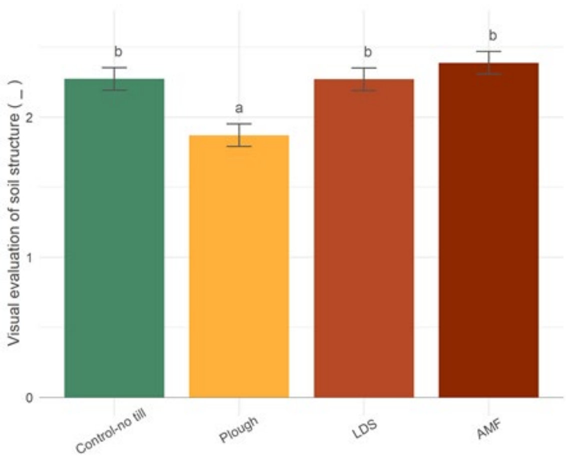


Analysis

When it comes to yield both the plots without physical compaction alleviation (control and AMF) showed the lowest results in year 1 (barley), with the subsoiler producing yields that were at least as high as those associated with ploughing. There was less yield difference across treatments in year 2 (beans).

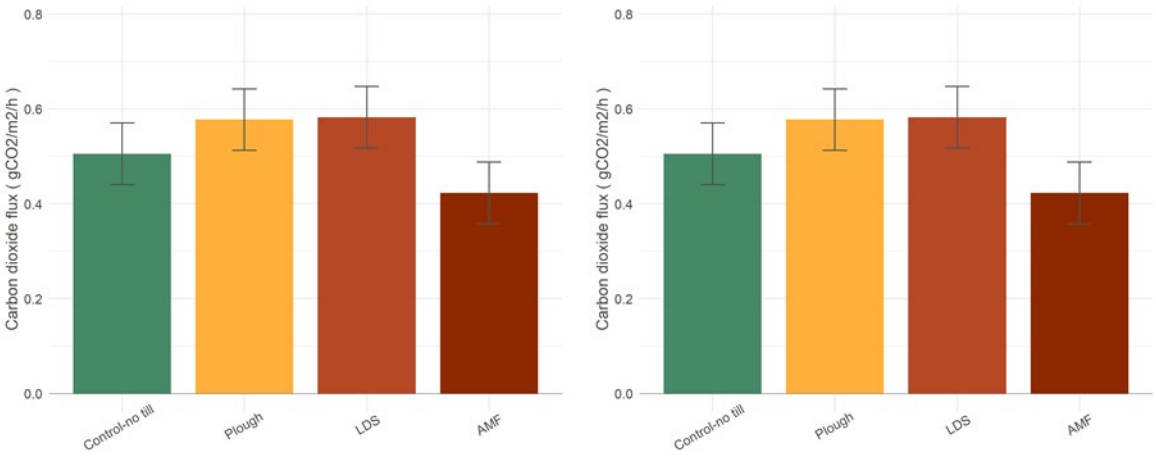
Water stable aggregates were slightly improved by AMF inoculation as fungi glue aggregates together. A significant difference was found between the control plot and AMF. AMF, therefore, improved soil structure, at least to an extent.

The SOC didn't present statistically significant differences among the treatments, whereas the earthworm numbers were consistently lower in the two cultivated treatments. This could have profound implications for soil structure and health.



The visual evaluation of soil structure (VESS, 1=good, 5=poor) scores was lowest in the ploughed plots. This indicates that ploughing was the most effective method for opening up the soil structure in the compacted soil.

Study site analysis



CO_2 emissions were higher in the cultivated plots than in the two non-cultivated plots. Although this does not appear significant when analysed together, this is due to the variability of the data between the summer and winter months. When analysing the winter months separately, significantly higher CO_2 emissions from cultivated plots were identified.

Socio-cultural dimension

Table 3 Impact of LDS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

Sociocultural data	LDS vs. no-till control		
	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.40	1.00	Complete
Workload	0.50	1.00	Complete
Perceived risks	0.00	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Table 4: Impact of AMF on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

Sociocultural data	AMF vs. no-till control		
	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.16	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	1.00	1.00	Complete

For the case of LDS vs. the no-till control there was an overall positive impact, with benefits in both reduced workload, and in improved farmer reputation. For AMF there was an overall negative impact, with the increased workload at peak times, and increased economic risk due to the price of the inoculant. There was still a perceived improvement in farmer reputation if this SICS was adopted. For the plough treatment the socio-cultural information was incomplete, so has not been included here.

Economical dimension

Table 5: Summary of the benefits of LDS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in £/ha

	AMT control	AMT SICS
Agricultural management technique	Direct drill	LDS
Investment costs	0	0
Maintenance costs	450	450
Production costs	87	117.1
Benefits	1052.8	1278.4
Summary = benefits - costs	515.7	711.26
Percentage change	37.9	

Table 7: Summary of the benefits of AMF (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in £/ha.

	AMT control	AMT SICS
Agricultural management technique	Control-no till	AMF inoculant
Investment costs	0	0
Maintenance costs	450	450
Production costs	87	0
Benefits	1052.8	1062.4
Summary = benefits - costs	515.8	612.4
Percentage change	18.8	

Table 9: Summary of the benefits of Plough (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in £/ha.

	AMT control	**AMT SICS**
Agricultural management technique	Direct drill	Plough
Investment costs	0	0
Maintenance costs	450	450
Production costs	87	153.8
Benefits	1052.8	1304
Summary = benefits - costs	515.7	700.2
Percentage change	35.8	

For both the LDS and AMF treatments the economic impact was positive. For the LDS treatment, this was due to an improvement in yield when the compaction was alleviated, seen in the Barley crop For AMF the economic benefit was much more marginal, due to a similar yield to the no-till control.

Overall analysis and main findings

- Earthworm numbers were consistently lower in the two cultivated plots. This supports previous research which found that ploughing reduces earthworm populations.
- Water stable aggregates were slightly improved by AMF inoculation. Fungi are known to stick aggregates together, so inoculation is improving soil structure, although very moderately.

- CO_2 emissions were higher in the cultivated plots than the two non-cultivated plots, this supports previous research which shows that cultivation stimulates the mineralisation of soil organic matter releasing CO_2.
- If there is a compaction problem, direct drilling will result in a yield penalty.
- Low disturbance subsoiling results in yield and economic responses that are equivalent to ploughing.

References

Papers in prep for the SoilCare special issue:

- Soil compaction and its control in Europe — Outcomes from SoilCare project study sites, Piccoli I., Alaoui A., Berti A., Börjesson G., Bussell J., Crotty F., Kirchmann H., Kätterer T., Sartori F., Seehusen T., Stoate C., Bolinder M.A.
- The effects of soil compaction on green-house gas emissions in ploughed and direct drilled plots. Bussell, J., Fox, G., Stoate, C.

I.6 GWCT Allerton Project (UK)

Report 2 on Monitoring and Analysis of Grass leys experiment

Study Site number: 6

Country: United Kingdom

Author(s): Jenny Bussell, Chris Stoate

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): GWCT Allerton Project

Experiment: Grass leys

Version: 1

Date: 01-02-2021

Experiment description

The main objective of the experiment is to evaluate the effect of deep-rooting grass leys for reducing flood risk and increasing soil organic matter, whilst maintaining food production. The experiment was established in 2016 and was set up in a randomized complete block design with three replication blocks, containing 6 plots each, 5 for the SICS treatments and 1 for the control treatment.

Experimental field information

The experiment is conducted on a farm field managed by the researchers in collaboration with another farmer. The experimental field is located in Tilton, Leicestershire, UK, at an altitude of about 198 m and covers an area of about 32400 m^2.

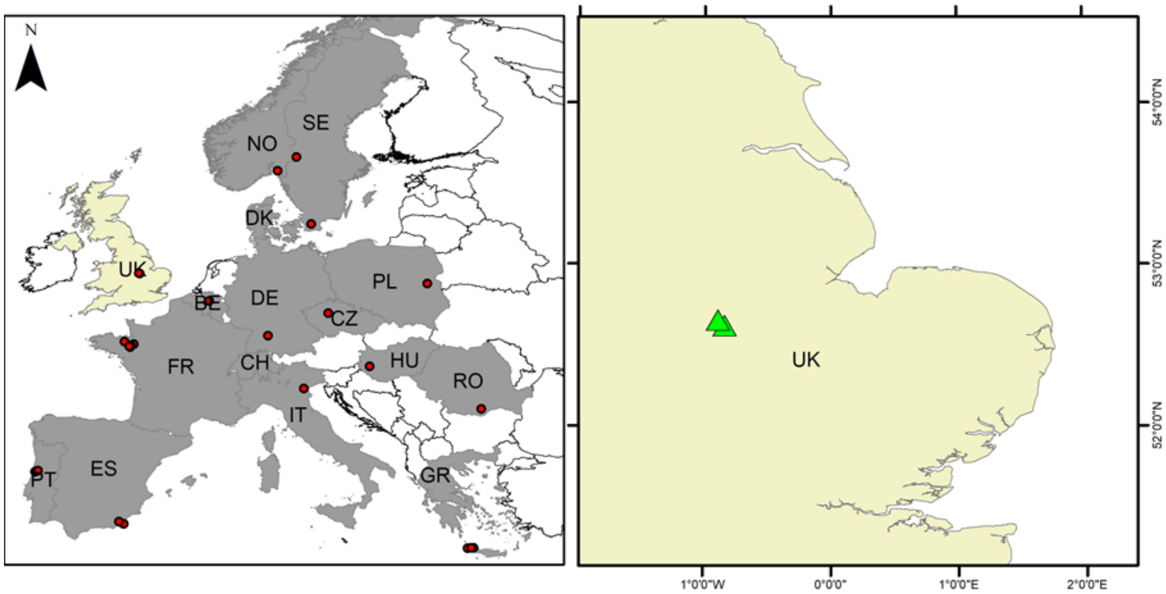


Figure 7: Location of the study site

The climate of the experimental field area

See the first experiment for an overview of the climate and the meteorological conditions for the experiment.

Cropping systems description

Treatments

The experiment that analysed consists of 6 treatments with the following codes in the SoilCare Database and the analysis following.

GWCT_EX2_TR1= Cultivar - Aberniche

GWCT_EX2_TR2= Cultivar - Perseus

GWCT_EX2_TR3= Cultivar - Fojtan

GWCT_EX2_TR4= Cultivar - Lofa

GWCT_EX2_TR5= Cultivar - Donata

GWCT_EX2_TR6= Control- ryegrass mixture with white clover (*Trifolium repens*) and red clover (*T. pratense*).

14 kg/ha of the different deep-rooted grasses and the control mixture drilled in September 2016.

Field operations

A 3 m wide strip was fenced off during years 3-4, in which no grazing or mowing took place to test the effect on root growth. The remaining trial area was cut for silage and grazed by weaned lambs in spring and autumn in line with normal management.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model. Variables with repeated in time measurements were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. For the variables measured only one time, the Treatment factor was used alone. The blocking was introduced in all models as a random effect, using statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

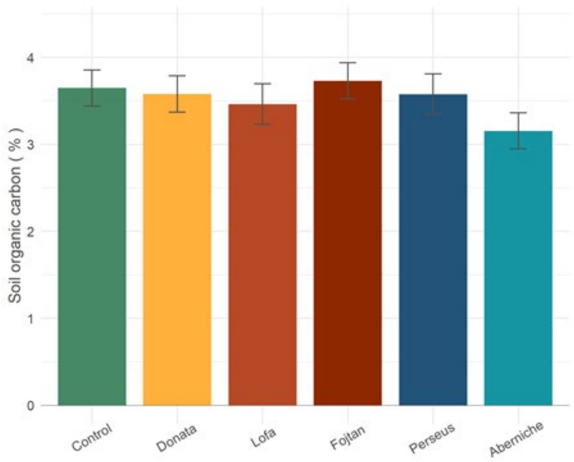
In the table. you can find the variables measured and analysed for this experiment. Results for all variables can be found in the ANNEXE II.

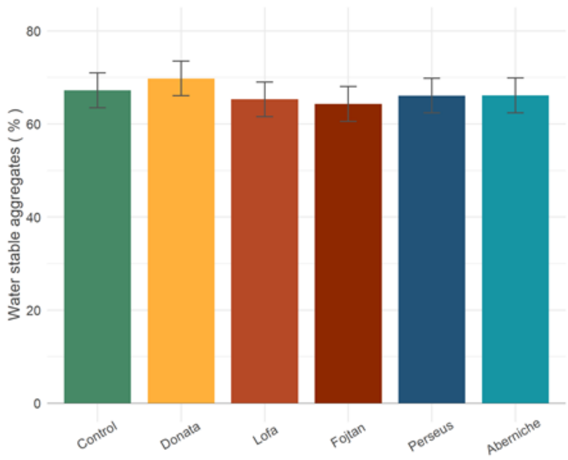
Table 11: Indicators measured and analysed

Observation code	Unit	Description
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density in topsoil
bd_bot	g/cm^3	Bulk density below the plough layer
penetration_score	kPa	Penetration resistance
p_avail	mg P/100 g Soil	Phosphorus
k_plus	cmol+/kg	Potassium
ca2_plus	cmol+/kg	Calcium
na_plus	cmol+/kg	Sodium
mg2plus	cmol+/kg	Magnesium

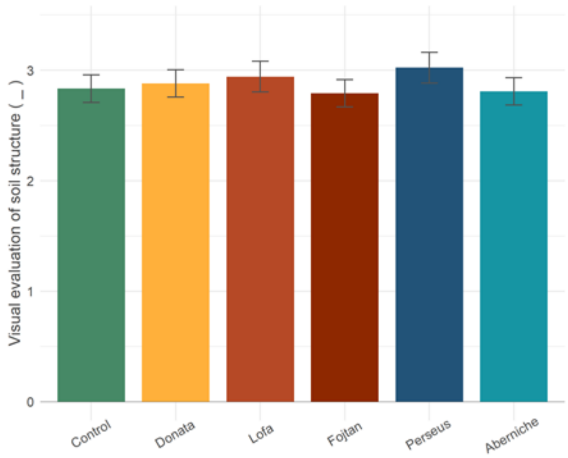
soc	%	Soil organic carbon
ph_kcl	_	pH
earthworm_no	Earthworms/m^2	Earthworm number
vess	_	Visual evaluation of soil structure
greenhouse_gas	gCO2/m2/h	Carbon dioxide flux
water_infiltration	mm/min	Water infiltration
soc_2	%	Soil organic carbon
earthworm_no_2	Earthworms/m^2	Earthworm number
water_infiltration_2	mm/min	Water infiltration

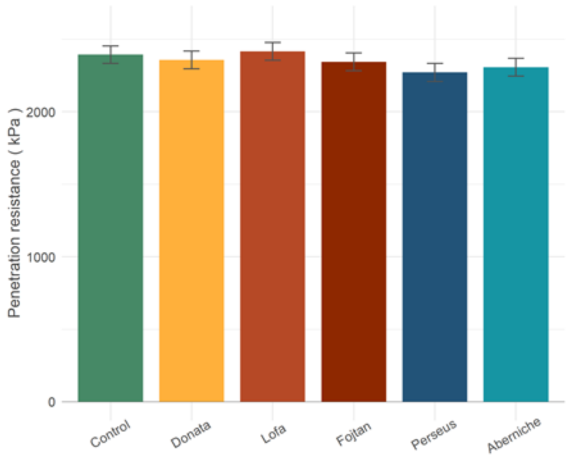
Results and analysis



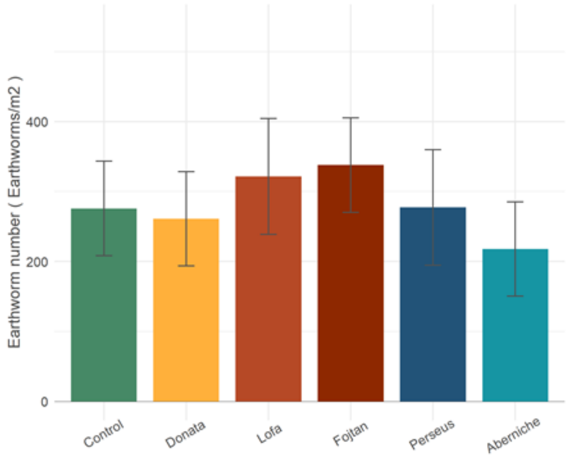


Soil organic carbon and WSA did not differ between treatments.





No significant differences were created by the different grass cultivars on the Visual Evaluation of Soil Structure (VESS) scores and penetration resistance.



No significant differences were found between the different grass cultivars on earthworm counts, though Fojtan and Lofa had slightly higher counts.

Study site analysis

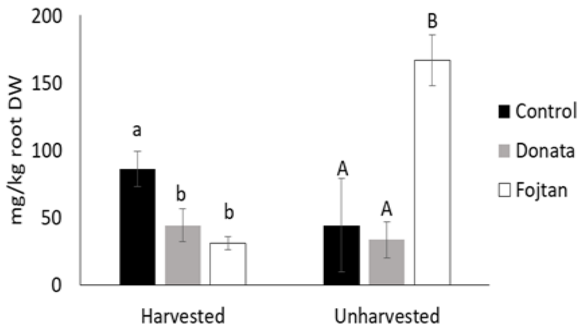


Figure 8 Amount of roots at 70 cm depth in cut and grazed, and unharvested sections of plots.

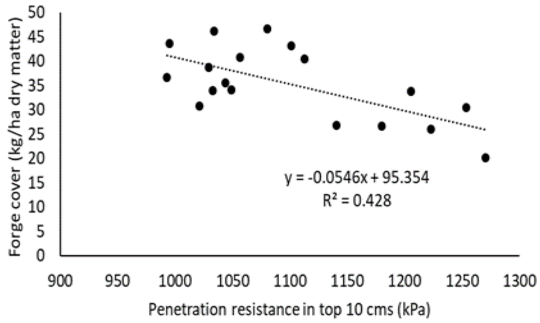


Figure 9: Relationship between forage amount and soil compaction to 10 cm in fenced unharvested sections of experimental plots

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Control plots had the highest root volume in harvested areas, whilst, Fojtan had significantly higher root volume in unharvested areas (Figure 8)

Penetration resistance was significantly lower in unharvested plots at 0-10 cm depth. This was correlated with the amount of forage (Figure 9)

Socio-cultural dimension

No Socio-cultural comparisons can be conducted between the grass varieties. An interview with the farmer and a stakeholder meeting to discuss how the findings of the study can be used by the wider agriculture community has been used to gather data on the socio-cultural aspect of this experiment.

Economical dimension

No economic comparison can be conducted between the grass varieties, but an interview with the farmer who owns the field was conducted to understand the economic impact of using a deep rooting grass ley in a field suffering compaction.

Overall analysis and main findings

- Fojtan and Donata are as productive and palatable to weaned lambs as conventional ryegrass and clover ley
- The different grass cultivars resulted in no significant differences in VESS (visual evaluation of soil structure) scores, earthworm numbers, soil organic carbon or penetration resistance.
- Cutting and grazing the forage created soil compaction and reduced root growth and soil infiltration.
- In unharvested plots, Fojtan had significantly higher root volume at depth than the control and other cultivars.
- Less intensive harvesting and lower associated compaction may increase the potential for reduced flood risk through Fojtan root growth, but infiltration rates were highest in Fojtan plots only in year 1.
- Using Fojtan may contribute to flooding risk management if combined with low-intensity harvesting.

General conclusions based on both experiments

Overall, when soil compaction forms in a direct drill system, a traditional method such as ploughing work well to alleviate compaction and increase yield, but subsoiling can be equally effective without the negative impacts on soil health associated with ploughing.

The second exeriment aimed to see if deep-rooting grass cultivars (Festuloliums) could perform better than a rye grass-clover mix control for sheep forage and help alleviate some compaction across the field. We expected to see improvements in SOC, infiltration and reduced penetration resistance due to the deep rooting grasses, but found no significant differences, although compaction was found to be lower within the top 10 cms in the fenced-off ungrazed areas. At the end of the SoilCare experiment, deep trenches (1 m depth) were dug in the soil across the grazed and ungrazed areas to look at root growth. The Festulolium cultivar, Fojtan had more roots at 70cm than the control, but with grazing pressure, this difference wasn't seen. This could explain the lack of differences between the grass cultivars measured in the grazed field.

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I.7 University Hohenheim (Germany)

Report 1 on Monitoring and Analysis of Soil Cover Experiment

Study Site number: 7

Country: Germany

Author(s): Paula Mayer-Gruner, Moritz Hallama, Stefan Pilz, Carola Pekrun, Ellen Kandeler

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): University of Hohenheim, Institute of Soil Science and Land Evaluation, Soil Biology Section

Experiment: Tachenhausen Cover Crops-Glyphoshate

Version: Complete

Date: 24-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate the interaction of cover crops and glyphosate on soil organisms. The experiment was established in August 2018 in a randomized complete block design with 4 blocks, containing 4 plots each, two for the SICS treatments with cover crops and two as a control (without cover crops). Plots were either treated with glyphosate or not. The size of each plot is 8x3m.

Experimental field information

The experiment is conducted on an experimental station managed by researchers. The experimental field is located in Tachenhausen, Germany at an altitude of 330 m above sea level and covers an area of about 1920 m^2. The topsoil texture is a very fine sandy loam textural class according to the USDA classification system.

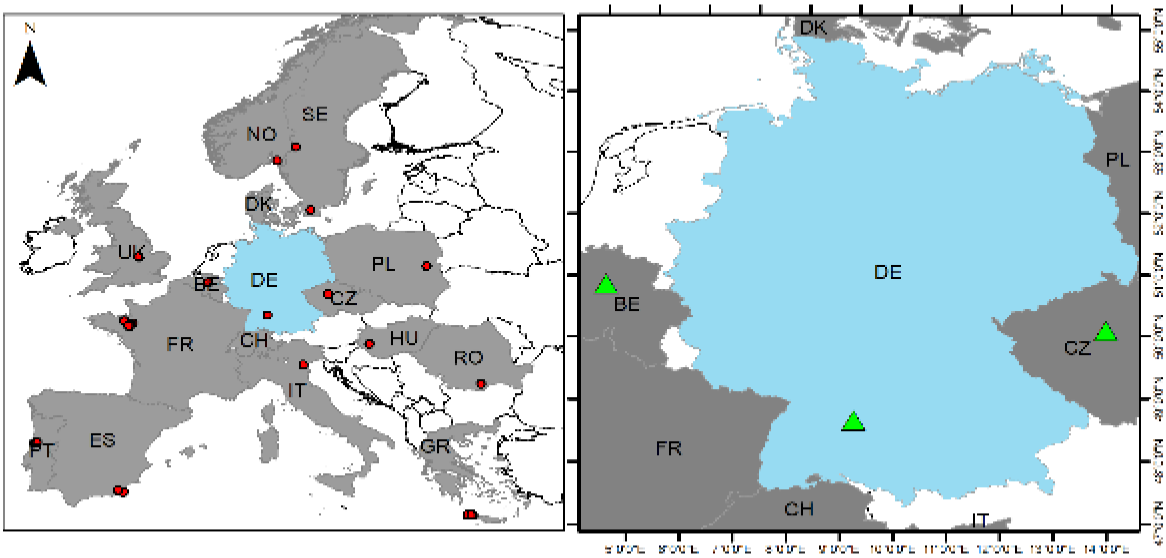


Figure 1: Location of the study site

The soil profile (up to 1.2 m) is characterized as Cambisol in the WRB soil classification system with 4 horizons, with a ploughing layer at 18 cm.

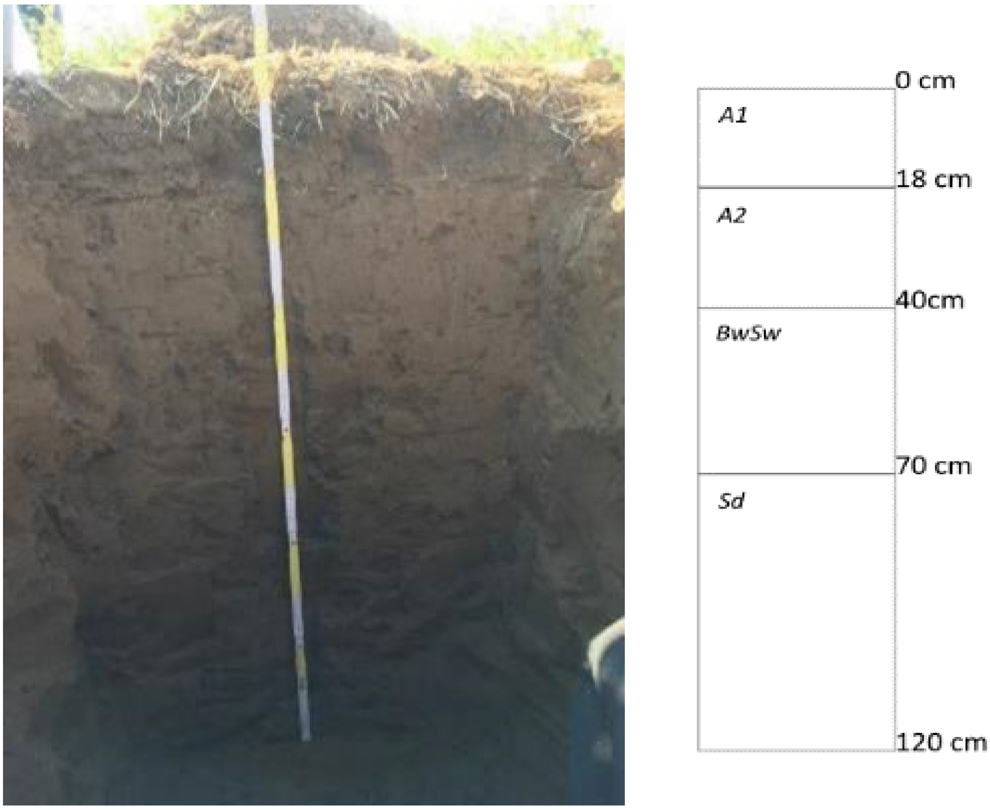


Figure 2: Soil profile (photo: Moritz Hallama)

The climate of the experimental field area

Tachenhausen has a weather station near the field experiments. The data are online available on the website of "*Agrar Meteo Baden Wurttemberg*" (https://www.wetter-bw.de/) starting from 1 August 2010 till now. The www.ECAD.eu contains long-term data for Stuttgart/Echterdingen. (ECAD 2763). This station covers 1953 until now and is located at 13 km distance to the experiment.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Stuttgart/Echterdingen. (ECAD 2763)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	13.2	4.5	718.9	764.9
2018	16.3	6.4	506.3	912.5
2019	15.8	5.6	660.7	874.6
2020	16.3	5.6	592.6	897.0

Table 2: Average Tmax, Tmin, Precipitation and ET0 for Tachenhausen

Year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
2018	16.7	6.3	582.4	941.2
2019	16.4	5.5	763.7	923.1
2020	16.9	5.7	675.7	932.0

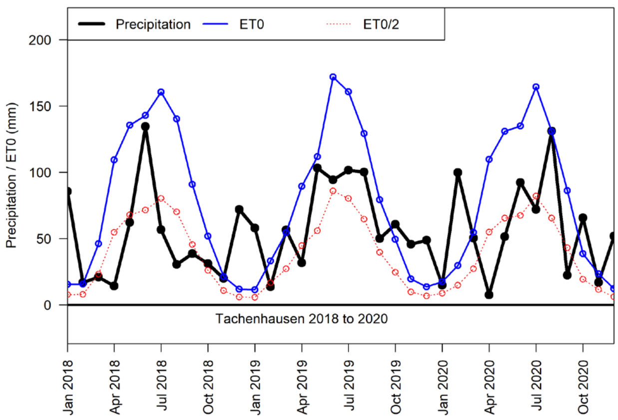


Figure 3: Monthly precipitation and ET0 for Tachenhausen

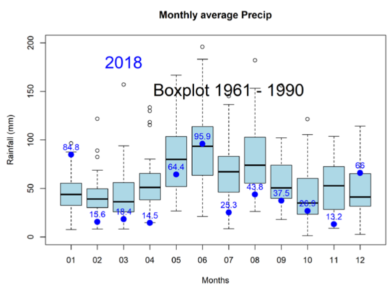


Figure 4: 7E Stuttgart 07Precip2018box

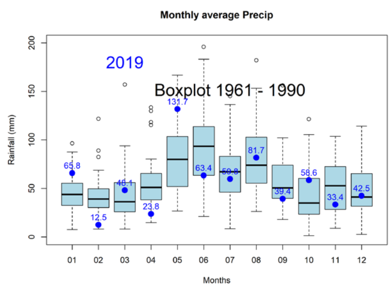


Figure 5: 7E Stuttgart 11Precip2019box

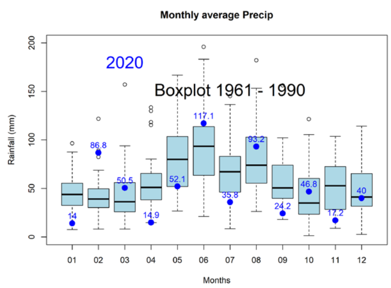


Figure 6: 7E Stuttgart 15Precip2020box

The experimental site has a temperate climate, the mean temperature at the Tachenhausen weather station from 2011-2019 was 10.5 °C, and the average precipitation was 725 mm.

The experiment started in Autumn 2018 with good growing conditions for the cover crops. The plants were well established at beginning of winter and frozen off at the end of February. Some heavy rainfall events occurred in summer 2019 and February 2020 and caused visible erosion gullies. After the warm winter, 2019/2020 spring barley had quite dry conditions for growing and grain filling.

Cropping systems description

Treatments

The experiment consists of 4 treatments with the following codes in the SoilCare Database and the analysis following.

UH_EX1_TR1: Cover crops with Glyphosate (SICS) – CC: GLY

UH_EX1_TR2: Cover crops without Glyphosate (SICS) – CC: noGLY

UH_EX1_TR3: No cover crops with glyphosate (Control CS) – noCC: GLY

UH_EX1_TR4: No cover crops without glyphosate (Absolute Control CS) - weed control with mechanical mowing. – noCC:no GLY

The cover crops, which are a mixture of species (V*icia sativa, Trifolium alexandrinum, Phacelia tanacetifolia, Helianthus annuus*) of 25 kg/ha are planted in rows of 20 cm at the beginning of September.

The glyphosate application amount in the relevant treatments is 3.75 Kg/ha.

Field operations

The experimental field is getting tilled a month before planting with a disc rotary harrow in a depth of ca. 9 cm. It gets nitrogen (90 kg/ha), phosphorus (17.5 kg/ha), potassium (53.1 kg/ha), magnesium (8.1 kg/ha), and sulphur (20 kg/ha) in the applied fertilizers.

The main crop of the field for the 2019 cropping season was *Zea mays* planted in spring and harvested in September and *Hordeum vulgare* for 2020 which was planted in late March and harvested end of July.

Bio-physical data analysis – WP5

Method

Differences between treatments were analysed with a Mixed-Effects Model

Variables with repeated time measurements were analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. The variables measured only once the Treatment factor used alone. The blocking was introduced in all models as a random effect, using the statement 1|Block.

In all diagrams, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

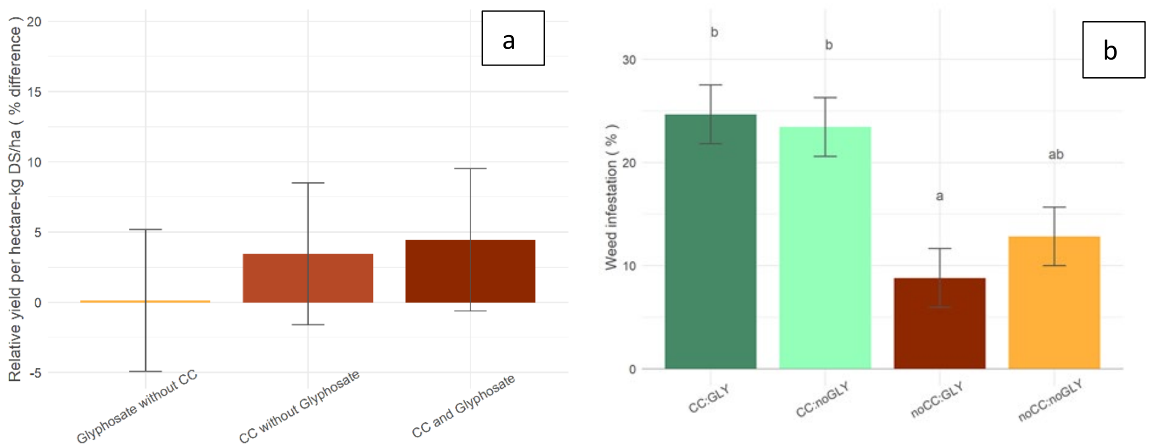
In the table, you can find the variables measured and analysed.

Table 3: Soil physical, chemical and biological properties analysed in the experiment

Observation code	Unit	Description
top_wc_pf1.08	m3m-3	Water content at pF1.08
top_wc_pf2.0	m3m-3	Water content at Field capacity (pF=2.0)
top_wc_pf2.5	m3m-3	Water content at Stress point (pF=2.5)
top_wc_pf4.2	m3m-3	Water content at Permanent wilting point (pF=4.2)
top_satur_wc	m3m-3	Water content at Saturation
Wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
top_clay	%	Percentage of clay fraction
top_silt	%	Percentage of silt fraction
top_sand	%	Percentage of the sand fraction
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorus
k+	cmol+/kg	Exchangeable Potassium
ca2+	cmol+/kg	Exchangeable Calcium
na+	cmol+/kg	Exchangeable Sodium (units of charge)
mg2+	cmol+/kg	Exchangeable Magnesium
Soc	%	SOC
ph_kcl	Unitless	pH in KCl
weed_infestation	%	Weed infestation (soil cover by weeds)

earthworm_no	No/m2	Earthworms
microb_biom_c	µgC_micg-1DM	Microbial biomass carbon
microb_biom_n	µgN_micg-1DM	Microbial biomass nitrogen
disolved_c	µgC_micg-1DM	Dissolved carbon of C extractable with 0.5 M K2SO4.
soil_cover	%	Soil cover
crop_yield	kg FS/plot	Crop yield of the plot- Fresh substance
crop_yield_ha	kg DS/hectare	Crop yield- Oven-dried substance
ß-Glu_activity	nmol/g/h	ß-Glucosidase
Xyl_activity	nmol/g/h	ß-Xylosidase
N-Ac_activity	nmol/g/h	N-Acetyl-ß-Glucosaminidase
Phos_activity	nmol/g/h	Phosphomonoesterase
K_avail	mg-K/100gr Soil	Available Potassium
Infiltration	mm/h	Infiltration rate
crop_protein_content	% DS	Crop protein content in grain
crop_full_barley_share	% of harvested grains	Crop grain size >2.5 mm

Results



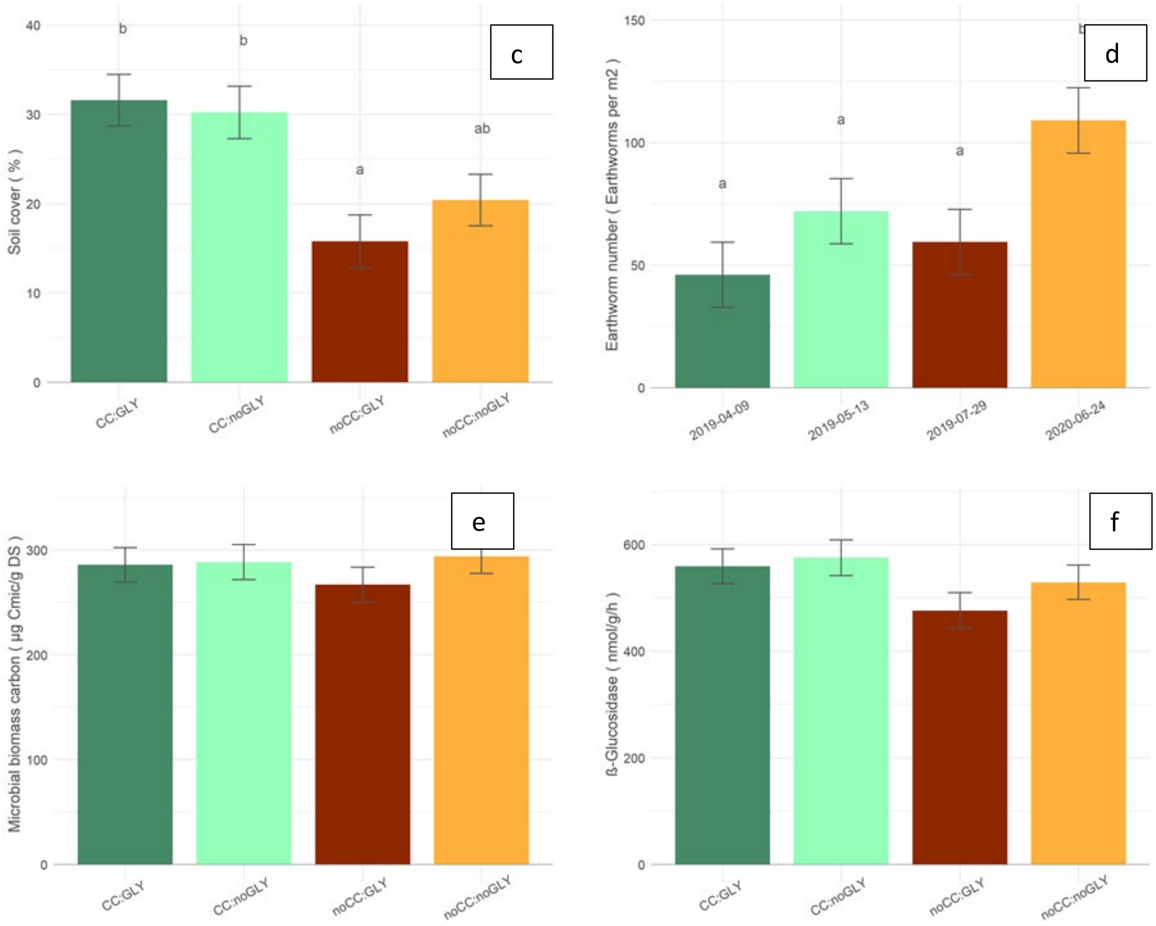


Figure 7: Response on cover crops (CC) and glyphosate (GLY) on relative yield (a), weed infestation (b), soil cover (c), earthworm abundance (d), soil microbial carbon (e), enzyme activities (e.g. beta-glucosidase) (f).

Analysis

Plant growth

With cover crops, a slight trend for higher yields was observed in comparison to the control treatment 4 (set at 100 %) (Fig. 7 a). The application of glyphosate had no significant effect on the crop yield, neither quantity nor quality, in both years. In June 2019, during maize growth, weed infestation (soil cover by weeds) was significantly higher in the cover crop treatments. There was no glyphosate effect. (Fig. 7 b). With higher weed infestation, overall soil covering was correspondingly higher: Treatments 1 and 2 had on average 30 % soil covered. There was no effect of glyphosate (Fig. 7 c).

Soil physical and chemical properties

There was no change with the treatments for the soil chemical and physical parameters (see Table 3). This was expected as these properties need some time to react.

Soil biological properties

The results of the 4 sampling dates showed no effect of glyphosate on earthworm abundance (Fig. 7 d). A slight trend was observed for earthworms being more abundant with more C input through cover crops.

There was no significant effect of treatments on soil microbial biomass carbon nor measured enzyme activities (Fig. 7 e, f)

Study site analysis

In the frame of the bachelor thesis of Marc Thomas, additionally to the abundance, the biomass of earthworms was investigated. The biomass of earthworms was significantly higher with cover crops and not influenced by glyphosate (Thomas, M. et al. 2020).

In a previous experiment with the same treatments, the abundance and biodiversity of soil microorganisms were enhanced by cover crops and were only slightly influenced by glyphosate. In this same experiment, 7 days after the application of glyphosate, there was a temporary stress response of microorganisms, indicated by an increase in ß-glucosidase activity. This reaction was stronger in the treatments without cover crops than with cover crops (Fig. 8) (Abdullah, S. 2021).

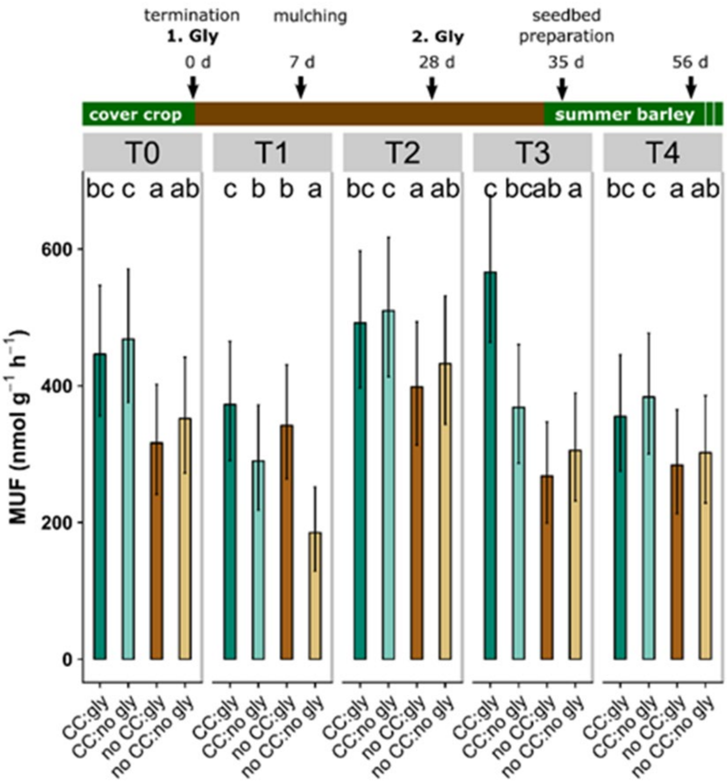


Figure 8: Modelled means of ß- glucosidase activity in response to the treatments (CC=cover crops; gly= glyphosate) over time: T0-T4 (0, 7, 28, 35 and 56 days after 1st glyphosate application). Error bars indicate 95% CI. Means with the same letter(s) are not significantly different (p < 0.05, Tukey) (Abdullah, S. 2021).

In the frame of the SoilCare project, we focused not only on cover crop-glyphosate interactions but also on cover crop – tillage interaction in soils. Based on our meta-analysis (Hallama et al. 2019) we could give a clear indication that cover crops could stimulate microbial and plant driven P mineralisation. The main crop could profit from the mineralised phosphate specifically under the low to medium P status of soils. Based on field experiments in Germany, Belgium and Denmark, different members of the SoilCare project could underpin the importance of soil microorganisms for P mobilisation in different cover crop – tillage and organic amendments experiments (Hallama et al. 2020 accepted, Christiensen et al. 2020 submitted, Christiensen et al. 2021 submitted, Houben et al. 2019).

Besides, we are invited by Dr Laura Bertha Reyes Sánchez (President-elect of the International Union of Soil Sciences) to contribute to a book that will be published at the end of 2021. The title of our chapter is: Can soil-improving cropping systems reduce biodiversity loss within agricultural soils? Again, the co-authors will be participants of the SoilCare project (the United Kingdom, The Netherlands and Germany): Crotty F., Hannula S.E., Termorshuizen A., Hallama M. and Kandeler E. This chapter will be based on our intensive literature research performed in the frame of working package 2.

Socio-cultural dimension

SICS: UH_EX1_TR1 – Cover crops with Glyphosate

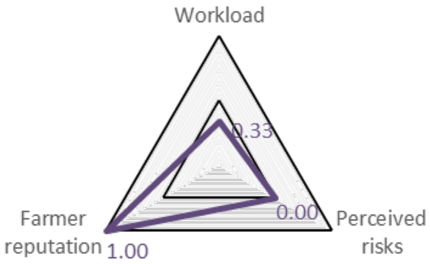
Control: UH_EX1_TR3 – no cover crops with Glyphosate

The assessment of the sociocultural dimension shows a slightly positive impact due to the positive farmer reputation and a slight increase in the workload due to the short time window left after harvest to perform sowing. In principle, the desirable combination of harvest–sowing is only possible in some combinations of main and cover crop. The farmer has a high reputation in the region and the neighbours adopted the same SICS later (Fig. 9 and Table 4).

Table 4: Impact of SICS on the socio-cultural dimension as compared to the control.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.07	1.00	Complete
Workload	-0.33	1.00	Complete
Perceived risks	0.00	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Figure 9: Impact of SICS on the socio-cultural dimension as compared to the control.



Economical dimension

In this case, the benefits of SICS are calculated about the costs for the entire crop rotation. The benefits of both control and SICS consist of the yield performance calculated for the entire crop rotation based on yield x market price. Since the straw is left in the field, it is the pure grain yield (or silage maize yield) multiplied by the average market price in the respective year. This case shows a negative impact of SICS in comparison to the control (Table 4).

Table 5: Summary of the benefits of SICS (SICS vs. control), the numbers are in euro/ha.

	AMT control	AMT SICS
Agricultural management technique	Reduced tillage without cover crops	Reduced tillage with cover crops
Investment costs	929.6	1035.7
Maintenance costs	225.6	258.3
Production costs	1942.4	2071.2
Benefits	2837.0	2999.0
Summary = benefits - costs	-260.5	-366.3
Percentage change	28.9	

Especially for the economic assessment of novel SICS, the approach of an economic cost-benefit-analysis is well justified. However, environmental and/or social aspects should be expressed in financial value for this analysis, because on farm-level many positive effects, as the conservation of soil, reduction of erosion and floods, as well as CO2-storage and biodiversity etc., do not enter the calculation. These aspects play a fundamental role in the selection of SICS, also regarding possible financial instruments by the EU. Due to the complexity of this kind of analysis, greater weight in the project, maybe a specific working package and specialized personnel would be required already in the planning stage.

Overall analysis and main findings

For the environmental dimension, no change was observed for biological, physical, and chemical properties. This is not surprising due to the short experimental period.

Soil organisms are an indicator of soil health and resilience. Looking deeper at fast-reacting soil biological properties we found the following trend: The SICS cover crops enhance the abundance and activity of soil organisms and therefore play an important role in soil health.

In the case of Germany, one dimension has been improved; this is the sociocultural dimension (Fig. 10). The farmer reputation has improved because of the visible support of biodiversity at the field by cover crops. Another benefit is that there are no potential risks of, e.g. health or conflicts, for implementation. A drawback is the increase of workload as the SICS cover crops has to be treated like the main crop for success.

The economic dimension has deteriorated. The seeding is cost-intensive. However, environmental aspects are not monetarized in this analysis, because at the farm-level many positive effects, as the conservation of soil, reduction of erosion and floods, as well as CO2-storage and biodiversity etc., do not enter in the calculation yet. These aspects play a fundamental role in the selection of SICS, also regarding possible financial instruments by the EU.

Worth to mention is that, as long as yields are not affected by increased weed populations, as it was in our case, conservation tillage with cover crops and without glyphosate can be recommended. In cases where weed infestation exceeds the economic threshold, additional herbicides need to be applied or soil tillage needs to be intensified. Where glyphosate is replaced by an increase in tillage for weed control, the positive effects of conservation agriculture, in particular regarding earthworm abundance and erosion control, will be reduced.

Environmental properties like the amount of soil erosion, surface runoff and soil biodiversity are important. It would be good to add these indicators in future monitoring and assessment plans. Ecological benefits as erosion control and enhanced soil biological fertility should be rewarded for the sustainability of the SICS.

Further assessments in the future are necessary to confirm these results.

Table 5: Impact of SICS on the socio-cultural dimension as compared to the control group.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.01	0.89	High
Environmental dimension	0.00	0.74	Medium
Economic dimension	-0.03	1.00	Complete
Socio-cultural dimension	0.07	1.00	Complete
Physical properties	0.00	0.85	High

Chemical properties	0.00	0.68	Medium
Biological properties	0.00	0.65	Medium

References

Scientific publications in the frame of SoilCare

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- Christensen J.T., Hansen E. M., Hallama M., Kandeler E., Rubæk, G.H. (2020) Phosphorus dynamics in soil-grown with the cover crop plants oat, corn cockle and lupine. Journal of Plant Nutrition and Soil Science (submitted, November 2020, under revision).
- Hallama M., Pekrun C., Pilz S., Jarosch K.A., Frac M., Uksa M., Marhan S., Kandeler E. (2020) Interactions between cover crops and soil microorganisms increase phosphorus availability in conservation agriculture. Plant and Soil (submitted 18.08.2020, accepted 22.02.2021).
- Hallama M., Pekrun C., Lambers H., Kandeler E. (2019) Hidden miners – the roles of cover crops and soil microorganisms in phosphorus cycling through agroecosystems. Plant and Soil, 434, 7-45. DOI10.1007/s11104-018-3810-7.
- Houben D., Michel E., Nobile C., Lambers H., Kandeler E., Faucon M.P. (2019) Effect of phosphorus forms in sewage sludge on soil phosphorus dynamics and availability in agroecosystem in northern France. Applied Soil Ecology 137, 178-186.

Further publications in the frame of SoilCare

- Abdullah S. (2021) Effect of glyphosate and cover cropping interaction with the soil microbial community. Master Thesis, University of Hohenheim, Stuttgart, February 2021.
- Hallama M., Pilz S., Kandeler E., Pekrun C. (2020) Mikrobielle Phosphormobilisierung mit Zwischenfrüchten – Bodenphosphate effizienter nutzen. Landwirtschaft ohne Pflug 05/2020, 22-29.
- Mayer-Gruner P. (2020) Bodenleben behauptet sich. BW Agrar 13/2020, 19.
- Pekrun C., Pilz S., Kandeler E., Hallama M. (2019) Zwischenfrüchte - Mehr Wurzeln, bessere Versorgung. DLG Mitteilungen Sonderausgabe 07/2019, 9-11.
- Thomas M., Marhan S., Pilz S., Kandeler E., Hallama M., Pekrun C. (2020) Das nützt Regenwürmern. Agrarheute 07/2020, 124-128.

General conclusions based on the experiment

The experiment was done to assess conservation agriculture, meaning reduced tillage in combination with cover crops and glyphosate. As the SoilCare monitoring plan focuses on parameters reacting in a long term, we added analysis on soil organisms to monitor short time reactions of these SICS on the soils.

In the short-term, we could only find a slight effect of glyphosate on soil microbial activities. Seven days after glyphosate application, the increase of a C-cycling enzyme (ß-glucosidase) indicated a short-term stress response of the soil microbial community. The SICS cover crops play an important role and maybe the key factor for suppressing harmful weeds, reducing the need for glyphosate, protection of soil against erosion and surface runoff and supporting soil organisms. Earthworm activity benefit from the SICS cover crops from the first cultivation onwards. In this case, weed infestation was higher after cover crops. As long as yields are not affected by increased weed populations conservation tillage can be recommended. In cases where weed infestation exceeds the economic threshold, additional herbicides need to be applied or soil tillage needs to be intensified.

For maximum erosion control, direct seeding systems are best, however, managing this without glyphosate is hardly possible. Conservation agriculture of the future, with reduced or no-tillage, needs to be developed without glyphosate. One important outcome of our last stakeholder meeting was that the banning of glyphosate could be replaced by shallow tillage and enhanced crop rotations including cover crops and perennial grasses to enable stable yields as well as to protect the soils and their organisms.

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I.8 ICPA (Romania)

Report 1 on Monitoring and Analysis

Study Site number: 8

Country: Romania

Author(s): Irina Calciu, Olga Vizitu

Compiled by WP5: Ioanna Panagea & Guido Wyseure

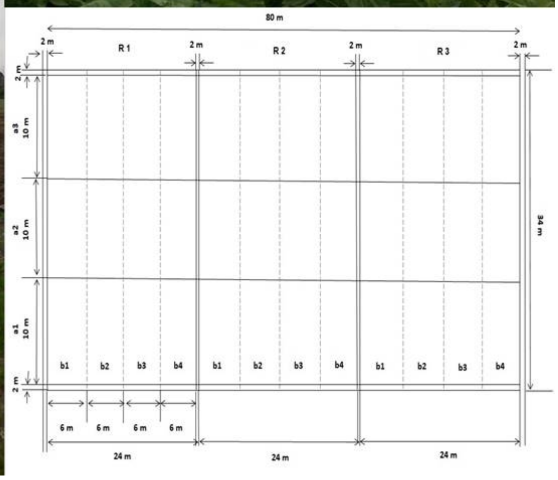
Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): ICPA

Experiment: Soil tillage effects on soil quality





Version: C

Date: 18-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate the effect of 4 different tillage practices to mitigate soil compaction under three different crop rotation schemes which include legumes and cereals. The experiment established in March 2018 and was set up in a split plot-randomized complete block design with 3 main plots, one for each crop rotation scheme and 3 blocks, containing 12 plots each. In each block, there is a combination of 3 different rotations and 4 tillage practices.

Experimental field information

The experiment is conducted on a farm managed by the researchers. The experimental field is located in Draganesti-Vlasca, Romania at an altitude of about 90 m and covers an area of about 2900 m^2. The topsoil has a clay loam texture according to the USDA classification system.

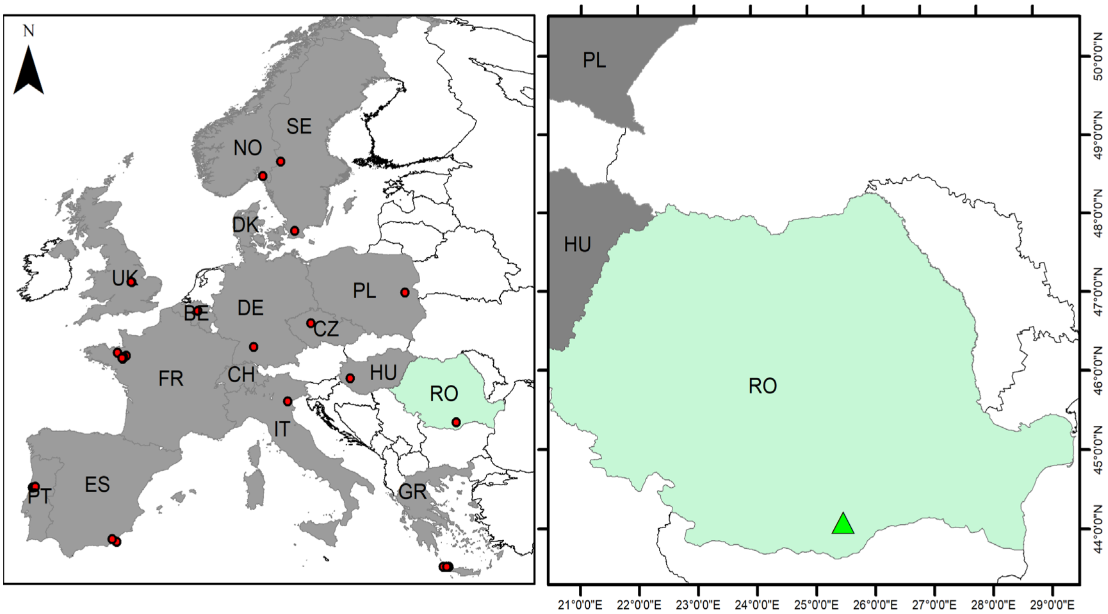


Figure 1: Location of the study site

The soil profile of 1.9 m which described in March 2018, has 11 horizons and is characterized as Chernozem according to the WRB soil classification system. The maximum rooting depth found to be at 0.3 m as at that depth there is a ploughing pan.

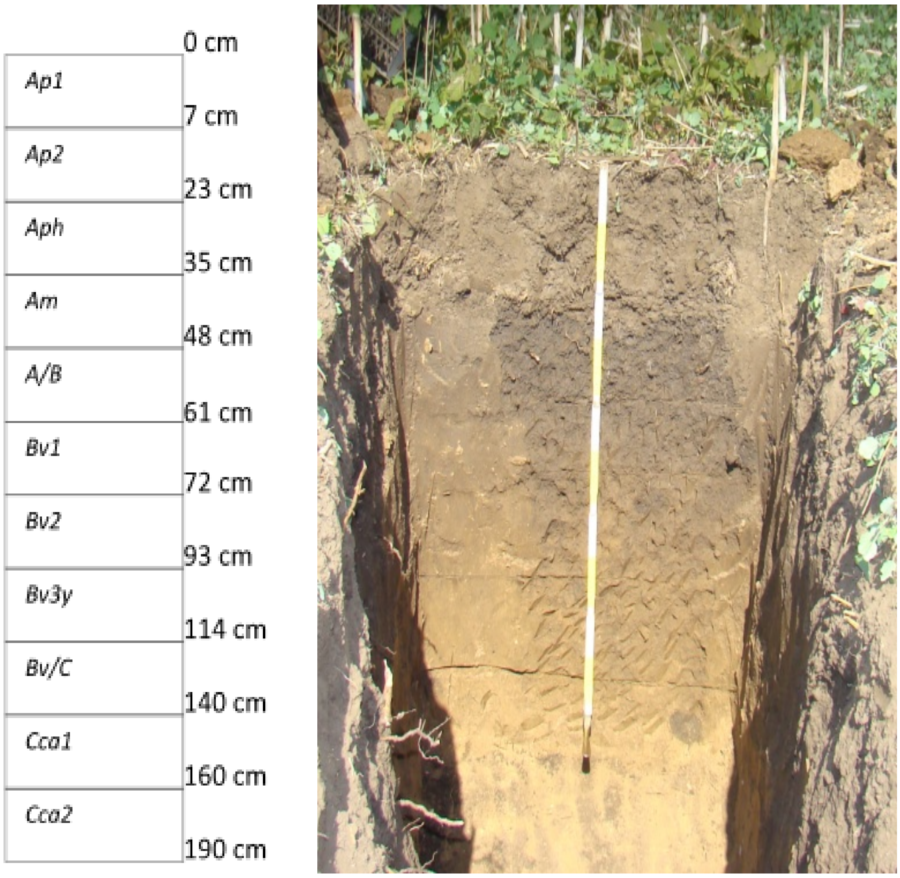


Figure 2: Soil profile

The climate of the experimental field area

The monitoring for Draganesti Vlasca stopped at the end of 2013 and therefore did not cover the period of the soil care experiments. As Bucarest has a long-standing station starting from 1881 for temperature under the name Bucuresti-Baneasa/Filaret, and available as ECAD station 219 up to inclusive November 2020. The blended series is at about 60 km distance from Draganesti Vlasca

Table 1: Table with the overview for Bucuresti and Dragenesti

	Period/year	Tmax (°C)	Tmin (°C)	Precipitation (mm)	ET0 (mm)
Bucuresti	1961-90	16.5	5.6	596.2	1008.2
Draganesti	1961-90	16.7	5.9	543.1	1024.9
Bucuresti	2018	18.2	6.4	673.2	1103.7
Bucuresti	2019	19.3	6.6	648.5	1121.3

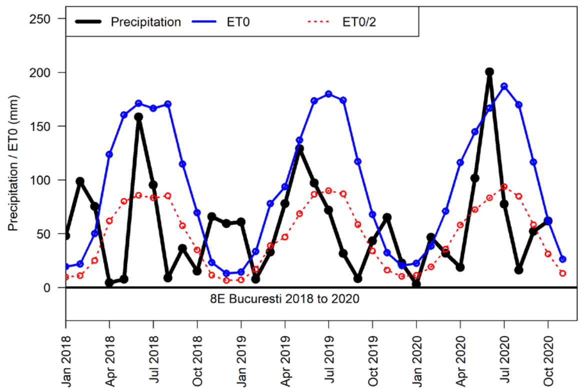


Figure 3: 8E Bucuresti 00aFAOgrow

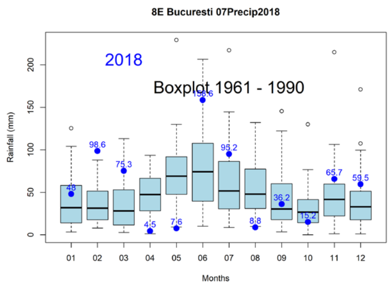


Figure 4: 8E Bucuresti 07Precip2018box

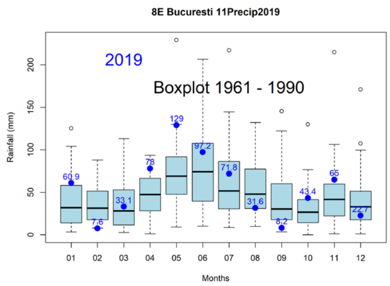


Figure 5: 8E Bucuresti 11Precip2019box

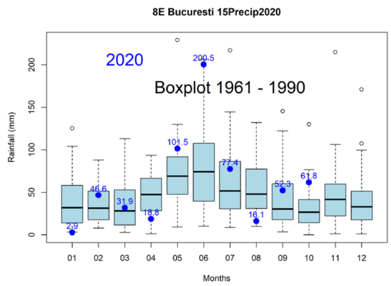


Figure 6: 8E Bucuresti 15Precip2020box

The comparing Draganesti meteo station with Bucuresti (ECAD 2019) the rainfall pattern for 1961-1990 appears to be very similar. Also, the yearly averages are very close (Table 1).

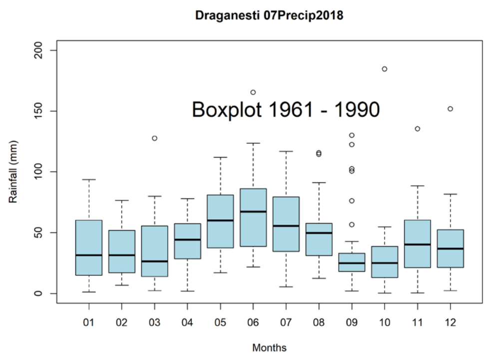


Figure 7: Draganesti 07Precipbox

In the study area, the climate is temperate continental. The case study is located in a specific agricultural area, affected by drought in 65 % of the years. The unfavourable climatic conditions negatively affect the crop plants productivity, even the soils have good fertility. The most common encountered unfavourable climatic phenomena are heat and prolonged pedological drought during the plant growing season, increased average annual temperature by 1-2°C when compared to the multiannual average (10.8°C), temperatures of over 30°C starting from April, with a maximum of 42-43°C and a minimum of -27-29°C, values that have increased in recent years due to global warming, unevenly distributed precipitation during the growing season, and high potential evapotranspiration levels.

From the values presented in table 1, it can be observed that the experimental years 2018 – 2020 had values of temperature (Tmax & Tmin) higher by 1-3°C when compared to the period of 1961 – 1990. Although the precipitation increased in the experimental years (2018 – 2020) in comparison with the reference period (1961 – 1990), the higher levels of potential evapotranspiration led to a higher water deficit during the plants growing season. The water deficit intensity increases are recorded mainly in the period between June – September, with a maximum in July. This period corresponds with the developing stages of the spring crops. Prolonged periods of drought during the summertime can lead to irreversible plants wilting, soil aridity, water scarcity and decreasing crop productivity.

Cropping systems description

Treatments

The experiment consists of 12 treatments with the following codes in the SoilCare Database and the analysis following.

ICPA_EX1_TR1= Ploughing + Rot 1 (Control)

ICPA_EX1_TR2= Ploughing + Rot 2

ICPA_EX1_TR3= Ploughing + Rot 3

ICPA_EX1_TR4= Subsoiling + Rot 1

ICPA_EX1_TR5= Subsoiling + Rot 2

ICPA_EX1_TR6= Subsoiling + Rot 3

ICPA_EX1_TR7= Disk + Rot 1

ICPA_EX1_TR8= Disk + Rot 2

ICPA_EX1_TR9= Disk + Rot 3

ICPA_EX1_TR10= Chisel + Rot 1

ICPA_EX1_TR11= Chisel + Rot 2

ICPA_EX1_TR12=Chisel + Rot 3

The treatments above are combinations of level from two factors, tillage and crop rotation.

- The tillage levels include moldboard ploughing with furrow inversion at 25 cm depth, subsoiling at 60 cm, disking at 12 cm depth and chiselling at 25 cm depth without furrow inversion.
- The three different rotations mentioned are:

  Rot1: Maize (22 kg/ha) / Soybean (100 kg/ha) / Barley (220 kg/ha)

  Rot2: Winter wheat (250 kg/ha) / Mustard (17 kg/ha) / Sunflower (10 kg/ha)

  Rot3: Spring barley (250 kg/ha) / Maize (25 kg/ha) / Soybean (150 kg/ha)

Field operations

The experimental field is getting fertilized every spring with a complex fertilizer NPK 15:15:15 and also 2 kg/ha Glyphosate is applied in May.

Bio-physical data analysis – WP5

Method

Differences between treatments for all response variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block).

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

For the yield and other crop-related characteristics, the relative change values of the SICS treatments compared to the control, calculated to exclude the effect of the different crops in the rotation and analyse only the treatments and date effects.

Data

In the table. you can find the variables measured and analysed for this experiment.

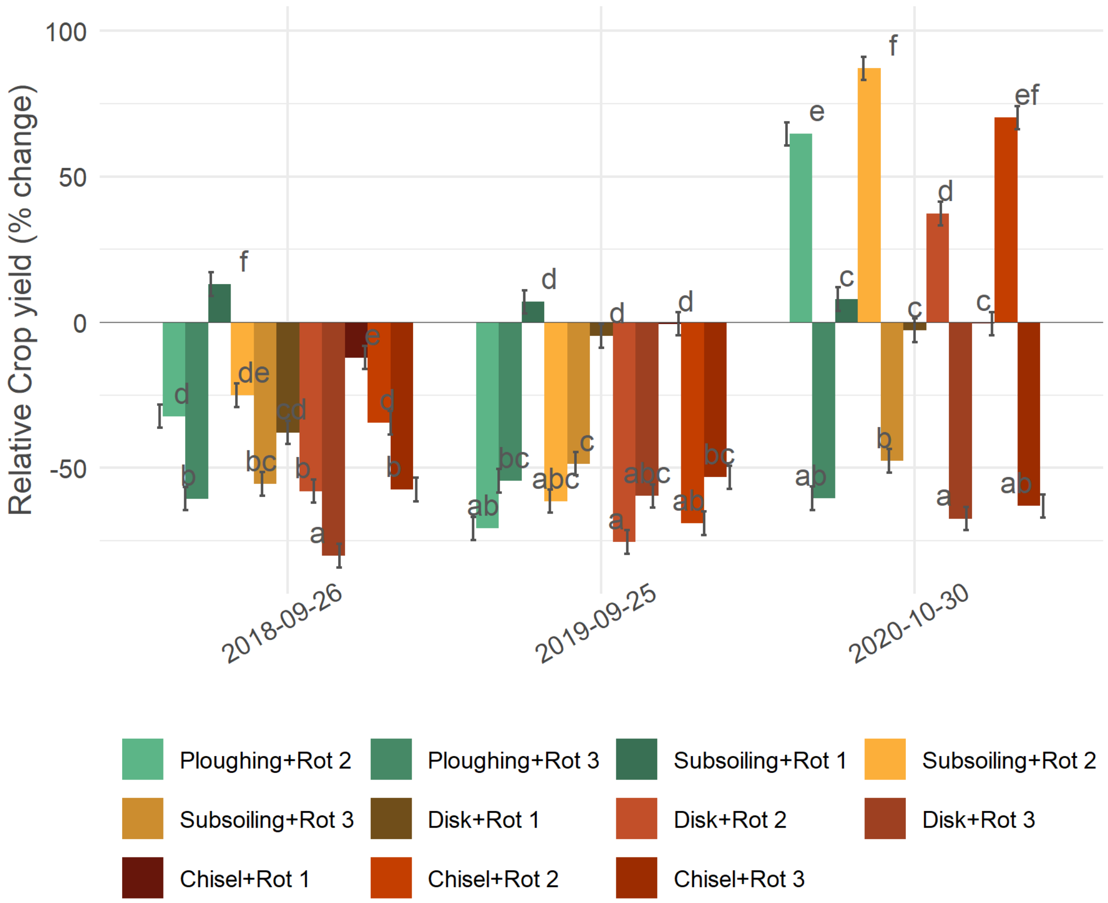
Table 2: Indicators measured and analyzed in the SS

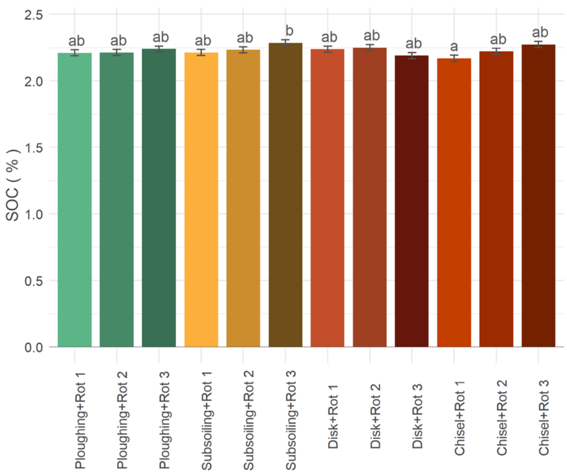
Observation code	Unit	Description
ksat	cm/h	Saturated hydraulic conductivity
top_wc_pf2_0	m^3m^{-3}	Water content at FC
top_wc_pf4_2	m^3m^{-3}	Water content at PWP
top_wc_pf2_7	m^3m^{-3}	Water content at pF2.7
top_wc_pf_1_8	m^3m^{-3}	Water content at pF1.08
top_satur_wc	m^3m^{-3}	Water content at Saturation

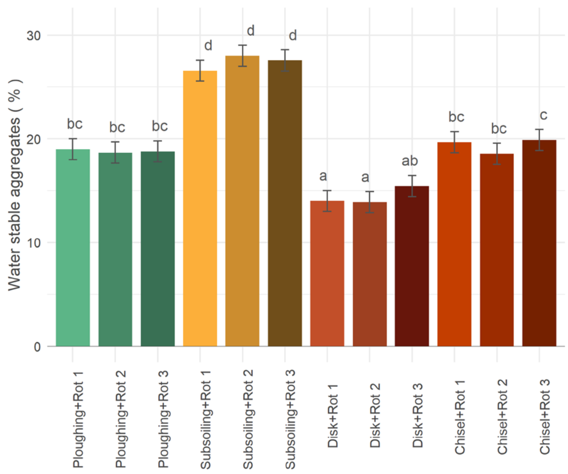
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density (10-20 cm)
bd_bot	g/cm^3	Bulk density (40-50 cm)
top_clay	%	Clay content
top_silt	%	Silt content
top_sand	%	Sand content
p_avail	mg-P/100gr Soil	Available Phosphorus
k_plus	cmol+/kg	Exchangeable Potassium
ca2_plus	cmol+/kg	Exchangeable Calcium
na_plus	cmol+/kg	Exchangeable Sodium
mg2plus	cmol+/kg	Exchangeable Magnesium
soc	%	SOC
ph_H2O	_	pH
ec1_5	dS/m	EC
crop_yield	kg/plot	Crop yield of the plot
crop_yield_ha	kg/hectare	Crop yield

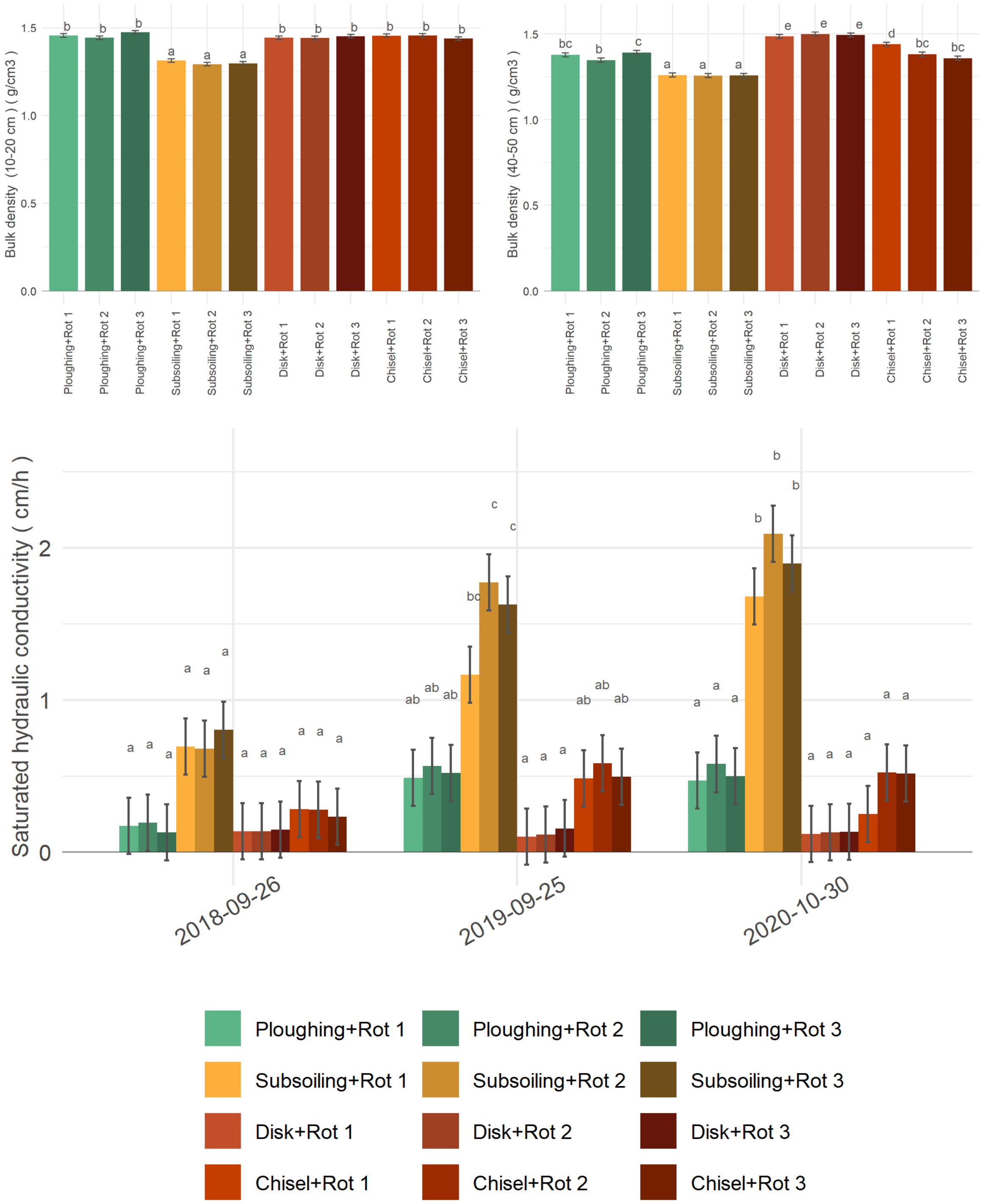
Results

In the figures below the figures of some of the variables measured for this experimental site are presented. These variables are the relative crop yield, soil organic carbon content (SOC), water-stable aggregates, saturated hydraulic conductivity and bulk density for both topsoil and subsoil.


Relative Crop yield (% change)
100
50
0
-50
2018-09-26
2019-09-25
2020-10-30
Ploughing+Rot 2
Ploughing+Rot 3
Subsoiling+Rot 1
Subsoiling+Rot 2
Subsoiling+Rot 3
Disk+Rot 1
Disk+Rot 2
Disk+Rot 3
Chisel+Rot 1
Chisel+Rot 2
Chisel+Rot 3


SOC (%)
2.5
2.0
1.5
1.0
0.5
0.0
Ploughing+Rot 1
Ploughing+Rot 2
Ploughing+Rot 3
Subsoiling+Rot 1
Subsoiling+Rot 2
Subsoiling+Rot 3
Disk+Rot 1
Disk+Rot 2
Disk+Rot 3
Chisel+Rot 1
Chisel+Rot 2
Chisel+Rot 3


Water stable aggregates (%)
30
20
10
0
Ploughing+Rot 1
Ploughing+Rot 2
Ploughing+Rot 3
Subsoiling+Rot 1
Subsoiling+Rot 2
Subsoiling+Rot 3
Disk+Rot 1
Disk+Rot 2
Disk+Rot 3
Chisel+Rot 1
Chisel+Rot 2
Chisel+Rot 3



Analysis

Among the measured physical properties, the saturated hydraulic conductivity values recorded the highest variability between both treatments and three experimental years. The recorded differences were statistically significant, and the values ranged from $28 \cdot 10^{-8}$ cm/h up to $581 \cdot 10^{-8}$ cm/h. High variability was obtained also for plant crops yields. In general, the treatment where subsoiling was applied led to production increases, while the treatments where disking and chiselling were done led to production decreases.

The soil organic carbon content (SOC, %) didn't vary statistically significant between the applied treatments, the recorded values ranging between 2.16 % and 2.30 % within all three experimental years.

The water-stable aggregates content (%) was statistically significant influenced by the experimental variants, the values falling within the range of 12 – 31 % in the case of all 4 treatments. However, the water-stable aggregates content variation within the same treatment was not statistically significant between the three experimental years.

The bulk density values recorded in the topsoil (10 – 20 cm depth) ranged between 1.43 – 1.50 g/cm^3 where either ploughing, disking or chiselling was done, while where subsoiling was performed the values ranged from 1.27 to 1.33 g/cm^3. The same trend was observed also in the case of measured bulk densities values in the subsoil (40 – 50 cm depth).

Regarding the measurement of soil chemical properties, they did not register statistically significant variations between the applied treatments and also between the three analysed years.

Socio-cultural dimension

The assessment of the environmental, sociocultural, and economic impacts of the selected SICS was done according to the monitoring plan developed by WP4. For this, 3 questionnaires were filled in which 3 SICS were compared with a control variant (disk). In this study site, the selected SICS were as follows: moldboard ploughing, subsoiling and chisel.

After analysis and comparison between all 3 selected SICS and the control variant, from the socio-cultural point of view, the implementation of SICS at the farm level may have a potential risk of crop failure and health risk mainly due to climatic conditions from the study area and use of high levels of chemical inputs.

In this report, as an example of the assessment of the environmental, sociocultural, and economic impact, the results of the comparison between mouldboard ploughing (SICS variant) and disk (control variant) are shown in the following tables.

SICS: ICPA_EX1_TR1-TR3 (Moldboard ploughing)

Control: ICPA_EX1_TR7-TR9 (Disk)

Respondent of the questionnaire is a researcher for all treatments.

Table 3: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

SICS: ICPA_EX1_TR1-TR3 (Mouldboard ploughing)
Control: ICPA_EX1_TR7-TR9 (Disk)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.20	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	0.00	1.00	Complete

Economical dimension

The economical dimension of the SICS implementation was assessed by using a single indicator, namely the cost-benefit indicator. Estimation of the cost and benefits were made to the selected SICS in plots where maize was cultivated. After the calculation of the costs and benefits, all 3 assessed SICS from the study area showed a positive impact when compared with the control treatment. Implementation of the SICS resulted in a positive impact on the overall sustainability of the SICS. The highest positive impact of SICS implementation at the farm level was recorded when subsoiling was applied (percentage change: 185 %), followed by mouldboard ploughing (percentage change: 134 %). On the contrary, the lowest positive impact of SICS implementation was recorded when chisel was applied (percentage change: 54 %).

SICS: ICPA_EX1_TR1-TR3 (Mouldboard ploughing)

Control: ICPA_EX1_TR7-TR9 (Disk)

Table 4: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	AMP SICS
Agricultural management technique	Disk	Mouldboard ploughing
Investment costs	0	0
Maintenance costs	1287	1860
Production costs	0	0
Benefits	1741	2923
Summary = benefits - costs	454	1063

Percentage change	134.0

Overall analysis and main findings

Summary of the results and interpretation

The soil from this study was characterized in terms of hydro-physical and chemical properties. The soil type is a Cambic Chernozem with clay loam texture, and a clay content varying between 42.9 % and 45.2 %. These high contents in clay resulted in higher values for bulk density within the soil profile. The bulk density values in the topsoil were higher in plots where ploughing, disking and chiselling were done, while where subsoiling was performed the values were lower. The same trend was observed also in the case of measured bulk densities values in the subsoil.

The soil from the study site is susceptible to degradation by natural subsoil compaction. Degradation of soils due to compaction is a worldwide problem, and the problems caused by this may be: a decreased root length, retarded root penetration and shallower rooting depth. The soil compaction can result in a greater concentration of roots in the upper soil layer and reduced root growth in the deeper soil layer, mostly due to excessive mechanical impedance such as hardpan which is formed below the tillage depth.

Soil structure represents one of the major attributes of soil quality and it affects the soil pore system and through it the water movement processes in soil, which is measured by saturated hydraulic conductivity. The saturated hydraulic conductivity of such fine-textured soil shows high variability and records low values, the most significant decrease being encountered in the control where disking tillage was done. Also, the saturated hydraulic conductivity values were highly variable between both treatments and three experimental years. The highest values of saturated hydraulic conductivity were determined in variants where subsoiling tillage was done. Moreover, it was observed that in these plots with subsoiling tillage, the saturated hydraulic conductivity values increased from year to year, meaning that the soil porous system continuity was not further disturbed by tillage and the water pathways in soil were not interrupted.

Soil porosity plays a significant role in the evaluation of the impact of management practices on the quality of soil structure. By adopting alternative tillage systems, such as subsoiling tillage treatment, the soil macro-porosity can increase and is more-homogeneously distributed through the profile when compared with a disking tillage variant, and the resulting soil structure has better quality, as confirmed by the higher hydraulic conductivity measured in the soil tilled by subsoiling. This is confirmed also by the values measured for water-stable aggregates, which were higher in the treatment with subsoiling tillage for all 3 investigated years.

The tested SICS treatments within the experimental field showed a high variability regarding the plant crops yields. In general, the treatment where subsoiling was applied led to production increases, while the treatments where disking and chiselling were done led to production decreases. The level of yields obtained in treatment where mouldboard ploughing was done ranged between those obtained in plots where subsoiling and chiselling tillage were done.

Regarding the chemical characterization of the studied soil, there were no statistically significant variations between the applied treatments and also between the 3 analysed years. The soil reaction values in case of all treatments varied between 5.99 – 6.63, which highlighted lightly acid soil.

The soil organic carbon content did not vary between the applied treatments, the content being moderate within all 3 experimental years. The investigated soil was highly supplied with available phosphorus, while for the potassium content the soil was low to moderately supplied.

Drawbacks and benefits for the experimental treatments

Since the impact of tested SICS depends on various factors such as local weather, socio-economic conditions, the assessment took into account the local specific conditions and the information provided by the stakeholders involved in the project.

Regarding the drawbacks and benefits of the **mouldboard ploughing SICS**, it was found that using high levels of chemical inputs there may increase the health risk due to nutrients leaching and infiltration in the groundwater table. In dry years, there is a potential risk of crop failure because of the water stress for crops during the growing season. On the contrary, if the ploughing tillage is done in the optimum water range for workability and trafficability, the machinery used to have low weight and low tyre pressure inflation and is used in combination with deep rooting system crops/legumes in crop rotation, the mouldboard ploughing has positive effects on infiltration rate, aggregate stability, increasing crop yields and profitability.

Regarding the drawbacks and benefits of the **subsoiling SICS**, it was found that applying it every year, is time and energy consuming leading to an increase in workload, and the financial benefits for farmers are not significant. Also, by using high levels of chemical inputs there may increase the health risk due to nutrients leaching and infiltration in the groundwater table. In dry years, there is a potential risk of crop failure because of the water stress for crops during the growing season. On the other hand, subsoiling improved the soil indicators such as infiltration rate and bulk density which resulted in an increase in crop yields and farm profitability leading to improving the farmer reputation.

Regarding the drawbacks and benefits of the **chiselling SICS**, it was found that using high levels of chemical inputs there may increase the health risk due to nutrients leaching and infiltration in the groundwater table. On such heavy textured soil, there is a potential risk of crop failure because the weed control cannot be realized adequately and the use of deep rooting system plants in combination with chisel tillage does not result in high crop yields. On the other hand, it has positive effects on aggregate stability because the soil disturbance by tillage implements is kept at a lower level.

Main important findings

Soil improving cropping systems can have positive effects on soil quality by protecting the soil from different threats. In our case study, the main soil threat found was natural subsoil compaction. This was mainly caused by heavy soil texture within the whole soil profile, but also can be due to soil tillage done in un-proper moisture conditions, un-controlled traffic at the soil surface, use of high axle load equipment and high tyre pressure.

The mouldboard ploughing SICS may be a solution for compaction alleviating if is done in optimum water range for workability and trafficability, low weight machinery is used and low tyre pressure, controlled traffic, use of deep rooting system crops/legumes in crop rotation.

Another solution for mitigation of the natural subsoil compaction on clayey soils may be the application of subsoiling as a measure used in practice by farmers. Based on the above-mentioned drawbacks and benefits of the subsoiling SICS, it is recommended that this tillage type should be done periodically at 3-4 years.

Another measure of soil quality conservation and compaction mitigation is the use of leguminous crops/deep rooting system crops in crop rotation. This can be an appropriate measure for nitrogen-fixing in soil, which results in decreasing the chemical fertilizers doses by the next cultivated crop in rotation. The leguminous crops also improve soil quality by increasing the structural aggregate stability leading to a good soil aeration status and water regime.

Overall general conclusions

Based on the assessment of the environmental, economic and socio-cultural indicators of the tested SICS in our study site area, the calculated overall sustainability impact index showed that the best

SICS to be implemented by farmers in practice is the one where subsoiling at 60 cm depth was applied as the main soil tillage (subsoiling SICS score: 0.34), followed by the mouldboard ploughing with furrow inversion at 25 cm depth (moldboard ploughing SICS score: 0.33) and, lastly, the chisel tillage without furrow inversion at 25 cm depth (chisel SICS score: 0.26).

One of the requirements of quality management of soils in general, and arable soils in particular, is knowledge of the dynamics of physical and chemical characteristics especially of those which are the most sensitive under human activities.

The impact evaluation of the application of the selected SICS on the environmental indicators showed that the most sensitive properties to the tested cropping systems were the physical ones. After field and laboratory monitoring it was observed that applying the subsoiling and moldboard ploughing tillage had positive influences on the soil physical indicators, mainly on infiltration rate, bulk density and aggregate stability.

SICS: ICPA_EX1_TR1-TR3 (Moldboard ploughing)

Control: ICPA_EX1_TR7-TR9 (Disk)

Table 5: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.13	0.79	Medium
Environmental dimension	0.24	0.47	Medium
Economic dimension	0.31	1.00	Complete
Socio-cultural dimension	-0.20	1.00	Complete
Physical properties	0.25	0.40	Medium
Chemical properties	0.07	0.43	Medium
Biological properties	0.20	0.35	Low

Table 6: Other indices

Benefits:	Infiltration; Aggregate stability; Crop yield; Cost-benefit;
Drawback:	Potential health risk; Potential risk of crop failure

General conclusions based on the experiment

The objective of the experiment established within the study area was to test the selected soil-improving cropping systems (SICS) at the beginning of the project and to determine which one is the most suitable to mitigate the soil threat in the area and, at the same time, to have financial benefits for farmers without further degradation of soil quality.

Within our study site, three soil-improving cropping systems were tested. These are as follows:

- main soil tillage by moldboard ploughing with furrow inversion at 25 cm depth.
- main soil tillage by subsoiling at 60 cm depth.
- main soil tillage by chisel without furrow inversion at 25 cm depth.

The soil threat within the study area is natural subsoil compaction due to high clay content throughout the whole soil profile.

The following conclusions may be drawn after the evaluation of the environmental, economic and socio-cultural indicators used for determining the impact of selected SICS on soil quality and establishing the overall sustainability of SICS implementation:

- To mitigate the natural subsoil compaction in the study area, the best solution with positive effects on both soil quality and farm productivity is to use a combination of the two SICS treatments which were tested, namely the application of the moldboard ploughing annually and the subsoiling periodically at 3-4 years. In this way is prevented the formation of the hardpan layer at the base of tillage depth.
- Also, on such clayey soil, it can be used in crop rotation the deep rooting system crops/legumes. Such crop types improve the soil quality by increasing the structural aggregation which can have positive influences on soil aeration status and water regime.

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I.9 University of Padova (Italy)

Report on Monitoring and Analysis

Study Site number: 9

Country: Italy

Author(s): Felice Sartori, Ilaria Piccoli, Antoni Berti

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): University of Padova

Experiment: TCC - Tillage and Cover Crop

Version:

Date: 18-02-2021

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Experiment description

The main objective of the experiment is to evaluate the effect of different soil coverings on soil fertility and compaction. The experiment established in March 2018 and was set up in a split-plot-complete randomized design with 2 main plots, one for each tillage level, containing 3 plots each for each crop type replicated twice.

Experimental field information

The experiment is conducted on an experimental field managed by the researchers. The experimental field is in Legnaro, Italy, at an altitude of about 7 m and covers an area of about 13160 m^2. The topsoil has a silty loam texture according to the USDA classification system.

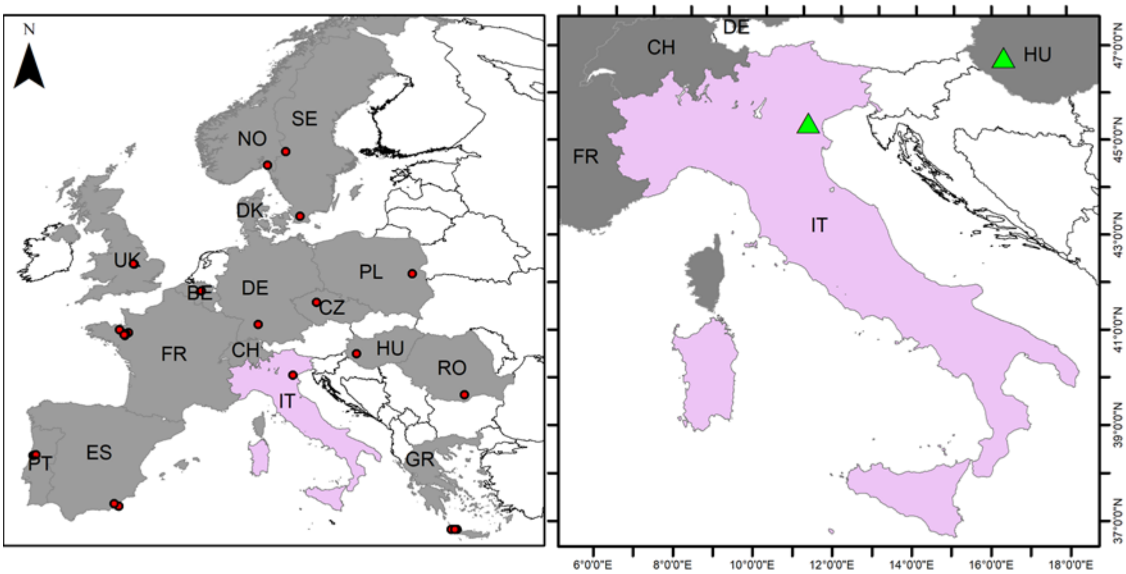


Figure 1: Location of the study site

The soil profile of 2 m which described in June 1994, has 5 horizons and is characterized as Cambisol according to the WRB soil classification system. The maximum rooting depth found to be at 1.25 m and the groundwater level depth at 1.65 m.

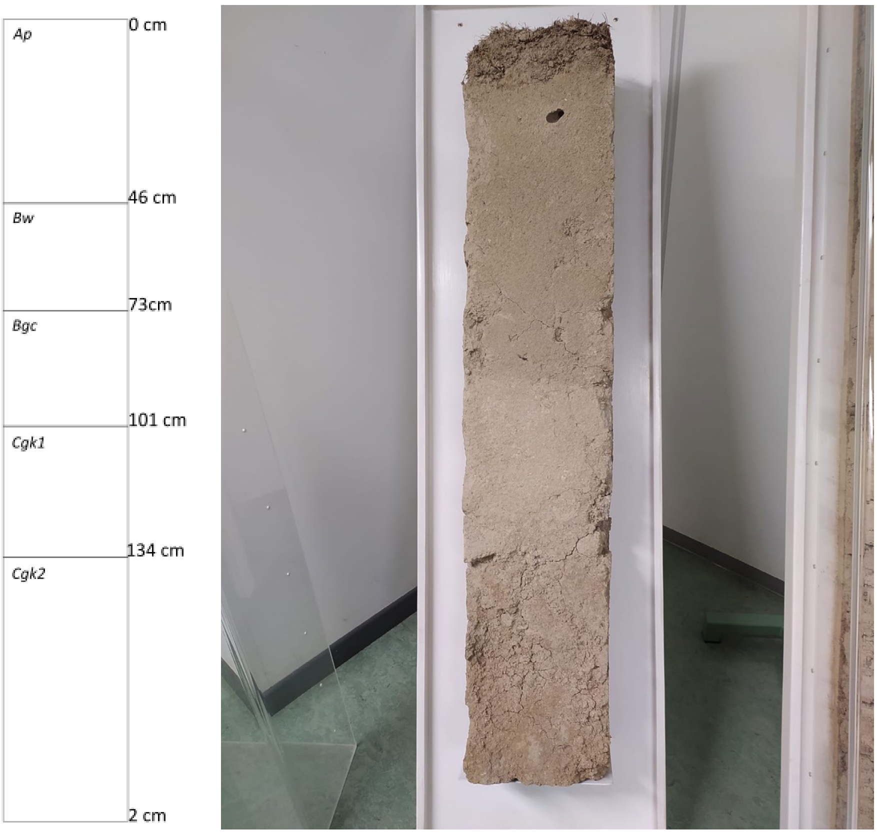


Figure 2: Soil profile of the SS

The climate of the experimental field area

The weather station Legnaro is on the experimental farm of the University of Padua. Monitoring is available from 1963 until now.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Legnaro

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1963-90	16.1	7.3	833.5	889.5
2018	19.3	10.2	853.2	1005
2019	19.3	9.7	864.6	981
2020	18.6	9.1	1262.2	991.5

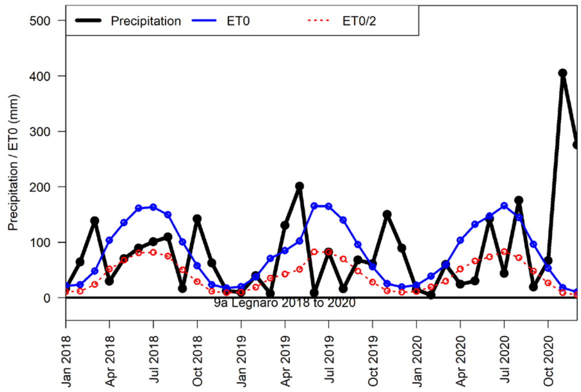


Figure 3: 9a FAO Growing season for 2018 until 2020 for Legnaro

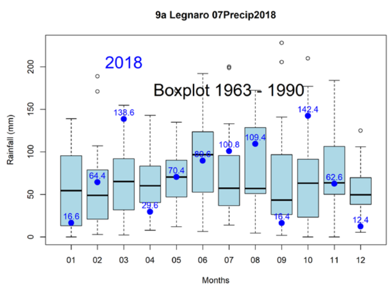


Figure 4: 9a Legnaro Boxplot vs 2018

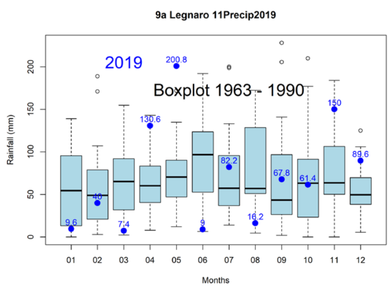


Figure 5: 9a Legnaro Boxplot vs 2019

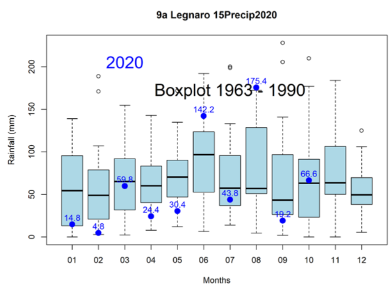


Figure 6: 9a Legnaro Boxplot vs 2020

Legnaro is in the low-lying Venetian plain where the climate is considered sub-humid, which receives about 850 mm of rainfall annually and reference evapotranspiration of 945 mm. The highest rainfall values are concentrated in June and October, and the lowest during winter. Lower temperatures are registered in January (-1.5° C on average), and the highest in July (maximum average: 27.2° C). Remark the difference in temperatures between the 1963-90 period as compared to the experimental years (Table 1). For 2020 the rainfall during November and December were very large and off-scale in Figure 6.

Cropping systems description

Treatments

The experiment consists of 6 treatments with the following codes in the SoilCare Database and the analysis following.

UNIPD_EX1_TR1=CT + BS

UNIPD_EX1_TR2=CT + WW

UNIPD_EX1_TR3=CT + TR

UNIPD_EX1_TR4=NT + BS

UNIPD_EX1_TR5=NT + WW

UNIPD_EX1_TR6=NT + TR

The treatments above are combinations of level from two factors, tillage and cover crop type.

- The tillage levels include:

  CT: Mouldboard ploughing at 45 cm

  NT: No-tillage
- The three different cover crops levels are:

  BS: No cover crop

  WW: Wheat cover crop

  TR: Radish cover crop

The cover crops are planted in autumn and mouldboard tillage takes place in spring and summer annually.

Field operations

The main crop in the field is corn (*Zea mays* L.) which is planted late spring or beginning of summer and is harvested at the beginning of autumn, depending on the weather conditions. The maize stover is shredded and returned to the field as mulches. Nitrogen, phosphorus and potassium are added in the field in the form of urea or NPK mineral fertilizer, and various herbicides and insecticides are also applied. Glyphosate is also applied for weed management. When meteorological conditions require it, drip irrigation is also applied to the crops.

Bio-physical data analysis – WP5

Method

Differences between treatments for all were analysed with a Mixed-Effects Model

Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

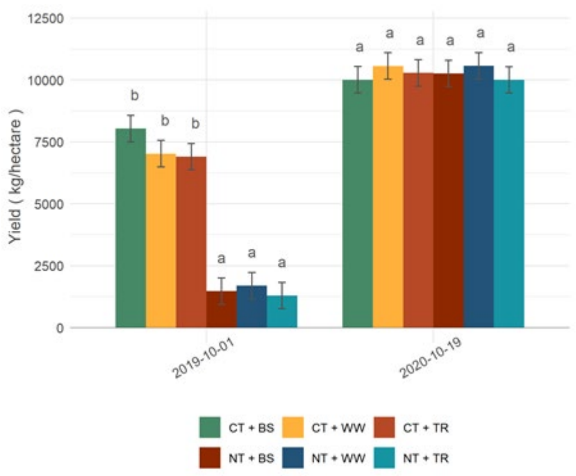
In the table, you can find the variables measured and analysed for this experiment.

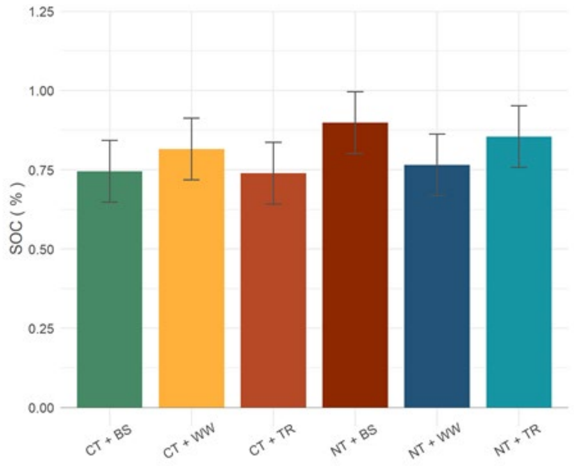
Table 2: Indicators measured and analysed

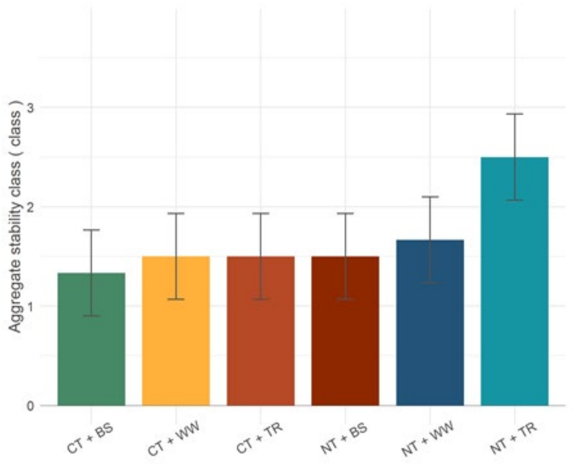
Observation code	Unit	Description
ksat	k_{sat}	m s^{-1}
top_wc_pf2_0	pF 2	m3m-3
top_wc_pf4_2	pF 4.2	m3m-3
top_wc_pf2_7	pF 2.7	m3m-3
top_wc_pf_1_8	pF 1.8	m3m-3
top_satur_wc	VWC_{sat}	m3m-3
wsa	Aggregate stability class	class
bd_top	BD_{10-20}	g/cm3
bd_bot	BD_{40-50}	g/cm3
top_clay	Clay	%
top_silt	Silt	%
top_sand	Sand	%
nmin_top	N_{min}	mg-N/Kg soil
p_avail	TP	mg-P/100gr Soil
k_plus	K^+	cmol+/kg
ca2_plus	CA^{2+}	cmol+/kg
na_plus	NA^+	cmol+/kg
mg2plus	MG^+	cmol+/kg

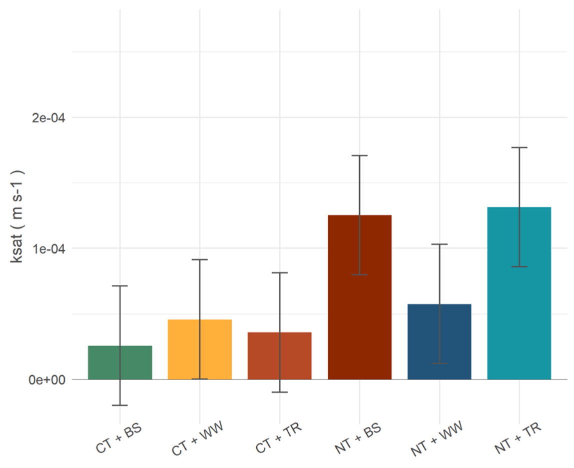
soc	SOC	%
ph_kcl	pH	unitless
weed_infestation	Weed infestation	%
earthworm_score	Earthworm score	unitless
earthworm_no	Earthworm no.	/m2
soil_cover	Soil cover	%
crop_yield	Yield	kg/plot
crop_yield_ha	Yield	kg/hectare

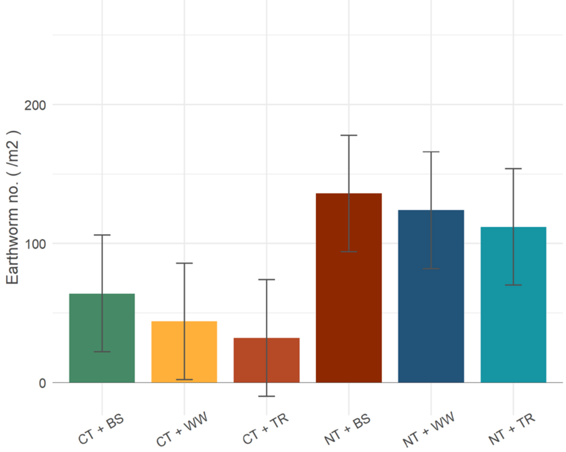
Results

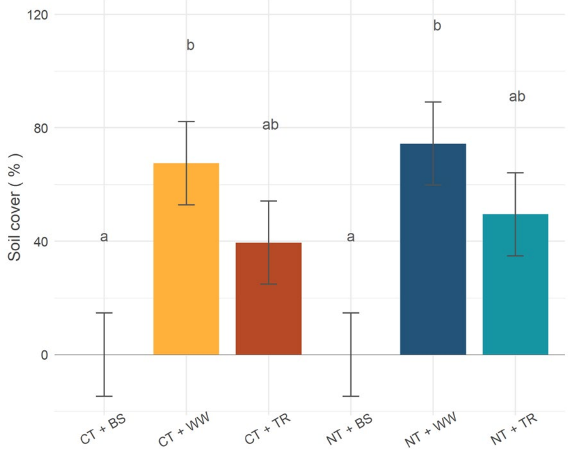








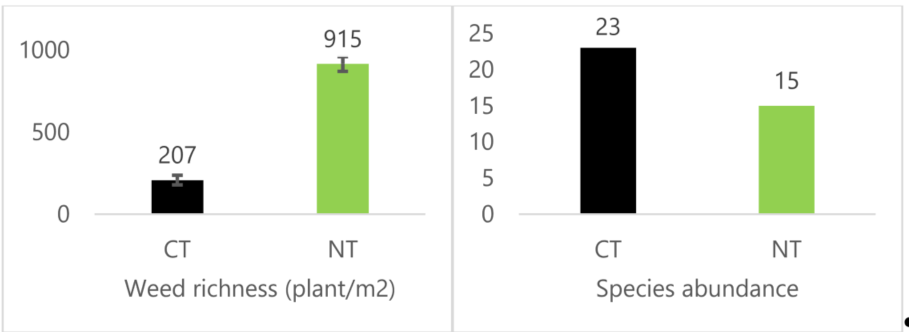




Analysis

Difficult meteorological conditions at seeding caused crop failure in 2019: all treatments registered from moderate to insufficient production. However, no significant difference in maize yield was found in 2020. SICS had a moderate effect on aggregate stability, which seems to benefit from NT+TR combination. Differently, soil hydraulic conductivity seems to be reduced in the TR treatment. Soil organic carbon did not change during the three years of treatment, but earthworms were positively correlated with conservation agriculture practices. Finally, the proximal image analyses showed that WW had better soil covering potential.

Study site analysis



A weed survey, conducted in June 2019, revealed a serious problem of weed infestation when the tillage is reduced. In No-tillage the weed population was highly specialised, with a reduced number of strongly competitive species.

Socio-cultural dimension

The socio-cultural analyses revealed that, according to technician and farmers, the SICS could significantly reduce the workload, nevertheless the risk of crop failure and the modest diffusion generate distrust among the agricultural operators. No effects were reported on the reputation of the respondents.

SICS: UNIPD_EX1_TR6: No-Till, radish cover crop

Control: UNIPD_EX1_TR1: Ploughed, no cover crop

Table 3: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.00	0.80	High
Workload	0.50	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	0.00	0.00	Low

Economical dimension

Table 4: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha.

	AMP control	AMP SICS
Agricultural management technique	Ploughed, no cover crop	No-Till, radish cover crop
Investment costs	0	0
Maintenance costs	0	0
Production costs	1670	1527
Benefits	1982	2104
Summary = benefits - costs	312	577
Percentage change	85.2	

The economic sustainability is positive, but the results obtained in 2019 indicates that there is a risk of crop failure, mainly related to possible adverse meteorological conditions in spring. It is then expected an important variability of the economic results. Results were positive in two years out of three and strongly negative in 2009. It is then necessary to properly evaluate the frequency of extreme events, considering also variability related to climatic change.

Overall analysis and main findings

No-tillage treatment was more susceptible to adverse environmental conditions, which could lead to crop failure and operators' distrust. Tillage radish did not have a clear effect on any of the parameters considered. Earthworm populations have benefitted from no-tillage. After a conversion time, conservation agriculture could reduce production costs, while maintaining high yields.

Table 5: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.02	0.83	High
Environmental dimension	0.00	0.72	Medium
Economic dimension	0.07	1.00	Complete
Socio-cultural dimension	0.00	0.80	High
Physical properties	0.00	0.60	Medium
Chemical properties	0.00	0.80	High
Biological properties	0.00	0.70	Medium

Table 6: Benefits and drawbacks of the SICS as compared to the control group

Benefits:	Reduction of workload; Cost-benefit;
Drawback:	Crop yield; Potential risk of crop failure; Potential risk of conflicts;

SICS improved the economic dimension, even if there is an inherent variability related to meteorological conditions; the short period of the experiment did not allow to obtain positive effects related to SOC increase and the improvement of soil physical traits.

References

Sartori, F., Loddo, D., Piccoli, I., & Berti, A. (2020, May). Weed infestation during the transition phase from conventional to conservation agriculture. In EGU General Assembly Conference Abstracts (p. 9838).

General conclusions based on the experiment

- In the short-term cover-crops have a little effect on soil physical traits
- No-tillage can have a positive effect on some soil characteristics
- No-tillage is more prone to be affected by adverse meteorological conditions, with a risk of crop failure
- The timing of sowing and the possibility to apply weed control in spring are the main factors affecting crop yield in NT
- Tillage radish showed some potentially interesting effect on soil health but still requires some fine-tuning to give reliable and appreciable effects. In particular winter temperature seems not sufficiently low to terminate the cover, thus requiring a later chemical weed control and delaying the degradation of the roots of the cover crop. This, in turn, reduces its potential effect on soil permeability during spring.
- No-till can be adopted with a short conversion time. The main critical aspects are related to sowing (timing and type of sowing machine) and trafficability in spring, allowing timely sowing and weed control.

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I.10 Institute of Agrophysics, Polish Academy of Sciences (Poland)

Report 1 on Monitoring and Analysis

Study Site number: 10

Country: Poland

Author(s): Magdalena Frąc, Jerzy Lipiec, Boguslaw Usowicz

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Institute of Agrophysics of the Polish Academy of Sciences

Experiment: Szaniawy

Figure 1: Estimating soil cover.

Version: Complete

Date: 22-02-2021

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Experiment description

The main objective of the experiment is to assess the effect of after crops (leguminous), liming and manure on soil properties and crop yields. The experiment established in March-August 2016 and was set up in a completely randomized experimental design where each treatment is replicated 3 times. The experiment includes 1 control and 4 SICS treatments.

Experimental field information

The experiment is conducted on an experimental field managed by the researchers and farmer jointly. The experimental field is located in Szaniawy, Poland at an altitude of about 160 m and covers an area of about 11000 m^2. The topsoil has a loamy sand texture according to the USDA classification system.

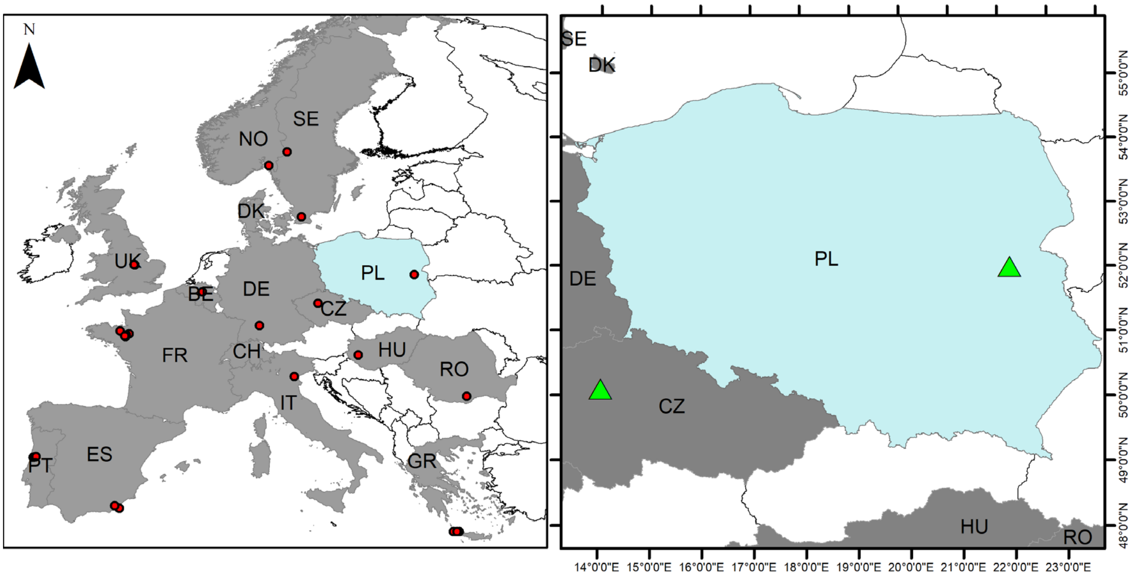


Figure 2:Location of the study site

The soil profile of 0.75 m which described in 2018, has 3 horizons and is characterized as Podzol according to the WRB soil classification system. The maximum rooting depth found to be at 0.5 m due to acidity. There is also a ploughing pan at 0.2 m.

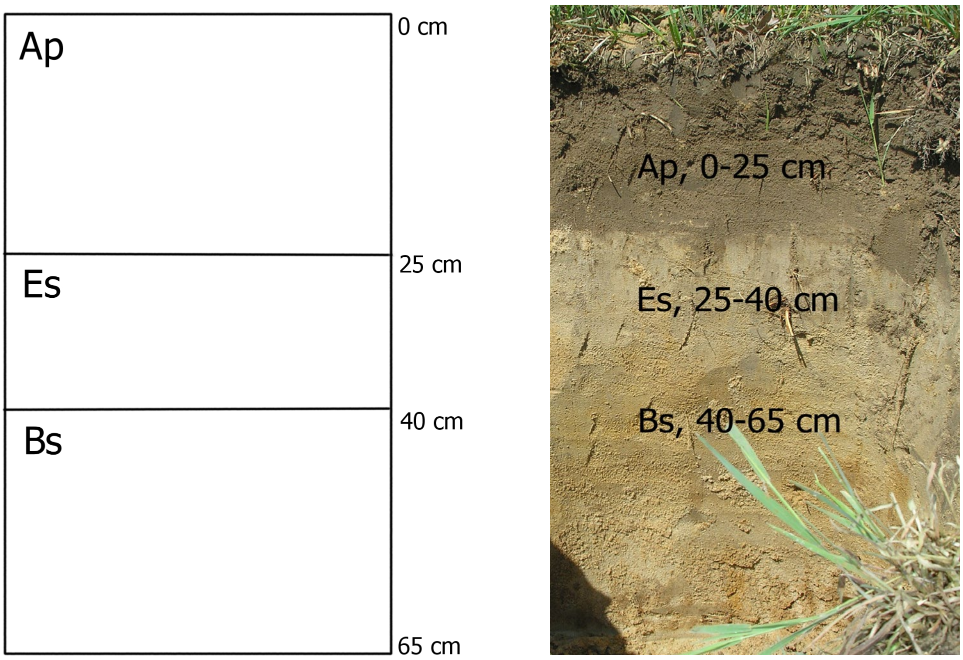


Figure 3: Soil profile in the SS; photo (Marcin Turski)

The climate of the experimental field area

The nearby meteorological station Siedlce (ECAD 333) was available from 1961 to 2020.

Table 1: Average Tmax, Tmin, Precipitation and ET0 for Siedlce (ECAD00333)

Period/year	Tmax	Tmin	Precip	ET0
	°C	°C	mm	mm
1961-90	11.6	3.0	533.2	733.1

2017	12.8	4.8	668.4	747.9
2018	14.2	4.6	513.0	853.8
2019	14.8	5.6	488.8	826.4
2020	14.4	5.3	666.2	795.6

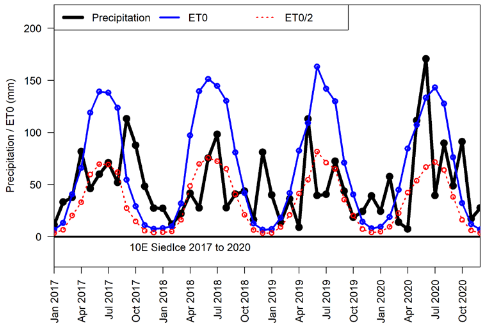


Figure 4: 10E Siedlce 00aFAOgrow

Traditionally the rainfall is higher during the summer coinciding with a higher evapotranspiration demand. Winter precipitation is relatively lower.

The annual precipitations in 2018 and 2019 were lower than those in 2017-2020 and the long-term average (Table 1). The lower precipitations, especially during intensive plant growth in the spring were reflected in reduced crop yield (Fig. 4).

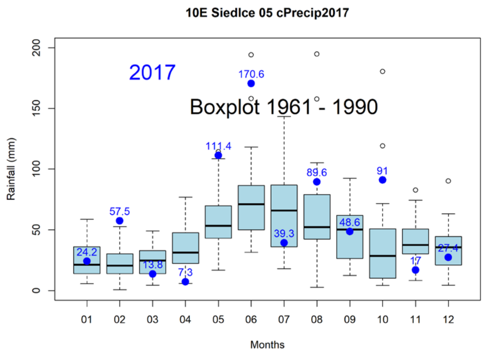


Figure 5: 10E Siedlce 05 cPrecip2017box

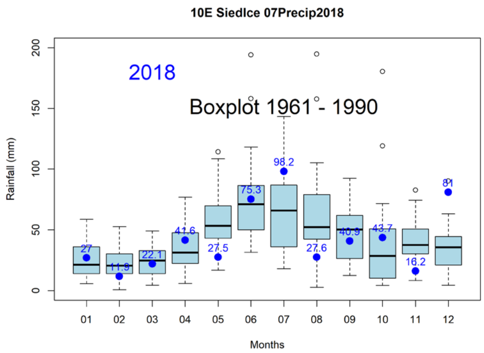


Figure 6: 10E Siedlce 07Precip2018box

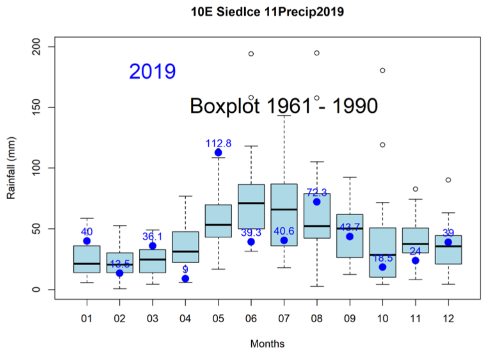


Figure 7: 10E Siedlce 11Precip2019box

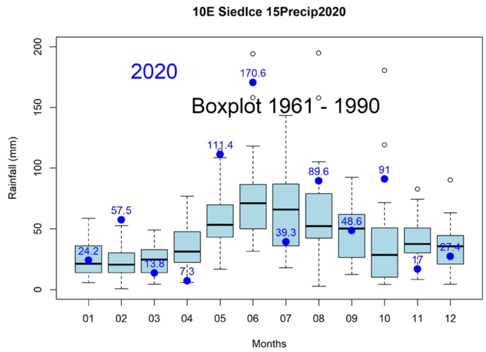


Figure 8: 10E Siedlce 15Precip2020box

Cropping systems description

Treatments

The experiment consists of 5 treatments with the following codes in the SoilCare Database and the analysis following.

IA_EX1_TR1= C

IA_EX1_TR2= L

IA_EX1_TR3= LU

IA_EX1_TR4= M

IA_EX1_TR5= M + L + LU

where

C: control

LL: liming with 5.6 t/ha CaCO3

LU: cover crops / intercrops – lupines + serradella +phacelia, respectively: 130 + 30 + 4 kg/ha

M: manure of 30 t/ha

M + L + LU: liming (CaCO3 5,6 t/ha) + lupines + serradella +phacelia (130 + 30 + 4 kg/ha) + manure (10 t/ha)

Field operations

Crop rotation is followed in this field. In 2017 oat, 2018 wheat, 2019 wheat and in 2020 oat planted in March and harvested in August. The experimental field is getting fertilized with 250 kg/ha Fertilizer of N 8%, P 24% , $K_2$4%, Sulphur 9%, just before seeding. Conventional mouldboard ploughing at 10 cm is happening before seeding, after harvesting and at 20 cm at the end of autumn. 0.75 kg/ha Chwastox (MCPA) herbicide is broadcasted in April after seeding.

Bio-physical data analysis – WP5

Method

Differences between treatments for variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

The yield and other crop-related characteristics change the relative values of the SICS treatments compared to the control, calculated to exclude the effect of the different crops in the rotation and analyse only the treatments and date effects.

Data

In the table, you can find the variables measured and analysed for this experiment.

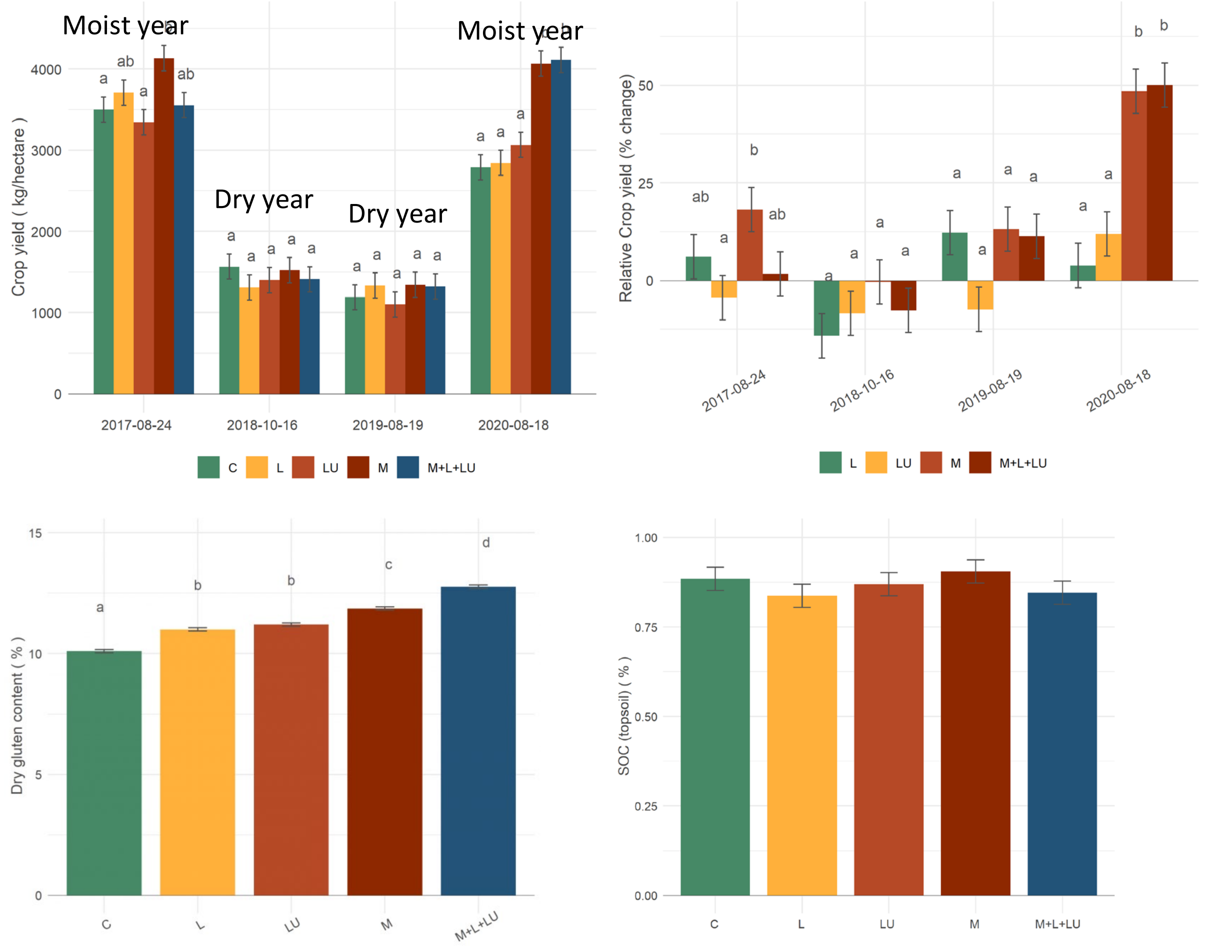
Observation code	Unit	Description
top_satur_wc	m^3m^{-3}	Saturated hydraulic conductivity
bd_top	g/cm^3	Bulk density (10-20 cm)
bd_bot	g/cm^3	Bulk density (40-50 cm)
top_clay	%	Clay fraction (topsoil)
top_silt	%	Silt fraction (topsoil)
top_sand	%	Sand fraction (topsoil)
nmin_top	mg-N/Kg soil	Mineral Nitrogen (topsoil)
p_avail	mg-P/100gr Soil	Available Phosphorus top (topsoil)
soc	%	SOC (topsoil)
ph_kcl	_	pH in KCl (topsoil)
ph_h2o	_	pH in water (topsoil)
thermal_conductivity	W/(m K)	Thermal conductivity (topsoil)
heat_capacity	$MJ/(m^3 K)$	Heat capacity (topsoil)
thermal_diffusivity	mm^2/s	Thermal diffusivity (topsoil)
thermal_ds_conductivity	W/(m K)	Thermal conductivity-dry soil (topsoil)
heat_ds_capacity	$MJ/(m^3 K)$	Heat capacity-dry soil (topsoil)
thermal_ds_diffusivity	mm^2/s	Thermal diffusivity-dry soil (topsoil)
water_thermal_conductivity	W/(m K)	Water thermal conductivity-saturated soil (topsoil)
water_heat_capacity	$MJ/(m^3 K)$	Water heat capacity-saturated soil

		(topsoil)
water_thermal_diffusivity	mm^2/s	Water thermal diffusivity-saturated soil (topsoil)
water_content	m^3/m^3	Water content (topsoil)
particle_density	g/cm^3	Particle density
k_avail	mg-K/100g of soil	Available Potassium (topsoil)
mg_avail	mg-Mg/100g of soil	Available Magnesium (topsoil)
cec	cmol/kg	CEC (topsoil)
soc_30_50	%	SOC (30-50 cm)
ph_kcl_30_50	_	pH in KCl (30-50 cm)
ph_h2o_30_50	_	pH in water (30-50 cm)
clay_30_50	%	Clay fraction (30-50 cm)
silt_30_50	%	Silt fraction (30-50 cm)
sand_30_50	%	Sand fraction (30-50 cm)
cec_30_50	cmol/kg	CEC (30-50cm)
thermal_conductivity_40_50	W/(m K)	Thermal conductivity (40-50 cm)
heat_capacity_40_50	$MJ/(m^3 K)$	Heat capacity (40-50 cm)
thermal_diffusivity_40_50	mm^2/s	Thermal diffusivity (40-50 cm)
thermal_conductivity_ds_40_50	W/(m K)	Thermal conductivity-dry soil (40-50 cm)
heat_capacity_ds_40_50	$MJ/(m^3 K)$	Heat capacity-dry soil (40-50 cm)
thermal_diffusivity_ds_40_50	mm^2/s	Thermal diffusivity-dry soil (40-50 cm)
water_thermal_cond_40_50	W/(m K)	Water thermal conductivity-saturated soil (40-50 cm)
water_heat_capacity_40_50	$MJ/(m^3 K)$	Water heat capacity-saturated soil (40-50 cm)
water_thermal_diff_40_50	mm^2/s	Water thermal diffusivity-saturated soil (40-50 cm)
water_content_40_50	m^3/m^3	Water content (40-50 cm)
wet_gluten_cont	%	Wet gluten content
dry_gluten_cont	%	Dry gluten content
gluten_inde	%	Gluten index

kernel_hardness_index	_	Kernel hardness index (SKCS)
kernel_weig	mg	Kernel weight
kernel_mois	%	Kernel moisture
kernel_diam	mm	Kernel diameter
crop_yield	kg/plot	Crop yield of the plot
crop_yield_ha	kg/hectare	Crop yield
yield_grain_straw	kg/hectare	Yield grain and straw
plant_height	cm	Plant height at harvest

Results

Figure 9: Mean values of crop yield, relative crop yield, dry gluten content in wheat kernels and soil organic carbon content.



Analysis

The most positive effect of manure alone and liming/cover crops/manure together on the yield of cereal grain and straw in a moist year (2020) was observed.

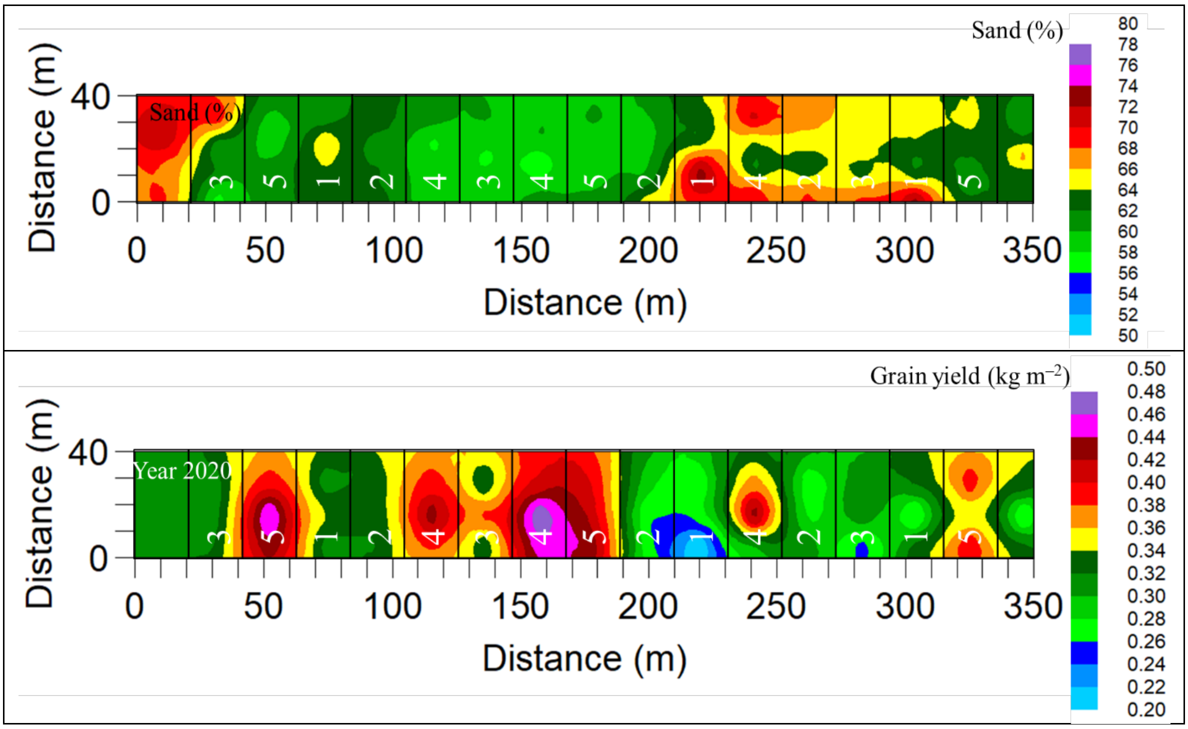
The crop yield was lower by over 50% during dry years versus moist years irrespective of soil-improving practice.

Soil-improving practices increased significantly dry gluten content in wheat kernels.

There was no significant effect of soil-improving practices on soil organic carbon content (SOC).

Study site analysis

Spatial distribution of sand content and oats field (in 2020). 1,2,3,4,5 correspond respectively to the treatments C, L, LU, M and M+L+LU.



Socio-cultural dimension

Farmer co-operators gained an increased understanding of soil organic amendments effects on crop yield. We observed they used more legume cover crops that were included in treatments of our experiment. These crops fixing atmospheric nitrogen can be a means of reducing synthetic nitrogen inputs and also improving soil structure in the long term.

Economical dimension

Application of manure alone and liming/cover crops/manure together increased significantly grain and straw yields of cereals in the last growing season. However, these yield increases did not compensate for additional production costs and consequently, the application of these practices in this short-term experiment was not profitable.

Overall analysis and main findings

Soil-improving practices had a significant effect on crop yield in moist in contrast to dry years.
Plots with liming/cover crops/manure had the highest topsoil mineral nitrogen content.

The period of the experiment (4 years) is too short to evaluate the effect of the soil-improving practices on soil organic matter (an important measure of soil quality) and the economical dimension.

Differences in crop yield between the tested soil-improving practices were relatively lower than those between the dry and moist years.
Plots with liming/cover crops/manure had the highest topsoil mineral nitrogen content, crop yield and dry gluten content in wheat kernels.

The highest cereal grain and straw yield and plant height in the last year of the 4-year study were recorded in plots with an application of manure or liming/cover crops/ manure together and the lowest in control plots. The spatial distribution of crop yield was similar to that of soil water content. The spatial kriging-interpolated maps of crop yield and soil properties will help to identify sub-field areas for applying localized management practices to improve crop productivity.

References

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3. Frąc, M., Pertile, B., Panek, J., Gryta, A. Oszust, K., Lipiec, J., Usowicz, B. Ecological responses of soil fungal community microbiome to the spent mushroom substrate and chicken manure amendments. Agronomy (under review).

General conclusions based on all the experiments

- Geostatistical analysis and 2 D maps allowed delineating low productive sub-field areas for targeted improvements.
- A combination of soil-improving practices compared to a single practice caused a higher increase in crop yields and dry gluten content.

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I.11 ESAC (Portugal)

Report 1 on Monitoring and Analysis of the Rotation System experiment

Study Site number: 11

Country: Portugal

Author(s): Antonio Ferreira, Anne-Karine Boulet

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation : ESAC – Escola Superior Agrária de Coimbra

Experiment: Rotation System – Biological Rice in rotation with perennial Lucerne

Version: 2

Date: 22-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to compare the effects of organic rice cultivation in rotation with organic perennial lucerne and a conventional monoculture rice cultivation system. The experiment was established in 2009 and set up in a control versus treatment experimental (elementary) design. The SICS treatment, as a rotation system is installed in two adjacent fields, that are cultivated in alternate 2 years of perennial lucerne / 2 years of organic rice and a control field also adjacent that is cultivated with a monoculture of conventional rice.

Experimental field information

The experiment is conducted on a demonstration field which is managed by the researchers in Montemor-o-Velho Municipality, Portugal. The field is located at an altitude of 2 m and covers an area of about 10000 m^2. The topsoil has a loamy texture according to the USDA classification system.

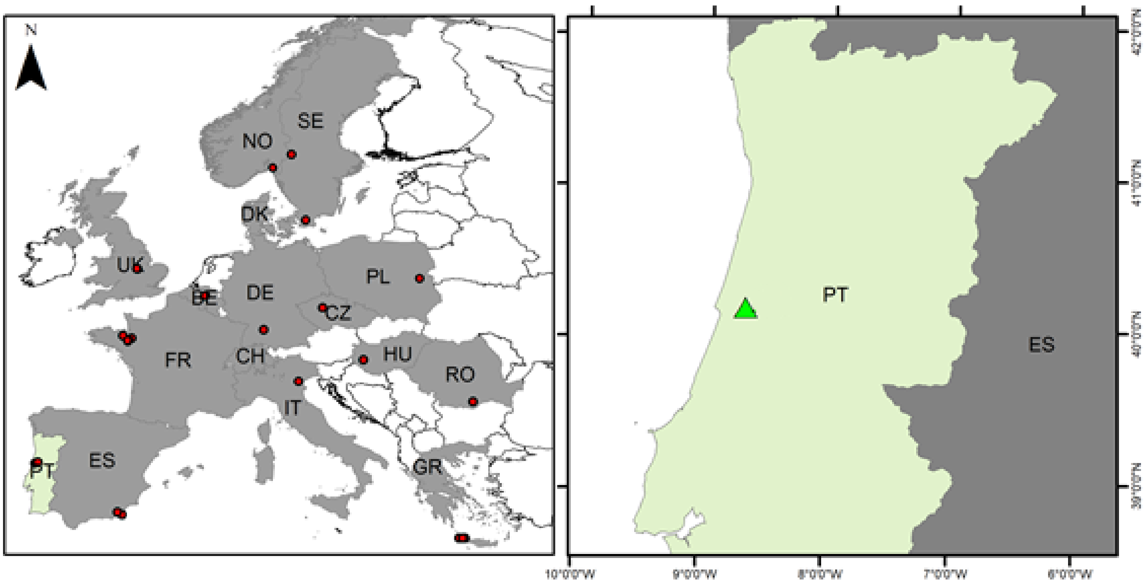


Figure 1: Location of the study site

The climate of the experimental field area

A long-standing station is available as "Coimbra/Geofisico". Measurements started in 1864 at ECAD station 213 but there are only available from 1900 till 1996. So, the period of the experiments is unfortunately not covered. The research station ESAC has its station. So, normal 1961-90 for "*Coimbra/Geofisico*" (as in ECAD213) is compared with the ESAC data for 2018 to 2020.

Table 1: Overview with yearly averages for Coimbra

Station	Year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
Geofysico	1961-1990	21.1	10.4	1015.9	1119.0
ESAC	2018	21.7	10.5	1069.4	1127.2
ESAC	2019	22.5	10.4	987.2	1201.4
ESAC	2020	23.0	11.4	755.2	1213

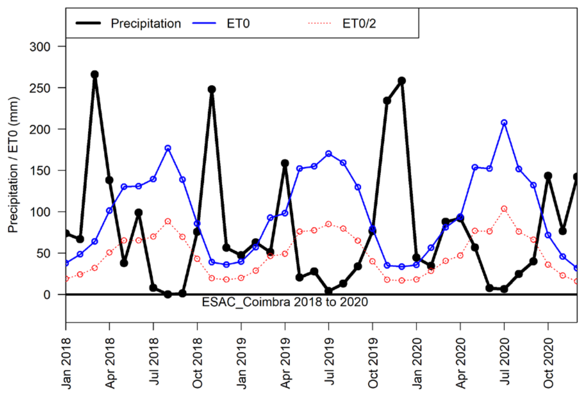
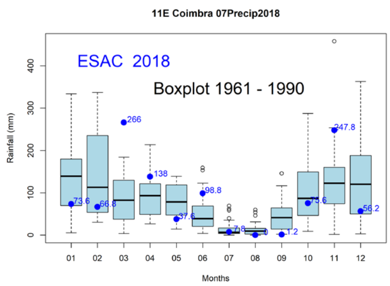
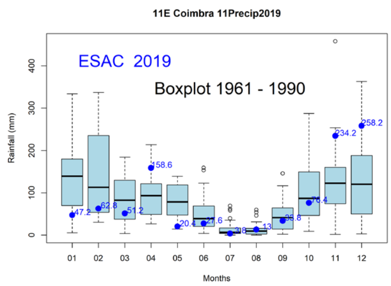


Figure 2: 11aESAC_Coimbra 00aFAOgrow





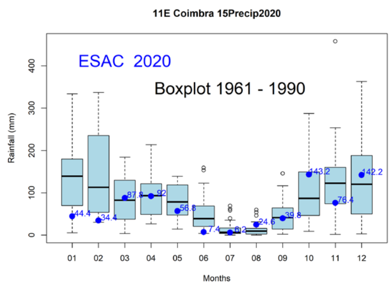


Figure 3: 11E COIMBRA 07Precip2018box Figure 4: 11E COIMBRA 11Precip2019box Figure 5: 11E COIMBRA 15Precip2020box

The temperature recorded during the study period 2018 to 2020 was slightly higher than the normal distribution of the reference 30 years period (1961-1990) with an annual maximum temperature average for 2018, 2019 and 2020 of respectively 0.6; 1.4 and 1.9 ºC superior to the normal and minimum temperature about 0.1; 0,0 and 1.0 ºC superior to the normal.

Evaporation is maximum from June to September (between 150-200mm per month) and corresponds to a period with a high monthly average temperature superior to 20ºC and a low precipitation period with an amount inferior to 50mm and about only 10mm for July and August. The year 2018 and 2019 were normal in term of annual rainfall even if the year 2018 suffered an exceptional amount of rainfall, two times superior to the normal in March and November, that didn't lead to an important period of soil ponding in the field. Nevertheless, the year 2019 presented two consecutive months of an exceptional amount of precipitation in November and December that lead to large floods and soil ponding for several days. The year 2020, was a dry year with an annual deficit of rainfall of 25% corresponding to 260mm. The winter months of January and February were exceptionally dry.

Cropping systems description

Treatments

The experiment analysed within the SoilCare project consists of 2 treatments with the following codes in the SoilCare Database and the following analysis.

ESAC_EX1_TR1 = Organic rotation

ESAC_EX1_TR2= Conventional monoculture (Control)

- The organic rotation (field 1 and field 2) corresponds to a system where two successive years of organic rice are cultivated in rotation with two successive years of organic perennial lucerne (Alfalfa). Rice is sown in May with a seed density of 200kg/ha and harvested in October. perennial lucerne is sown in May with a seed density of 30kg/ha and suffer 3 to 4 cut (for hay) the first year and about 5 cut the second year. The fertilization plan only included the application of 80 kg of Phosphorus at the seeding, annually for rice and only the first year for lucerne, no Nitrogen or Phosphate was applied. Any pesticides are applied in this system, weed control is managed manually.
- The conventional monoculture of rice (field 3) refers to a system where rice is sown annually with a seed density of 200kg/ha. Annually a ternary fertilizer NPK is applied 100 kg of Nitrogen 50kg of phosphorus and 50kg of Phosphate.

Field operations

<u>Organic Rice:</u>

The operation started in spring with one pass of disk arrow, one pass of furrow plough at 30 cm deep, one more pass of disk arrow, a pass of laser levelling, one pass of chisel and finally one pass of the rototiller.

Then is made the blind sowing to control the weeds, the field is flooded for 2 weeks and then water is removed and the young weeds are destructed mechanically with a pass of vibrocultor and one more pass of the rototiller. Then the rice is broadcast sown.

Four weeks after the sowing, the cover fertilization is realized with an iron wheels tractor able to move in flood areas.

No pesticides are applied, weed control is manual.

The harvest is made with a special harvester for rice.

Conventional Rice:

The operation started in spring with one pass of disk arrow, one pass of furrow plough at 30 cm deep, one more pass of disk arrow, a pass of laser levelling, one pass of chisel and finally one pass of the rototiller.

No blind sowing is realized for conventional rice cultivation.

The rice is broadcast sown.

Four weeks after the sowing, the cover fertilization is realized with an iron wheels tractor able to move in flood areas.

In the function of the specific needs are also realized during the growing period 2 passes of the tractor with a sprayer to apply herbicides and more two passes to apply fungicides. No insecticides are usually necessary.

The harvest is made with a special harvester for rice.

Organic Lucerne:

The operation started in spring with one pass of disk arrow, one pass of furrow plough at 30 cm deep, one more pass of disk arrow, and finally one pass of the rototiller.

Then the Lucerne is broadcast sown.

No pesticides are applied, no weed control is performed

The biomass cut is made with a rotary slasher with a chain 3 to 4 times the first year of cultivation and about 5 times the second year. The biomass is dried and sold as hay for horses.

Bio-physical data analysis – WP5

Methods

- For analysing the indicators, the raw values averaged per date and treatment and are presented. The standard deviation is presented with dashed lines and represent the variation in the two SICS plots (when measurements existed for both plots).

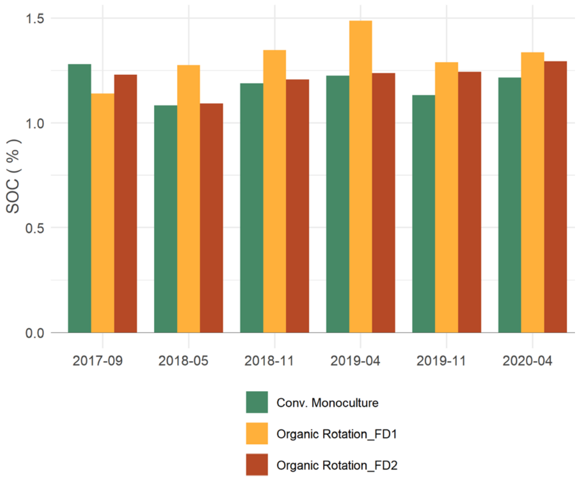
Data

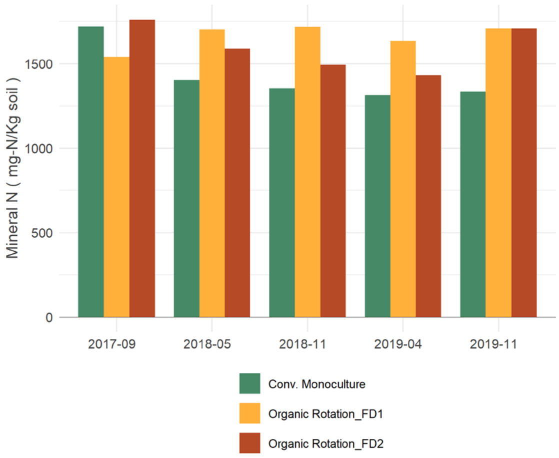
In the table, you can find the variables measured and analysed for this experiment in all treatments.

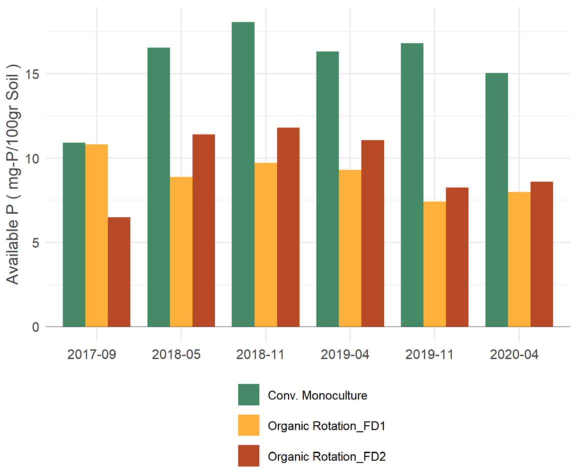
Table 2: Indicators measured and analyzed

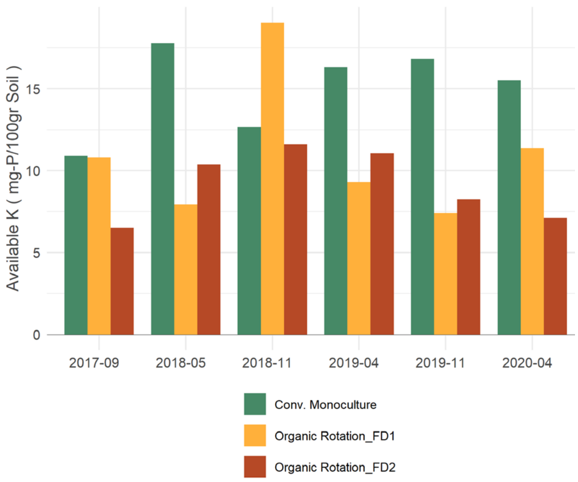
Observation code	**Unit**	**Description**
bd_top	%	g/cm3
nmin_top	g/cm3	mg-N/Kg soil
p_avail	g/cm3	mg-P/100gr Soil
k_plus	m/s	cmol+/kg
ca2_plus	mg-N/Kg soil	cmol+/kg
na_plus	mg-P/100gr Soil	cmol+/kg
mg2plus	cmol/kg	cmol+/kg
soc	cmol/kg	%
ph_kcl	cmol/kg	_
ph_h2o	cmol/kg	_
ec1_5	%	dS/m
weed_infestation	_	%
earthworm_no	mg C/kg	no/m2
crop_yield_ha	mg/kg	kg/ha
K_avail	mg/kg	mg-K/100gr Soil
Ksat	mg/kg	mm/h

Results







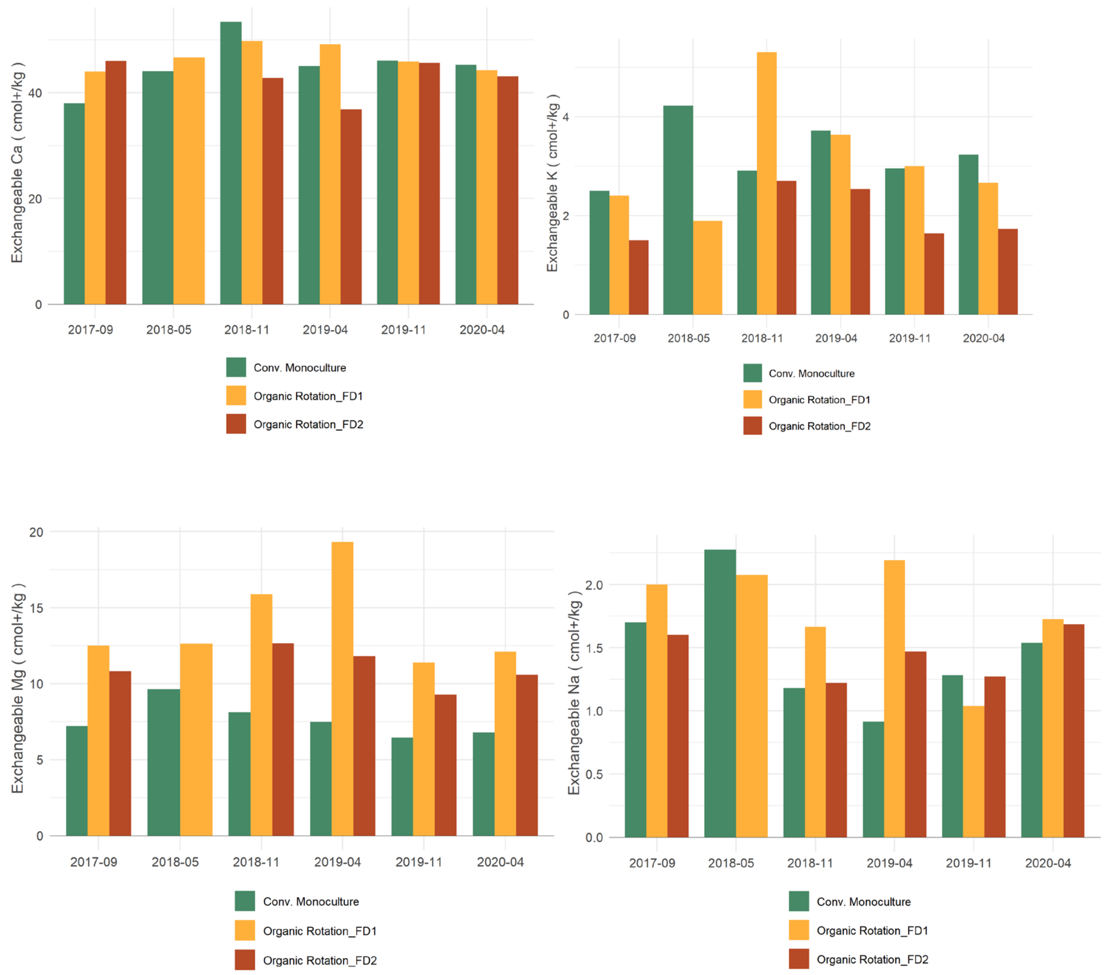


Analysis

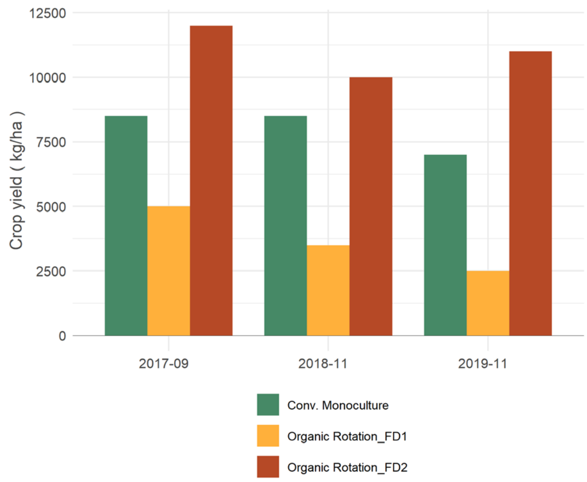
In term of soil quality, the overall level of Soil Organic Carbon is low, nevertheless, the SICS fields (FD1 for organic lucerne and FD2 for organic rice) presented a Soil Organic Carbon content slightly higher than the control field (FD3 for conventional monoculture of rice).

In term of macronutrient NPK, the Total Nitrogen content is also higher for the SICS fields (above 1500 mg-N/kg of soil) even if any amendment of Nitrogen is performed for many years at the SICS fields.

Soil available Phosphorus and Potassium are present in high concentration for the control field (higher than 10 mg/kg soil of P2O5 and K2O), and medium concentration for the 2 SICS fields that maintained a good level of fertility with only a reduce fertilization of P and no K fertilization.



The exchangeable cation Ca2+ presents a medium concentration in the soil, relatively stable in time and without any significant difference between SICS and control. The exchangeable K+ presents also a medium concentration in the soil, but with a much higher variability turning more difficult the highlight of a tendency. The exchangeable cation Mg2+ are present in low concentration in the soil for the Control and medium concentration for the SICS. The exchangeable cation Na+ is present in low concentration for SICS and Control fields with high variability.



The rice yield is much higher for the control that for the SICS, in general, the grain production for conventional rice is around 7 tonnes per ha. The organic rice yield produces about 5 tonnes the first year after Lucerne and about 3 tonnes the second year after Lucerne. The dry biomass of organic perennial lucerne is, on the contrary, lower the first year usually about 8 to 10 tonnes and higher in the second year about 10 to 12 tonnes.

In term of weed control, no exhaustive survey was performed, but in a general way, for the control field, 2 herbicide applications allow to maintain the level of weed infection below 20 % and limit yield production lost. For the organic rice, the technic of blind seeding reduced drastically the weed emergence at rice emergence phase rice, allowing an optimum rice installation. In a later phase, the weed control is made manually when the weed infection overpass 20 %. For the lucerne field, any weed control is performed. The first year after seeding, weed infection (depending on the climatic conditions at the emergency phase) varies between 20 and 40%, nevertheless after various cuts and due to the good regrow capacity of the Lucerne, the weed infection percentage decrease drastically.

In term of physical parameters, soils presented has a high per cent of clay, a very weak infiltration capacity, a very high resistance to penetration and bulk density, especially for the conventional rice field.

Socio-cultural dimension

Table 3:Sociocultural dimension

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.06	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	0.00	1.00	Complete
Farmer reputation	1.00	1.00	Complete

The principal negative point of the SICS is the increase of workload, due to the need for extra soil mobilisations to perform the blind seeding, the huge supplementary amount of workload necessary for weed control and the numerous cut of Lucerne for hay.

No special risk is associated with this SICS.

The farmer reputation will be improved, organic farming use to transform the image of the farmers especially for the city dweller.

Economical dimension

The table presents the annual average cost and benefits, calculated on a 4 years base, for a complete rotation (2 years of organic rice + 2 years of organic Lucerne for the SICS; and 4 years of rice monoculture for the Control)

Table 4:Benefits and costs

	AMT control	AMT SICS
Agricultural management technique	Monoculture of conventional rice	Rotation of organic rice with organic lucerne
Investment costs	0.0	0.0
Maintenance costs	2325.5	0.0
Production costs	0.0	1648.0
Benefits	3124.0	2843.0
Summary = benefits - costs	798.5	1195.0
Percentage change		++ 49.7%

In a general way, the SICS increases significantly (about 50%) the annual farmer remuneration compared to the Control.

In fact, in term of selling income, even if the rice yields are much lower for organic production (3 to 5 tonnes) than for conventional production (about 7 tonnes) the selling price is much higher for organic rice (600 euros per tonne vs 360 euros) representing very similar selling income for both about 2400 euros per year. The high biomass production of Lucerne (8 to 12 tonnes) sold as high-quality hay (160 euros/ton) allows in average an income of about 1600 euros per year, that turn globally the income in average for the 4 years of rotation 450 euros lower for the SICS that for the Control (2000 vs 2450 euros).

It is important to note that a large part of the income is not linked to the commercialization of crop production but is inerrant to the CAP subsidies. Rice growers benefit from 3 subsidies (RPB subsidies; Greening and subsidies linked to production) attaining an amount of 675 euros per year. Organic rice producers received also complementary subsidies for organic production about 530 euros per year.

In term of Costs, the production costs of organic and conventional rice are high and very similar (about 2300 euros per year), the lower cost in fertilizer and pesticide for organic rice is balanced by the high human labour cost need for weed control. The production costs of organic lucerne are also much lower (about 1000 euros per year) which globally on average on the 4 years of rotation decreases the production costs of the SICS and turn them lower that for the conventional rice in monoculture.

Globally, the rice production net income comes principally from the CAP subsidies. For Control, (conventional rice) for 800 euros of net income 675 euros come from the subsidies, and for the SICS (organic rice in rotation with lucerne) for an average annual income of 1200 euros about 850 euros come from the subsidies.
One issue that is not contemplated in this table is the cost of certification that is extremely high for the farmer who has a small production area and avoids conversion to organic production. This problem is a structural problem difficult to solve except with land re-parcelling measures very difficult to implement

Overall analysis and main findings

- Overall results of this study show that:
- The SICS improves soil fertility in term of soil organic matter content with all the benefits link to the increase of SOM in soils. It maintains a macronutrient pool in the medium class of soil analyses interpretation, with very low mineral fertilization reduced to Phosphorus input.
- The SICS that avoid any mineral nitrogen fertilization is a very conservative technic in term of nutrient leaching. It encourages the accumulation of Nitrogen in the soil using the Nitrogen biological fixation capacity of the Lucerne. This nitrogen will be uptake by the rice after 2 years

of Lucerne cultivation reducing drastically the risk of leaching and the pollution of the groundwater.

- The choice of a cultivar of rice (*Arroz carolino: ariete and allório*) with reduced nutrient requirements, allows to attain the expected yield and preserve grain qualities for the variety with a low input of mineral fertilizer. These cultivars with high tasty qualities are very appreciated in the region it exists a high demand. Combined with the organic mode of production it would be very interesting to improve this cultivar agronomically, to organize their commercialization (for example no separate infrastructure exist yet for peeling and drying organic rice at the agricultural cooperative) and promote the sell to develop and valorise the production to attain a sustainable amount of production in the region. It already exists in the "*baixo Mondego*" region an *IGP Indicação Geográfica Protegida (*protected geographic indication) for the conventional rice "*Arroz Carolino do Baixo Mondego*".
- Weed control is currently a major issue for rice cultivation. Weed resistance to herbicides is increasing every year as the number of active molecules available for treatment become always fewer with the increasing severity of the phytosanitary legislation. The SICS allows maintaining the weed infection rate in a proportion that will not affect the corn yield. Blind seeding is an efficient technique very easy to implement with reduce cost (only soil mobilization cost) avoiding the use of herbicide at the emergence phase. The manual weed control used for the SICS is an extremely workload technique and difficult to implement for a large area. Nevertheless, due to the low cost of human labour in Portugal, and the very high cost of pesticides, the saved money in pesticide would be equivalent to 100 hours of human labour per ha, corresponding to the workload necessary for manual weed control. The introduction of perennial lucerne in the production system, with a high capacity of biomass production, is very efficient in term of weed control and permit to decrease drastically the weed emergence during the growing period. Nevertheless, the positive effect in seed bank reduction for the rice production is limited by the fact that weeds infecting rice (able to grow in flooded areas as wild rice) are different from the weeds infecting the Lucerne, but even so, it allows to decrease significantly the weed pressure on the rice cultivation.
- A second problem to be solved would be the lack of human workload for seasonal service, but also not impossible to solve. This issue is a key technical question for organic rice management and needs to be investigated. Some techniques have been already tested as rice seeding inline combined with biodegradable mulch film applied to the soil surface and limiting the weed infection or dry seeding technique in line, with mechanical hoeing or the planting of young

plants of rice in tillering phase combined with blind seeding or mechanical hoeing but until now none of them gave satisfactory results.

- In conclusion, the SICS tested in this study reveal to be more sustainable in term of environmental and economic issues that the Control with a
    - i) slight increase of the SOM content with all the benefits due to this improvement in soil quality,
    - ii) decrease of use of mineral fertilizers, especially of nitrogen, mitigating the risk of nutrient leaching and groundwater pollution,
    - iii) no use of pesticides leading to mitigate soil air and water pollution, improve biodiversity, and protect animal and human health;
    - iv) improvement of the framer net income.
- Exists some conditioners
    - i) an increase of the weeds control problem leading to the need for a high amount of human labour for a specific period;
    - ii) a problem of rice processing and commercialization due to the nonexistence of the organic rice sector in the region.
- The organic rice production in rotation with Lucerne is a sustainable SICS that deserve to be promoted and develop by the farmer associations and organizations with the ambit to trial innovative methods for weed control and guarantee to the farmers the processing and commercialization of their products in rice or lucerne hay.
- In term of the market, it exists an emergent market for high quality and differentiated products. Farmers must learn to communicate better and to value the quality of their products, to sell the product at a fair price that compensates the effort and turn them independent from subsidies.
- Market niches have to be organized in cooperation with cooperatives, or producer associations. The quality of the product (bio rice and lucerne hay) must be evidenced with the choice of differentiated bio rice varieties, with specified characteristics, to bet on a high price, justified by the quality. It could be also a long-term strategy to promote the region, for example through the development of IGP certification - Protected Geographical Indication

References

- Boulet, A.-K., Ferreira, A.J.D., Crispim, O., Alarcão, C., Jordão A. & Hessel, R. (2018, May 8-10) Seleção e teste de sistemas produtivos agrícolas com potencial para melhorar a qualidade do solo no Baixo Mondego, métodos e resultados preliminares [Poster session]. Conferência Internacional de Ambiente em Língua Portuguesa. Aveiro. Portugal.

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Report 2 on Monitoring and Analysis of the Organic Fertilization experiment

Study Site number: 11

Country: Portugal

Author(s): Antonio Ferreira; Anne-Karine Boulet

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): ESAC

Experiment: Organic Fertilization - with urban Sludge

Version:

Date: 22-02-2021

Experiment description

The main objective of the experiment is to compare the effects of urban sludge used as organic fertilizer for conventional corn crop with mineral fertilization for the conventional corn crop. The experiment was established in 2018 and set up in a control versus treatment experimental (elementary) design. The two treatments of the experiment are replicated once.

Experimental field information

The experiment is conducted on a farm field which is managed by a farmer in São Silvestre, Portugal. The field covers an area of about 59400 m^2 at an altitude of 12 m, topsoil has a sandy loam texture according to the USDA classification system.

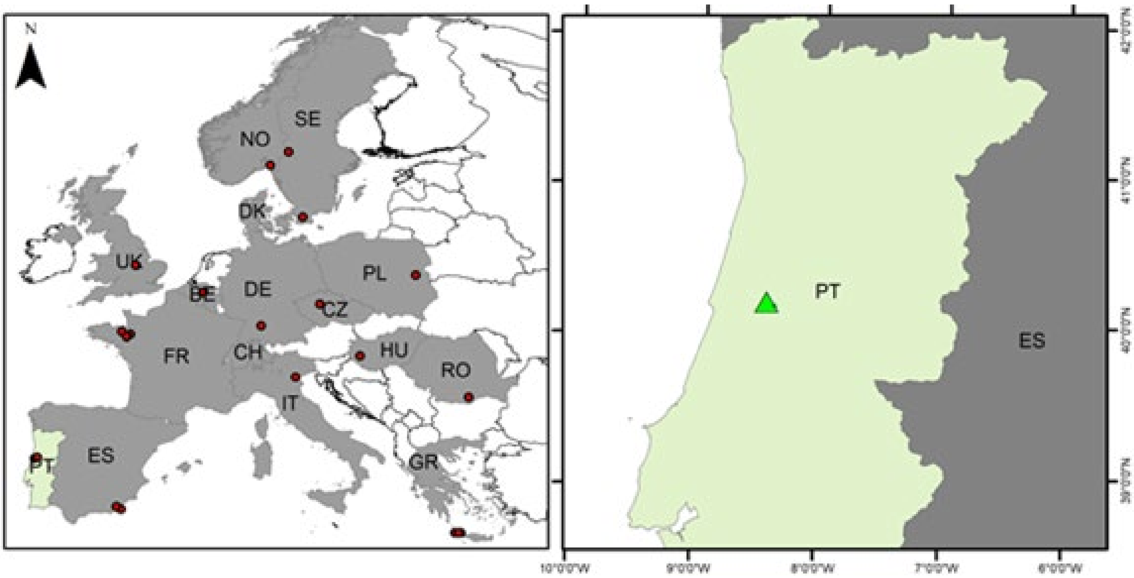


Figure 6: Location of the study site

The climate of the experimental field area

See relevant section in Report 1

Cropping systems description

Treatments

This experiment analysed within the SoilCare project consists of 2 treatments with the following codes in the SoilCare Database and the following analysis.

ESAC_EX3_TR1 = Urban Sludge amendment

ESAC_EX3_TR2 = Mineral amendment

Urban Sludge amendment:

The treatment with urban sludge amendment (field 1), corresponds to a monoculture of grain corn that is fertilized annually in spring before sowing with 20 ton/ha of urban sludge.

The urban sludge presented about 15% of dry matter and a concentration of 60 g/kg of N; 30 g/kg of P and 4 g/kg of K, corresponding to an organic amendment of 180 kg/ha of N, 90 kg/ha of P and 12 kg/ha of K. An extra NPK mineral amendment (100 kg of Nitrogen and 70 kg of potassium) is made to cover the needs of the corn crop with an expected grain yield of 14ton/ha.

Mineral amendment:

The treatment with mineral amendment (field 2) is the control field situated at about 800m from field 1. It also corresponds to a monoculture of grain corn but that is only fertilized annually in spring with mineral amendment NPK corresponding to 280 kg/ha of N; 140 kg/ha of P and 140 kg/ha of K.

Field operations:

The main crop is FAO 500 grain corn *(Zea mays*) which is planted late April or May (with a seed density of 85.000 seeds per ha) and is harvested between October and November.

About one week before seeding, it is made 2 passes in the fields with a disk harrow. In the case of urban sludge application, at this stage, the sludge is spread at the soil surface with a mechanic shovel and then buried in the soil with a furrow plough at 30 cm deep. Then the K fertilizer is spread and it is made one more pass of a rotary tiller.

The seeding is made in the line (75cm between line and about 15cm between seeds), with a combined pneumatic seeder that applies at the same time the fertilizer.

The herbicides and insecticides are applied according to the needs and furrow irrigation are opened to allow irrigation by gravity system as necessary.

Bio-physical data analysis – WP5

Methods

- For analysing the indicators, the raw values averaged per date and treatment and are presented. The standard deviation is presented with dashed lines and represent the variation in the two SICS plots (when measurements existed for both plots).

Data

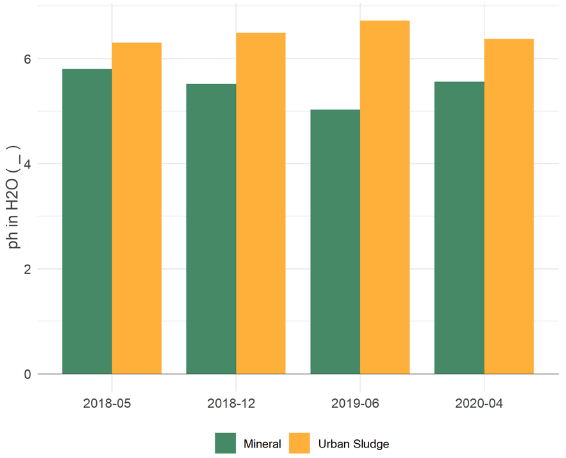
In table 5, you can find the variables measured and analysed for this experiment in all treatments.

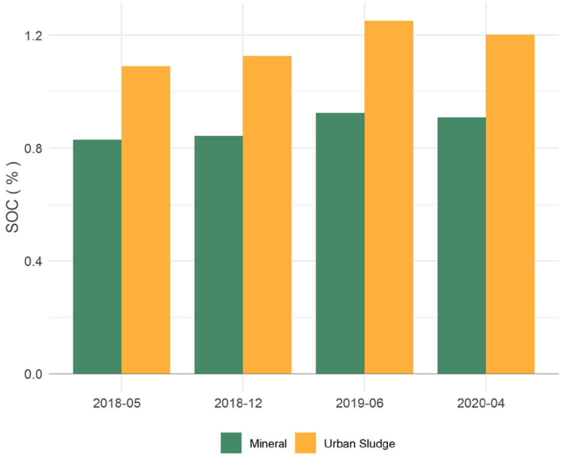
Table 5:Indicators measured and analyzed

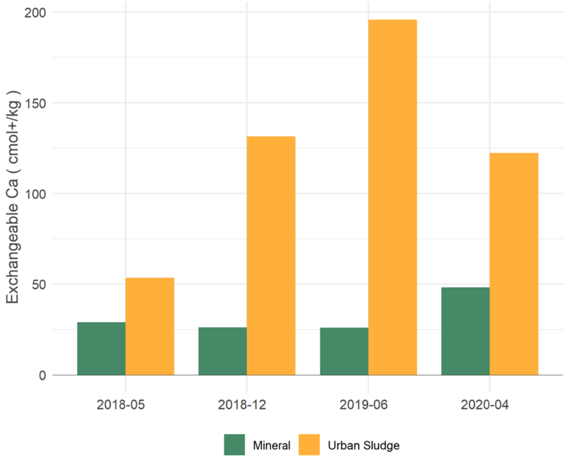
Observation code	Unit	Description
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P

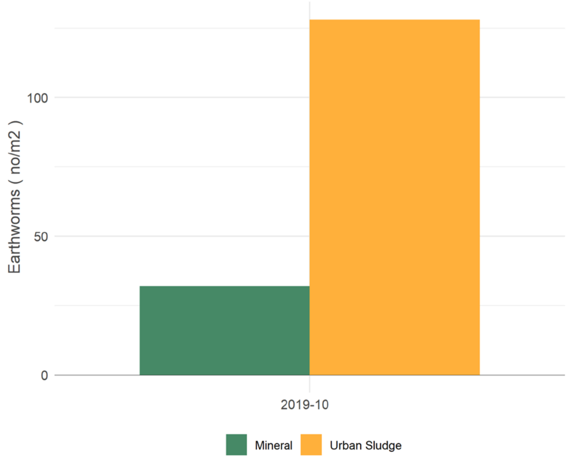
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	ph in KCl
ph_h2o	_	ph in H2O
ec1_5	dS/m	EC
weed_infestation	_	%
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
K_avail	mg-K/100gr Soil	Available K
Ksat	mm/h	Ksat

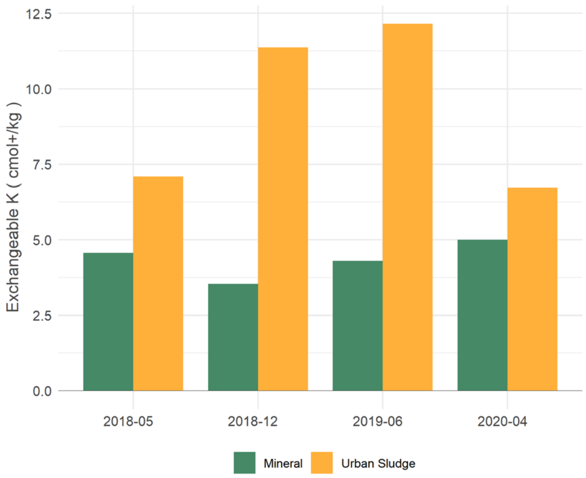
Results











The SICS field has been fertilized by urban sludges during 3 consecutive years in spring, from 2016 to 2018. After this date, no more sludge application was realized.

The results presented in the figures demonstrate that the application of urban sludge as SICS leads to important alteration of the soil quality.

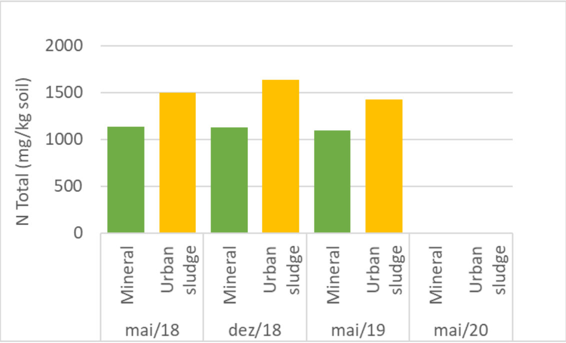
In term of pH, the SICS soil pH was significantly higher (between 6 and 7) that the Control soil pH more acidic (from 5.0 to 5.5). The sludge application modifies the soil class that passes then from the soil with slightly acidic pH to soil with neutral pH.

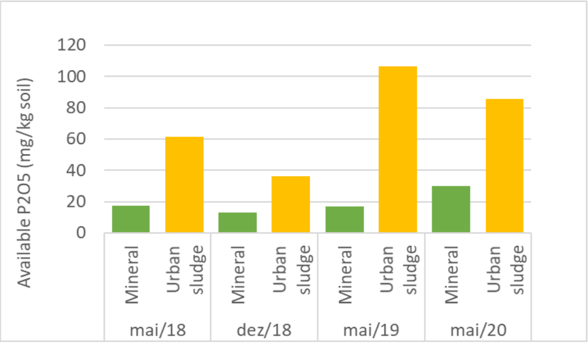
The Soil organic content also increases significantly by about 0.3% in absolute value from 0.8% to 1.1%, representing an increase of 30% about the initial SOC. The soil fertility class of the soil passing from low to medium fertility.

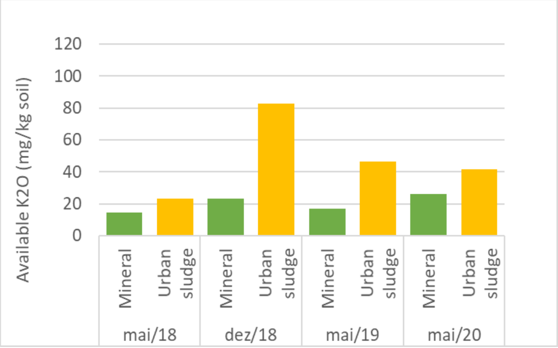
In term of exchangeable cations, SICS presents a high increase in Ca2+ that present concentration 2 to 10 times higher than the Control. The Control present value of about 2 cmol/kg of soil bellowing to low fertility class as the SICS presents values about 150-200 cmol/kg corresponding to high or very high fertility class of soil.

It was also highlighting an important increase in earthworms density, 4 times more numerous in the SICS passing from 30 to 130 individuals per m2.

Study site analysis







The levels of macronutrients as Total Nitrogen, Available Phosphorus (P2O5) and Available Potassium (K2O) are also much higher for SICS that for Control. Total Nitrogen content in soil is about 30 to 40% higher for SICS, with values exceeding 1500mg/kg of soil. Available Phosphorus is on average 3 times higher for SICS that for Control with values ranging respectively from 40 to 100 and 15 to 30 mg/kg of soil. Available Potassium is on average 1.5 to 3 times higher for SICS that for Control with values ranging respectively from 20 to 80 mg/kg for 15 to 25 mg/kg of soil. In term of soil fertility class relative to Available Phosphorus (P2O5) and Available Potassium (K2O), the Control soils vary between the class of high (10-20mg/kg of soil) and very high fertility (>20mg/kg of soil) as the SICS Soils presented concentration extremely high, much superior to the inferior limit of very high fertility class, especially for available P2O5.

Heavy metal results tables in autumn 2018 after 3 consecutive years of sludge application:

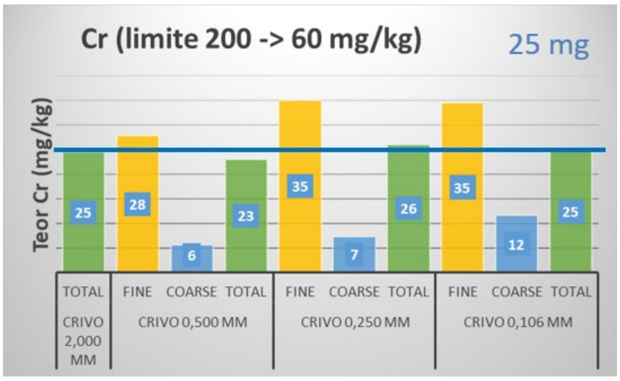
a) Concentration of Heavy metal in SICS Soil for different sieving methods (at the left)

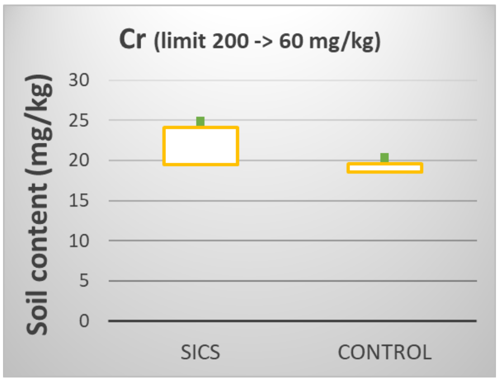
b) Concentration of Heavy metal in SICS and CONTROL Soils for sieving at 2mm methods (at the right)

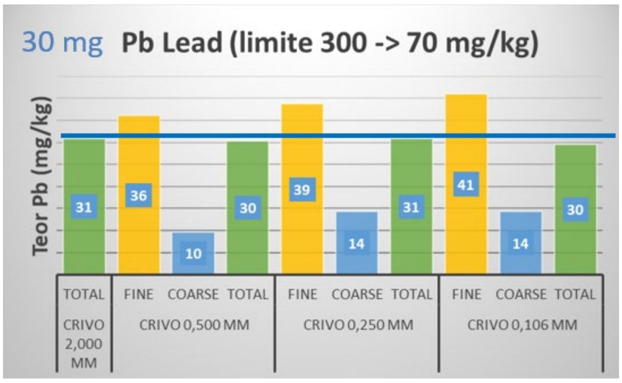
Title limit: Maximum concentration of heavy metal in soil (Decret-Law 276/2009) at the left

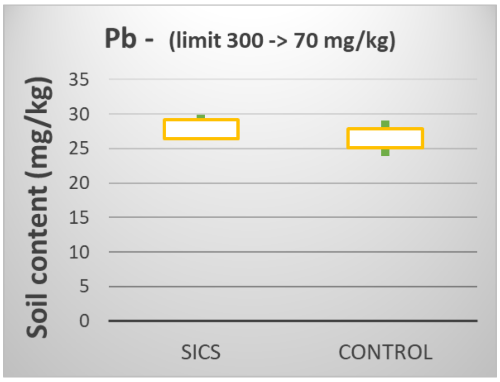
The maximum concentration of heavy metal in soil (Decret-Law 103/2015) at the right

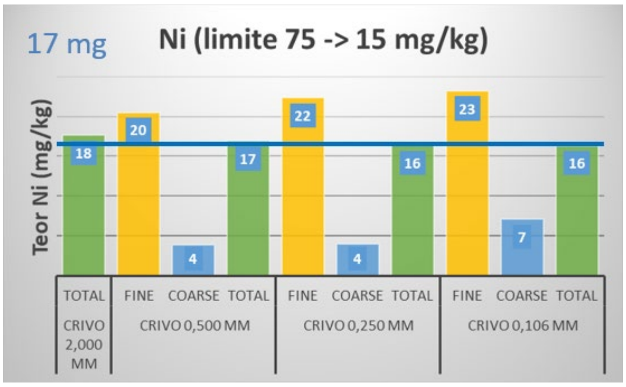
The number in blue is the average for soil fraction under 2mm.

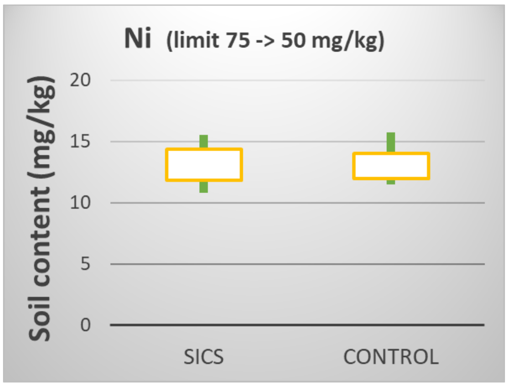


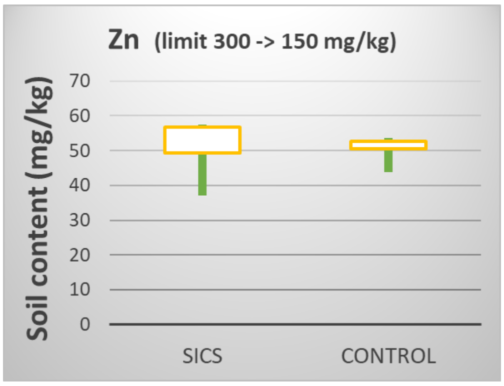


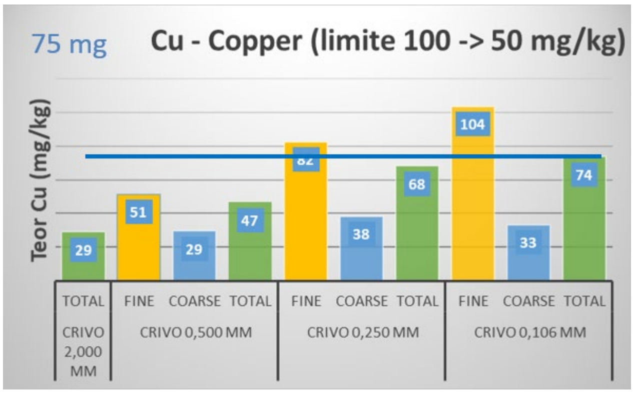


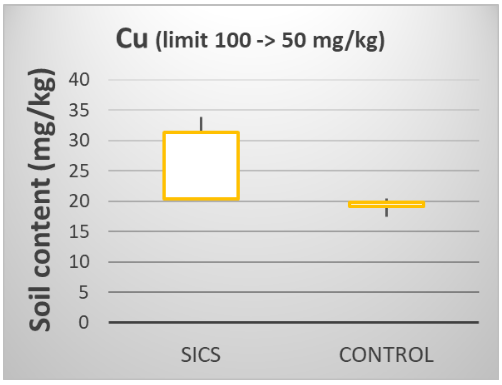


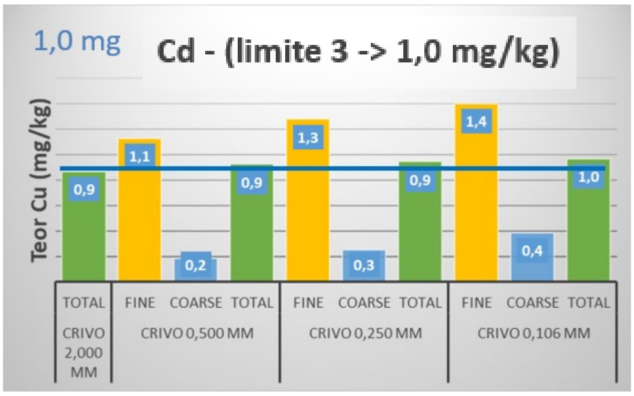












<u>Portuguese legislation (Decret-Law 276/2009)</u>

specific sludge regulation

Table 6: Maximum concentration of heavy metal in the soil for sludge application

Valores limite de concentração de metais pesados nos solos em função do seu *pH*

Parâmetro	*pH* ≤ 5,5	5,5 < *pH* ≤ 7	*pH* > 7 (*)
	mg/kg de matéria seca		
Cádmio	1	3	4
Cobre	50	100	200
Níquel	30	75	110
Chumbo	50	300	450
Zinco	150	300	450
Mercúrio	1	1,5	2
Crómio	50	200	300

<u>Portuguese legislation (Decret-Law 103/2015)</u>

nonspecific for sludge regulation but fertilizers in general

Table 7: Maximum concentration of heavy metals in the soil for fertilizer application

Quadro n.º 8 — Valores máximos admissíveis dos teores «totais»* de metais pesados nos solos (reportados à matéria seca) em que se pretenda aplicar a matéria fertilizante

Elemento	Valores máximos admissíveis no solo (miligramas por quilograma)		
	5 ≤ pH < 6	6 ≤ pH < 7	pH ≥ 7
Cádmio (*Cd*)	0,5	1	1,5
Chumbo (*Pb*)	50	70	100
Cobre (*Cu*)	20	50	100
Crómio (*Cr*)	30	60	100
Mercúrio (*Hg*)	0,1	0,5	1
Níquel (*Ni*)	15	50	70
Zinco (*Zn*)	60	150	200

The application of urban sewage sludge amendments in agriculture soils is a sensitive topic in Portugal and has also been investigated the risk of long term accumulation of heavy metals and consequent contamination of the soil. The most recent Portuguese legislation (Decret-Law 103/2015) is more restrictive than the precedent one (Decret-Law 276/2009) in terms of maximum concentrations of heavy metals in agricultural soils tolerated for sludge application. The analytical quantification of heavy metals, however, raises some methodological questions associated with soil sample pre-treatment, due to some imprecision in standard analytical methods, especially related to the samples sieving. That's why the results are presented for various size of sieving with 2mm, 500µm, 250µm and 106µm meshes (soil aggregates were broken softly but the soil was not milled). Finer and coarser fractions were weighted and analyzed separately. Heavy metals were extracted with the Aqua Regia method, using a mass for analyzing of 3g, and quantified by atomic absorption spectrophotometer with a graphite furnace (Cd) and flame (Cu, Ni, Pb, Zn and Cr).

Overall results show that the concentrations of heavy metals in soil are slightly higher for the SICS that for the Control fields, not always significant, but normally with a major dispersion of the result in term of interquartile value.

The median chromium (Cr) concentration increases significantly from 19.1 mg/kg of soil for the Control to 23.7 mg/kg for the SICS, with an interquartile range also increasing from 1.1 to 4.6 mg/kg. Nevertheless, this value stays much lower than the limits admitted by law (200 to 60 mg in the function of the decree)

The median lead (Pb) concentration increases significantly from 26.4 mg/kg of soil for the Control to 28.5 for the SICS, with an interquartile range stable from 2.7 to 2.8 mg/kg. Nevertheless, this value stays much lower than the limits admitted by law (300 to 70 mg/kg in the function of the decree).

The median nickel (Ni) concentration maintains stable from 13.3 mg/kg of soil for the Control to 13.4 mg/kg for the SICS, with an interquartile range also stable from 2.1 to 2.6 mg/kg. Nevertheless, this value stays much lower than the limits admitted by law (75 to 50 mg/kg in the function of the decree).

The median zinc (Zn) concentration increases significantly from 51.8 mg/kg of soil for the Control to 54.7 mg/kg for the SICS, with an interquartile range also increasing from 2.1 to 7.4 mg/kg. Nevertheless, this value stays much lower than the limits admitted by law (300 to 150 mg in the function of the decree).

The median copper (Cu) concentration increases significantly from 19.6 mg/kg of soil for the Control to 28.5 mg/kg for the SICS, with an interquartile range also increasing from 0.7 to 11.0 mg/kg. Nevertheless, this value stays much lower than the limits admitted by law (100 to 50 mg in the function of the decree).

The analyse of cadmium (Cd) failed but the data obtained for the experiment about sieving size indicated that the concentrations of Cadmium in the SICS about 1.0 mg/kg were very close to the limits admitted by law (3 to 1 mg in the function of the decree).

In conclusion, except for Ni that doesn't show any alteration, the analyse of the result demonstrated that the application of sludge in agricultural soil increases slightly heavy metal concentrations for Pb an Zn and more significant way for Cr and Cu, nevertheless the concentrations stay much lower than the limits admitted by law for sludge or fertilizer application. The cadmium seems closer to the limit, but the results are not reliable due to a technical problem in the detection limit for a very low concentration of heavy metal.

Socio-cultural dimension

Table 8: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

Sociocultural data

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.56	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.25	1.00	Complete

Farmer reputation	-1.00	1.00	Complete

Socio-cultural survey results show in general a strong negative impact of the urban sludge fertilization technique.

In term of workload, the spread of the sludge is much more laborious than the application of mineral amendment and is coincident with a work pic period in term of soil mobilization relative to seeding bed preparation for the main crop. It is also very restrictive in term of meteorological conditions for application and restrictive in time to be incorporated in the soil (24h to 48h in the function of dry matter content) and also restrictive in term of authorized application areas.

The sludge application technique itself is not very complicated but time-consuming, not only in term of fieldwork but it also requires the approval of a sludge management plan by various entities that is a lengthy and tedious administrative process that discourage many farmers to use this technique. The conditions of application of sludge are closely regulated (soil analysis, sludge analysis, specific weather conditions, quantity to apply, localization…) All procedures are extremely well described and must be followed.

In term of perceived risks and farmer reputation, the agricultural valorization of sludge is always associated, in the mind of the population, with the bad smell of the product and the potential risks of groundwater pollution by nutrient leaching and soil contamination by heavy metals. Due to the origin and the novelty of its use in agriculture, sludge generally has a bad reputation at the level of the farmers and the population... constituting a great barrier to its implementation and acceptance.

Economical dimension

Table 9: Summary of the benefits of SICS (SICS vs. control), this case shows a positive impact of SICS in comparison to the control, the numbers are in euro/ha (AMT: Agricultural Management Technique)

	AMT control	AMT SICS
Agricultural management technique	Monoculture of grain corn with the mineral amendment	Monoculture of grain corn with urban sludge amendment
Investment costs	0.0	0.0
Maintenance costs	2122.4	0.0
Production costs	0.0	1809.4
Benefits	2960.0	2960.0
Summary = benefits - costs	837.6	1150.6
Percentage change		++ 37.4 %

Globally the SICS allows increasing the annual net income of the farmer by 37% compared with the Control corresponding to a financial amount of about 310 euros per ha and year.
The SICS implementation does not involve any extra cost in term of urban sludge acquisition and transport as the agricultural valorisation of the sludge permits to solve partially a new social problem that is the final destiny of urban waste from the Wastewater Treatment Plant. The sludges are delivered for free to the farmers by the sludge treatment operators. The farmers are responsible for the spread and the incorporation of the sludge in the soil, corresponding to an extra cost in machinery use and human labour of about 80 euros per ha. This cost is compensated by a gain in mineral fertilizer allowed by the high concentration in nutrients of the sludge, especially in term of nitrogen and phosphorus application corresponding to 390 euros.

Grain corn selling incomes are similar for the SICS and the Control. The grain corn yields are sensibly the same due to the adjustment of the mineral fertilization in the function of the quantity of nutrient presents in the sludge to attain the expected production of 14ton/ha corresponding to a financial income of 2660 euros. For this SICS, European subsidies (about 300 euros) represented only 10% of the gross total income but a non-neglected part of the net income, 35% for the control and 25% for the SICS.

Overall analysis and main findings

Overall results of this study show that:

- After 3 consecutive years of urban sludge application in the agricultural field, the SICS improved significantly soil fertility, almost all the parameters analyses in this study show a positive impact of the urban sludge application. It improved pH, SOC content, Total Nitrogen, Available Phosphorus and Potassium, exchangeable cations (Ca2+ and K+) and also Earthworms density. Nevertheless, the SICS soil analysis highlight values extremely high of Phosphorus and Potassium, especially Phosphorus, indicating a disequilibrium in the soil probably driven by an over complementing mineral fertilization, that can lead to leaching of the excess of nutrients and the pollution of the groundwater. Special attention has to be pay to the adjustment of the mineral fertilization in the function of the nutrients contained in the sludge. Even if the complementary fertilization doses recommendations are provided by the sludge operator in the function of the nutrient composition of the sludge spread in the field, farmers tend to apply a higher quantity of mineral fertilizer than necessary to avoid any risk of crop yield lost. It is then important to make aware the farmer of the risk of nutrient leaching and soil/water pollution relative to the excessive application of fertilizer.

- Concerning the polemic topic of heavy metal accumulation in the soil, this study doesn't show any relevant increase of heavy metal concentration in the soil. The concentrations maintain much lower than the limits defined by the national law for sludge application or fertilizer application in general.
- The SICS shows also an increase of 37% in term of financial benefit, corresponding to a gain of about 300 euros per year compared to the Control. This improvement in term of net income can be attributed mainly to the reduction in the mineral amendment (especially in Nitrogen and Phosphorus) allowed by a large amount of nutrient contained in the urban sludge.
- The part most problematic of the SICS is the socio-cultural part. The SICS required extra work that corresponds to a pic of activity in the seeding period that can be difficult to manage. It also can delay the seeding in case of bad meteorological conditions that exclude the sludge application.
- The approval of a sludge management plan by various entities is a lengthy and tedious administrative process that discourage many farmers to use this technique. A simplification of the administrative procedures (but not of the environmental and application norms) could encourage the farmers to use this technique.
- In term of perceived risks and farmer reputation, the agricultural valorization of sludge is perceived very badly by the population in general and also the farmers constituting a great barrier to its implementation and acceptance. The dissemination of study results on the environmental impact of sludge in seminars or dissemination to the general public would demystify the use of sludge, explaining that risks are controlled through the sludge management plan
- One solution would be the reduction of the smell that is technically possible by stabilization of the organic matter, through digestion, dehydration, or by composting. But these techniques have a high cost and could be implemented on a larger scale if farmers start paying for the agricultural valorization of the sludge (free of cost until now), to participate in the sludge treatment costs.

Table 10: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.02	0.89	High
Environmental dimension	0.35	0.72	Medium
Economic dimension	0.15	1.00	Complete
Socio-cultural dimension	-0.56	1.00	Complete
Physical properties	0.32	0.60	Medium
Chemical properties	0.65	0.80	High
Biological properties	0.20	0.70	Medium

Table 11: Other indices

Benefits:	Mineral nitrogen; SOC; pH; Earthworm density; Crop yield; Cost-benefit;
Drawback:	Infiltration; Aggregate stability; Increase of workload; Potential risk of conflicts; Farmer reputation worsened;

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Report 3 on Monitoring and Analysis of the Loreto-Succession System experiment

Study Site number: 11

Country: Portugal

Author(s): Antonio Ferreira and Anne-Karine Boulet

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): ESAC

Experiment: Loreto Succession System – Legume winter Cover crop use as green manure for the main crop.

Version: 2

Date: 22-02-2021

Experiment description

The main objective of the experiment is to compare the effects of a conventional grain corn crop integrated in a succession with legumes (clovers, pea, trefoil….) used as winter cover crop, and incorporated in the soil as green manure in spring in comparison with a grain corn monoculture with winter fallow. The experiment was established in 2018 and set up in a control versus treatment experimental (elementary) design. The seven treatments of the experiment are replicated once.

Experimental field information

The experiment is conducted in the Loreto, a demonstration field from the Baixo Mondego Experimental Center, an agricultural station managed by the Regional Directorate of Agriculture and Fisheries of the Central Region of Portugal.

The field covers an area of about 5250 m^2 and its topsoil has a loamy sand texture according to the USDA classification system.

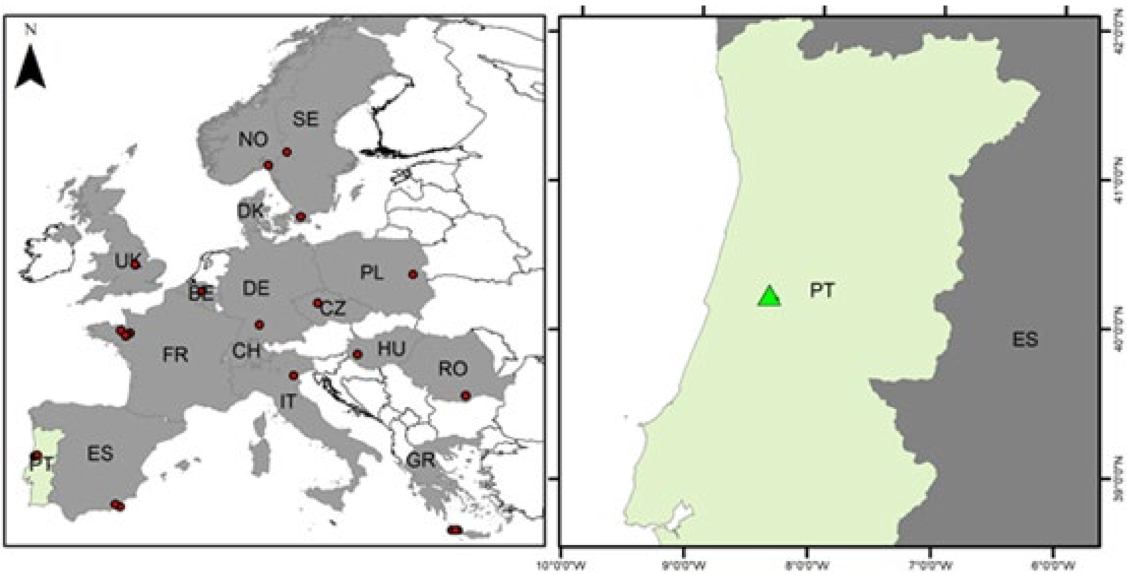


Figure 7: Location of the study site

The climate of the experimental field area

See Report 1

Cropping systems description

Treatments

The experiment that analysed within the SoilCare project consists of 6 treatments with the following codes in the SoilCare Database and the analysis following.

ESAC_EX4_TR1 = pre-inoculated Pea

ESAC_EX4_TR2 = pre-inoculated Crimson Clover

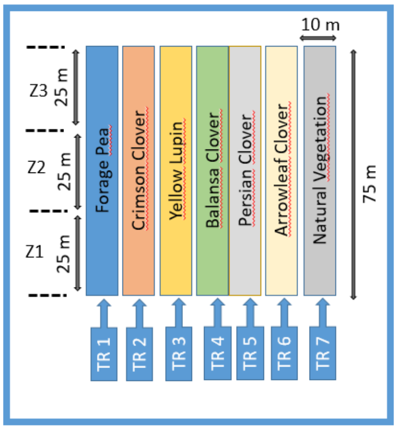
ESAC_EX4_TR3 = pre-inoculated Yellow Lupin

ESAC_EX4_TR4 = pre-inoculated Balansa Clover

ESAC_EX4_TR5 = pre-inoculated Persian Clover

ESAC_EX4_TR6 = pre-inoculated Arrowleaf Clover

ESAC_EX4_TR7 = Fallow (control)



The 6 legume cover crops (LCC) species were sown as winter cover crops following the harvest of the main crop, grain corn (FAO 300) sown in spring of the same year. All six LCC were cut at full flowering stage, (as typically done by farmers due to optimal C/N ratio of the biomass at that time and also because it avoids seeds production) and then integrated into the soil as green manure. During the first year of the study, due to technical limitations, the cut was performed on the same date for all LCC species. In the second year, the cut was performed on different dates according to the stage of maturity of the species.

Field operations

Soil preparation for LCC seeding included two passes with a disk harrow to break up and incorporate corn residues into the soil, followed by seedbed preparation with a rotary hoe. Legume seeds were manually broadcast. Seed density and other information on agronomics parameters are summarized in the table below. No fertilizer or pesticide was applied during the LCC growing season.

Table 12: Agronomic parameters

Code	Common name	Latin name	Seeding rate (kg/ha) Year 1 - Year 2	Sowing date Year 1 - Year 2	Cutting date Year 1 - Year 2	Growing days Year 1 - Year 2
FP	Forage Pea	*Pisum sativum*	60 - 60	11/12/2018 - 03/12/2019	18/04/2019 - 02/04/2020	128 - 121
RC	Crimson Clover	*Trifolium pratense*	30 - 30	11/12/2018 - 03/12/2019	18/04/2019 - 23/04/2020	128 - 142
YL	Yellow Lupin	*Lupinus luteus*	60 -60	11/12/2018 - 03/12/2019	18/04/2019 - 02/04/2020	128 - 121
BC	Balansa Clover	*Trifolium michelianum*	20- 30	11/12/2018 - 03/12/2019	18/04/2019 - 23/04/2020	128 - 142
PC	Persian Clover	*Trifolium suaveolens*	** - 25	**/**/**** - 03/12/2019	**/**/**** - 07/05/2020	*** - 156
AC	Arrowleaf Clover	*Trifolium vesiculosum*	20 - 35	11/12/2018 - 03/12/2019	18/04/2019 - 07/05/2020	128 - 156
NV	Natural vegetation	* * *	* * - * *	**/**/**** - **/**/****	18/04/2019 - 02/04/2020	128 - 121

Corn seeding was performed mechanically in spring (in line with 75cm between line and 14.5 cm between seed corresponding to a seed density of about 90.000 seeds/ha) after two passes of disk harrow and soil surface levelling with a rotary hoe. Mineral fertilizer was applied at corn seeding and after four weeks. The fertilizer applied was nitrogen-phosphorus-potassium (NPK) with respectively 110-24-24 kg/ha the first year and 110-0-0 kg/ha the second year. Fertilization alterations were based on local soil properties assessment.

Bio-physical data analysis – WP5

Methods

- For analysing the indicators, the raw values averaged per date and treatment and are presented. The standard deviation is presented with dashed lines and represent the variation in the two SICS plots (when measurements existed for both plots).

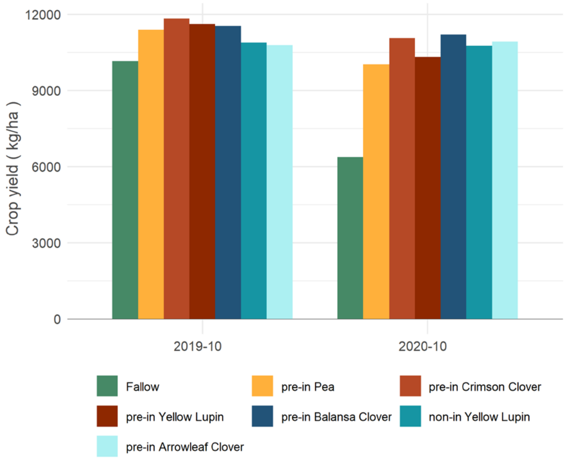
Data

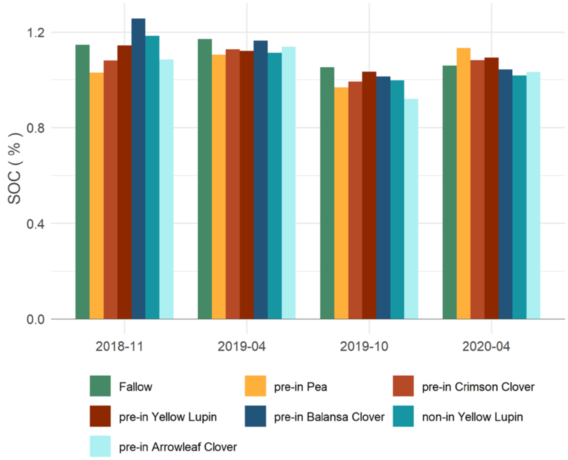
In the table below, you can find the variables measured and analysed for this experiment in all treatments.

Table 13:Indicators measured and analyzed

Observation code	Unit	Description
bd_top	g/cm3	Bulk density
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	ph in KCl
ph_h2o	_	ph in H2O
ec1_5	dS/m	EC
weed_infestation	%	Weed infestation
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
cover_crop_yield	kg/ha	Cover crop yield
K_avail	mg-K/100gr Soil	Available K
Ksat	mm/h	Ksat

Results





Analysis

Overall results in term of soil quality evolution don´t see any clear evolution for any physical, chemical or biological parameter through the 2 first winter legume cover crop campaigns. Excepted the SOC content that shows seasonal behaviour and also a decrease through time, that will be better described in the next chapter.

Study site analysis

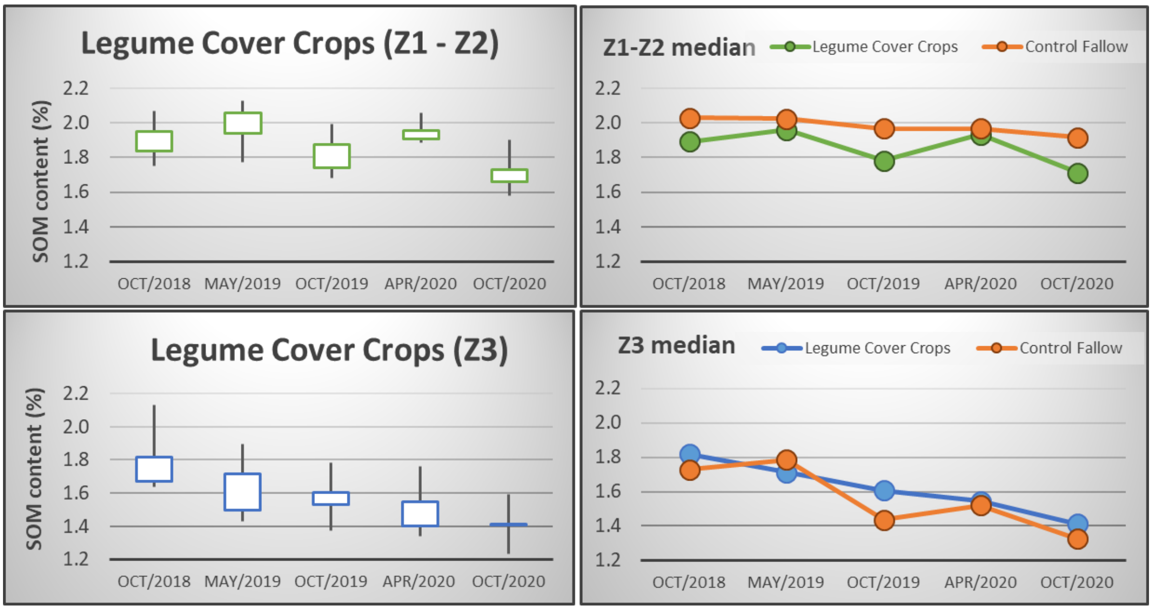


Figure 8:Soil Organic Matter content evolution

Over the two study years was realized 5 soil sampling campaigns: 3 campaigns in autumn (after harvesting of corn and before seeding the LCC) and 2 campaigns in spring before the incorporation of LCC in the soil.

Overall SOM content measured was low and showed large temporal and spatial variations within plots and sub-plots, ranging from 1.23% to 2.13%, with lower values consistently registered at the most distal part of the plots.

To take into account the spatial variability of the soil fertility, the data set has been separated into two series. The first series included the values of SOM from plots with high initial soil fertility (Z1 and Z2) and the second series contained a plot with low initial soil fertility (Z3).

This analysis highlights for the SICS, a clear seasonal behaviour of the SOM content for the most fertile areas (Z1-Z2), that presented higher SOM content in spring (in the median from 1.93% to 1.96%) and lower SOM content in autumn (in the median from 1.71% to 1.89%). The increase of the SOM during the winter was comprised between 0.07% and 0.15% and the decrease during the summer between -0.18% and -0.22%, that leads to a general progressive decrease of the SOM content during the two studies that lost 0.18% passing from 1.89% at the beginning of the study to 1.71% after 2 years. Nevertheless, the decrease concerned more specifically the autumn measurements, the spring measurements presenting more stable SOM content values (1.96 and 1.93%). At the Control plot (with winter fallow) for the most fertile areas (Z1-Z2) the seasonal variability amplitude of the SOM content was very reduce and did not exceed +/- 0.6%, with a general diminution over time also much lower about 0.09% decreasing in the median from 2.03 to 1.92% after 2 years.

Concerning the plots situated in the less fertile areas Z3, any seasonal behaviour of the SOM content can be demonstrated. A clear regular general decrease of the SOM exists through time, with a loss of 0.38% of SOM that passed in the median from 1.82% to 1.44% in two years. The control plot (with winter fallow) also presented a large decrease of the SOM content about 0.40% passing from 1.73 to 1.33%, but also a clear seasonality with an increase of the SOM during the winter between 0.06 and 0.08% and a decrease during the summer from – 0.19 to -0.35.

In a general way, the zones Z3 less fertile showed a more important decrease in the SOM content that the most fertile areas.

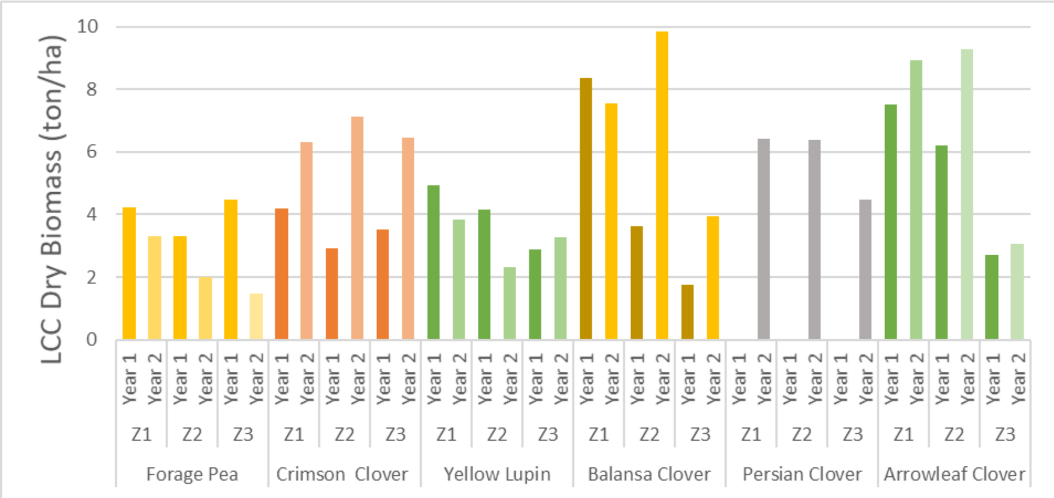


Figure 9:Production of cover crop biomass and main crop yield.

Overall LCC biomass production varied widely in the function of the legume species, soil fertility (Z1, Z2, Z3), and year. In terms of overall biomass production, clover species produced the higher yields of biomass attaining maximum production for one-third of the subplots superior to 8t/ha for arrowleaf and balansa clover, with maximum biomass of almost 10 to/ha for balansa clover. Crimson and Persian clover presented biomass production slightly lower varying between 4 and 6 ton/ha. Yellow lupin and forage pea showed lower biomass production respectively between 2 and 5ton/ha and 2 and 4 ton/ha.

Biomass production varied also in function of the year. The second-year revealed a clear increase in biomass production for 3 species of clover but particularly for crimson clover that passed from 3 to/ha the first year to almost 6 ton/ha the second year. This clover species showed lower overall biomass production than the other clover species in the first year. In contrast. yellow lupin and forage pea showed a smooth decrease in biomass production from the first to the second (2019/2020) year.

Biomass production varied in function of soil fertility. For the sub-plots, Z3 presented coefficient fertility equal or inferior to 5, the biomass production decrease widely. Balansa clover and arrowleaf clover showed around 50% lower productivity in areas with low soil fertility (sub-plot Z3). Persian clover productivity was less affected by soil fertility decrease. Forage pea, yellow lupin, and crimson clover are grown in sub-plots with only medium and high fertility (coefficient fertility superior or equal to 6) did not show relevant biomass differences across the plot.

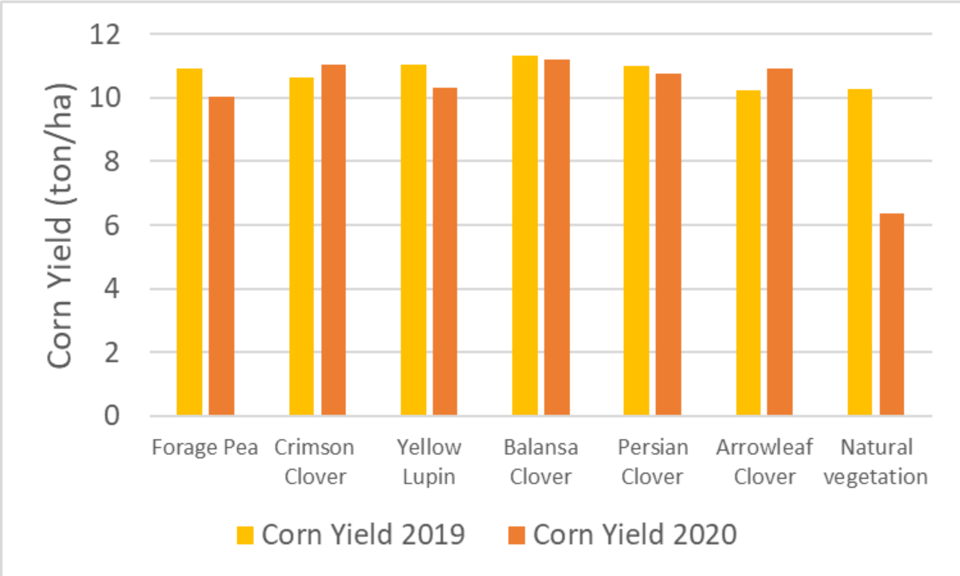


Figure 10:Corn yield

Grain corn yields for the SICS are comprised between 10 and 11 ton/ha for the two campaigns. Nevertheless, for the second year of the study, it is notable a significant decrease in the yield for the SICS in fallow (Natural vegetation) that only attained 6 ton/ha.

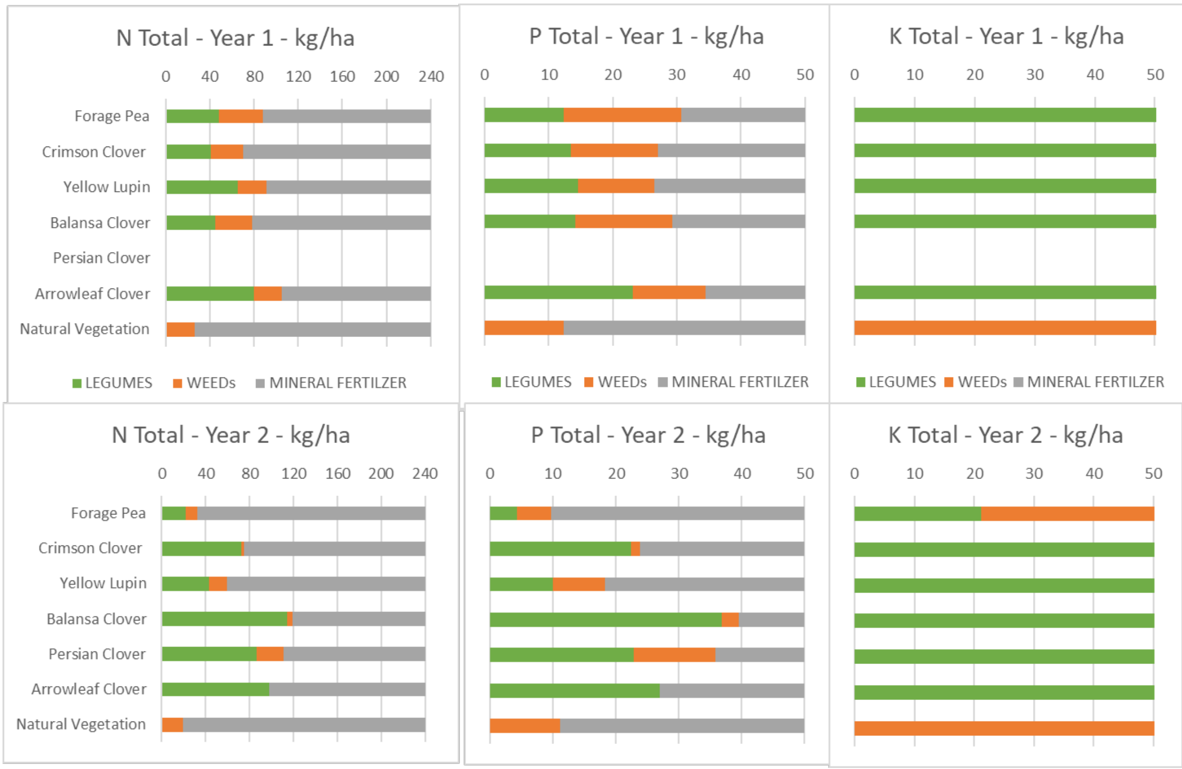


Figure 11: Nutrients available for the main crop (grain corn)

The figure presents for each legume species, the number of nutrients provided by the legume and weed incorporation in the soil, and the complementing mineral fertilizer amount necessary to cover the NPK uptake by corn crop of 240-50-50 calculated for an expected yield of 12 ton/ha, and NPK mineralization coefficient of 0.5-0.6-1.0.

The LCC plots (including legume species and weeds) were able to supply 30-40% of N, 40-80% of P, and almost 100% of K required by the corn crop. In the fallow (control) plot, the natural vegetation provided much fewer nutrients to the corn, about 10% of the N. 20% of P needs, and 100% of K.

On average for all the species and the years, the legume green manure contribution (legumes + weeds) equals about 85-25-180 kg of N/P2O5/K2O mineral fertilizer. Balansa clover presented the highest values corresponding to an amendment of 120-40-250 kg of N/P2O5/K2O.

During the first year, a relevant proportion of the nutrients incorporated into the soil through green manuring was provided by weeds. In the second year, the legume biomass yield was higher, especially for the clover species, which led to an increase in the relative contribution of nutrients by the legumes and a decrease in the contribution from the weeds in absolute and relative terms.

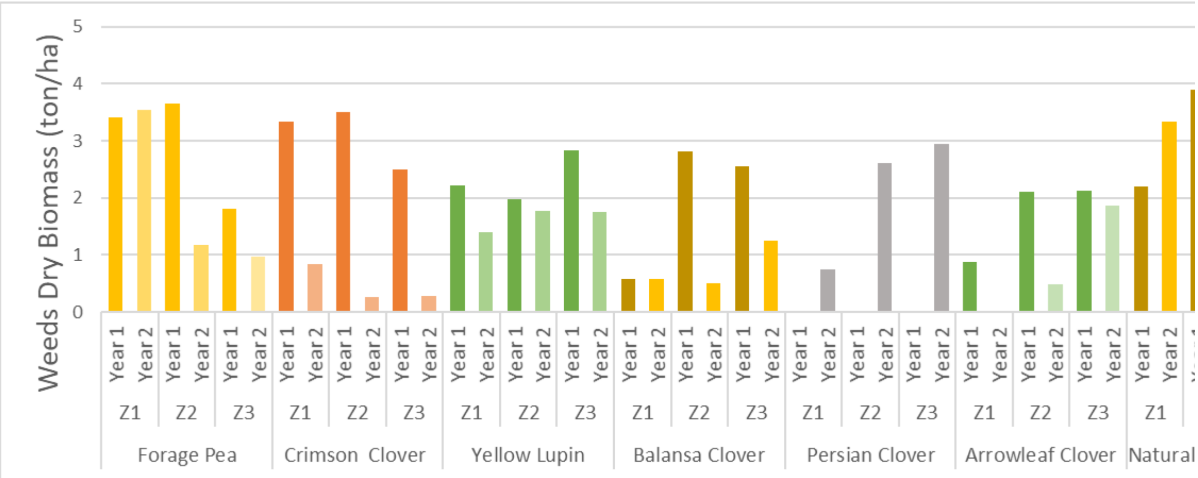


Figure 12:Weed control capacity

In terms of weed control performance, the results in the first year did not show any greater efficiency of LCC in decreasing the weed biomass compared with the control biomass (natural vegetation). The LCC species did not seem to influence weed emergence and development, with weed biomass in LCC plots being similar to that in the control lot (1-3 ton/ha of dry biomass).

However, in the second year of the study, there was a clear reduction in weed biomass in the LCC plots for three of the four clover species (crimson, balansa, arrowleaf). In these plots, the weed biomass decreased from 2-3 ton/ha in the first year to <1 ton/ha in the second year (figure 7a). In general, the clover species (except Persian clover) showed higher efficiency in controlling weed emergence during the winter than forage pea and yellow lupin, particularly in the second year of the study. The crimson, balansa and arrowleaf clovers kept weed biomass below 0.5 ton/ha in six of the nine sub-plots, whereas weed biomass reached 3-4 ton/ha in the control plot. This indicates that overall weed infestation in the crimson, balansa and arrowleaf clover sub-plots was less than 10%. Forage pea, yellow lupin, and Persian clover plots had similar weed biomass to the control plot, indicating a weaker capacity for weed control by these LCC species.

Table 14: Pearson's correlation coefficient between legume biomass (LB), weed biomass (WB), weed percentage (WP), and soil fertility (SF, based on overall fertility coefficient)

	LB/WB	LB/WP	LB/SF	WB/SF	WP/SF
Forage Pea	0.98	0.88	0.73	0.56	0.31
Red Clover	-0.68	-0.71	0.34	0.45	0.42
Yellow Lupin	-0.81	-0.99	-0.14	-0.47	0.00
Balansa Clover	-0.96	-0.96	0.85	-0.97	-0.96
Persian Clover	-0.62	-0.80	0.99	-0.71	-0.87
Arrowleaf Clover	-0.95	-0.99	0.98	-1.00	-1.00
TOTAL	-0.63	-0.91	0.28	0.05	-0.16

Considering the overall biomass production, there was a weak negative correlation between legume and weed biomass (-0.63; $p<0.05$) but a stronger negative correlation between legume biomass and weed percentage (-0.91; $p<0.05$). This discrepancy disappeared when the correlation was evaluated by species, which highlights the importance of legume species in controlling weeds. Arrowleaf and balansa clover showed the highest negative correlation between legume and weed biomass production (>-0.95; $p<0.05$), showing that weed control is strongly related to legume biomass production. The crimson and Persian clovers and yellow lupin showed weaker correlation values between weed and LCC biomass (-0.62 to -0.81; $p<0.05$).

Soil fertility played an important role in terms of weed percentage for the balansa, Persian, and arrowleaf clover, as indicated by high negative correlation coefficients (-0.96; -0.87; -1.00, respectively; $p<0.05$), indicating that the efficiency of these clover species in controlling weeds decreases with decreasing soil fertility. The other legume species did not display clear relationships between soil fertility and legume biomass or weed percentage.

Socio-cultural dimension

Table 15: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

Sociocultural data

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.26	1.00	Complete
Workload	-0.66	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	1.00	1.00	Complete

In term of the socio-cultural dimension, it exists a constraint in term of workload in autumn. The legumes have to be seeded as early as possible after corn harvesting to benefit from good climatic conditions (still soft temperatures and not too rainy) providing an optimal legume cover crop emergence. Farmers in general only start cover crop seeding after the harvest of all the main crop area. In the case of a large area of grain corn, the harvesting is usually completed at the end of November depending on the meteorological conditions. Then if the cover crop seeding is delayed i) the success of the cover crop seeding is compromised with the associate risk of low legume biomass production, ii) the own seeding can be compromised if the soil moisture content is too high and the machinery cannot enter in the field for seedbed preparation and seeding.

It also exists some risk associated with the common flood event or at least soil ponding occurrence after intense rainfall events in the winter period in the region, then can lead to the death of the legumes cover crop or at least to a significant loss of biomass production. In term of temperature, even if the region uses to present soft temperature during the winter, it also exists a potential risk of an exceptional period of low temperature (around 0ºC) that can also lead to the death of the winter cover crop.

The farmer reputation increases positively, as winter cover crop use to be associated with positive environmental impact in the mind of the rural populations and town dwellers, especially in term of biodiversity and also in esthetical term (one of the most common reflections during the open days in the field with the stakeholders at the flowering stage was that it were beautiful fields)

Economical dimension

Table 16: Cost and benefits

	AMT control	AMT SICS
Agricultural management technique	Monoculture of grain corn with winter fallow	Monoculture of grain corn with winter legume cover crops used as green manure
Investment costs	0.0	0.0
Maintenance costs	2127.1	0.0
Production costs	0.0	2077.5
Benefits	2960.0	3054.0
Summary = benefits - costs	832.9	976.5
Percentage change		++ 17.3 %

In terms of supplementary cost, the legume cover crop management implied i) legumes seed purchase, ii) soil mobilisation for the seedbed preparation and the seeding and iii) cut and the burring of the biomass in the soil in spring before main crop seeding that represents in total an extra cost of 300 euros. Nevertheless, as the legume cover crop is used as green manure for a rustic grain corn variety producing about 11 ton/ha, this technique allows decreasing the amount of mineral fertilizer leading to a gain of 290 euros compared to fertilizer cost for a conventional corn-producing 14 ton/ha.

Also, the variety of corn that was sown for the SICS is a short cycle FAO 300 with small grain that is very appreciated for chicken feeding and sells for a higher price to the cooperative that the conventional grain corn (234 vs 190 euros/ton). It results that even if the corn production yields are much lower for the SICS that for the conventional monoculture of corn with fallow during the winter (11ton/ha vs 14t/ha), the total income of the sell is only 100 euros lower for the SICS.

The SICS also qualify farmers to receive Greening subsidies. In fact, in Portugal, it is possible to substitute the mandatory requirement of 'crop diversification (in this case meaningless of 75% of the area cropped with corn, a requirement that highly specialized farms do not comply) by the equivalent practice of 'soil cover during winter'. The use of legume cover species qualifies farmers for CAP subsidies and increase their income by about 180 euros.

The implementation of the SICS will allow a small increase of the farmer net income of about 17% corresponding to 140 euros per year and per ha.

Overall analysis and main findings

The substitution of the winter fallow by the sown of winter legume cover crop is a SICS adapted to the Mediterranean conditions and even if doesn't show an increase in Soil fertility, provides an interesting advantage in term of environmental sustainability.

LCC produce high amounts of biomass far above the quantities registered for most of the studies developed in a colder climate, as they survive to the winter and presented an important growing phase in spring before to be cut. The clover species even if the reduced size of their seeds that turn the installation more delicate (obliging to a finer preparation of the seeds bed) and a very slow start-up of the growing phase, presented a final biomass production much higher than forage pea or yellow lupin even if the initial growing phase of this 2 species is earlier and quicker. This fact leads to the potential best performance of the forage pea and yellow lupin (and also crimson clover that is the most precocious of the clovers) in term of nutrient leaching mitigation that occurred mostly during the autumn season for the first rainfall events after the summer. Nevertheless, it is important to notice that no pesticides have been used for legumes cultivation, then at the initial growing phase, the percentage of weed infection is extremely high. It implies that a large part of the initial mitigation of the nutrient leaching is provided by the weed and not by the legumes. Considering the entire vegetative period, legumes allow an important uptake of nutrients from the soil, contributing to mitigating the loss of nutrients, but the majority during the spring period, and not during the critical period in term of nutrient leaching. That lead to put in light the importance of the seeding date that has to be the sooner as possible to avail the last weeks of soft temperatures allowing a rapid installation of the legumes and an optimization of the nutrient immobilization by the legumes.

In term of green manure services, it is important to divulge these results and deliver to the farmers' simple tools, allowing them to estimate the number of nutrients that various species of legumes can provide in which conditions and the corresponding amount of mineral fertilizer that they could save.

This study also highlights for an expected grain corn yield of 12t/ha, grown in good soil fertility conditions, that it is possible theoretically to reduce the amount of NPK mineral fertilizer of respectively (40, 60 and 100% corresponding to saving 100, 30 and 50 kg/ha of N, P_2O_5, K_2O) on account of the nutrient recycling provided by green manure incorporation. It is interesting to note that the second year of the project, it was obtained a maize yield of 11 ton/ha, with a mineral fertilization NPK rate extremely low (100-0-0) indicated that the number of nutrients effectively available for the corn growth was higher than the expected following our calculations and estimations (the organic matter degradation velocity and rate being extremely difficult to estimate).

This express the need to test the various quantity of mineral fertilization to determine empirically the optimal rate of fertilization to maintain the level of production and limits loss nutrients.
The study of the effect of some environmental conditions cannot be planed, just be observed when happened and needs various consecutive years of study to cover a vast set of conditions. For example, it was possible to determine during the second year of the study that presented a very wet winter, that some species were more resistant to pounding that others, like yellow lupin or crimson clover, what is an important factor in a region where the terrain is frequently inundated. The effect of the frost should be possible to evaluate for the 3rd campaign during which we had 2 weeks of negative temperatures in January.

In conclusion, the Legume Cover Crop species (treatments) showed good adaptation to the regional conditions, producing high amounts of dry matter especially in the case of clover species, which reached yields of up to 8 ton/ha for good soil fertility conditions. Nevertheless, the variability of the result inter and intraspecies is very high due to the influence of many parameters, like precipitation amount and intensity leaving to soil pounding, and lethality of the plants or spatial variability of soil fertility, or the sowing date more or less precocious and the cutting date.
LCC incorporation into the soil had no clear effect in terms of soil properties, excepted a decrease seasonal variation pattern of the SOM and a slight decrease in time. The fallow control plot does not suffer such seasonal variation, which may reflect important modifications in soil nutrient cycles due to the incorporation of LCC biomass with high decomposition potential.
The uptake of macronutrients by the LCC was extremely high (medium NPK uptake 176-20-172 kg/ha), due to their generally high biomass production, highlighting the high potential for mitigating nutrient leaching mitigation. However, it is very important to adjust the sowing date to the critical rainfall period and perform early seeding to maximize nutrient uptake by cover crops.
The capacity of LCC to provide green manure services enabled a substitution of at least 40% of N, 30% of P, and 100% of K supplied by mineral fertilizers. The quick-release of nutrients by the LCC incorporated into the soil (generally after 0-3 months) shows that legumes are a useful cover crop before a grain corn crop.
The use of LCC was also important for weed control, although only in the second year of the experiment. Three clover species (crimson, balansa, and arrowleaf clover) performed best in terms of weed control (0.5 ton/ha, compared with 3-4 ton/ha in the control plot), due to early establishment and/or high biomass production in later growth stages, ensuring strong competition with weed species.

In general, clover species performed best in the provision of agro-ecological services, in particular arrowleaf, balansa, and crimson clover. Future studies should investigate the long-term impacts of LCC on soil fertility and weed control, and thus their contribution to sustainable agriculture systems. In term of sociocultural aspects, the SICS increase the need of workload during pics and also presented a risk of failure of the legume cover crop cultivation due to the climatic conditions, but is very well perceived by the community and increase positively the reputation of the farmer. It also has a small positive economic impact on the net income of the farmer.

Table 17: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.03	0.93	High
Environmental dimension	0.11	0.82	High
Economic dimension	0.03	1.00	Complete
Socio-cultural dimension	-0.26	1.00	Complete
Physical properties	0.25	0.65	Medium
Chemical properties	0.02	0.85	High
Biological properties	0.15	0.80	High

Table 18: Other indices

Benefits:	Mineral nitrogen; Crop yield; Weed diseases; Farmer reputation improved; Cost-benefit;
Drawback:	SOC; Increase of workload; Potential economic risk; Potential risk of crop failure;

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SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

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I.12 Technical University of Crete (Greece)

Report 1 on Monitoring and Analysis of the erosion experiment

Study Site number: 12

Country: Greece

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Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Technical University of Crete

Experiment: Erosion

Version: 3

Date: 17-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate and estimate the effect of different management practices on soil erosion rates. The experiment initiated in 2017 and was set up in a control versus treatment (SICS, elementary) experimental design with no replicates. It includes different sets of treatments (1 control vs 1 SICS) located in three different fields. The different set of experiment's treatments target different cultivations (Vineyards, Fruit orchards, Olive orchards) for which relevant management practices are tested.

Experimental field information

The experiment is conducted on three farm fields managed by farmers in three different areas of Chania, Crete, Greece.

FD1: The vineyard is located in Alikampos, Greece, at an altitude of about 254 m and covers an area of about 3000 m^2. The slope gradient of the field is about 15%. The investment began in 2013. The topsoil has a clay loam texture according to the USDA classification system. The closest meteorological station is Vrysses.

FD2: The fruit orchard (Orange and Avocado) is located in Koufos, Greece, at an altitude of about 86 m and covers an area of about 2000 m^2. The slope gradient of the field is around 10-15%. The topsoil has a clay loam texture according to the USDA classification system. The nearest meteorological station is Alikianos.

FD3: The olive orchard is located in Astrikas, Greece, at an altitude of about 260 m and covers an area of about 3000 m^2. The slope gradient of the field is about 6%. The topsoil has a clay loam texture according to the USDA classification system. The closest meteorological station is Kolympari.

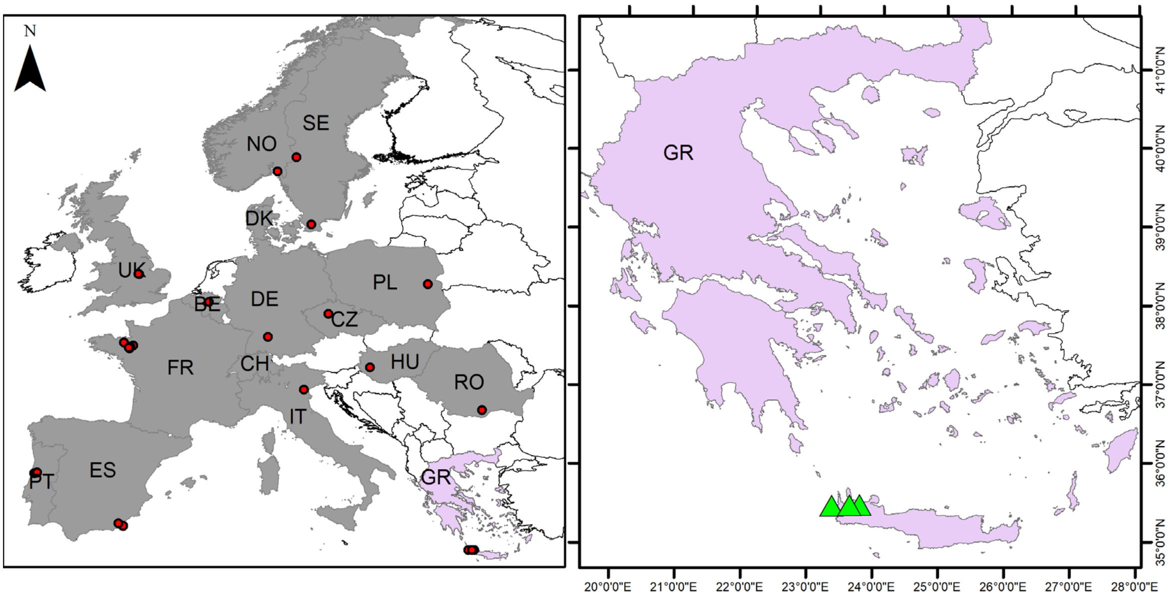


Figure 1: Location of the study site

The climate of the experimental field area

The experiments took place in three distinct locations, each one having a representative meteorological station. However, the period of temperature, precipitation and evapotranspiration observations is not very long. Vrysses started gauging in 2007, Alikianos in 2012, and Kolympari in 2016. Chania has the longer-term observations stored in ECAD, with station number 327. Unfortunately, no recent data are available for Chania.

Table 1: Overview of the yearly Temperature, Precipitation and ET0 for the experiments, provided by TUC

Station	period/year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
Chania (327)	1961-90	22.1	13.6	647.9	1113
Vrysses	2018	23.6	11.7	759.4	1303.8
Kolympari	2018	23.1	14.4	704	1128.8
Vrysses	2019	23.3	11.2	1866.6	1295.9
Kolympari	2019	22.8	13.8	1332	1137

Vrysses	2020	23.2	11.1	1453.8	1305.5
Kolympari	2020	23	13.9	667.2	1154.5
Alikianos	2020	23.1	13.2	1165.6	1220.2

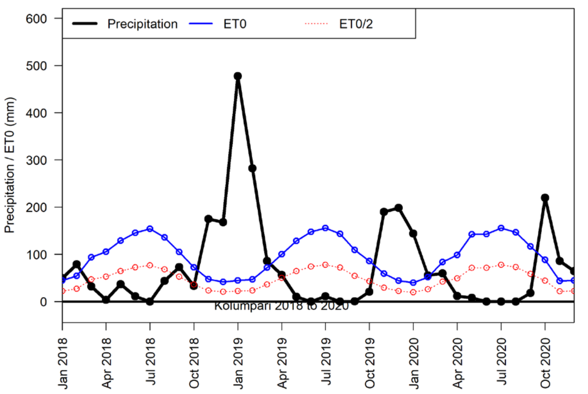


Figure 2: 12aKolympari 00aFAOgrow

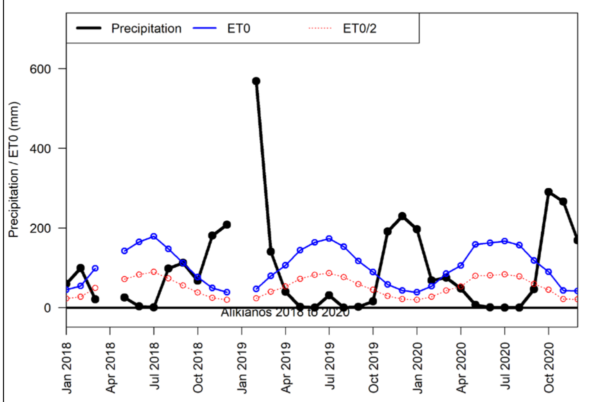


Figure 3: 12bAlikianos 00aFAOgrow

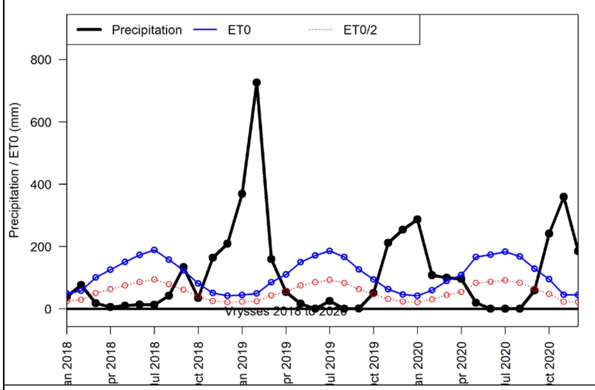


Figure 4: 12cVrysses 00aFAOgrow

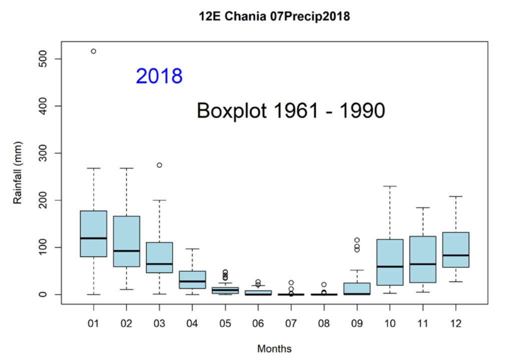


Figure 5: 12E Chania 07Precip2018box

Crete has a typical Mediterranean island environment with about 53% of the annual precipitation occurring in the winter, 23% during autumn and 20% during spring while there is negligible rainfall during summer (Koutroulis, Vrohidou and Tsanis, 2011; Koutroulis *et al.*, 2013). The average precipitation for a normal year in the island of Crete is approximately 934 mm with a markedly non-uniform distribution, a reduction of almost 300 mm from the west to the east part of the island and a strong orographic effect. Noticeable are the high rainfall winters and the dry summers in the Chania Prefecture (Tsanis *et al.*, 2011).

Regarding the hydrometeorological conditions during the years of the experiment, on October 26, 2017, as well as on February 15 and 24, 2019, Western Crete suffered excessive rainfall and flooding. The October 2017 event was a high-intensity and short-duration rain event, resulting in flash floods in the low-elevation agricultural and urban areas on the northern part of the Chania Prefecture.

Persistent storm events in February 2019 resulted in flooding, extensive riverbank erosion, landslides and rocks throughout the road network of Chania Prefecture, as well as in the collapse (YouTube video connected) of the 111-year-old historical Keritis bridge over Alikianos River. For the entire Chania region, 2018 was a dry year followed by an exceptionally wet 2019 mainly due to the record high (URL with form the news) precipitation accumulations of February (1202mm/month for Askifou station, Chania), and a normal 2020.

As for relative mean climate conditions between the study sites during the experiment, safe results cannot be extracted due to the distance of the meteorological stations from the sites, differences in altitude and microclimate. In general, the vineyard site located in Alikampos receives the highest amount of mean annual rainfall (~1400mm) and has the lowest mean temperature (due to lower minimum temperatures at the place). The fruit orchard (orange and avocado) is located in probably the most fertile and intensively cultivated valley of Chania prefecture with an average precipitation of about 1200mm/year, while the olive orchard site located in Astrikas receives less precipitation and has a higher mean annual temperature despite the higher altitude.

Cropping systems description

Treatments

The analysed experiment within the SoilCare project consists of 6 treatments, having the following codes in the SoilCare Database, as well as in the analysis below.

TUC_EX1_TR1= No cover crop (Control)

TUC_EX1_TR2= Cover crop (SICS)

TUC_EX1_TR3= Orange orchard (Control)

TUC_EX1_TR4= Avocado trees (SICS)

TUC_EX1_TR5= No-till (SICS)

TUC_EX1_TR6= Till (Control)

- Treatment 1 and Treatment 2 refer to the vineyard. The cover crop seeded between the vine lines is vetch (*Vicia faba*).
- Treatment 3 and Treatment 4 refer to the conversion of an orange orchard to an avocado orchard. The orange trees were planted in 1988 and the conversion of part of the orange orchard to an avocado orchard took place in 1998. The Avocado trees' first plantation included 40 trees per 1000 m^2, whereas the orange trees' first plantation included 120 trees per 1000 m^2.

- Treatment 5 and Treatment 6 refer to the olive orchard. The olive trees were planted in a dense of 90 trees per 1000 m^2 in 2016. The tillage method is moldboard ploughing at 20 cm depth that occurs every spring.

Field operations

FD1: Vineyard

Manure is applied every two years in the orchard. Mouldboard ploughing at 20cm is a standard farm operation. The field is drip irrigated during the summer period.

FD2: Fruit orchard

The fruit orchards receive ammonium sulphate and potassium fertilizers, applied in the irrigation water during the summer period, whereas solid potassium nitrate is banded on the soil surface in the winter period. Every year soil mulching with cut branches takes place in the form of wood chips. Also, manure is applied every year on avocado trees. Mouldboard ploughing at 20 cm depth occurs every two years and glyphosate is banded on the soil surface every year for weed management. Finally, the field is drip irrigated according to the needs of each summer period.

Bio-physical data analysis – WP5

Method

For the analysis of the experiment's observation data, the raw values are presented per date and treatment, since there are no replicates. The analysis is done per set of treatments (control vs SICS) in each experimental field.

Data

In the table below, the measured and analysed variables for this experiment in the different sets of treatments can be found.

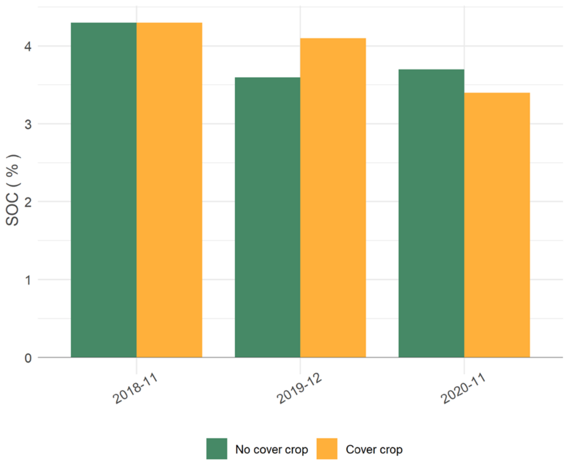
Table 2: Variables measured and analysed in both tested treatments (Control and SICS) for the three farm fields

Observation code	Unit	Description
ksat	cm s^{-1}	Saturated hydraulic conductivity
wsa	-	Water stable aggregates score
bd_top	g/cm^3	Bulk density of topsoil (10-20 cm)
bd_bot	g/cm^3	Bulk density of bottom soil (40-50 cm)
nmin_top	mg-N/Kg soil	Mineral Nitrogen

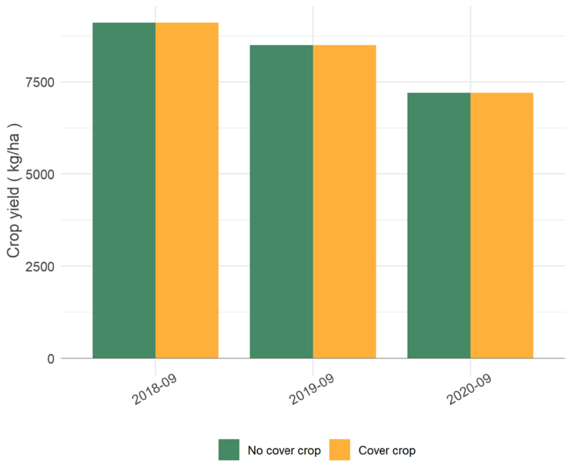
p_avail	mg-P/100gr Soil	Available Phosphorous (P)
k_plus	cmol+/kg	Exchangeable Potassium (K^+)
na_plus	cmol+/kg	Exchangeable Sodium (Na^+)
mg2plus	cmol+/kg	Exchangeable Magnesium (Mg^{2+})
soc	%	Soil organic carbon (SOC)
ph_h2o	_	pH in water
ec1_5	dS/m	Electrical Conductivity (1:5 soil:water)
weed_infestation	%	Percentage of Weed infestation
earthworm_no	no/m^2	Earthworm number per m^2
crop_yield_ha	kg/ha	Crop yield
soil_erosion_ha	tn/ha	Soil erosion

Results

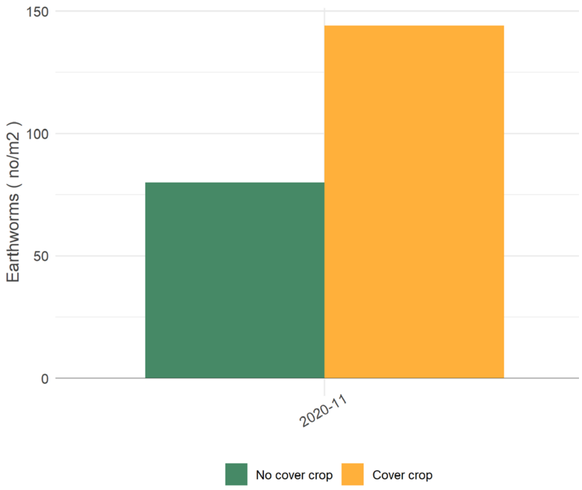
FD1: Vineyard

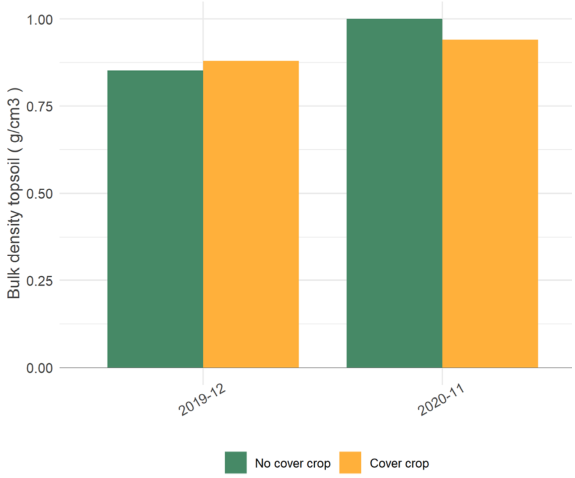


Soil Organic Carbon (%)



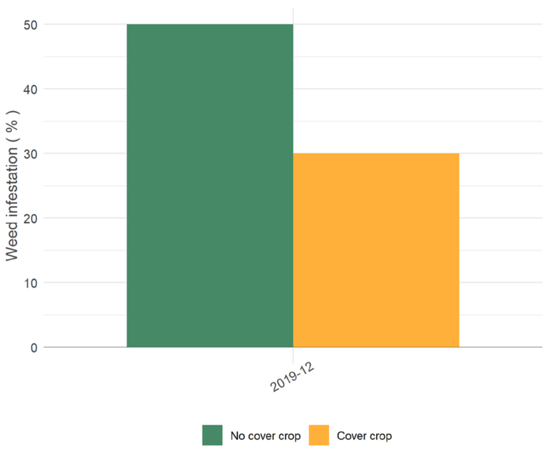
Crop yield (kg/ha)





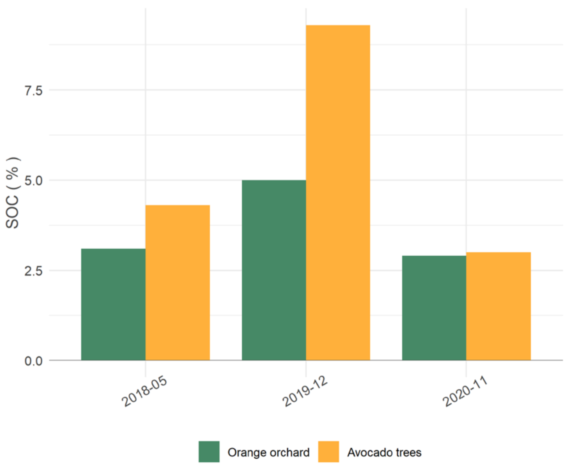
Earthworm numbers per m²

Bulk density of the topsoil (g/cm³)

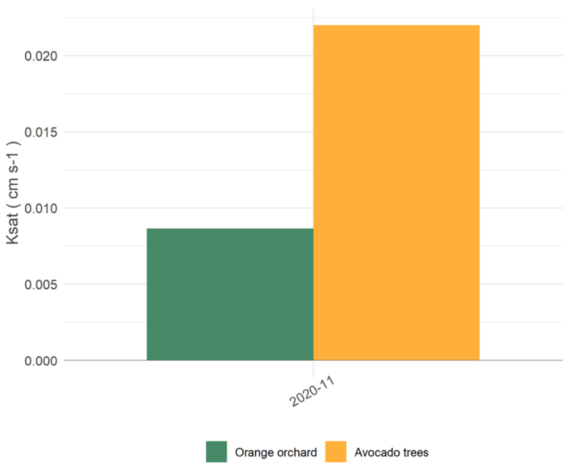


Weed infestation (%)

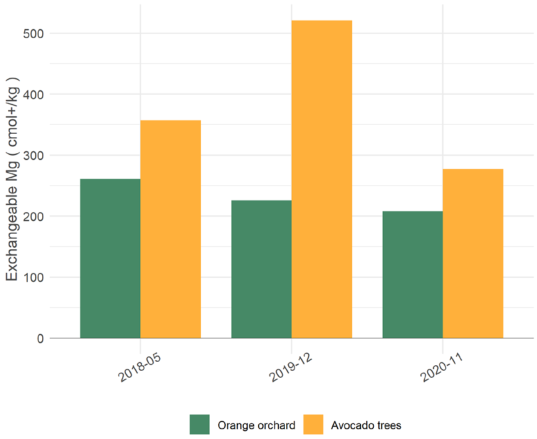
FD2: Fruit Orchard



Soil Organic Carbon (%)

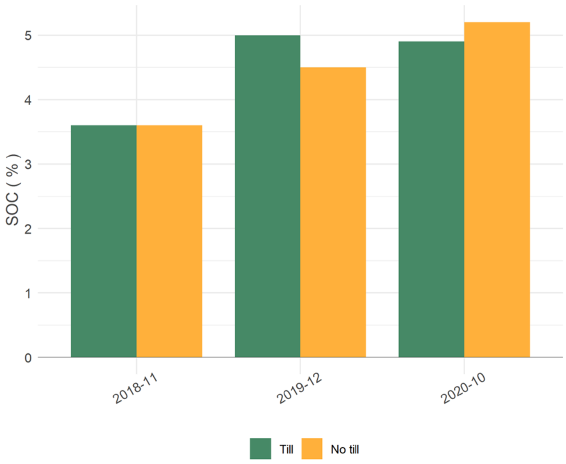


Saturated hydraulic conductivity (cm/sec)

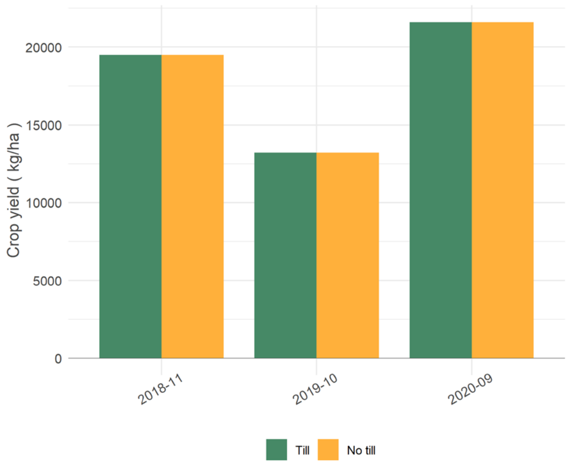


Exchangeable Magnesium

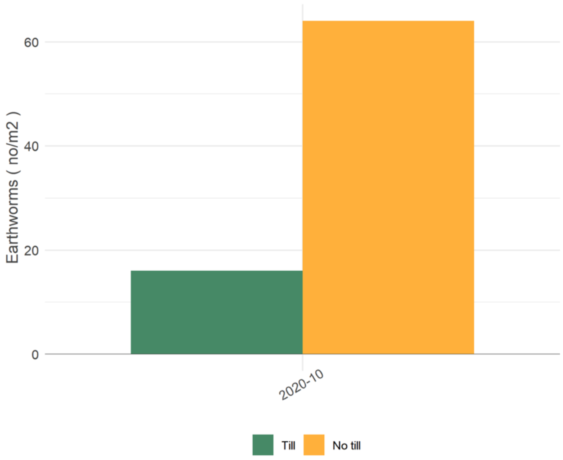
FD3: Olive Orchard



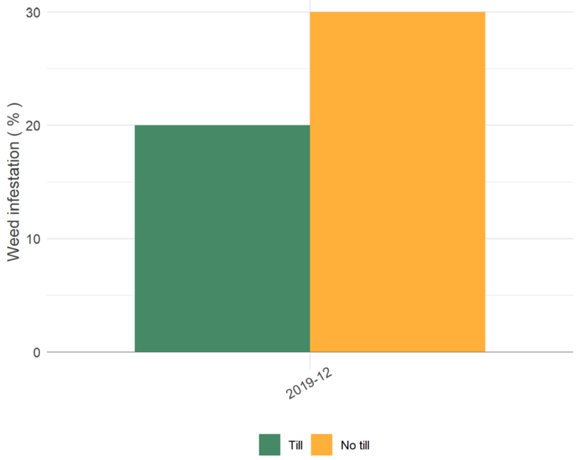
Soil Organic Carbon (%)



Crop yield (kg/ha)



Earthworm numbers per m²



Weed infestation (%)

Analysis

FD1: Vineyard

The soil organic carbon does not follow a specific trend; it is relatively satisfactory around 4% in both plots (Control and SICS) from 2018 to 2020.

The crop yield was the same at both plots (Control and SICS), having a slightly decreasing trend during the 3-year monitoring.

Earthworms per m^2, which is a soil health indicator, were considerably higher in the vineyard with the cover crop applied.

The bulk density of the topsoil (10-20cm) was slightly lower in the vineyard with the cover crop by the end of 2020, a good indicator of soil functioning.

The percentage of weed infestation was 20% less in the vineyard with the cover crop.

FD2: Fruit Orchard

The soil organic carbon rate was higher in the avocado trees, compared to the orange orchards.

The saturated hydraulic conductivity was considerably higher in the avocado trees' plot compared to the orange trees' plot, in the 2020 measurement.

The exchangeable magnesium was also higher in the avocado trees compared to the orange orchards, during the 3-year monitoring.

FD3: Olive Orchard

The soil organic carbon rate had an increasing trend in both plots from 2018 to 2020 and was slightly higher in the last year, which is probably due to the animal manure application.

The crop yield was the same at both plots (Till and no Till), and was increased in 2020 compared to the years 2018 and 2019.

Earthworms per m^2 were substantially higher in the non-tilled plot compared to the tilled one, in the 2020 measurement.

Weed infestation was slightly higher (10%) in the non-tilled plot compared to the tilled one, which cannot be assumed as a considerably higher hazard.

Study site analysis

Soil erosion problem and approach, the experimental design, and results.

The problem and approach

FD1: Vineyard

Vineyards in Crete are susceptible to soil loss due to erosion (Alexakis *et al.*, 2019; Vozinaki *et al.*, 2020). There is a need to find practices that prevent soil erosion without reducing the profitability of the vineyards. The simplest and most natural way to prevent erosion is through planting vegetation. Cover crops keep ground covered over storm events with high rain rates and winds, which can cause erosion. Plants establish root systems that stabilise the soil and prevent erosion. Moreover, cover crops can reduce the need for fertilizer and supply organic Nitrogen if leguminous.

FD2: Fruit Orchard

In the Chania Prefecture of Crete, orange cultivation is a major crop, but due to severe market competition producer prices have significantly dropped leaving little or no profit. Recently, avocado plantations have been proposed as a sustainably profitable alternative to oranges, but little is known about their soil erosion rates or their effect on soil quality. The yield is expected to be profitable after the fifth year of application.

FD3: Olive Orchard

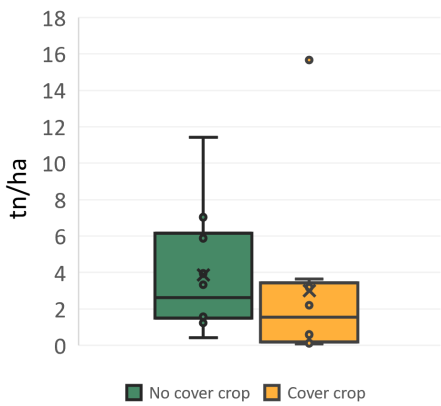
Olives are the most important crop grown on the island of Crete, covering 64% of the arable land and representing 86% of the tree plantations on the island. Conventional practices often lead to on-site and off-site environmental problems, such as soil erosion. There is a need to find practices that prevent soil erosion without reducing the profitability of the crop. Less tillage can improve soil health by reducing organic matter decline, keeping soil microbiology intact, and limit compaction through less machine passes across fields, as well as reduce fuel use and related emissions.

Experimental setup

FD1: Vineyard

The experiment compared a vetch cover crop with a no vetch plot. The grape variety was *Vitis vinifera* and the plots were located on a corporate organic farm of 0.46 ha.

Positions of the cross-sections in which soil erosion measurements were made

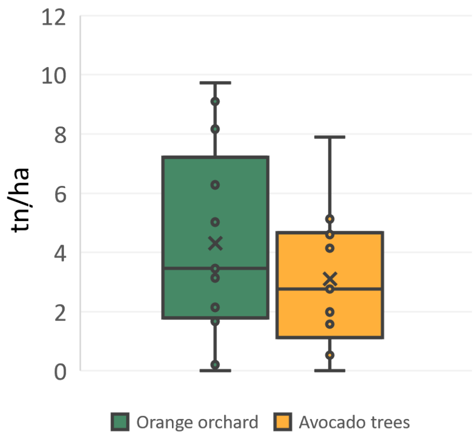


Soil erosion (ton/ha)

FD2: Fruit Orchard

The experiment compared an orange orchard area, which served as the Control plot, with a rotation crop area of avocado trees, served as the treatment (SICS). The orange orchard variety was *Citrus × sinensis*, whereas the crop switch variety was *Persea Americana*, and the plots were located on a family conventional farm of 0.5 ha.

Fruit Orchard: orange and avocado trees



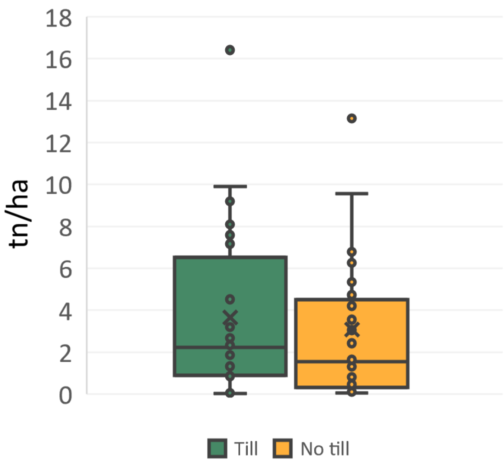
Soil erosion (ton/ha)

FD3: Olive Orchard

The experiment compared tilled plots and no-till treatment in two areas. Two olive varieties were studied in the experiments, *Olea europaea* and *Koroneiki*, located on an organic farm of 0.29 ha.

Till plot

No-till plot - Sediment fence (Alexakis et al., 2018)



Soil erosion (ton/ha)

Results

FD1: Vineyard

Extreme storm events occurred on 15/02/2019 and 24/02/2019. The nearby rain station recorded an exceptional accumulation of 726.2 mm during this period. These events created soil erosion rills in the examined field. In the vetch plot, the rills were shorter compared to the no Vetch plot.

In 2020, top & bottom soil bulk densities of the Vetch plot were lower compared to the no vetch plot, indicating improved water and solute movement, as well as soil aeration.

The application of the vetch treatment had a direct impact on soil erosion over the 2-year monitoring period (January 2019 to December 2020). Soil loss rate monitoring revealed that the vetch coverage reduced mean soil erosion by over 16% (roughly from 3.7 ton/ha in the no vetch plot to 3.1 ton/ha in the Vetch plot), during the 2 years experiment.

FD2: Fruit Orchard

An extreme rainfall event occurred on 26/10/2017, leading to more than 2 kg of soil trapped in the sediment fences of a 3 m^2 area, corresponding to about 7 ton/ha.

Further extreme precipitation events, which caused severe flooding in the wider area, occurred in February 2019, triggering further erosion in the field.

Field measurements showed that the cropping switch to avocado trees reduced mean soil erosion compared to the orange orchards (Control), over 2.5 years of monitoring (May 2018 to December 2020). Soil loss rate monitoring revealed that the avocado conversion caused over a 25% reduction in mean soil erosion, roughly from 4.7 to 3.4 ton/ha, during the 2.5 years experiment.

FD3: Olive Orchard

Field measurements showed that the no-till treatment had a considerable impact on soil erosion rates. Soil loss rate monitoring revealed that the application of no-till treatment reduced mean soil erosion by over 20%, roughly from 4 to 3 ton/ha, during the 2 years experiment (November 2018 to December 2020).

Considerably more earthworms were observed in non-tilled plot compared to the tilled ones, indicating better soil health and condition.

Topsoil bulk density was slightly higher in the no-till plot. Bottom soil bulk density was found at the same levels in both plots.

Exchangeable Mg had an increasing trend in both plots from 2018 to 2020.

Mineral Nitrogen and available Phosphorus concentrations were lower in the no-till plots, both in 2019 and 2020.

Socio-cultural dimension

The analysis of the socio-cultural dimension was carried out only for the fruit orchards' field since it contained complete economic data. The results of the comparison derived from the survey (Table 3) show that the impact on the reputation of the farmers is positive while the risks perceived are mainly associated with the high costs associated with the new crop plantation and the high risk of crop failure due to severe weather conditions (low temperatures and hail). Another negative perception is the long period between the first investment and the first harvest which, depending on the growth level of the planted trees, vary from 3 to 5 years.

Table 3: Impact of SICS on the socio-cultural dimension as compared to the Control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.00	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	1.00	1.00	Complete

Economical dimension

The analysis of the economic dimension was also carried out only for the fruit orchards' field due to complete economic data. Tables 4 and 5 indicate a strong positive economic impact of SICS in comparison to the Control for the fruit orchard field. Latest local market data oranges and avocados are being sold for 0.17 euros/kg and 2.60 euros/kg, respectively. It is evident the financial benefit from the specific crop switch treatment to avocado crops. However, the implementation of the specific SICS includes high economic risks for farmers since the risk for crop failure risk due to the high sensitivity of the avocado crop to the extreme hydrometeorological event is high.

Table 4: Summary of the benefits of SICS vs. Control, implemented on fruit orchards (the amounts are in euros/stremma)

	AMP control	AMP SICS
Agricultural management technique	Orange orchards	Avocado trees
Investment costs	0	1580
Maintenance costs	911	370
Production costs	450	1200
Benefits	1800	15120
Summary = benefits - costs	439	11970
Percentage change	2626.7	

Overall analysis and main findings

The main findings of the results presented already can be summarised in several bullet points for each study site:

FD1: Vineyard

- Cover crops contributed significantly to reduced soil erosion.
- Soil aggregate stability test resulted in good soil stability and resistance to erosion for both plots, however, for the vetch applied plot, slaking effect was slightly less observed, indicating better structure maintenance.
- The biological health and condition of the vetch cover plots were better compared to the no vetch.
- High content of soil organic carbon concentration was measured at both plots.
- Water and solute movement as well as soil aeration is slightly improved in the case of cover crop application.

FD2: Fruit Orchard

- The biological health and condition of the avocado plot were inferior to the orange tree plots, as assessed from the earthworm density experiment.
- Water and solute movement, as well as soil aeration, are in good status for both cultivations, as identified by the top and bottom soil bulk density experiments.
- A high content of soil organic carbon concentration was measured at both plots. Orange orchards presented reduced soil organic carbon compared to avocado trees, during the 3-year monitoring, probably due to higher inputs.
- The level of weed infestation was 10% less in the avocados field compared to the orange trees field.
- Electric conductivity values indicate high salinity levels in both plots. Even higher values were observed for avocado trees.

FD3: Olive Orchard

- Intensified tillage contributed significantly to increased soil erosion and affected the rooting system of the crop, causing exposed tree roots.
- The biological health and condition of the no-till plots were better compared to the tilled plots.
- Apart from tillage, irrigation also increases soil erosion since irrigated trees are less resilient to water stress due to shallow roots.
- A high content of soil organic carbon concentration was measured at both plots.
- Water and solute movement as well as soil aeration are appropriate even in the case of no-till.

Table 6 below presents the overall sustainability of the fruit orchard field with the implementation of the crop rotation from orange orchards to avocado trees. For the following results, the environmental dimension was based on qualitative assessment. Besides the environmental dimension, besides, taking into account the economic and socio-cultural dimension, as well as the field's physical, chemical and biological properties, the analysis showed a positive impact on the sustainability of the fruit orchard farm (Table 6).

TUC_EX1_TR4= Avocado trees (SICS)

TUC_EX1_TR3= Orange orchard (Control)

Table 6: Impact of SICS on the overall sustainability of the fruit orchard field

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	0.24	0.82	High
Environmental dimension	0.03	0.56	medium
Economic dimension	0.76	1.00	Complete
Socio-cultural dimension	0.00	1.00	Complete
Physical properties	0.02	0.55	Medium
Chemical properties	0.22	0.74	Medium
Biological properties	0.05	0.45	Medium

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Alexakis D.D., Tapoglou E., Vozinaki A.-E. K., and Tsanis I.K., 2019. Integrated Use of Satellite Remote Sensing, Artificial Neural Networks, Field Spectroscopy, and GIS in Estimating Crucial Soil Parameters in Terms of Soil Erosion, Remote Sensing, 11, 1106, doi:10.3390/rs11091106.

Koutroulis, A.G., Tsanis, I.K., Daliakopoulos, I.N., Jacob, D., 2013. Impact of climate change on water resources status: a case study for Crete Island, Greece. Journal of Hydrology 479 (4) pp. 146-158. DOI: 10.1016/j.jhydrol.2012.11.055.

Koutroulis, A. G., Vrohidou, A.-E. K. and Tsanis, I. K., 2011. Spatiotemporal characteristics of meteorological drought for the Island of Crete, Journal of Hydrometeorology, 12(2). doi: 10.1175/2010JHM1252.1.

Tsanis, I.K., Koutroulis, A.G., Daliakopoulos, I.N., Jacob, D., 2011. Severe climate-induced water shortage and extremes in Crete. Climatic Change 106 (4), pp. 667-677. DOI: 10.1007/s10584-011-0048-2.

Vozinaki, A.-E., Alexakis D., and Tsanis I., 2020. Monitoring and Estimating Soil Loss in Agricultural Areas – Case Studies in Chania, Crete, Greece. EGU General Assembly 2020, Online, 4–8 May 2020, EGU2020-6578, https://doi.org/10.5194/egusphere-egu2020-6578, 2020 (abstract)

General conclusions based on the experiments in Crete

Soil-Improving Cropping Systems (SICS) application seems to play an alleviating role in soil loss processes; therefore it is recommended to properly inform the farmers about the tested practices within the field.

The most remarkable conclusions are:

regarding the **FD1: Vineyard**

- Crop cover treatment (vetch) has a substantial impact on soil erosion/deposition *(over 16%)*.
- Vetch application is an inexpensive solution and is recommended to control soil erosion.
- The correct application of cover crop is a determinant in improving soil quality.

regarding the **FD2: Fruit Orchard**

- Crop type change (avocado) has a substantial impact on soil erosion/deposition *(over 25%)*.
- Avocado farms, besides significantly higher financial benefits, can also maintain a comparably overall good soil quality.

regarding the **FD3: Olive Orchard**

- The no-tillage practice is substantially beneficial for controlling soil erosion *(over 20%)*, improving soil health and keeping good soil structure.
- Olive farmers should consider reducing tillage practices in olive orchards, control the tillage depth, and at the same time limit its application especially during severe drought periods.

This experiment demonstrates that soil-improving cropping techniques have a significant impact on soil erosion and as a result of soil water conservation that is of primary importance, especially for the Mediterranean dry regions. As reported in other studies, tillage erosion is considered to be one of the most important processes of land degradation in cultivated areas. The effect of tillage in soil erosion was also recorded during the SoilCare experiment even for the minimum tillage practice. Results of the study also show that crop cover treatment (vetch) and crop type change have a substantial impact on soil erosion. The proposed sustainable soil-improving practices are already been applied in many parts of the region. Especially the change from orange to avocado trees has been adapted by many farmers as a response to the reduced orange prices and the high income from avocado cultivation. Our results highlight the crucial role of soil-improving cropping systems for sustainable land management.

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I.13 SLU (Sweden)

Report 1 on Monitoring and Analysis of Subsoil loosening experiment

Study Site number: 13

Country: Sweden

Author(s): Gunnar Börjesson, Martin A Bolinder, Thomas Kätterer, Holger Kirchmann

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): SLU

Experiment: Subsoil loosening

Version: Final

Date: 18-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to increase the topsoil depth by loosening the subsoil to combat compaction. The experiment established in September 2018 and was set up in a randomized complete block design with 4 blocks, containing 3 plots each, 2 for the SICS treatments and one for the control treatment.

Experimental field information

The experiment is conducted on a farm field managed jointly by the farmer and the researchers. The experimental field is located in Orup, Sweden at an altitude of 78 m and covers an area of about 3600 m^2. The topsoil has a coarse sandy loam texture according to the USDA classification system.

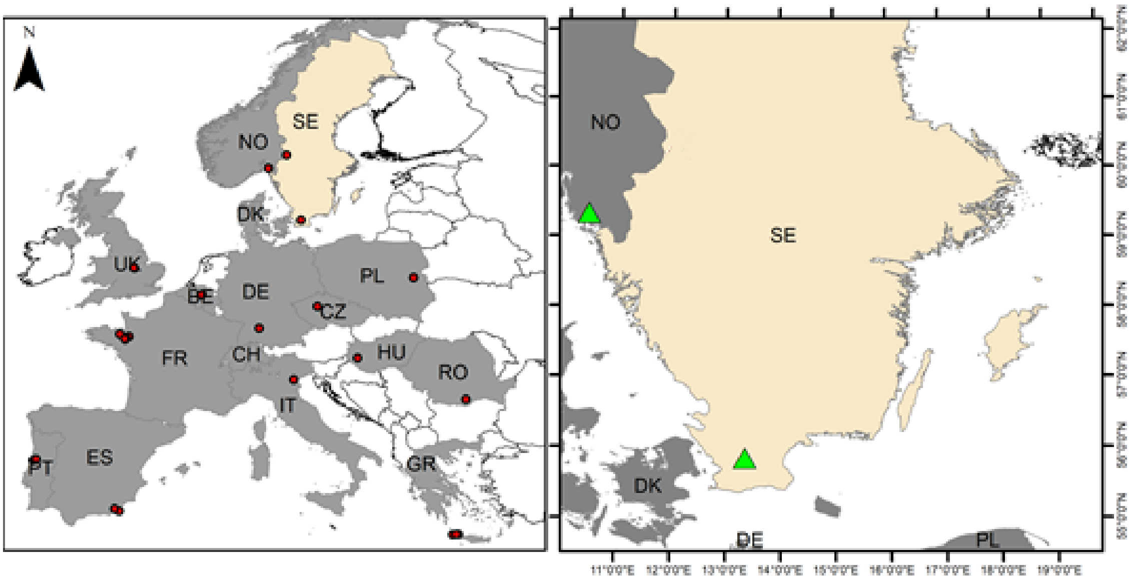


Figure 1: Location of the study site

According to the soil profile of 1.4 m which described by Kirchmann and Eriksson, in 1993 the soil has 3 horizons and is characterized as Aquic Haploboroll; Haplic Phaeozem (FAO). The maximum rooting depth is at 0.4 m depth because of compaction by land ice, and there is a ploughing pan at 0.25 m

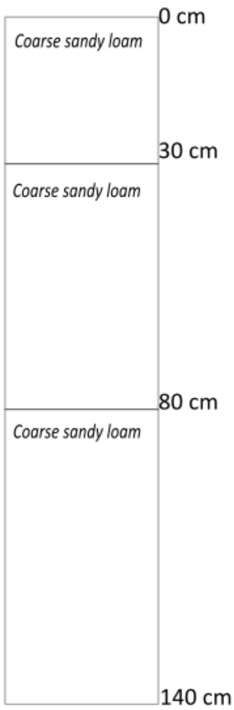


Figure 2:Soil Profile

Photo: Gunnar Börjesson

The climate of the experimental field area

For the longer-term data, use was made of Lund (ECAD 463) whereby data started in 1882 up to November 2020 at the time of producing this report. More nearby are Horby_A data which are also ECAD station 5184. They start in 1995 and include also November 2020.

Table 1: Overview of Temperature, Precipitation and ET0 for Lund and Horby_A

Station	period/year	Tmax	Tmin	Precip	ET0
Lund	1961-90	11.3	4.9	665.8	602.9
Lund	2018	14.1	6.7	477.1	739.2
Horby_A	2018	13.1	5.5	572.5	721.9
Lund	2019	14.0	6.8	707.2	689.9
Horby_A	2019	12.9	5.8	740.6	656.5

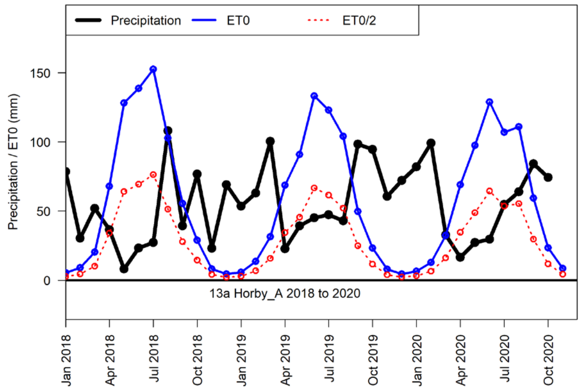


Figure 3: 13a Horby_A 00aFAOgrow

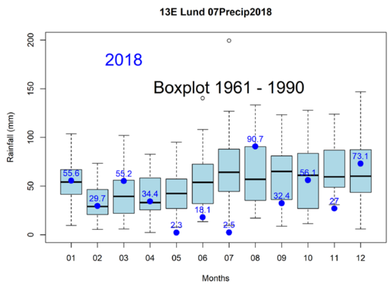


Figure 4: 13E Lund 07Precip2018box

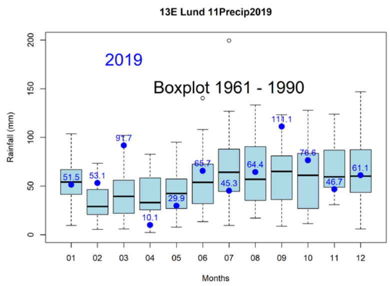


Figure 5: 13E Lund 11Precip2019box

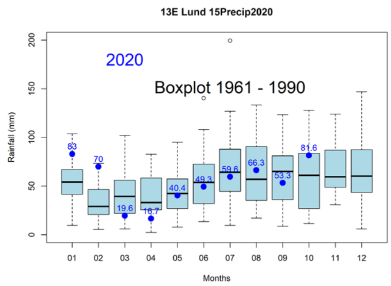


Figure 6: 13E Lund 15Precip2020box

2019 was a normal summer and for the winter wheat that had been sown the previous autumn, the conditions were fairly good. 2020 had also good conditions, with 253 mm rain between fertilisation and harvest on the experimental site.

Cropping systems description

Treatments

The experiment consists of 3 treatments with the following codes in the SoilCare Database and the analysis following.

SLU_EX1_TR1 = Ploughing (control)

SLU_EX1_TR2 = Loosening

SLU_EX1_TR3 = Loosening + straw

Factors include:

Ploughing: Normal mouldboard ploughing at 25 cm depth in September 2018

Loosening: Sub soiling loosening at 35 cm depth in September 2018

Straw: 25 ton/ha straw pellets which are consist of 5 t/ha wheat straw and 20 t/ha rapeseed straw injected at 24 to 35 cm depth in September 2018

Field operations

In the experimental field, 185 kg/ha of wheat (*Triticum aestivum*) sowed in 2018 and harvested at the end of August 2019 and beets (*Beta vulgaris*) planted in April 2020 and harvested in October 2020. In the field NPK fertilizer banded beneath the surface in spring 2019 and 2020.

Bio-physical data analysis – WP5

Method

Differences between treatments for all response variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure “Treatment*Date” or the “Treatment+Date” depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using the statement “1|Block”.

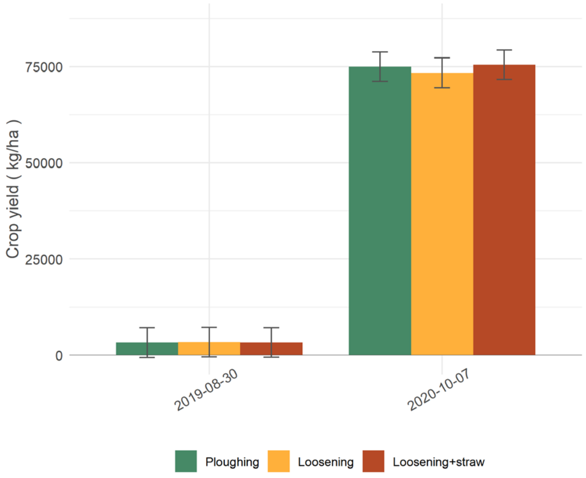
In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models’ standard error.

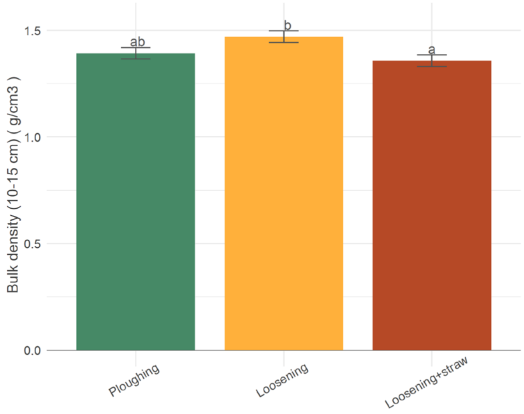
Data

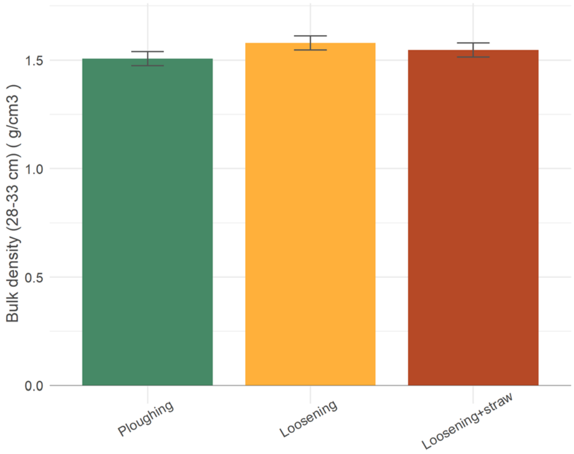
In the table. you can find the variables measured and analysed for this experiment. Results for all variables can be found in ANNEXE II.

Observation code	Unit	Description
crop_yield_ha	m3m-3	Crop yield
bd_top	m3m-3	Bulk density (10-15 cm)
bd_bot	m3m-3	Bulk density (28-33 cm)
top_gravel_fraction	%	Percentage of gravels fraction >2 mm

Results







Study site analysis

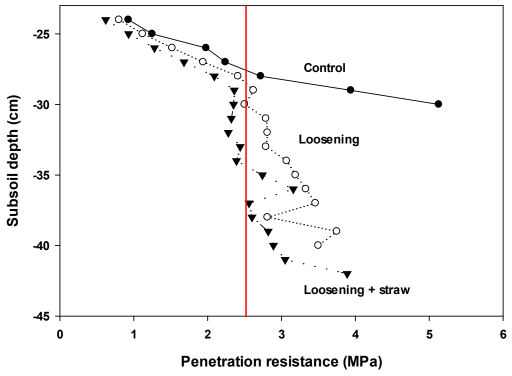


Figure 7: Changes in the penetration resistance upon loosening and loosening + straw incorporation in the Orup field study. The red line (2.5 MPa) indicates the critical limit for root penetration. Measurements made across treatment stripes covering a width of about 40 cm

Table 2: Presence of roots by visually counting the number of roots along a 10-cm line at various depths

Treatment	Number of roots along a 10 cm line at various depth		
	10cm	20cm	30cm
Control	31	22	3
Subsoiling row	32	54	19
Subsoiling + straw row	63	64	16

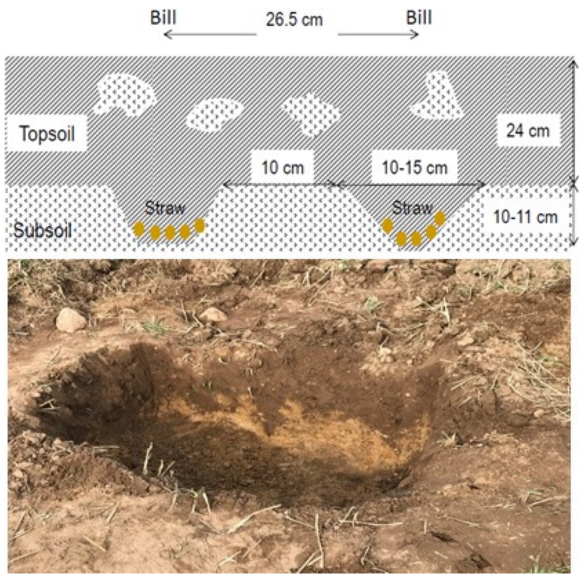


Figure 8: Illustration (top) and photo of a soil profile for evaluation of the effects of subsoiling. The volume percentage of the subsoil affected through loosening and straw incorporation varied between 38 to 45%.

Table 3: Relative yield compared to the winter wheat yield of the control (3221 kg ha-1) considering subsoiling treatments were affecting only a portion of the subsoil volume

Treatment	Grain yield on the whole field (kg ha^{-1})	Relative yield on subsoil rows considering 38% of subsoil affected	Relative yield on subsoil rows considering 45% of subsoil affected
Control	3221[a] (100)	100	100
Subsoiling	3323[a] (103)	108	107
Subsoiling + straw	3270[a] (102)	105	104

A column with grain yield is also showing the relative yields in parenthesis.

Socio-cultural and Economical dimension

This was a pilot study, where the primary objective was testing the feasibility of our approach using prototype machinery that a consultant was devised specifically for the experiment. We have currently no clear ideas exactly for which cropping systems, climatic and edaphic conditions this approach will possibly be useful at a large scale. Neither do we know if we can devise this machinery (and at what cost) so that it could be applicable at a larger scale nor what type of organic material would be the most appropriate (both from a practical point-of-view and local availability). Therefore, it is impossible to make an economic and socio-cultural assessment.

Overall analysis and main findings

The subsoiling treatments were both moving subsoil irregularly into the topsoil and forcing topsoil into the subsoil. Straw was not mixing with subsoil in rows; it was rather located at the bottom of the subsoil rows together with topsoil. The volume percentage subsoil affected by the subsoiling treatments varied between 38-45% (Fig. 2.)

Visual observations showed that more roots were present in the two subsoiling treatments, while there were almost no roots present in the subsoil for the control treatment (Table 1). Changes in the penetration resistance were indicating that the maximum penetration into the subsoil (>24 cm) was only about 4 cm in the control, but up to 11 cm in the subsoiling treatments. While maximum rooting depth was about 27 cm in the control, 30 in subsoiling alone and 35 cm for the subsoiling + straw treatment (Fig. 1.).

Crop growth measurement was indicating that the subsoiling treatments were not significantly affecting yields. However, measured yields of the whole field is a mean value of the treated (38 to 45%) and untreated subsoil volume. Scaling yield results against the volume percentage of subsoil influenced by subsoiling (using the yield of the control treatment as a baseline) increases the effect of subsoiling on relative yields (Table 2). Conceptually, calculating yields as the mean of affected and unaffected subsoil may be a more reasonable indicator for the effect of subsoil loosening. One needs to consider that subsoiling does not affect the whole hectare but only a portion of the area (distinct subsoil rows) and differs in this sense from other soil or crop treatments affecting the whole area.

The analysis for all the physical and chemical measurements are not yet fully completed. Notably the subsoiling treatment effects on dry soil bulk density and its variation concerning soil carbon, texture and percentage (volume and weight) gravel and stones.

References

Kirchmann, H., and Eriksson, J. 1993. Properties and classification of soils of the Swedish long-term fertility experiments: II. Sites at Örja and Orup. Acta Agriculturae Scandinavica, Section B – Soil & Plant Science. 43: 193-205.

General conclusions based on all the experiments

This short-term pilot study on a site having a naturally compacted subsoil showed that subsoiling loosening treatments, with or without the incorporation of straw pellets, have a positive impact on root growth and rooting depths. Subsoiling did not significantly affect yields. However, there is a need for longer-time studies on other crop and soil types, using other sources of organic materials and for examining the effects of repeated subsoil loosening treatments through time.

I.14 Crop Research Institute (Czech Republic)

Report 1 on Monitoring and Analysis of Tillage and different N application experiment

Study Site number: 14

Country: Czech Republic

Author(s): Helena Kusá

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): Crop Research Institute

Experiment: Tillage and different N application experiment

Version: 2

Date: 22-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate and observe the effect and influence of individual kinds of N-fertilisers with different forms of nitrogen (ammonium, amidic, nitrate form and influence of urease inhibitor) and the reaction of crops under different level of soil cultivation. The experiment established in 1995 and was set up in strip-plot -randomized complete block design with four replications of the SICS treatments and 3 of the control treatments, and with 3 main plot strips, one for each soil cultivation method. The experiment is replicated in two fields with different four crop season rotation system.

Experimental field information

The experiment is conducted on an experimental field managed by the researchers. The experimental field is located in Prague 6, Czech Republic, at an altitude of about 360 m and covers an area of about 7500 m^2. The soil is characterized as Orthic Luvisol, with the topsoil to have a silty clay loam texture according to the USDA classification system.

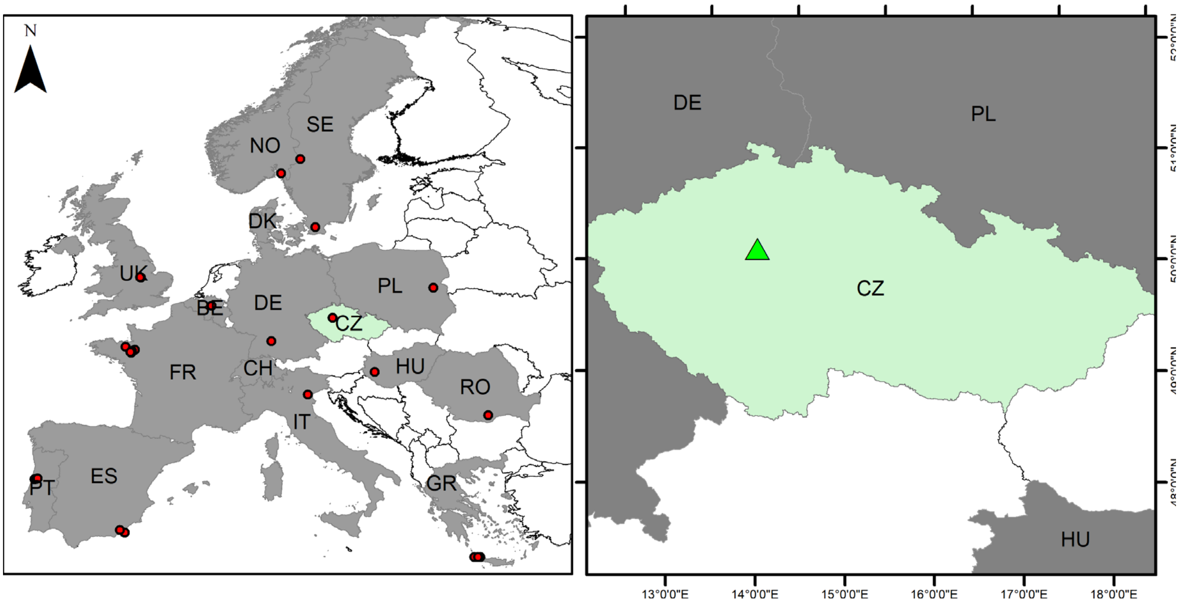


Figure 1: Location of the study site

The climate of the experimental field area

Praha Klementinum (ECAD 27) is the first and most long-standing Czech meteorological station. Measurements started in 1775 making it the oldest on in the world. The research station CRI has a meteorological station next to the experiments.

Table 1: Overview of meteorological data per year and period.

Station	period/year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
Praha/Klem	1961-90	13.7	6.4	470.6	747.3
Praha/Klem	2018	16.7	8.9	363.7	860.2
VURZ_CZ	2018	16.0	6.0	345.3	930.8
Praha/Klem	2019	16.6	8.8	379.5	841.9
VURZ_CZ	2019	15.9	5.9	430.7	901.9
VURZ_CZ	2020	15.5	5.6	504.8	879.0

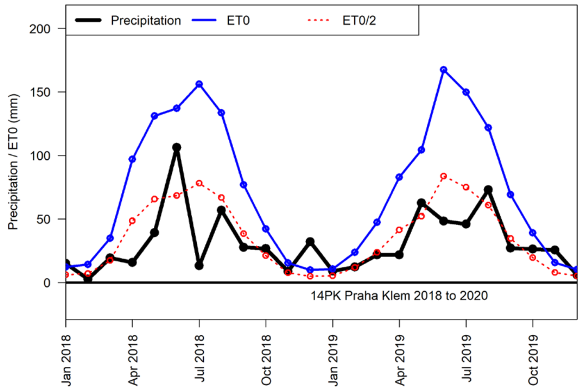
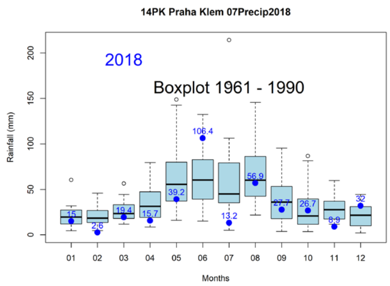


Figure 2: 14PK Praha Klementinum 00aFAOgrow



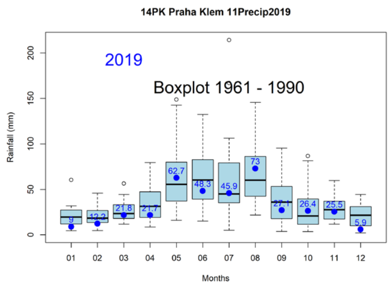


Figure 3: 14PK Praha Klementinum

Figure 4: 14PK Praha Klementinum

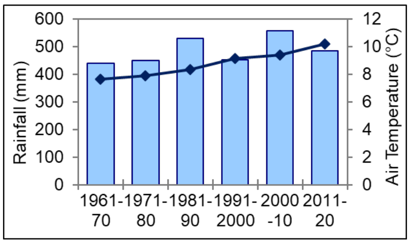
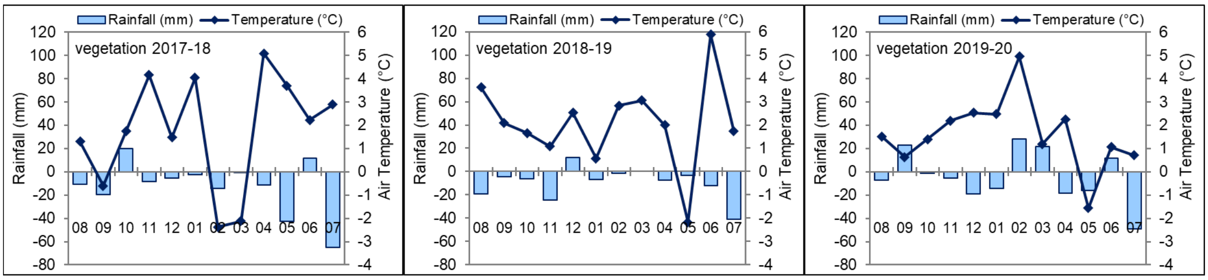


Figure 6: 14P Annual average rainfall and temperature in decades (Prague-Ruzyne)

The study site is located in the warm-dry (T1) to warm-slightly dry (T2) climatic region. The annual average temperature is increasing continuously. The last decade was the warmest one (ann. Aver. Temp. 10.2°C). The last exper. Years were extremely warm without snow. In 2018 February and March were cold (2.0-2.5°C below long-term, normal), the spring vegetation started late. The following month until the harvest was extremely warm and dry, solid fertilizers remained on the soil surface, nutrients were not available for crops. These facts adversely affected crop yields. The whole vegetation period of 2019 was very dry (up to 40 mm per month below the long-term normal) and, except for May, very warm again (2 to 6°C above long-term normal). The winter of 2019-20 was very warm, with precipitation in February and March improving the water supply in the soil and releasing nutrients from the applied fertilizers. The following months were mostly warm (except May) and dry, but conditions were not as extreme as in 2019



Figures 7 to 9: 14P Monthly average temperature and total precipitation compared to the long - term normal 1981 – 2010 (Prague-Ruzyne)

Cropping systems description

Treatments

The part of the experiment that analysed within the SoilCare project consists of 15 treatments with the following codes in the SoilCare Database and the analysis following and only the one field selected.

VURV_EX1_TR1= Conventional ploughing + No N application

VURV_EX1_TR2= Conventional ploughing +CAN

VURV_EX1_TR3= Conventional ploughing +UREA

VURV_EX1_TR4= Conventional ploughing +UREA stabil

VURV_EX1_TR5= Conventional ploughing+ CAN + UAN

VURV_EX1_TR6= Minimum tillage + No N application

VURV_EX1_TR7= Minimum tillage +CAN

VURV_EX1_TR8= Minimum tillage +UREA

VURV_EX1_TR9= Minimum tillage +UREA stabil

VURV_EX1_TR10= Minimum tillage + CAN + UAN

VURV_EX1_TR11= Zero tillage + No N application

VURV_EX1_TR12= Zero tillage +CAN

VURV_EX1_TR13= Zero tillage +UREA

VURV_EX1_TR14= Zero tillage +UREA stabil

VURV_EX1_TR15= Zero tillage + CAN + UAN

The treatments above are combinations of level from two factors, five different N fertilization forms levels and three variants of tillage.

- The different forms of N fertilization are:

  CAN: Calcium ammonium nitrate solid, broadcast, not incorporated applied in two doses

  UREA: Urea, broadcast, not incorporated, applied in two doses

  UREA^{stabil}: Urea with urease inhibitor, applied in two doses

  CAN + UAN: Solid calcium ammonium nitrate broadcast, not incorporated applied in the first spring dose, and Urea ammonium nitrate solution, sprayed in the second and third (if any) spring dose.

- The tree different soil cultivation levels are:

  Conventional ploughing: turning of stubble up to 10 cm and mouldboard ploughing up to 22 cm (Control)

  Minimum tillage: turning of stubble up to 10 cm where a minimum of 30% of the residues remain on the soil surface (SICS 1)

  Zero tillage: all crop residues remain on the soil surface (SICS 2)

Field operations

The treatments are applied in a field with a 4-course crop rotation of *Brassica napus (oil rapeseed), Triticum aestivum (winter wheat), and Pisum sativum (Peas).* The crop rotation follows the row oil-seed rape – winter wheat – peas – winter wheat. Supplemental P and K, Mg and S fertilizers are applied on all the experimental plots. Also, different herbicides, insecticides, fungicides and growth regulators are applied depending on the conditions. The only organic input is the post-harvest crop residues which depending on the soil cultivation system either incorporated in the soil or remain on the soil surface.

Bio-physical data analysis – WP5

Method

Differences between treatments were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure “Treatment*Date” or the “Treatment + Date” depending on which model presented lower AIC. For the variables measured only one time, the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

In the table, you can find the variables measured and analysed for this experiment in all treatments.

Table 2: Indicators measured and analysed

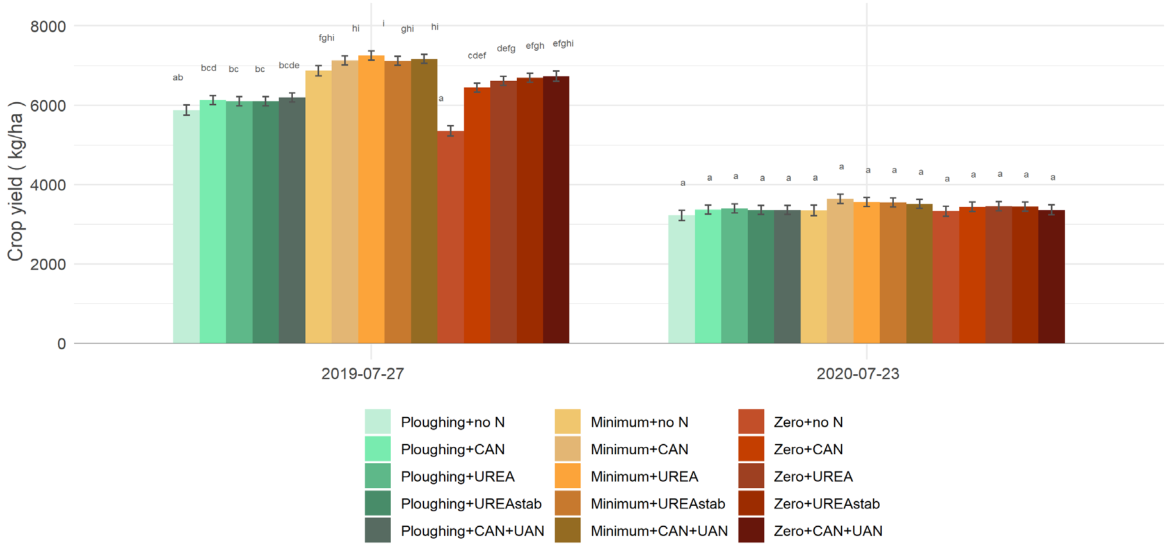
Observation code	Unit	Description
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
top_clay	%	Clay
top_silt	%	Silt
top_sand	%	Sand
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in H2O
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
gluten_index	_	Gluten index
crop_n_cont	% of dry mass	Nitrogen content

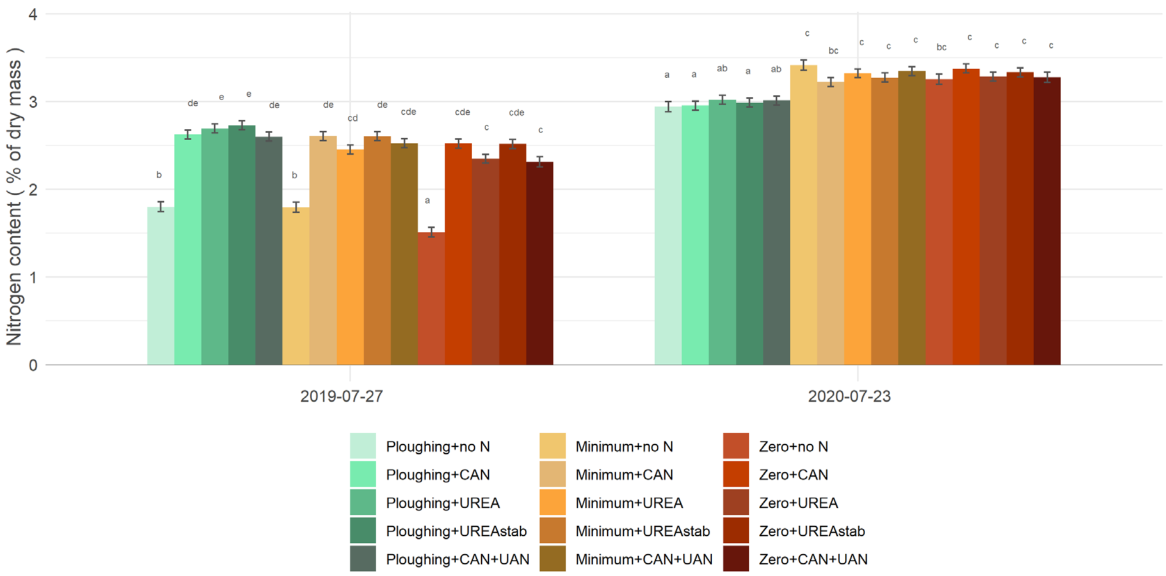
In the table below you can find the variables measured and analysed for this experiment in the three treatments where CAN is applied combined with the 3 different tillage methods. Results for all variables can be found in ANNEXE II.

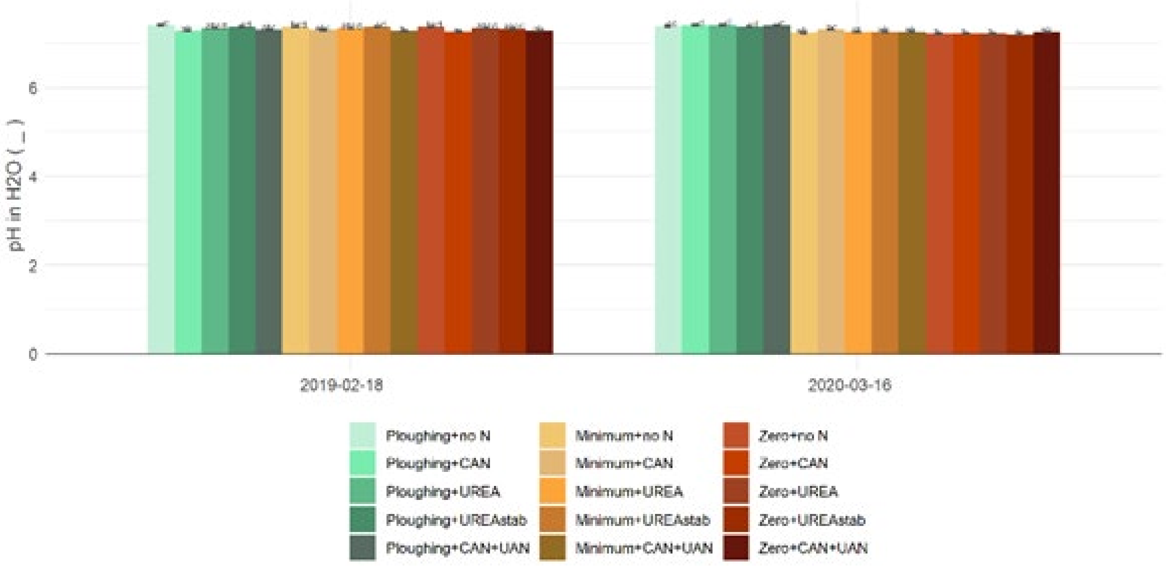
Table 3:Indicators measured only for the three tillage treatments where CAN is applied

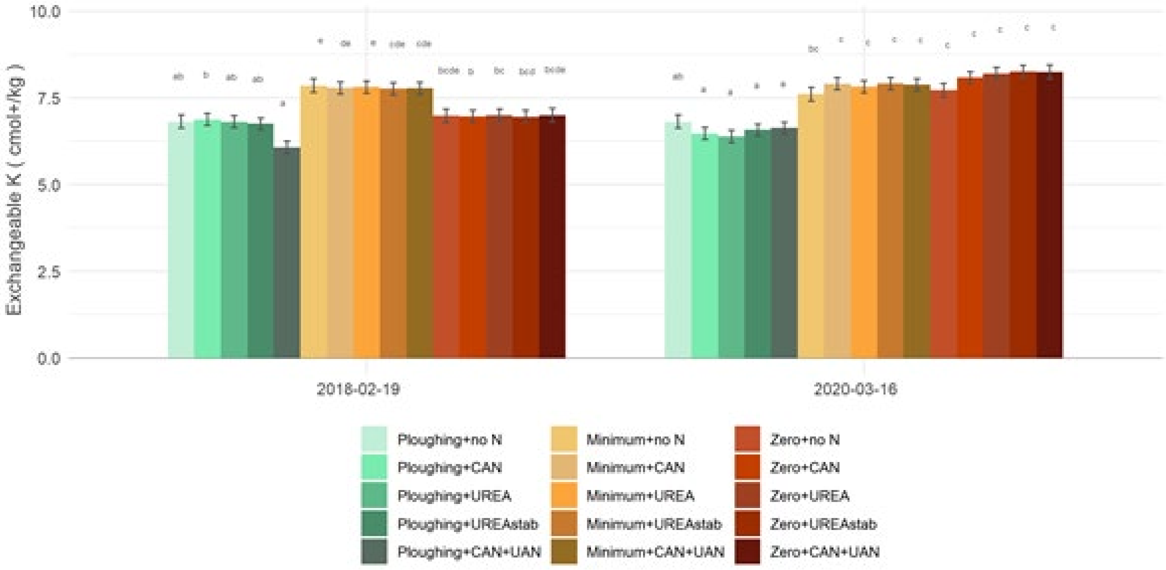
Observation code	Unit	Description
top_wc_pf2_0	m3m-3	Water content at FC

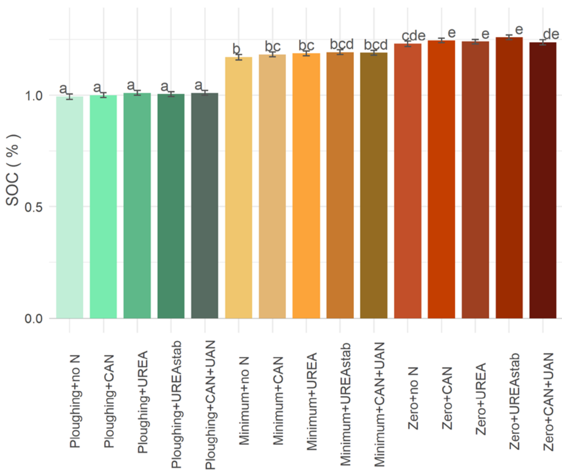
top_wc_pf4_2	m3m-3	Water content at PWP
top_wc_pf2_7	m3m-3	Water content at stress point
top_wc_pf_1_8	m3m-3	Water content pF1.08
top_satur_wc	m3m-3	Water content Saturation
wsa	%	WSA
bd_top	g/cm3	Bulk density topsoil
soc	%	SOC

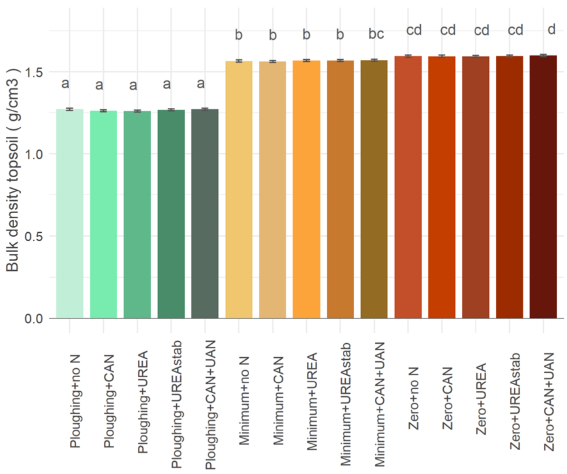


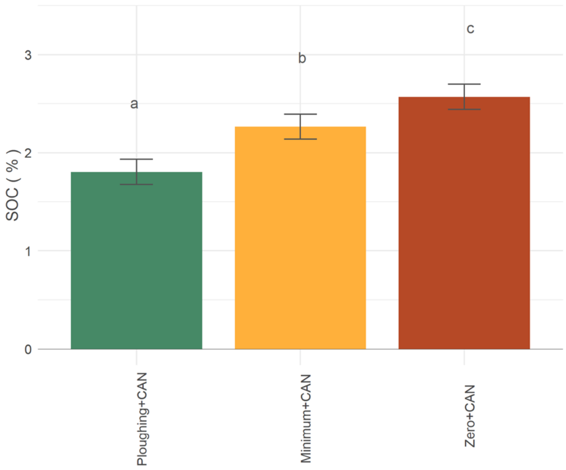


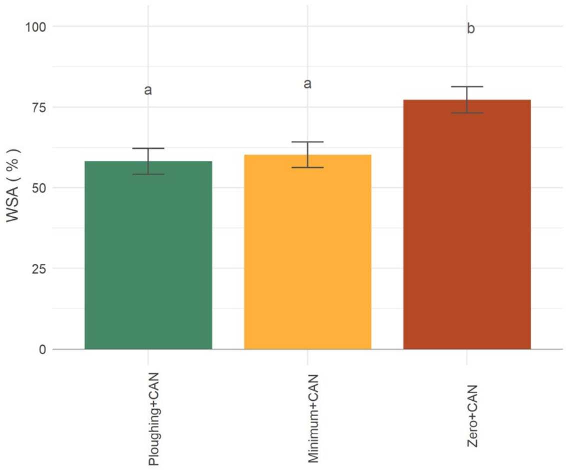

pH in H2O (_)
0
2
4
6
2019-02-18
2020-03-16
Ploughing+no N
Ploughing+CAN
Ploughing+UREA
Ploughing+UREAstab
Ploughing+CAN+UAN
Minimum+no N
Minimum+CAN
Minimum+UREA
Minimum+UREAstab
Minimum+CAN+UAN
Zero+no N
Zero+CAN
Zero+UREA
Zero+UREAstab
Zero+CAN+UAN


Exchangeable K (cmol+/kg)
0.0
2.5
5.0
7.5
10.0
2018-02-19
2020-03-16
Ploughing+no N
Ploughing+CAN
Ploughing+UREA
Ploughing+UREAstab
Ploughing+CAN+UAN
Minimum+no N
Minimum+CAN
Minimum+UREA
Minimum+UREAstab
Minimum+CAN+UAN
Zero+no N
Zero+CAN
Zero+UREA
Zero+UREAstab
Zero+CAN+UAN


SOC (%)
0.0
0.5
1.0
a a a a a b bc bc bcd bcd cde e e e de
Ploughing+no N
Ploughing+CAN
Ploughing+UREA
Ploughing+UREAstab
Ploughing+CAN+UAN
Minimum+no N
Minimum+CAN
Minimum+UREA
Minimum+UREAstab
Minimum+CAN+UAN
Zero+no N
Zero+CAN
Zero+UREA
Zero+UREAstab
Zero+CAN+UAN


Bulk density topsoil (g/cm3)
0.0
0.5
1.0
1.5
a a a a a b b b b bc cd cd cd cd d
Ploughing+no N
Ploughing+CAN
Ploughing+UREA
Ploughing+UREAstab
Ploughing+CAN+UAN
Minimum+no N
Minimum+CAN
Minimum+UREA
Minimum+UREAstab
Minimum+CAN+UAN
Zero+no N
Zero+CAN
Zero+UREA
Zero+UREAstab
Zero+CAN+UAN





Analysis

The decrease of SOC in soil without manure fertilization was the main reason for reducing the intensity of soil tillage. After 25 years using different tillage systems the increase in SOC content with decreasing tillage intensity is visible and statistically significant, as documented in the figures given above. A larger increase in SOC content was found in soil without treatment (ZT), which is the main benefit of ZT. This soil is not aerated and the intensity of mineralization processes and organic matter decomposition in low.

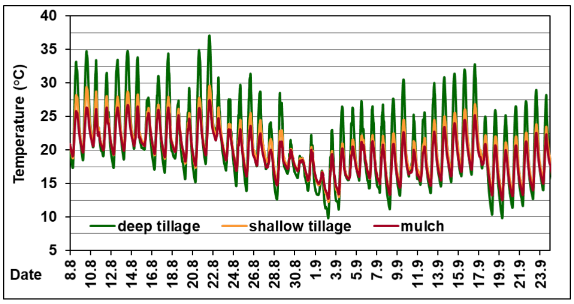
Lower mineralization also means less accessible nutrients for plants. Therefore, the lowest yields from all monitored systems are obtained on a long-term average at ZT. This trend was not observed in the experimental years 2019 and 2020. In 2019, lack of rainfall and high temperatures were limiting factors, and therefore the protection of the soil surface by plant residues played an important role at ZT. In consequence of low nitrogen uptake by crops due to low crop yields in dry 2019, the peas had a sufficient nutrients supply and favourable conditions in 2020. Tillage systems did not affect yield this year. The increase in crop yields and nitrogen content in them after the application of mineral N fertilizers is the most significant at ZT, precisely due to the low mineralization of nutrients from the soil. The differences between control and fertilized variants on CT and MT are less significant, they are often not statistically significant. In the long-term observation, the highest yields are achieved on MT due to the best combination of mineralization intensity, soil aeration, moisture and temperature of all tested tillage systems. The effect of individual fertilizers has mainly influenced the fact of how soon after their application precipitation comes. There are no significant differences in early precipitation. The addition of a urease inhibitor to urea slows down its hydrolysis and keeps it in a mobile form for a longer time. The advantage over urea itself is evident when precipitation occurs within two weeks after fertilizer application. In the long-term observation, the best results (yield and nitrogen/protein content in products) are achieved for fertilizers with a mobile form of nitrogen (nitrate – N, amidic-N with urease inhibitor). The lower intensity of soil tillage or its omission, favourable for the preservation of organic carbon in the soil, also has negatives. The surface layer is stressed by repeated application of fertilizers. Mobile nutrients (e.g. Mg, Ca, NO_3-N) are shifted by precipitation into the soil profile. Accumulation of slow-moving nutrients (e.g. P, K) in the surface layer of the soil occurs when the soil is not turned. In general, acidification of the surface layer of the soil occurs as a result of mineralization and nitrification processes in the soil accelerated after fertilizer applications. This phenomenon is not very significant at the site in Prague-Ruzyně, where high natural content of calcium is in the soil, and it is replenished from the soil supply.

Study site analysis

Soil temperature and humidity, mineralization

Greater attention to soil care and its ability to retain water from precipitation and to manage it efficiently while reducing losses by unproductive evaporation, surface runoff, erosion, etc. must be carried out in the event of anticipated climate change. Tillage (esp. in the summer period) should be less invasive than it is now owing to limiting degradation (mineralization) of organic matter in soil including CO_2 emissions and nitrate formation. Each machine crossing should be assessed in terms of possible damage to the soil structure, water loss and decomposition of organic matter in the soil. The soil should be covered for as long as possible during the year with plants or plant residues, which reduce the risk of water and wind erosion, reduce evaporation and warming of the soil in the summer months.

For illustration:



Figures: The temperature, moisture and NO_3-N content in soil of soil under deep (up to 12 cm) and shallow (up to 6 cm) tillage and without tillage under mulch. Soil tillage 7th August 2020.

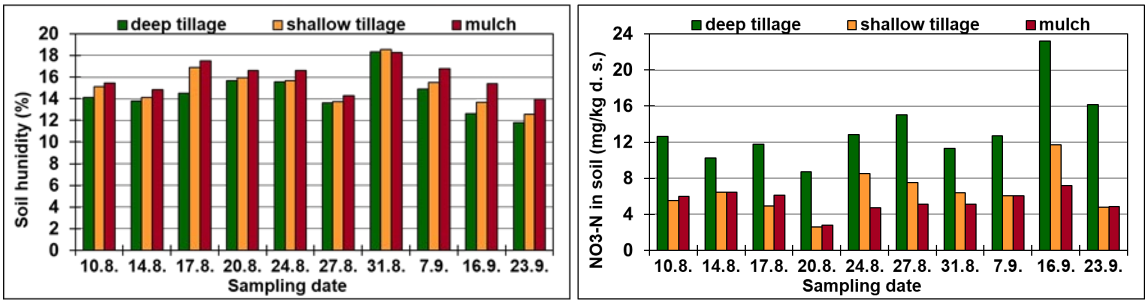
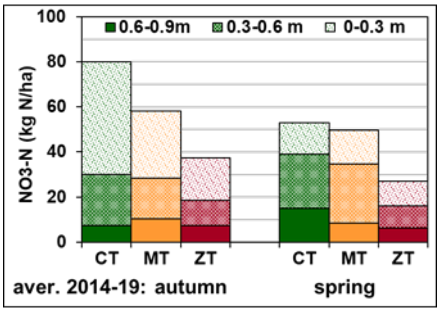


Figure: Nitrate nitrogen content in soil profile before and after winter



Lower nitrification in soils under minimum or zero tillage is welcome if winter crops consuming a considerable amount of nitrogen during autumn (e.g. such as winter rape) are not seeded. The lower nitrate content on the soil before winter, the lower risk of nitrates leaching during the non-vegetative period.

Higher humidity of soil under shallower or zero tillage after harvest makes better conditions for the emergence of self-seeded crops or early seeded winter crops (e.g winter rape). For winter wheat seeded at the turn of September and October, a faster and more balanced emergence is observed at MT than at CT. Crops at MT usually are larger and in an advanced stage of development before winter. The drier autumn, the bigger differences. Under ZT, higher humidity favourably affects the emergency of crops, but lower soil temperature has the opposite effect. Significant differences are observed in the spring. Slow warming of the soil and mineralization of nutrients at ZT results in a later and slower beginning of spring vegetation of crops. Early application of the regenerative dose of nitrogen is more significant here than at CT and MT. In the long-term observation, the biomass of winter wheat (plants) and nitrogen uptake by plants under ZT is significantly lower than under CT or MT at the beginning of stem elongation (phase). During vegetation, the lower temperature and high humidity of soil under ZT affect plants growth positively, esp. in dry and warm years. The grain yields obtained at tested tillage systems do not differ much at fertilized treatments. Decreasing mineralization and availability of nutrients with reducing intensity (or even omission) of soil tillage are documented by yields obtained from control treatment without mineral nitrogen fertilization, and also by lower protein content in grain under ZT.

Figure: temperature in soil (5 cm depth) under winter wheat

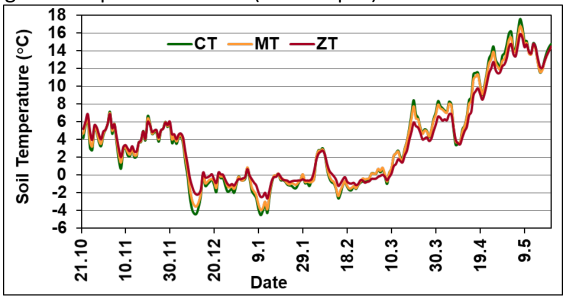


Figure: Biomass of winter wheat and nitrogen uptake by plants at the beginning of stem elongation

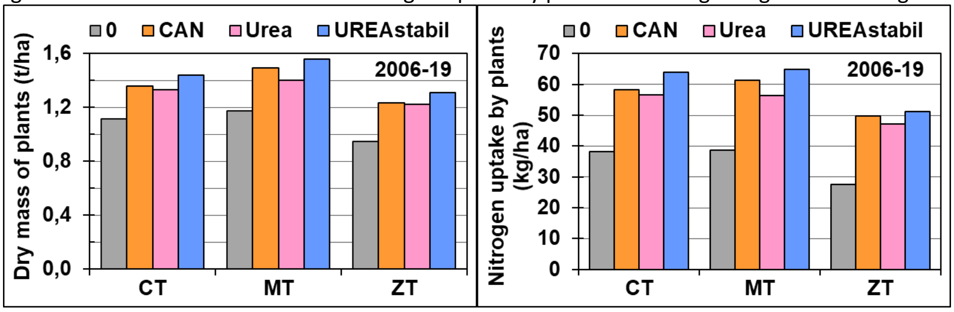
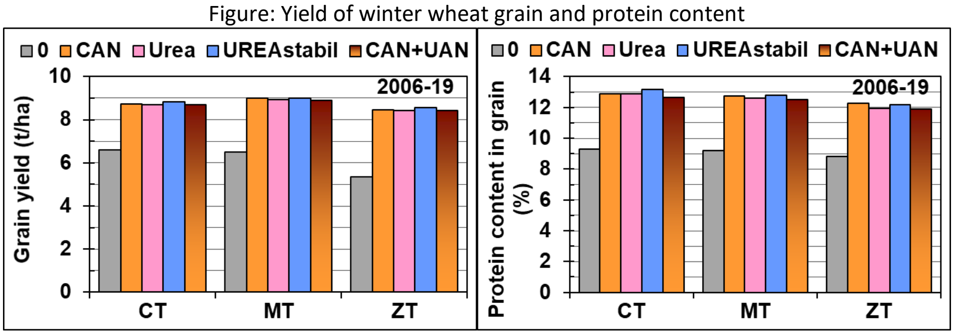


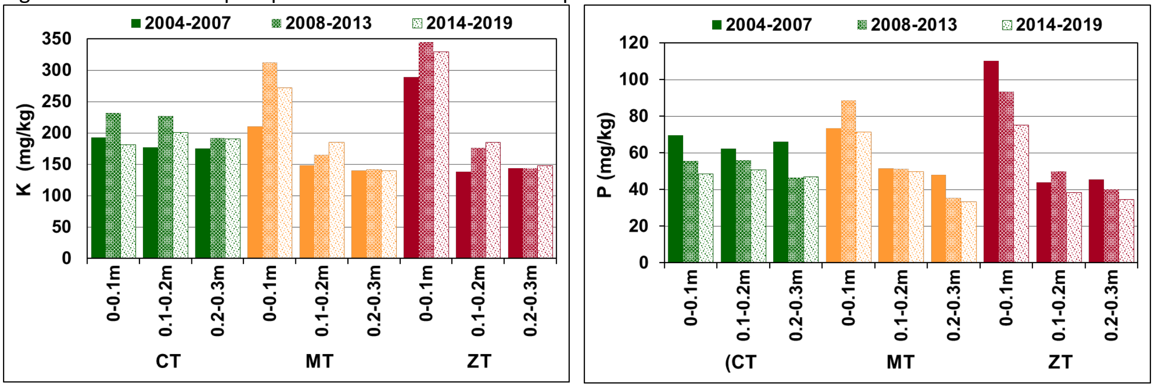
Figure: Yield of winter wheat grain and protein content



Nutrients distribution in soil

In all tillage systems, the fertilizers are applied broadcast on the soil surface. Fertilizers (P, K, Mg, S) applied in the autumn are incorporated into the soil by ploughing up to 22 cm (at CT), mixed in a 10 cm layer of soil (at MT) or stay on the surface (ZT). All nitrogen fertilizers during vegetation are applied without incorporation. The surface layer is stressed by repeated application of fertilizers. Distribution of mobile nutrients (e.g. Mg, Ca, NO_3-N) into the soil profile is ensured by infiltrating water. Problematic are non-mobile nutrients like phosphorus and especially nutrients in the form of monovalent cations, which are adsorbed onto the soil complex and have little mobility in the soil. A more detailed analysis of 10 cm layers of soil showed P and K concentrations increase in the upper soil layer (0-0.1) with decreasing soil tillage intensity and duration of the experiment. In the 2014-2019 period, the average concentration of phosphorus and potassium was by 65% and 50 % resp. higher in the soil at ZT than CT. In soil under CT, their concentrations are fairly balanced in all analysed layer, it sharply decreased in deeper layers at MT and ZT.

Figure: Potassium and phosphorus distribution in the soil profile



Consequently, the most problematic layer 0-0.1 m was divided into surface 2 cm and rest 2-8 cm and analysed separately for K, Mg, Ca content. Under CT the contents of all elements were almost equal. Under minimum or zero tillage higher contents of K and Mg applied annually in mineral fertilizers were determined in the surface layer. Potassium contents in the top 2cm were twice and four times higher than below at MT and ZT resp., for magnesium, it was one and a half times and twice.

The ration of mono- and divalent cations is important for soil structure, aggregate stability or water infiltration into the soil. The optimal ratio of chemical equivalents given in the literature is K:Mg:Ca = 1:2:10 (or better 1:3:13.5-15). Our values are given in the table below. The worst values were found in the soil without treatment. The infiltration of water into the soil on this technology is aided by the macropores formed by crop roots or the macro-edaphone. Natural porosity non-damaged by tillage is also important.

Figure: Bad surface structure of soil with a high content of potassium

Table: Nutrient ratio in soil

CS	Depth (cm)	K:Mg:Ca
CT	0-2	1: 1.1: 7.9
	2-10	1: 1.1: 8.4
MT	0-2	1: 0.8: 4.1
	2-10	1: 1.2: 8.7
ZT	0-2	1: 0.8: 3.5
	2-10	1: 1.5: 9.4

Figure: Macropores formed by crop roots or macro-edaphone

Soil organic carbon

The most important benefit of minimum and/or zero tillage systems against conventional ploughing is increasing the content of organic carbon in the soil as given above. The largest differences were found in the surface layer up to 0.1 m, which is ploughed and turned (CT), only loosened without turning (MT) or left without processing (ZT). After more than 20 years of implementation of these systems, the content of organic carbon in the soil layer up to 0.3 m was increased by 10 and 15 t/ha under MT and ZT respectively (in comparison with CT).

Figure: SOC distribution in soil profile

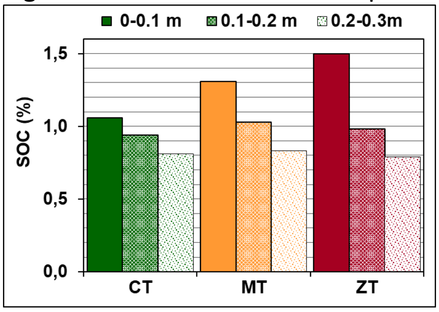
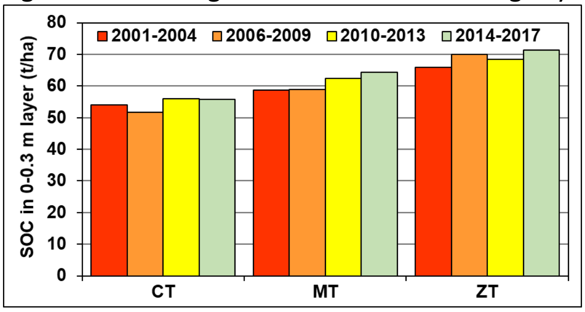
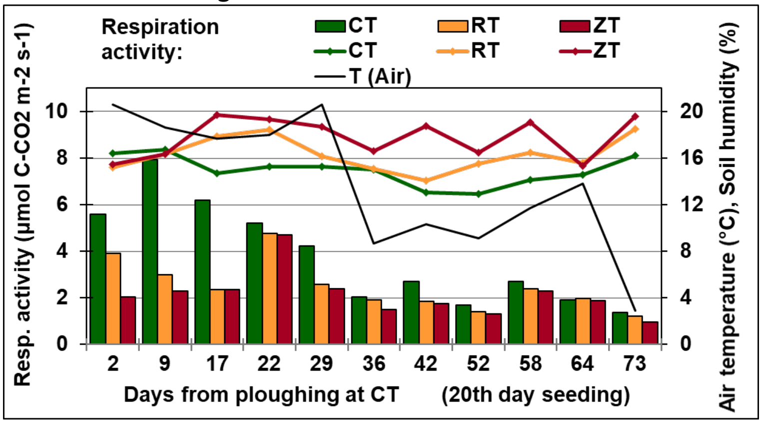


Figure: SOC during the use of different tillage systems



Reduction of intensity or omission of soil tillage significantly reduces respiration activity and CO_2 emissions from soil.

Figure: CO_2 emissions from soil



Socio-cultural dimension

The study of the socio-cultural dimension was not fully completed due to the covid pandemic and quarantine measures. Of course, it was possible to fill in the questionnaires during the telephone interview, but this is not very credible for our farmers. They prefer personal contact. We, therefore, present here a summary of our experience from companies that use some form of minimum tillage and with which we work.

1.1 Gender

Men decide on SICS and men implemented SICS.

Their wives usually take care of administration and economic affairs when it is a small family farm. Everything is provided by employees and wives do not usually participate in the operation, if men are managers or owners of a large company.

1.2 Workload

The SICS 1 (minimum tillage) implementation did not affect the workload of women and men.

The SICS 2 (zero tillage) consist of fewer operations, which decreased the workload of men operating agricultural machinery. It does not affect the workload of women in the administration.

2. Risks

SICS 1: No risk

SICS 2: There may be a risk of conflicts with neighbours, especially when they are environmentally conscious, owing to greater amounts of chemical sprays (herbicides).

3. Social relations and farmer reputation

Cooperation with other land users depends it depends mainly on the nature of the farmer and the type of farm. Small family farms work more independently. They pass on experience through the Association of Private Agriculture. Small family farms work more independently. They pass on experience through the Association of Private Agriculture. Farmers discuss with others during meetings at various workshops and field demonstrations organized by researchers, manufacturers of agricultural machinery, seeds or pesticides. Large (i. e. often richer) farms organize their field days, demonstrations and have the ability (power) to influence the surrounding farmers.

4. Knowledge exchange on SICS

a) From whom and how often

Soil Care researchers: aver. 3-5 times

Extension service: producers of agricultural machinery: aver. 1-2 times

Media: newspaper, magazine, CRI website > 5 times

Farmer network: farmer organization: 1-2 times

Economical dimension

	AMT control	AMT SICS 1	AMT SICS 2
Agricultural management technique	Conventional ploughing	Minimum tillage	Zero tillage
Investment costs	0	0	0
Maintenance costs	0	0	0
Production costs	604	565	567
Benefits	983	1135	1016
Summary = benefits - costs	379	570	449
Percentage change		50.4	17.5

No investments and maintenance costs were calculated because the tested SICS did not require special agricultural machines besides compared to the control CS. The SICS 1 (MT) did not use a plough but only a stubble cultivator (e.g. disc tiller) used in CT also. The SICS 2 (ZT) did not use any tillage machines at all, only a mulching machine is needed. The most expensive operation of all was ploughing up to 22 cm. Only shallow soil cultivation at SICS 2 means saving working time and fuel. AT CICS 2, repeated soil tillage is replaced by a single glyphosate spraying. It consumes significantly less fuel and a less powerful tractor is sufficient. Nevertheless, the production costs of ZT were at the level of MT, because there were higher inputs (chemicals).

Production cost and benefits given in the table were calculated for winter wheat of food quality. In the dry and warm year, the yields (i.e. benefits) were higher at SICSs with postharvest residues on the soil surface limiting soil warming and water evaporation. The best economical balance was achieved at MT (SICS 1) followed by ZT (SICS 2) 50% and 17% higher than at control CS resp. In normal and wet years, the yields on individual tillage systems are more balanced and the profits of SICSs are lower.

The SICS 1 procedure is thus not followed exactly in agricultural practice. Farmers usually carry out undermining after several years of minimization, which is a demanding operation that reduces the resulting profit. It is true, the sowing procedure often does not allow the use of MT for a long time. Deeper tillage or ploughing is necessary before sowing/planting root crops.

Systems without tillage are very uncommon in our agricultural practice, so far it is more a matter of experiments.

Overall analysis and main findings

SOC - the main benefit of SICSs

The decrease of SOC in soil without manure fertilization was the main reason for reducing the intensity of soil tillage. Reduction of intensity or omission of soil tillage significantly reduced respiration activity and CO2 emissions from soil. So, both SICS (minimum tillage and zero tillage) led to an increase in the SOC content of the soil. The largest differences were found in the surface layer up to 0.1 m, which is ploughed and turned (CT), only loosened without turning (MT) or left without processing (ZT). A larger increase in SOC content was found in soil without treatment (ZT), which is the main benefit of ZT.

Soil humidity, post-harvest residues

Post-harvest residues on the soil surface reduced soil warming and water evaporation at MT and namely at ZT, they also reduce the risk of water and wind erosion. Higher humidity of soil under minimum or zero tillage made better conditions for the emergence of crops.

Soil temperature, mineralization processes, crop yield

No aeration and lower temperature of the soil at ZT covered by post-harvest residues led to a lower intensity of mineralization processes. It resulted, among other things, in a lower content of nitrate-nitrogen in the soil. But, lower temperature led to later onset of mineralization processes spring vegetation of crops. Lower mineralization also means less accessible nutrients for plants. Therefore, the lowest yields from all monitored systems were obtained on a long-term average at ZT under the same fertilization. In the long-term observation, the highest yields are achieved on MT due to the best combination of mineralization intensity, soil aeration, moisture and temperature of all tested tillage systems.

Nutrients distribution in soil

In all tillage systems, the fertilizers were applied broadcast on the soil surface. Fertilizers (P, K, Mg, S) applied in the autumn were mixed in the 10 cm layer of soil at MT or stay on the surface (ZT). All nitrogen fertilizers during vegetation were applied without incorporation. The surface layer was stressed by repeated application of fertilizers. The increasing accumulation of nutrients, especially with low mobility in soil (such as P, K) was observed in the surface soil layer with decreasing soil tillage intensity and duration of SICSs usage. The application of calcium (or magnesium) crude materials is necessary to maintain the suitable value of ration of mono- and divalent cations important for soil structure, aggregate stability or water infiltration into the soil. Growing catch crops with high potassium consumption is suitable. Decomposition of their roots with accumulated potassium will divide it deeper into the soil. Liming is convenient owing to acidification of the surface layer in consequence of mineralization and nitrification processes in the soil accelerated after fertilizer applications. This phenomenon was not very significant in our experimental site, where high natural content of calcium is in the soil, and it is replenished from the soil supply.

SICS 1: Minimum tillage

Advantages (against control CS)

- Lower evaporation, Higher soil humidity, better emergence of crops
- The best combination of mineralization intensity, soil aeration, moisture and temperature of soil resulted in the highest crop yields and benefits in the long- term view
- Lower CO_2 emissions, higher SOC content increased by 10 t/ha in layer up to 0.3 m after more than 20 years of SICS 1 implementation
- Shallower soil tillage, lower fuel consumption

Disadvantages

- Higher content of nutrients with low mobility in the soil in the tilled 10 cm surface layer
- The need to avoid undermining or deeper processing before sowing/planting of root crops. This leads to the loss of saved carbon from the soil supply.

SICS 2: Zero tillage

Advantages (against control CS)

- The main benefit: Increasing SOC content in soil (by 15 t/ha in layer up to 0.3 m after more than 20 years of SICS 2 implementation)
- Post-harvest residues on the soil surface reducing soil warming and water evaporation esp. in the summer period, reducing water and wind erosion
- No soil tillage, less powerful machinery with lower fuel consumption is sufficient
- Fewer operations in the crop rotation = fuel-saving, labour savings
- Lower CO2 emissions and lower fuel consumption = lower carbon footprint

Disadvantages

- The later onset of mineralization processes and spring vegetation of crops due to slower soil warm-up
- Lower mineralization = less accessible nutrients for plants. A different fertilization system will be needed to achieve the same yields as for other CS.
- Cannot be used when including root crops in the crop rotation
- A special disc drill machine is necessary for seeding
- Higher environmental impact of chemicals, higher consumption of herbicides

References

Published articles were aimed at our farmers and therefore published namely in the Czech language in our national periodicals. E.g:

- Růžek, P., Kusá, H., Vavera, R. 2020. Winter wheat and winter rape fertilization after this winter. Selská revue, No. 2:46-48
- Růžek, P., Kusá, H., Mühlbachová, G. 2020. How better to retain water, nutrients and organic matter in the soil during tillage? Selská revue, č. 5: 37
- Růžek, P., Kusá, H., Mühlbachová, G. 2020. New practices in plant fertilization in relation to climate change. Úroda 68(6): 38-41
- Růžek, P., Kusá, H., Vavera, R. 2020. Wintering of winter crops and N_{min} supply in the soil after this winter. Zemědělský týdeník 23 (11): 8-9
- Mühlbachová, G., Vavera, R., Kusá, H. & Růžek, P. 2019. Storage of organic carbon in soil at different tillage systems. Farmář, 25(9): 18-19.
- Růžek, P., Kusá, H., Mühlbachová, G. & Vavera, R. 2019. Sustainability of current systems of soil management. Naše pole, 23(4): 22-24.
- Mühlbachová, G., Vavera, R., Kusá, H. & Růžek, P. 2019. CO2 emissions and changes in organic carbon content in different tillage systems. In: Šimek, M. (ed.). Skleníkové plyny z půdy a zemědělství: vlastnosti, produkce, spotřeba, emise a možnosti jejich snížení. Academia, Praha, pp. 164-168
- Káš, M., Mühlbachová, G. & Kusá, H. 2019. Winter wheat yields under different soil-climatic conditions in a long-term field trial. Plant, Soil and Environment, 65(1): 27-34.

General conclusions based on the experiment

Highlights

- Increasing the carbon content of the soil with minimum and especially zero tillage thanks to lower CO_2 emissions (+)
- Reduce soil warming and inefficient evaporation due to post-harvest residues on the soil surface (min. 30% at MT, all at ZT) (+)
- Reduction of water and wind erosion (+)
- Earlier and more balanced emergence of plants in soils with high moisture esp. at MT (+)
- The later onset of mineralization processes and spring vegetation of crops due to slower warm-up of soil covered by post-harvest residues at ZT (-)
- Lower mineralization at ZT = less accessible nutrients for plants (-)
- Greater year-on-year stability of crop yields esp. at MT (+)
- Accumulation of nutrients with low mobility in the soil in the surface layer (-)
- Risk of acidification of the surface layer in consequence of mineralization and nitrification processes in the soil accelerated after fertilizer applications (-)
- Fewer operations in the crop rotation at ZT = fuel-saving, labour savings (+)
- Lower CO_2 emissions and lower fuel consumption, esp. at ZT = lower carbon footprint (+)
- The need to interrupt the established SICS by deeper tillage once every few years when root crops appear in the crop rotation (-).

Conclusion

The SICS 2 zero tillage system is not yet used at all in our agricultural practice. He is not very suitable for heavy soils where special disc seed drills are needed. It also cannot be used in crop rotations where root crops occur (this is mainly potatoes and beets in the conditions of the Czech Republic). However, this system was the most effective in storing carbon in the soil: after more than 20 years of implementation of ZT, the content of organic carbon in the soil layer up to 0.3 m was increased by 15 t/ha in comparison with control CS with moldboard ploughing in our experiment. Two tillage operations were replaced by one weeding spray in this system. This saved fuel and labour but increased the environmental impact of chemicals.

The SICS 1 with minimum tillage not so effective in the deposition of carbon into the soil as ZT (after more than 20 years of implementation of MT, the content of organic carbon in the soil layer up to 0.3 m was increased by 10 t/ha in comparison with control CS). Part of the post-harvest residues on the soil surface and shallower tillage without turning had a positive effect on soil temperature and humidity as well as reducing CO_2 emissions. The best combination of mineralization intensity, soil aeration, moisture and temperature of soil resulted in the greater year-on-year stability of crop yields and highest crop yields and benefits in the long- term view. Implementing this SICS does not require investment costs. The same machines as for conventional tillage with ploughing are used (except for the plough). In our agricultural practice, minimum tillage is used especially in drier areas in the cultivation of cereals, oilseeds, legumes or corn.

The disadvantage of reduction of intensity or the omission of tillage is the accumulation of nutrients in the surface soil layer, esp. those with low mobility in soil. . The application of calcium (or magnesium) crude materials is necessary to maintain the suitable value of ration of mono- and divalent cations important for soil structure, aggregate stability or water infiltration into the soil. Growing catch crops with high potassium consumption is suitable. Decomposition of their roots with accumulated potassium will divide it deeper into the soil. Liming is convenient owing to acidification of the surface layer in consequence of mineralization and nitrification processes in the soil accelerated after fertilizer applications.

Back to TOC

I.15 University of Almeria (Spain)

Report 1 on Monitoring and Analysis of Agua Amarga experiment

Study Site number: 15

Country: Spain

Authors: Julián Cuevas, Virginia Pinillos, Fernando Chiamolera, Fernando del Moral, Yolanda Cantón, Jose Ángel Aznar, Emilio Galdeano.

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation: University of Almeria

Experiment: Agua Amarga

Version: 2

Date: 22-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to evaluate the effect of different irrigation schemes combined with different soil cover or cultivation methods for reducing wind erosion and increasing soil fertility in a stone fruit crop farm. The experiment was established in July 2018 and was set up in a split-plot randomized complete block design with 3 blocks, containing 6 plots each, five for the SICS treatments and one for the control treatment. The split-plot refers to the different irrigation schemes applied.

Experimental field information

The experiment is conducted on an orchard managed by employees of a large private company. The experimental field is located in Agua Amarga, Spain, at an altitude of 20 and covers an area of about 4860 m^2. The topsoil has a sandy-loam texture according to the USDA classification system.

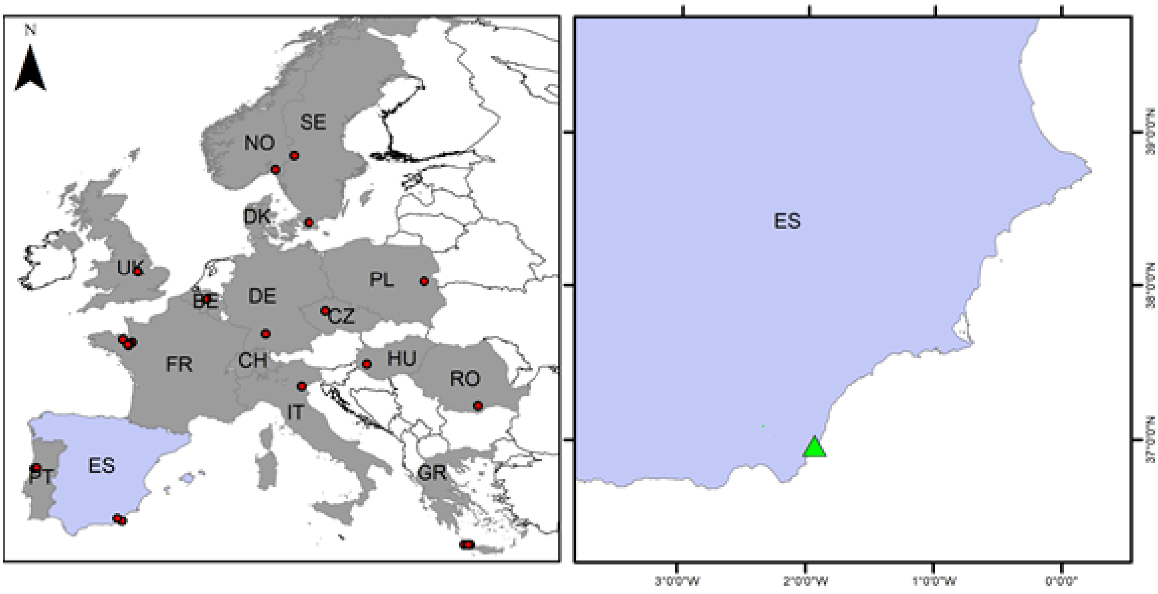


Figure 1: Location of the study site

According to the soil profile of 0.9 m which was described by Fernando del Moral Torres, Emilio Rodríguez Caballero and Julián Cuevas González, in May 2018 the soil is characterized as Regosols in the WRB soil classification system with 5 horizons.

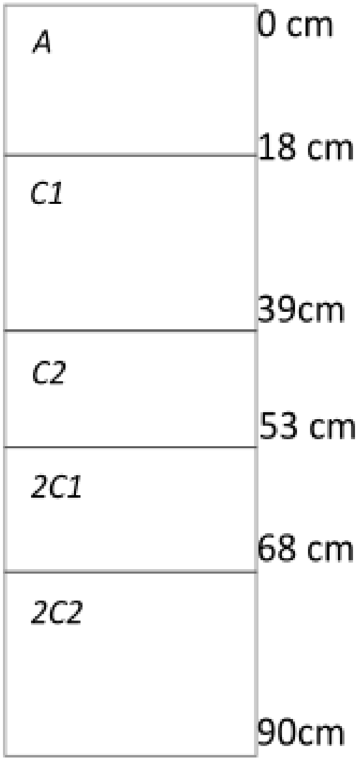


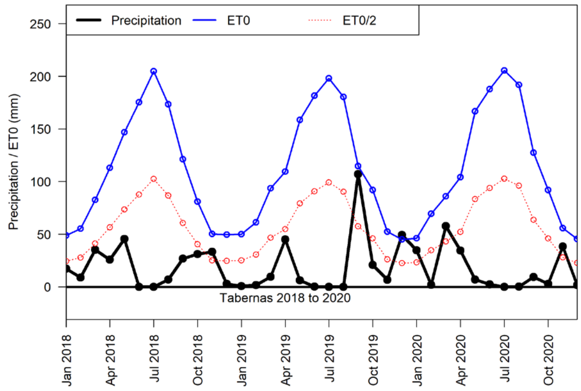
Figure 2:Soil profile in the Study site (photo Fernando del Moral)

The climate of the experimental field area

Almeria has a blended meteorological station with number 3907 in ECAD. The measurements started from 1961 till Oct 2020. Closer to the experiment sited in Aguamarga, we have the weather station Níjar, which is part of the network by the Junta de Andalucía and which can easily be downloaded from their website. Near the experiments carried out in Tabernas, we have also a weather Station part of the network by the Junta de Andalucía.

Table 1: Overview of yearly averages for Almeria (1961-2020), and Níjar and Tabernas

Station	Period/year	Tmax (°C)	Tmin (°C)	Precip. (mm)	ET0 (mm)
Almeria	1961-90	22.3	14.5	203.7	1034.3
Tabernas	2018	22.7	9.3	233.1	1302.1
Níjar	2018	22.9	12.9	267.6	1326.9
Tabernas	2019	23.2	9.0	247.0	1337.1
Níjar	2019	23.7	13.9	369	1367.3
Tabernas	2020	23.8	9.3	190.4	1378.2
Nijar	2020	23.9	13.9	152	1357.0



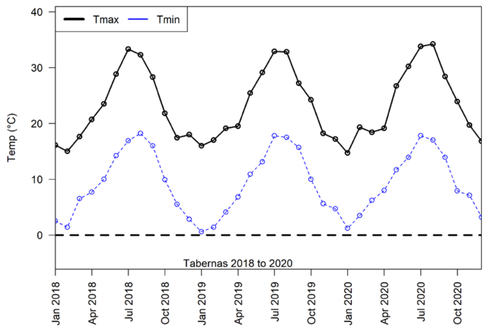
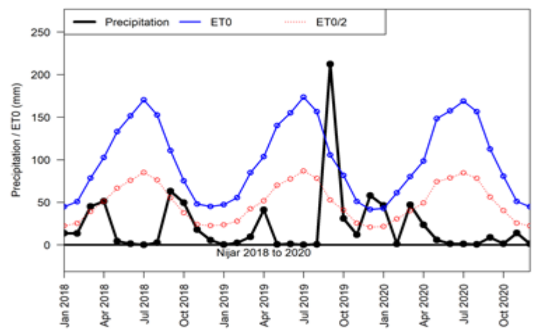


Figure 3: 15bTabernas 00aFAOgrow Figure. Maximum and minimum temperatures in Tabernas



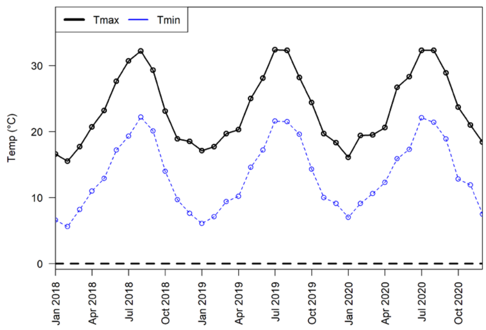


Figure 5: 15E Níjar 00FAOgrow *Figure 6: 15E Temperatures*

The area around Almeria is known as one of the driest areas in Europe. The yearly evapotranspiration demand (ET0) is roughly 5 times the rainfall, 10 in the case of Tabernas. Rain episodes are scarce, but sometimes heavy rain, as in 2019 in Aguamarga, takes place causing severe soil erosion. The experiment was carried out in two seasons 2018/19 and 2019/20 with quite different conditions, especially regarding rain. The first season was very dry, while in the second the amount of rain was higher.

Temperatures in Agua Amarga (Níjar Station) never dropped below zero, and rarely was above 30ºC (in summer) characterizing a quite benign Subtropical Mediterranean climate. In the case of Tabernas, whose location sited in the only desert of Europe, the climate was more extreme: very dry too, but with harsh temperatures too. Figures show winter temperatures close to zero and circa 40ºC in summer during some days.

Cropping systems description

Treatments

The experiment consists of 6 treatments with the following codes in the SoilCare Database and the analysis following.

UAL_EX1_TR1 Full Irrigation (FI) + No-Tillage (Control)

UAL_EX1_TR2 FI + weeds

UAL_EX1_TR3 FI + cover crops

UAL_EX1_TR4 Regulated Deficit Irrigation (RDI) + No-tillage

UAL_EX1_TR5 RDI + weeds

UAL_EX1_TR6 RDI + cover crops

The experiment's treatments are a combination of two factors, irrigation and topsoil management practices.

- The irrigation factor has two levels:

FI: Full Irrigation through a drip irrigation system which volumes applied changing along the season depending on the plant requirements

RDI: Regulated Deficit Irrigation, through a drip irrigation system applying more water in critical periods and saving more water in less sensible phases.

- Topsoil management includes three levels:

No tillage: Use of herbicides

Weeds: Weeds/ natural vegetation tolerated and late removed

Cover crops: Cover crops late removed

Field operations

The experimental field is a nectarine orchard *(Prunus persica)* established in 2014 (Nursery provided plantlets-1 tree per 15 m2 (5*3m)). Sheep manure incorporated in the whole field before planting. Annually it gets all fertilizers required (NPK, Manganese, Iron, Zinc and a complex of Cu+Zn+Mn) along the season through the drip irrigation system. The same system is used for providing organic fertilizers in the field like the humid acid "*Blackjack*" and the aminocide "*Naturamin- WSP*" applied 3-5 times per season. Several fungicides and insecticides are applied according to the needs.

Bio-physical data analysis – WP5

Method

Differences between treatments for all response variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure “Treatment*Date” or the “Treatment+Date” depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented and the error bars represent the models’ standard error.

Data

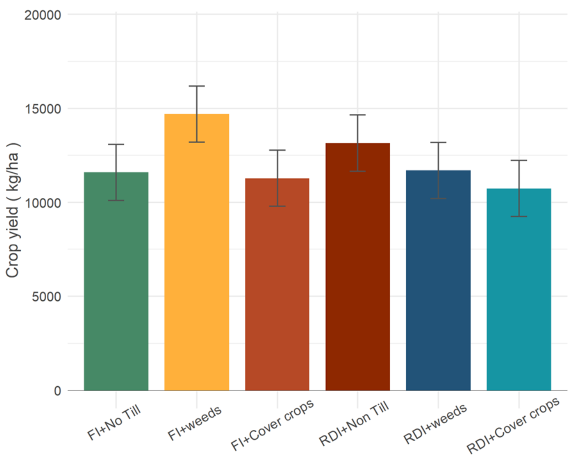
In table 2, you can find the variables measured and analysed for this experiment.

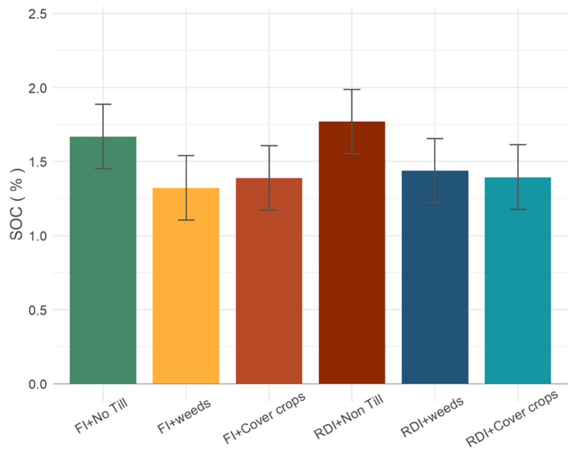
Table 2: Indicators measured and analysed

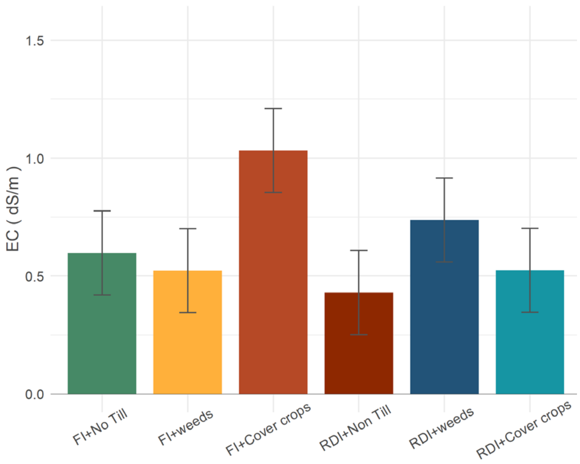
Observation code	**Unit**	**Description**
top_wc_pf2_0	m3m-3	Water content FC
top_wc_pf4_2	m3m-3	Water content PWP
top_wc_pf2_7	m3m-3	Water content pF2.7
top_wc_pf_1_8	m3m-3	Water content pF1.8
top_satur_wc	m3m-3	Water content Saturation
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
top_clay	%	Clay
top_silt	%	Silt
top_sand	%	Sand
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl

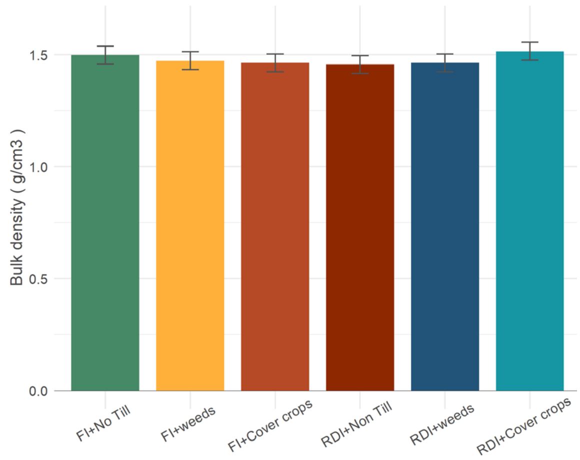
ph_h2o	_	pH in H2O
ec1_5	dS/m	EC
crop_yield_ha	kg/ha	Crop yield
labileC	mg/kg	Labile C
Cr	% (w/w)	Cr
Mn	% (w/w)	Mn
Fe	% (w/w)	Fe
Ni	% (w/w)	Ni
Cu	% (w/w)	Cu
Zn	% (w/w)	Zn
As	% (w/w)	As
Pb	% (w/w)	Pb

Results









Analysis

The application of different combinations of irrigation and topsoil managements did not cause significant differences any year neither in yield nor in fruit quality. The intended reduction in pruning needs by reducing tree vigour was not accomplished either and roughly the same amount of wood was removed in all treatments as the time needed to perform pruning occurred. Fruit quality, estimated by size, skin colour and sweetness, was not modified either.

Soil characteristics did not change in the short term. Although an unexpected increase in EC was observed by the use of cover crops. Not easy explanations are deduced and sustained effects should be checked since salinization is one of the main thread in the cultivation area.

Study site analysis

Short term study did not allow a clear response to reducing pest and disease incidence. However, the literature suggests that the use of cover crop may facilitate pest control acting as shelter and mating place for natural enemies of plagues. Weeds growth should be also limited when using cover crops that may compete with weeds. These effects were not noted.

Socio-cultural dimension

The implementation of different SICS resulted in positive socio-cultural impacts. The improvements in the soil properties were modest when measured in the short term, but it was higher in the cost-benefit angle. The most important effect could be observed in the reputation of the land user. This aspect is particularly important in this experimental site since it is located within a National Park where regulations are very strict. Therefore, land user not only aligns with mandatory regulations but also adopt practices that increase sustainability and their reputation.

Economical dimension

Despite no significant differences were obtained, benefits were produced as a consequence of higher yields in 2019 in some combinations of treatments. Yields were, on the contrary, were similar in 2020 in all combinations, as expected in a crop in which fruit load is finally adjusted by hand thinning. Water savings achieved by regulated deficit irrigation (RDI) added some benefits too. However, it seems that allowing the growth of weeds and/or cover crops under RDI diminish profits. Although these practices may suppose certain risks if weed and cover crops are not eliminated on the time, the results are due to slightly no significantly different lower yields in these two treatments.

Table 3: Summary of the benefits of SICS (SICS vs. control). The numbers are in euro/ha.

	AMT control	**AMT SICS 1**	**AMT SICS 2**	**AMT SICS 3**	**AMT SICS 4**	**AMT SICS 5**
	UAL_EX1_TR1	UAL_EX1_TR2	UAL_EX1_TR3	UAL_EX1_TR4	UAL_EX1_TR5	UAL_EX1_TR6

Agricultural management technique	Full irrigation (FI) + pruning wood chopped, but without cover crop (CC)	Full irrigation (FI) + pruning wood chopped and with natural vegetation (weeds)	Full irrigation (FI) + pruning wood chopped and cover crop (CC)	Regulated deficit irrigation (RDI) + pruning wood chopped, but without cover crop (CC)	Regulated deficit irrigation (RDI) + pruning wood chopped and with natural vegetation (weeds)	Regulated deficit irrigation (RDI) + pruning wood chopped and cover crop (CC)
Investment costs	350.00	350.00	400.00	350.00	350.00	400.00
Maintenance costs	500.00	500.00	600.00	500.00	500.00	600.00
Production costs	65.47	65.47	245.71	65.47	65.47	245.71
Benefits	27616.80	35526.00	25906.80	34137.07	27444.67	27575.47
Summary = benefits - costs	26701.33	34610.53	24661.09	33221.60	26529.20	26329.76
Percentage change		29.62	7.64	24.42	-0.64	-1.39

Overall analysis and main findings

Water savings (between 8-15% depending on the year) was achieved in an area with severe limitations in water availability without a negative effect on yield or fruit quality.

Topsoil management did not change either the results. It is important to underline that cover crop establishment was scarce and difficult. Very low rain during the first season made rabbits living in the field consume seedling as they emerged. The second season cover crops development was better. One irrigation after sowing was applied, but the results in cover crop emergence were modest.

Farmer irrigation schedule is, in fact, very well adjusted and little improvement is possible. Deficit irrigation strategies applied saved 8%, first season, and 15%, the second. Nonetheless, the levels of water stress measured by stem water potential were mild and limited to the hotter periods of summer, a postharvest period for this crop harvested between April and May. Vigour control was not obvious under deficit irrigation and pruning wood and the time needed for its execution was not significantly reduced.

Nectarines are peach with their skin free of pubescence. As with other types of peach, nectarines set fruit heavily and fruit thinning is ordinarily needed. The results show a higher yield first season for some SICS than for control trees. This improvement in yield in 2019 was not related to heavier fruit. Therefore, a higher number of fruits per tree is deduced, being crop load usually strictly regulated. This result was not confirmed in the second season (2020) when the number of fruit per tree was effectively counted. This circumstance made a positive impact on farmer profits that have to be verified. In any case, fruit quality was negatively affected. Fruit size, colour, and sweetness were not modified by any SICS. Measurements of plant water status revealed mild water stress of a short duration in summer.

A serious drawback observed in treatments involving the use of cover crops comes from the difficult implantation of the seedlings. Germination is difficult if rain or irrigation does not occur, the latter implying higher costs. As mentioned above, the many rabbits present in the area entered the experimental plot in absence of natural vegetation in dry years and consumed cover crops.

Irrigation planning is designed taking into consideration the evapotranspiration of an average year. There is a risk that very dry and hot years cause a reduction in yield, mainly thru smaller fruits. Changes in the irrigation plans are possible if plant water status is monitored continuously, something farmers rarely do. Scarce but heavy episodes of rain seemed to put in value the use of pruning residues and cover crops in reducing soil erosion.

In conclusion, different soil-improving cropping systems were successfully implemented. Land users are satisfied with the positive results and request the experimentation to continue increasing water saving up to 25%.

References

Cuevas, J.; Daliakopoulos, I.N.; del Moral, F.; Hueso, J.J.; Tsanis, I.K. A Review of Soil-Improving Cropping Systems for Soil Salinization. *Agronomy* **2019**, *9*, 295. https://doi.org/10.3390/agronomy9060295

Report 2 on Monitoring and Analysis of the Tabernas experiments

Study Site number: 15

Country: Spain

Authors: Julián Cuevas, Virginia Pinillos, Fernando Chiamolera, Fernando del Moral, Yolanda Cantón, Jose Ángel Aznar, Emilio Galdeano.

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation: University of Almeria

Experiment 1: Tabernas – Continuous Deficit Irrigation

Experiment 2: Tabernas – Regulated Deficit Irrigation

Version: 2

Date: 22-02-2021

Experimental field information

The experiments are conducted on an olive field managed by the farmer. The experimental field is located in Tabernas, Spain at an altitude of 490 and covers an area of about 8000 m^2. The topsoil has a fine loamy sand texture according to the USDA classification system.

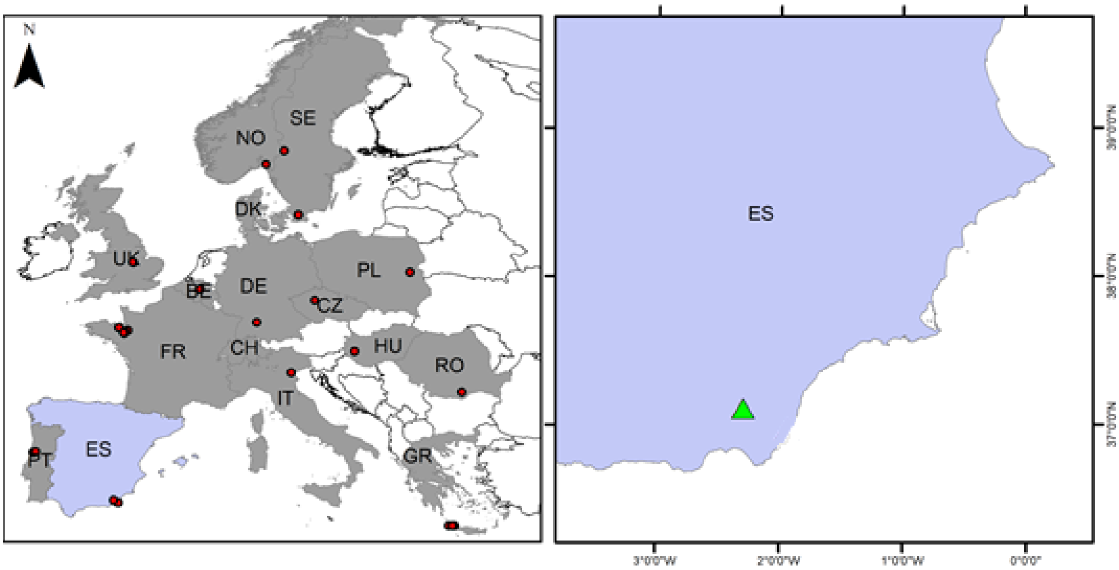


Figure 7: Location of the study site

According to the soil profile of 0.5 m which described by Fernando del Moral Torres, Emilio Rodríguez Caballero and Virginia Pinillo Villatoro, in June 2018, the soil is characterized as Regosols in the WRB soil classification system with 4 horizons, with maximum rooting depth at 0.5m because of solid continuous rock at that depth.

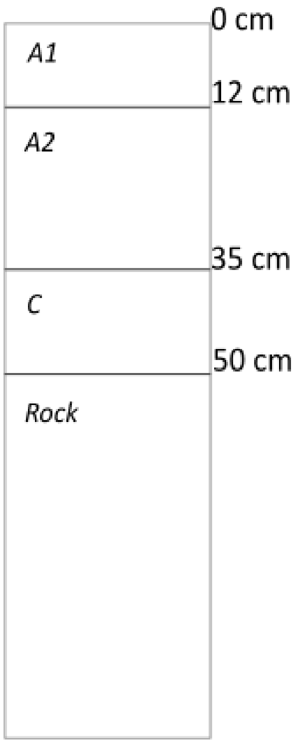


Figure 8:Soil profile of the SS (photo: Fernando del Moral)

The climate of the experimental field area

See Report 1

The experiment of Continuous Deficit Irrigation

The main objective of the experiment is to evaluate the soil fertility in an olive orchard by covering the soil either with a cover crop versus pruning woods chopped while applying continuous deficit irrigation to the olive trees and minimum tillage. The experiment started in December 2018 and was set up in a randomized complete block design with 3 blocks, containing 3 plots each, two for the SICS treatments and one for the control treatment.

Cropping systems description

Treatments

The experiment consists of 3 treatments with the following codes in the SoilCare Database and the analysis following.

UAL_EX2_TR1 = Control

UAL_EX2_TR2 = Pruning wood

UAL_EX2_TR3 = Temporal cover crops

Pruning woods: Pruning woods chopped added in row middles

Temporal cover crops: Cover crops in row middles removed in late spring

Field operations

The experimental field is an olive orchard established in 1998 in a square design (Nursery provided plantlets-1 tree per 49 m2 (7*7m)). The whole field receives underground continuous deficit drip irrigation almost daily, starting in May and gets minimum tillage. Occasionally, it gets all fertilizers required (Manganese, Zinc) through the drip irrigation system. Also sulphate potassium (90 kg/ha) combined with organic allowed pest controlling treatments sprayed in spring, summer and autumn. Organic fertilization includes annual application through the irrigation system of aminoacids in spring, and 4 t/ha sheep manure + "solid waste from crushed olive fruits ("*alperujo*") which are broadcasted and incorporated in the soil.

Bio-physical data analysis – WP5

Method

Differences between treatments for all response variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment+Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error.

Data

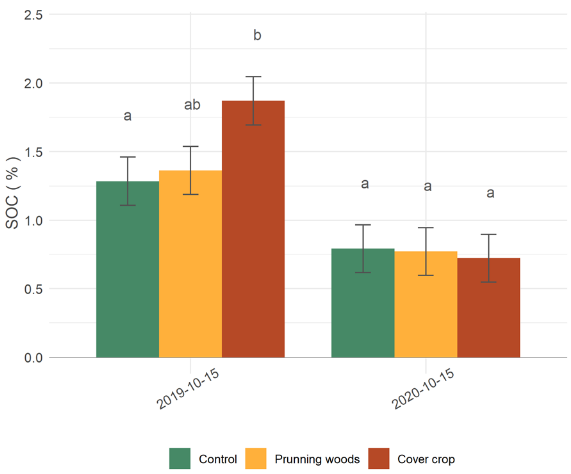
In Table 4, you can find the variables measured and analysed for this experiment

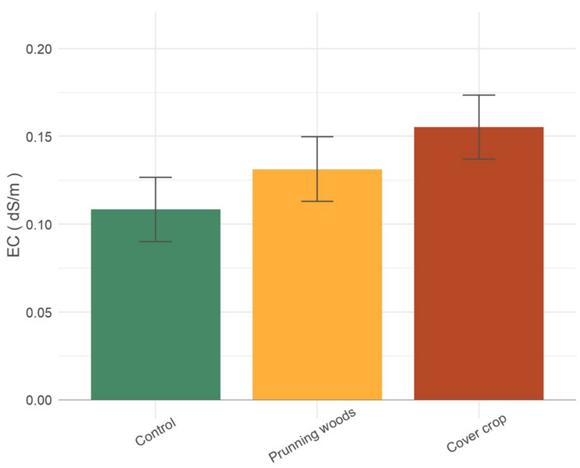
Table 4: Indicators measured and analysed

Observation code	**Unit**	**Description**
top_wc_pf2_0	m3m-3	Water content FC
top_wc_pf4_2	m3m-3	Water content PWP
top_wc_pf2_7	m3m-3	Water content pF2.7
top_wc_pf_1_8	m3m-3	Water content pF1.8
top_satur_wc	m3m-3	Water content Saturation
wsa	%	Water stable aggregates

bd_top	g/cm3	Bulk density
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in H2O
ec1_5	dS/m	EC
labileC	mg/kg	Labile C
Cr	% (w/w)	Cr
Mn	% (w/w)	Mn
Fe	% (w/w)	Fe
Ni	% (w/w)	Ni
As	% (w/w)	As
Cu	% (w/w)	Cu

Results





Analysis

Continuous deficit irrigation represents the current irrigation schedule put in practice by the owner due to the strong restriction in water availability and regulation in the area (Tabernas desert). Under this severe scenario, adding chopped pruning wood and the use of cover crops represent a challenge. However, the estimated yields based on fruit set measured in each treatment and yield per plot suggest, on the contrary, beneficial effects of disposing pruning wood chopped between tree rows, with higher yields than control in both seasons. Cover crops had mixed results, positive first year, but slightly negative the second. An improvement in organic matter limited to the first season suggest that effects depend on climate and year. As observed previously in the experiments carried out in Agua Amarga cover crops seem to increase significantly Electric conductivity. As mentioned before, the reasons for these effects are unclear and deserve close monitoring. The short-term results avail, however, the implementation of both SICS.

Study site analysis

Olive exhibits alternate bearing, producing high yields one year, followed by little or nothing the second year. The alternation in yield is due to the lack of flowering the second year by inhibition of flower induction by heavy yields. Although the effects are observed at the tree level, it is not strange to see trees aligned in their blooming habit. The results measured of shoot growth (that sustain next year fruit), flowering intensity and flower fertility show no negative effects of SICS. Therefore, not accentuating alternate bearing.

Economical dimension

Table 5: Summary of the benefits of SICS (SICS vs. control). The numbers are in euro/ha.

	AMT control	**AMT SICS 1**	**AMT SICS 2**
	UAL_EX2_TR1	UAL_EX2_TR2	UAL_EX2_TR3
Agricultural management technique	Continuous DI (CDI), without cover crop (CC), without pruning wood chopped (PW)	CDI + PW, without CC	CDI + CC, without PW
Investment costs	0.00	600.00	272.50
Maintenance costs	0.00	500.00	500.00
Production costs	150.00	79.72	323.42
Benefits	3707.86	4268.24	3603.10
Summary = benefits - costs	3557.86	3088.52	2507.18
Percentage change		-13.19	-29.53

Continuous deficit irrigation represents the current practice of irrigation put in practice by the owner due to a strong restriction in water availability and regulation in the area (Tabernas desert).

In this experiment, negative impacts on the economy of the land user were produced after implementing the use of pruning wood chopped between tree rows and the use of cover crops too (higher in this case). The negative impacts of both SICS are mostly related to the needed investment and maintenance costs in machinery (woodchopper and plough). In control, a cost of 150€ per ha to remove pruning wood (usually achieved every two years) is considered.

Overall analysis and main findings

The analysis can in some way be misleading because a strong negative effect on cost-benefit is observed. However, this result is explained by the higher costs imposed by the use of machinery to triturate pruning wood. The alternative is to remove olive pruning wood from the orchard and dispose of it away (certainly it can be sold too and use as biomass). Nonetheless, the experience is that the incorporation of the pruning wood chopped in the middles row enhances soil characteristics after a few years. A similar situation applied to the use of the cover crop, although in this case, the costs are modest and related to the sowing. The improvement in soil properties is noticeable.

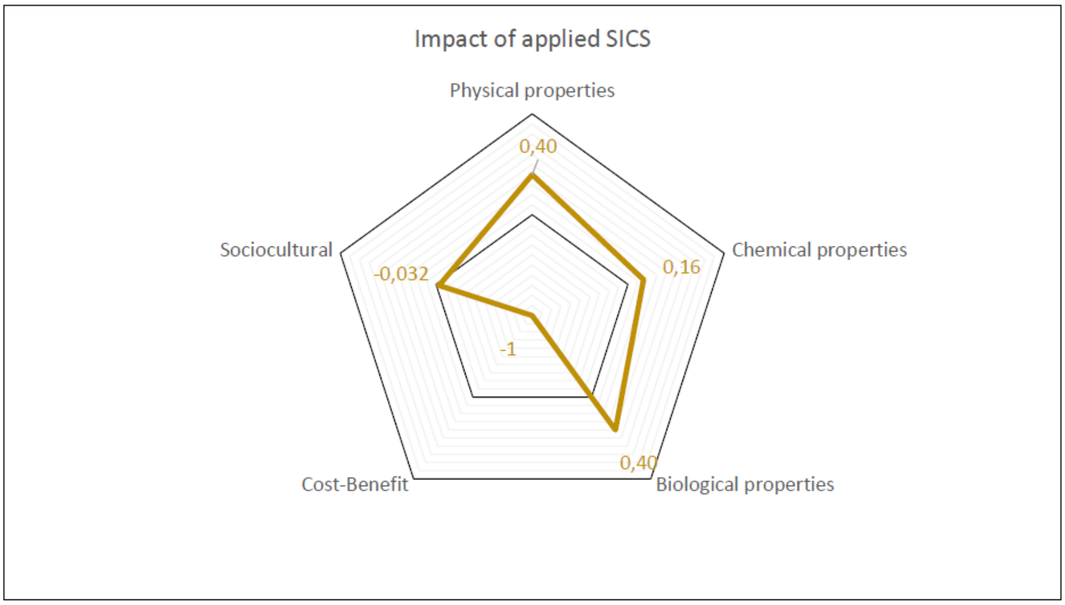


Figure 9: Overall sustainability of the temporal cover crops as compared to the control

Table 6: Sustainability of the SICS versus the control

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.16	0.92	High
Environmental dimension	0.30	0.87	High
Economic dimension	-0.90	1.00	Complete
Socio-cultural dimension	-0.03	0.92	High
Physical properties	0.40	0.95	High
Chemical properties	0.16	0.95	High
Biological properties	0.40	0.95	High

A negative economic impact was due to the acquisition of equipment needed to perform the tasks of both SICS. Positive effects on soil characteristics are expected after prolonged use of both SICS, but differences were not obvious in the short term.

As previously observed in experiment 1, a deterioration in electric conductivity was observed when using cover crops. This result has not an easy explanation, and deserve more attention in the future, given the serious thread that salinization represents in the area.

The owner has decided to switch from Continuous Deficit Irrigation (CDI) to Regulated Deficit Irrigation (RDI) (see below Experiment 3).

References

Aznar-Sánchez J.A., Velasco-Muñoz J.F., Galdeano-Gómez E., Del Moral-Torres F. (2020) Smart Agricultural Waste Management in Traditional Mediterranean Crops. In: Hussain C. (eds) Handbook of Environmental Materials Management. Springer, Cham. https://doi.org/10.1007/978-3-319-58538-3_184-1

The experiment of Regulated Deficit Irrigation

The main objective of the experiment is to evaluate the soil fertility in an olive orchard by covering the soil either with a cover crop or pruning woods when applying regulated deficit irrigation to the olive trees and minimum tillage. The experiment started in December 2018 and was set up in a randomized complete block design with 3 blocks, containing 3 plots each, two for the SICS treatments and one for the control treatment.

Cropping systems description

Treatments

The experiment consists of 3 treatments with the following codes in the SoilCare Database and the analysis following.

UAL_EX3_TR1 = Control

UAL_EX3_TR2 = Pruning wood

UAL_EX3_TR3 = Temporal cover crops

Pruning woods: Mulching with pruning woods

Temporal cover crops: Cover crops removed in spring

Field operations

The experimental field is an olive orchard, which established in 1998 in a square design (Nursery provided plantlets-1 tree per 49 m2 (7*7m)). The whole field receives underground continuous regulated drip irrigation and gets minimum tillage. Occasionally, it gets all fertilizers required (Manganese, Zinc) through the drip irrigation system. Also sulphate potassium (90 kg/ha) combined with pest controlling treatments are sprayed in spring, summer and autumn. Organic fertilization includes annual application through the irrigation system of aminoacids in spring, and 4 t/ha sheep manure + "solid waste from crushed olive fruits (“alperujo") which are broadcasted and incorporated in the soil.

Bio-physical data analysis – WP5

Method

Differences between treatments for all response variables were analysed with a Mixed-Effects Model. Variables with repeated in time measurements analysed with either the full model fixed structure “Treatment*Date” or the “Treatment+Date” depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models’ standard error.

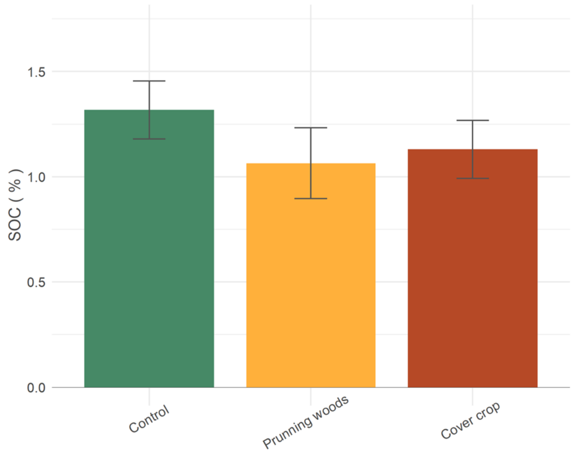
Data

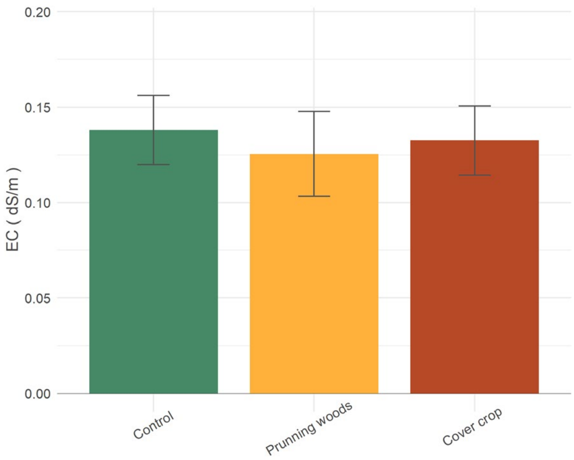
In Table 6. you can find the variables measured and analysed for this experiment

Table 7: Indicators measured and analysed

Observation code	Unit	Description
top_wc_pf2_0	m3m-3	Water content FC
top_wc_pf4_2	m3m-3	Water content PWP
top_wc_pf2_7	m3m-3	Water content pF2.7
top_wc_pf_1_8	m3m-3	Water content pF1.8
top_satur_wc	m3m-3	Water content Saturation
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in H2O
ec1_5	dS/m	EC
labileC	mg/kg	Labile C
Cr	% (w/w)	Cr
Mn	% (w/w)	Mn
Fe	% (w/w)	Fe
Ni	% (w/w)	Ni
As	% (w/w)	As

Results





Analysis

This experiment aims to determine if adopting regulated deficit irrigation instead of continuous deficit irrigation, the current practice of the farmer, may improve farmer profits. The rationale behind this experiment is to apply water cuts to the olive trees in less sensitive periods while applying a higher amount in critical phases (blooming and setting). The comparison with the results obtained in experiment 2 rejects the initial hypothesis since as a whole and especially in the first season yields were higher under CDI (exp. 2) and fat content did not change significantly.

The differences among soil management treatment were small and non-significant. Contrarily to what was observed in experiment 1 and 2, soil salinization (EC) did not worsen significantly by the use of cover crops; no increase in the organic matter was observed either, probably for the short term of the trial and the problems to have seedlings established in dry winters.

Economical dimension

Table 8: Summary of the benefits of SICS (SICS vs. control). The numbers are in euro/ha.

	AMT control	AMT SICS 1	AMT SICS 2
	UAL_EX3_TR1	UAL_EX3_TR2	UAL_EX3_TR3
Agricultural management technique	Regulated deficit irrigation (RDI), without cover crop (CC), without pruning wood chopped (PW)	RDI + PW, without CC	RDI + CC, without PW
Investment costs	0.00	600.00	272.50
Maintenance costs	0.00	500.00	500.00
Production costs	150.00	79.72	323.42
Benefits	3146.89	3409.75	3265.80
Summary = benefits - costs	2996.89	2303.03	2169.88
Percentage change		-25.59	-27.60

As happened before in Experiment 1, the positive modest results in terms of benefits achieved by both SICS are obscured by the balance with the higher costs obliged by them. Again, the amortisation of machinery bought for chopping and aligning pruning wood and a plough (useful for other tasks and crops, but here limited to the sowing of cover crops) penalized the treatments involving their use. In this experiment to a higher extent than in Experiment 2, because olive oil yield increase was lesser that there.

Overall analysis and main findings

A negative economic impact was due to the acquisition of equipment needed to perform the tasks of both SICS. Positive effects on soil characteristics are expected after prolonged use of both SICS, but differences were not obvious in the short term. The owner has decided to switch from Continuous Deficit Irrigation to Regulated Deficit Irrigation

References

Aznar-Sánchez, J.A.; Velasco-Muñoz, J.F.; López-Felices, B.; del Moral-Torres, F. Barriers and Facilitators for Adopting Sustainable Soil Management Practices in Mediterranean Olive Groves. *Agronomy* **2020**, *10*, 506. https://doi.org/10.3390/agronomy10040506

General conclusions based on all the experiments

- Different deficit irrigation strategies can be implemented in fruit tree orchards without negative effects on yield and fruit quality.
- The implementation of different topsoil management strategies is feasible and suitable in dry areas if close monitoring of plant water status is performed. However, it can reduce profits due to higher investment and management costs.
- Some modest improvements in soil characteristics were detected but have to be confirmed in the long term.
- A major drive in the adoption of SICS is the enhancement of farmer reputation by using them. The experimental orchards selected for these experiments are in zones under strong legal regulations and short availability of irrigation water.
- In conclusion, after two years of experimentation, the results avail SICS implementation.
- When higher costs exist due to the implementation of SICS subsidies could be considered.

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I.16 FRAB (France)

Report 1 on Monitoring and Analysis of the Wheat Early Sowing experiment

Study Site number: 16

Country: France

Author(s): Robin Guilhou, Antonin Le Campion, Goulven Maréchal

Compiled by WP5: Ioanna Panagea & Guido Wyseure

Database organization, statistical and meteorological analysis by WP5

Acknowledgement to WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): FRAB

Experiment: Wheat Early Sowing

Picture of the SICS (left) and the control (right) in November

Version: Complete

Date: 23-02-2021

Table of Contents

Experiment description

The main objective of the experiment is to reduce winter soil erosion, anticipating tillage operations to foster aggregate stability, and catching autumnal nitrate leaching by early sowing of wheat (end of august) against November as normal. In August, wheat is associated with buckwheat, white clover, Egyptian clover and Nyjer, in organic farming. The experiment established in 2019 was set up in a control versus treatment experimental (elementary) design with 3 replicates. It includes 2 treatments (1 control vs 1 SICS) replicated in two different fields.

Experimental field information

The experiment is conducted on-farm fields managed jointly by farmers and researchers in two different areas of Brittany, France

FD1: The first field located at an altitude of about 90 m and covers an area of about 16000 m^2. The topsoil has a silty loam texture according to the USDA classification system.

FD2: The second field located at an altitude of about 109 m and covers an area of about 4900 m^2. The topsoil has a silty loam texture according to the USDA classification system.

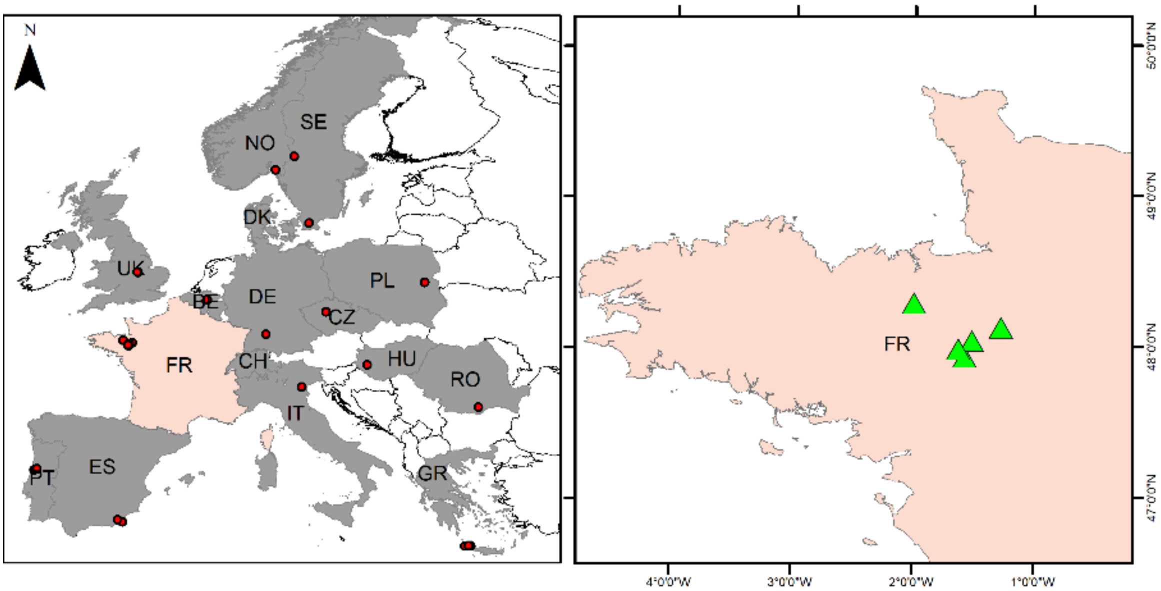


Figure 1: Location of the study site

The climate of the experimental field area

The station, Rennes Saint Jacques, listed in ECAD with the number 322. It covers 1944/ 11/01 until November 2020. This station is located 19 km from the experiments.

Table 1: Overview of yearly meteo data for Rennes-Saint-Jacques

Period/year	Tmax (°C)	Tmin (°C)	Precip (mm)	ET0 (mm)
1961-90	15.6	7.1	648.8	802.5

2018	17.7	8.1	659.3	913.8
2019	17.4	8.0	748.0	900.4

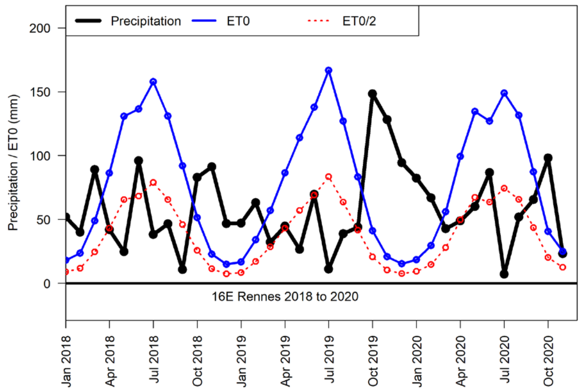
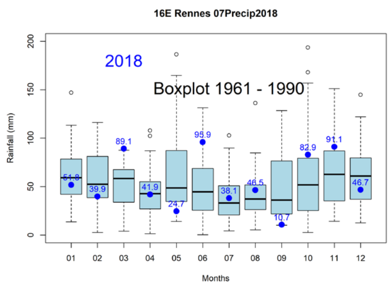
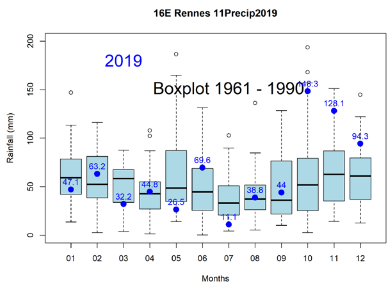


Figure 2: 16E Rennes 00aFAOgrow





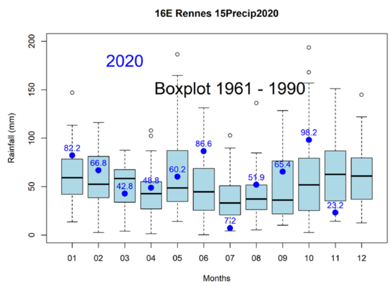


Figure 3: 16E Rennes 07Precip2018box Figure 4: 16E Rennes 11Precip2019box Figure 5: 16E Rennes 15Precip2020box

For 2019 trials: September (2018) was very dry. As a consequence, the germination and emergence of early sowing wheat were heterogeneous. The winter (2018) was quite dry and temperatures were above normal which managed early spring mineralization and good wheat growing during spring.

For 2020 trials: rainfall and temperatures in the normal managed good early sowing conditions (September 2019). But very rainy conditions from October (2019) to January (2020) managed very poor sowing conditions for the control wheat. Some plots which were supposed to be sow in autumn could be sown in spring. Temperatures were above normal during this period.

Cropping systems description

Treatments

The experiment that analysed within the SoilCare project consists of 2 treatments with the following codes in the SoilCare Database and the analysis following.

FRAB_EX1_TR1= early sowing

FRAB_EX1_TR2= classic sowing (control)

- The early sowing of wheat took place mid- September and is associated with buckwheat, white clover, Egyptian clover, Nyjer, in organic farming
- The classic sowing took place at the beginning of December and harvested by the end of March and then barley was seeded in the first field.

Field operations

Several soil cultivation methods used in both fields both for tillage and soil preparation. Conventional mouldboard ploughing up to 25 cm depth takes used in both fields.

Bio-physical data analysis – WP5

Methods

- Differences between treatments for indicators that measured the same dates in both fields and included replicates were analysed with a Mixed-Effects Model considering the two fields as blocks.

  Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

  In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error with solid lines.

- For analysing the indicators that measured in the two fields and there were no replicates (mixed sample taken per treatment from the three replicates) the raw values averaged per date and treatment and are presented. The standard deviation is presented with dashed lines and represent the variation in the two fields (when measurements existed for both fields).

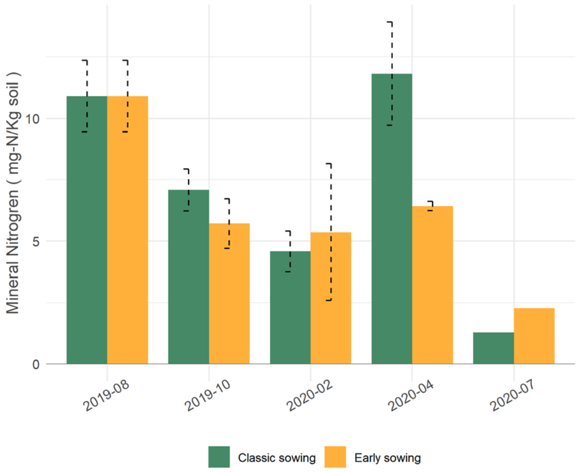
Data

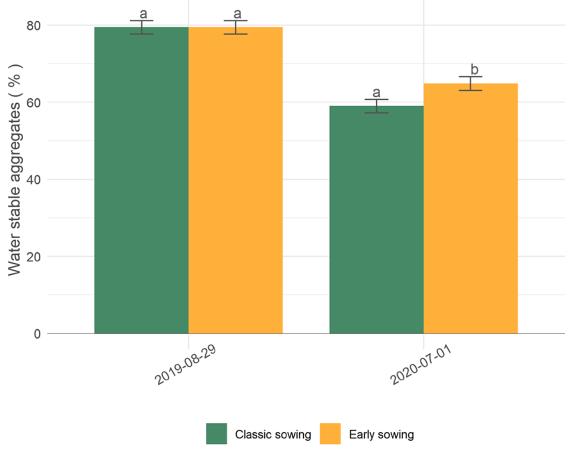
In the table, you can find the variables measured and analysed for this experiment in all treatments.

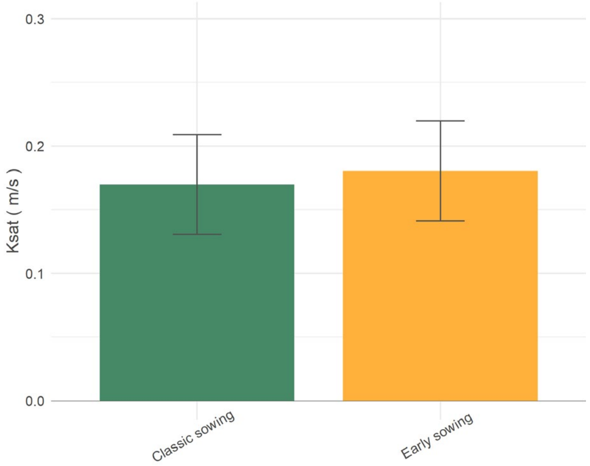
Table 2: Indicators measures and analysed

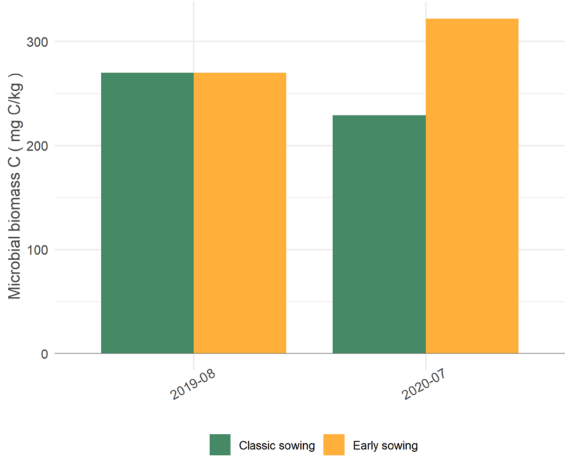
Observation code	Unit	Description
	Mixed model	
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
kunsat	m/s	Ksat
	Simple analysis	
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol/kg	Exchangeable K
ca2_plus	cmol/kg	Exchangeable Ca
na_plus	cmol/kg	Exchangeable Na
mg2plus	cmol/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
microb_biom_c	mg C/kg	Microbial biomass C
cu	mg/kg	Cu mg/kg EDTA
mn	mg/kg	Mn mg/kg EDTA
zn	mg/kg	Zn mg/kg EDTA
fe	mg/kg	Fe mg/kg EDTA
cec	méq/kg	CEC Metson
N_NO3_0_30_cm	kg/ha	N-NO3 (0-30 cm)
N_NO3_30_60_cm	kg/ha	N-NO3 (30-60 cm)
N_NH4_0_30_cm	kg/ha	N-NH4 (0-30 cm)
N_NH4_30_60_cm	kg/ha	N-NH4 kg/ha (30-60 cm)

Results









The percentage of water-stable aggregates was statistically significantly higher in the early sown plots the second year of the experiment compared to the beginning.

There was no difference between control and SICS for mineral nitrogen evolution during autumn and winter. Mineral nitrogen was statistically significantly higher in the control plots in spring (April).

Microbial biomass seems to improve when the wheat is sown earlier in autumn.

No significant difference in Ksat was quantified between control and early sowing plots.

Analysis

As tillage operations were managed in spring to allow the sowing of the control, the significant difference between the two modalities in mineral nitrogen (April) can be explained by soil preparation operations at the end of winter (March).

The higher percentage of water-stable aggregates could be linked to the early tillage operations for wheat sowing. A measurement in autumn, just before winter rainfalls would provide a more interpretable result.

The result on microbial biomass provides the first trend: the microbial abundance was higher in the early sowing wheat in one site. This observation could be linked to water-stable aggregates: in our soil context (Brittany), soil structure cannot be related to clay humic complex. In Brittany, soil structure and aggregation are mostly driven by microbiological activity. Although we can not conclude (one site only), the higher percentage of water-stable aggregates could be explained by a more intense microbiological activity.

Study site analysis

Some visuals observations on the crop were conducted during the experiment:

- a nitrogen deficiency was noticed in the early sowing of wheat at the beginning of spring
- weed infestation was significantly higher in the early sowing wheat modality

Figure 6: Weed infestation and nitrogen deficiency symptom in early sowing of wheat

Socio-cultural dimension

Table 3: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	Data completeness index (DCI) 1 = All input variables have been considered 0 = No input variables have been considered	Data completeness rating DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	-0.20	1.00	Complete
Workload	0.00	1.00	Complete
Perceived risks	-0.50	1.00	Complete
Farmer reputation	0.00	1.00	Complete

The SICS does not generate more labour for land users. Besides, some farmers indicated that it permits to spread of the workload on the year. But its implementation involves an economic risk. The risk of crop failure is high for most farmers. The SICS and his implantation has no impact on land users' reputation.

On the global analysis, the SICS has a quite strong negative impact on the socio-cultural dimension, mostly because of the risk of failure in its implementation.

Economical dimension

Table 4: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha (AMT: Agricultural Management Technique)

	AMT control	**AMT SICS**
Agricultural management technique	Normal sowing date	Early sowing date
Investment costs	0	0
Maintenance costs	34,6	23,7
Production costs	317.5	211.5
Benefits	1350	0
Summary = benefits - costs	998	-235,2
Percentage change	-123.5	

Based on our trials, a negative impact of the SICS is estimated on the economical dimension. This observation is related to the heavy risk of crop failure: no farmer harvested wheat on SICS modality. In consequence, the benefit is indicated as null. In our trial conditions, the economic impact of SICS was strongly negative. However, if we detailed the economic aspect, SICS revealed less maintenance and production costs because of less stubble cultivation operations.

Overall analysis and main findings

The wheat early sowing experiment provides several understandings:

- the risk of failure is very high with this SICS
- to be successful this technic needs to be improved (companion plants, sowing rates) and needs optimal climate conditions (good sowing conditions, frozen in winter, the warm temperature during spring)

- several indicators show that this SICS could prevent soil erosion

The observed differences in mineral nitrogen between SICS and control (April) underlined one major limiting factor with the SICS: the early sowing of wheat had earlier nitrogen requirements and soil mineralization could not respond to its high nitrogen demand. Early sowing of wheat may help to reduce soil erosion due to the increase in water-stable aggregates or microbial biomass.
In both years of the experiment, farmers did not find an economic interest in the harvesting of the early sowing wheat (too many weeds, weak number of spikes). As underlined by the socio-cultural and economic analysis, the risk of crop failure is high and the expected gain on soil properties and economic dimension are not sufficient for farmers.

Table 5: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.36	0.78	Medium
Environmental dimension	-0.08	0.46	medium
Economic dimension	-0.89	1.00	Complete
Socio-cultural dimension	-0.20	1.00	Complete
Physical properties	-0.10	0.30	Low
Chemical properties	-0.26	0.65	Medium
Biological properties	-0.05	0.35	Low

Table 6: Other indices

Benefits:	Erosion
Drawback:	Mineral nitrogen; Weed diseases; Potential economic risk; Potential risk of crop failure; Cost-benefit;

Report 2 on Monitoring and Analysis of the Associated maize experiment

Study Site number: 16

Country: France

Author(s): Robin Guilhou, Antonin Le Campion, Goulven Maréchal

Compiled by WP5: Ioanna Panagea & Guido Wyseure

In cooperation with WP4 for the socio-cultural and economic dimension: Abdallah Alaoui, Felicitas Bachmann & Roger Baer

Affiliation (s): FRAB

Experiment: Associated maize

Picture of maize and buckwheat association

Version: Complete

Date: 23-02-2021

Experiment description

The main objective of the experiment is to evaluate the effect on the soil of buckwheat associated with maize on the row, to try to limit/reduce weeds on the row and limit the number of passes in mechanical weeding. The experiment established in April 2020 and was set up in a control versus treatment experimental (elementary) design with 3 replicates. It includes 2 treatments (1 control vs 1 SICS) replicated in two different fields.

Experimental field information

The experiment is conducted on-farm fields managed jointly by farmers and researchers in two different areas of Brittany, France

FD3: The first field located at an altitude of about 123 m and covers an area of about 17000 m^2. The topsoil has a silty loam texture according to the USDA classification system.

FD4: The second field located at an altitude of about 40 m and covers an area of about 22000 m^2. The topsoil has a silty loam texture according to the USDA classification system.

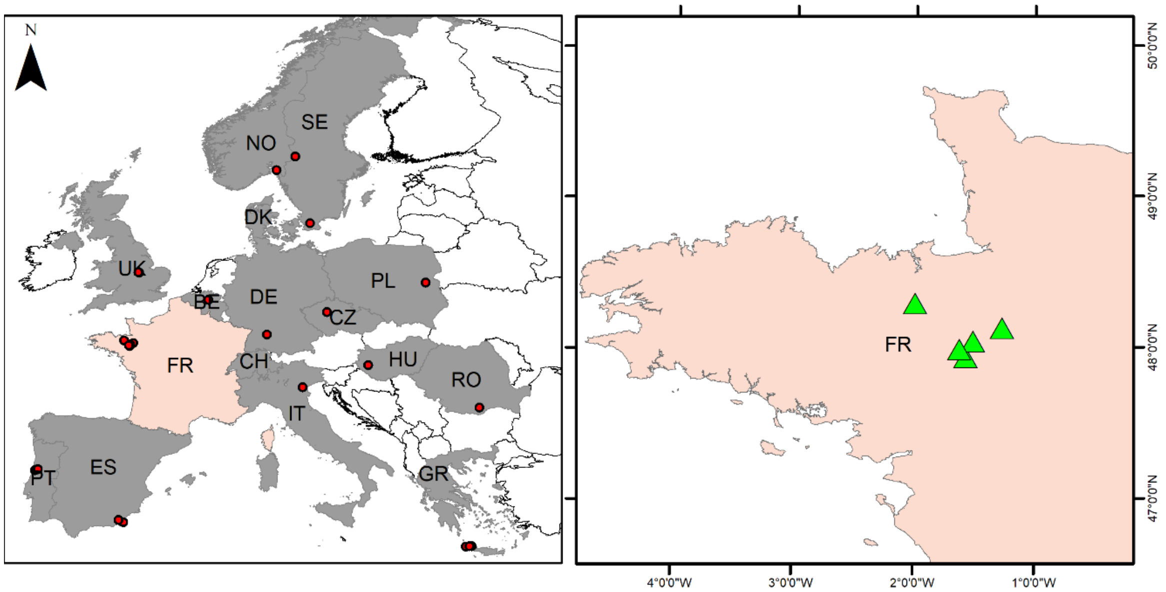


Figure 7: Location of the study site

The climate of the experimental field area

See Report 1.

From April to October, the temperatures were approximatively normal.

About rainfalls, April and May were in the normal, but the repartition of rainfalls during this period was particularly suitable for mechanical weeding operations. June was very rainy but most mechanical weeding operations were realized before rainfall occurs.

Cropping systems description

Treatments

The experiment that analysed within the SoilCare project consists of 2 treatments with the following codes in the SoilCare Database and the analysis following.

FRAB_EX2_TR1= maize - buckwheat

FRAB_EX2_TR2= pure maize (control)

- The maize - buckwheat treatment refers to the sowing of maize and sowing of buckwheat on the row that took place in May 2020.
- The pure maize treatment refers to the classic sowing of maize only on the row that took place in May 2020.

Field operations

Several soil-cultivation methods used in both fields both for tillage, soil preparation and weeding (stubble cultivation, ploughing, harrow, rotary hoe, interrow hoe etc). Conventional mouldboard ploughing up to 25 cm depth takes used in both fields.

Bio-physical data analysis – WP5

Methods

- Differences between treatments for indicators that measured the same dates in both fields and included replicates were analysed with a Mixed-Effects Model considering the two fields as blocks.

  Variables with repeated in time measurements analysed with either the full model fixed structure "Treatment*Date" or the "Treatment + Date" depending on which model presented lower AIC. The variables measured only one time the Treatment factor used alone. The blocking was introduced in all models as a random effect, using statement 1|Block.

  In all the diagrams for this experiment, the estimated marginal means of the fitted models are presented, and the error bars represent the models' standard error with solid lines.

- For analysing the indicators that measured in the two fields and there were no replicates (mixed sample taken per treatment from the three replicates) the raw values averaged per date and treatment and are presented. The standard deviation is presented with dashed lines and represent the variation in the two fields (when measurements existed for both fields).

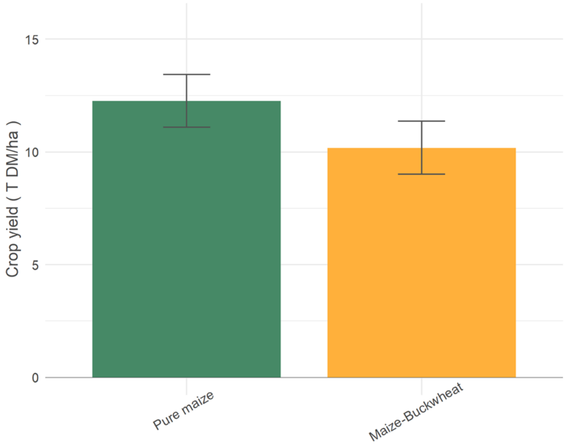
Data

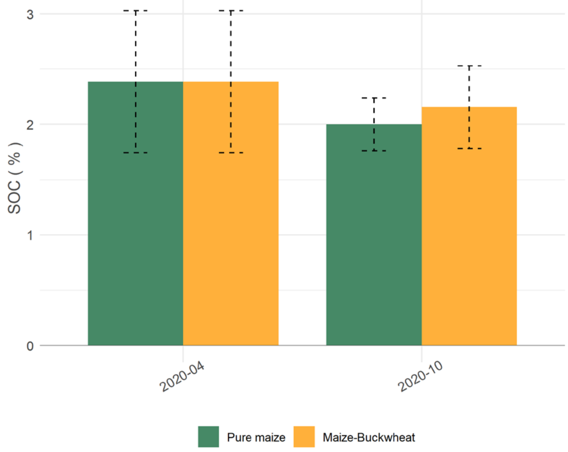
In the table, you can find the variables measured and analysed for this experiment in all treatments. Results for all variables can be found in ANNEXE II.

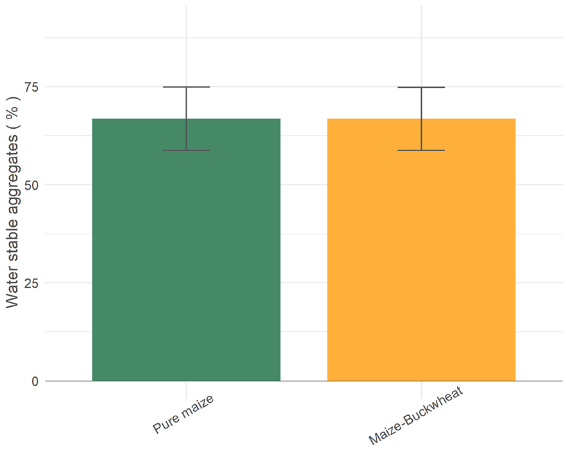
Table 7: Indicators measured and analysed

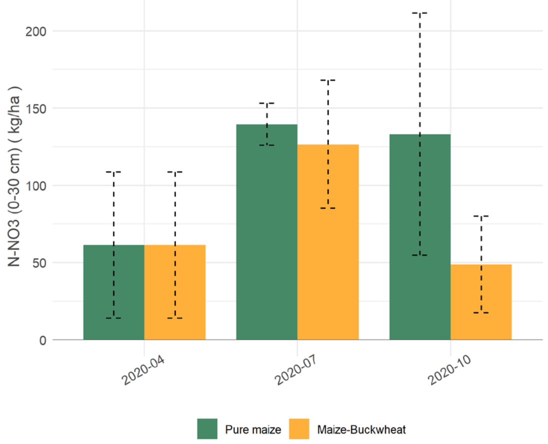
Observation code	Unit	Description
	Mixed model	
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
crop_yield_ha	ton DM/ha	Crop yield
kunsat	m/s	Ksat
	Simple analysis	
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol/kg	Exchangeable K
ca2_plus	cmol/kg	Exchangeable Ca
na_plus	cmol/kg	Exchangeable Na
mg2plus	cmol/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
microb_biom_c	mg C/kg	Microbial biomass C
cu	mg/kg	Cu mg/kg EDTA
mn	mg/kg	Mn mg/kg EDTA
zn	mg/kg	Zn mg/kg EDTA
fe	mg/kg	Fe mg/kg EDTA
cec	méq/kg	CEC Metson
N_NO3_0_30_cm	kg/ha	N-NO3 (0-30 cm)
N_NO3_30_60_cm	kg/ha	N-NO3 (30-60 cm)
N_NH4_0_30_cm	kg/ha	N-NH4 (0-30 cm)
N_NH4_30_60_cm	kg/ha	N-NH4 kg/ha (30-60 cm)

Results









There was no significant difference in the percentage of water-stable aggregates between the associated maize and the control (pure maize). About mineral nitrogen, a strong difference between SICS and control could be observed on one side only. There was a crop yield reduction in the associated maize in comparison to the control on one site and no significant difference on the other.

Analysis

A different hypothesis could explain the observed difference in mineral nitrogen after harvest (qualitative assessment – one site):

- Mineralization activity could have been enhanced by hoeing operation in June (control)
- Mineral nitrogen could have been captured by buckwheat

This high level of mineral nitrogen after harvest (October) in this plot, revealed a high risk of nitrogen leaching on this control.

The yield loss for the SICS (one site) could be explained by the competition between maize and buckwheat for mineral nitrogen and water

Study site analysis

Some visuals observations on the crop were conducted during the experiment:

- weed infestation was significantly higher in the associated maize modality

Figure 8: Difference in weed infestation between control (left) and SICS (right)

Socio-cultural dimension

Table 8: Impact of SICS on the socio-cultural dimension as compared to the control group (perceived risks are these related to economic risk and the risk related to the crop failure)

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Socio-cultural dimension	0.10	1.00	Complete
Workload	0.50	1.00	Complete
Perceived risks	-0.25	1.00	Complete
Farmer reputation	0.00	1.00	Complete

The SICS generated a slight reduction in labour for land users (one hoeing less). But its implementation involved a potential economic risk. The buckwheat on the row competed with maize and maize yield losses occurred. The SICS and his implantation had no impact on land users' reputation.

On the global analysis, the SICS had no-impact on the socio-cultural dimension.

Economical dimension

Table 9: Summary of the benefits of SICS (SICS vs. control), this case shows a negative impact of SICS in comparison to the control, the numbers are in euro/ha (AMT: Agricultural Management Technique)

	AMT control	**AMT SICS**
Agricultural management technique	Normal sowing date	Early sowing date
Investment costs	0	0
Maintenance costs	47,7	45,2
Production costs	590	670
Benefits	4736	3104
Summary = benefits - costs	4098,3	2388,8
Percentage change	-41,8	

Based on our trials, a negative impact of the SICS was estimated on the economical dimension. This observation can be explained by the potential reduction in yield due to competition between maize and buckwheat. Besides, even if one hoeing operation was saved in the implementation of the SICS, buckwheat seeds represented an extra production cost in comparison with the control. As a consequence, production costs are slightly higher with the SICS.

Overall analysis and main findings

The association between maize and buckwheat provided several understandings:

- Buckwheat is too competitive to be associated with maize. The risk of yield loss in comparison with pure maize is quite high.
- Mechanical weeding was more efficient than the association with maize and buckwheat to control weed infestation
- Even if less mechanical weeding operations are realized on maize and buckwheat association, the production cost is higher in comparison to pure maize (buckwheat seed cost)
- Although our trials do not permit clear conclusions, there is a difference in nitrogen dynamics between the SICS and the control.
  We hypothesise that hoeing operations (control) would promote nitrogen mineralization during summer, but this available mineral nitrogen would be not caught by the crop and could be leached in winter. The presence of a cover crop (ex: buckwheat) could catch this mineral nitrogen and prevent leaching.

FRAB_EX2_TR1= maize - buckwheat

FRAB_EX2_TR2= pure maize (control)

Table 10: Impact of SICS on overall sustainability.

	Impact index -1 = Strong negative impact (red) 0 = No significant impact (white) 1 = Strong positive impact (green)	**Data completeness index (DCI)** 1 = All input variables have been considered 0 = No input variables have been considered	**Data completeness rating** DCI = 1: Complete 1 > DCI >= 0.8: High 0.8 > DCE >= 0.4: Medium 0.4 > DCI: Low
Sustainability	-0.10	0.85	High
Environmental dimension	-0.07	0.64	Medium
Economic dimension	-0.33	1.00	Complete
Socio-cultural dimension	0.10	1.00	Complete
Physical properties	-0.20	0.60	Medium
Chemical properties	-0.09	0.80	High
Biological properties	-0.10	0.55	Medium

Other trials involving more covering cover crops (ex: squash) were conducted but did not provide successful outcomes.

It would be interesting to re-test this experimentation with less competitive cover crops (ex: dwarf clover) to prevent yield loss and negative economic impact.

Table 11: Other indices

Benefits:	Infiltration; Reduction of workload;
Drawback:	Crop yield; Weed diseases; Potential economic risk; Cost-benefit;

General conclusions based on all the experiments

- The two SICS represent an economic risk for the land user. The risk of crop failure is particularly high for the early sowing of wheat.
- The early sowing wheat SICS is very technical and its success is strongly dependent on climate conditions
- The sowing of buckwheat in association with maize is not adapted. However, some results (less mechanical weeding operations, mineral nitrogen dynamics) show that it would interesting to improve this SICS with a more adapted cover crop and a reduced row spacing (maize)

1. Belgium: Figures from the statistical analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1: Indicators measured in the SS

Observation code	Unit	Description in the Y-axis
Ksat	m/s[1]	Saturated hydraulic conductivity
Was	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
Soc	%	SOC
ph_kcl	_	pH (KCl)
earthworm_no	no/m^2	Earthworms
Nmin1	kg N/ha	Mineral N in 0-30 cm layer
Nmin2	kg N/ha	Mineral N in 30-60 cm layer
Nmin3	kg N/ha	Mineral N in 60-60 cm layer
crop_yield_ha	kg/ha	Crop yield
byproduct_yield_ha	kg/ha	Yield of by-product
totalbiomass_production_ha	kg DM/ha	Total biomass production
grain_proteincontent	%	Grain protein content
yield_DMcontent	%	DM content of the yield
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
byproduct_DMcontent	%	DM content of by-product
plant_number	% of DM	N-content of by-product

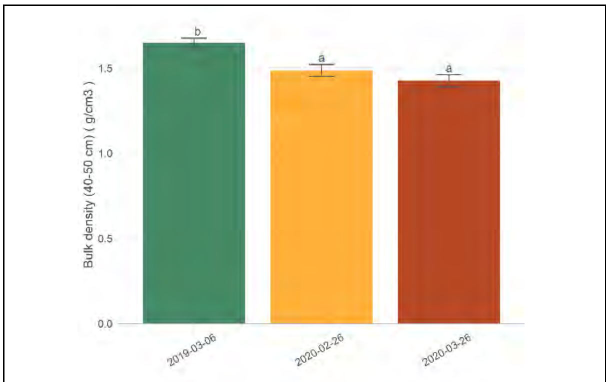

Figure 1: BDB_EX1_NSI_date_bd_bot

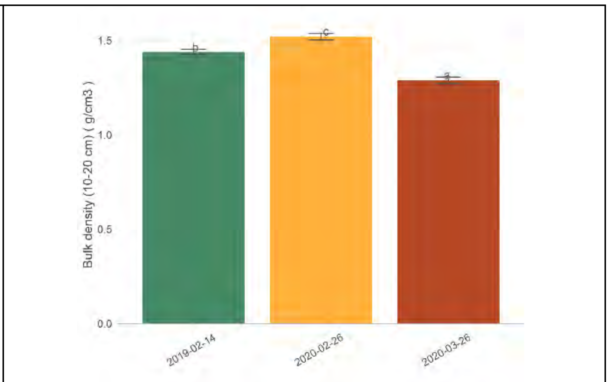

Figure 2: BDB_EX1_NSI_date_bd_top

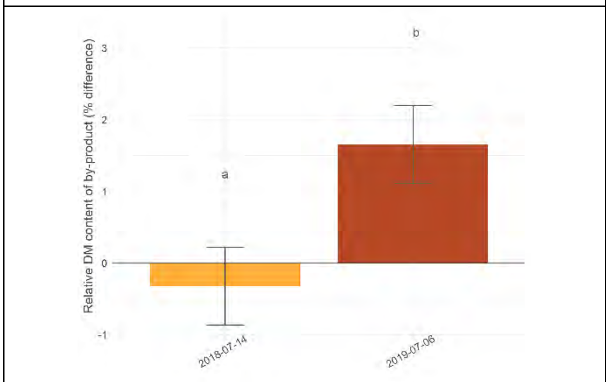

Figure 3: BDB_EX1_NSI_date_byproduct_DMcontent

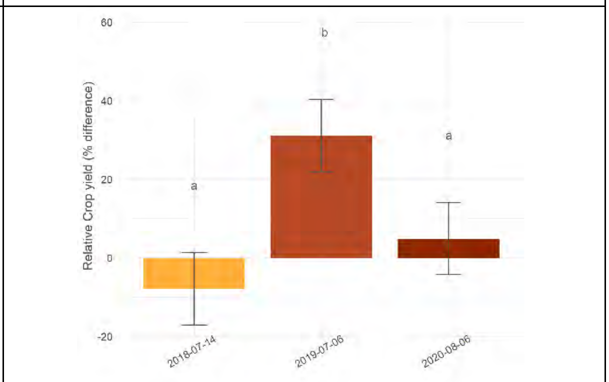

Figure 4: BDB_EX1_NSI_date_crop_yield_ha

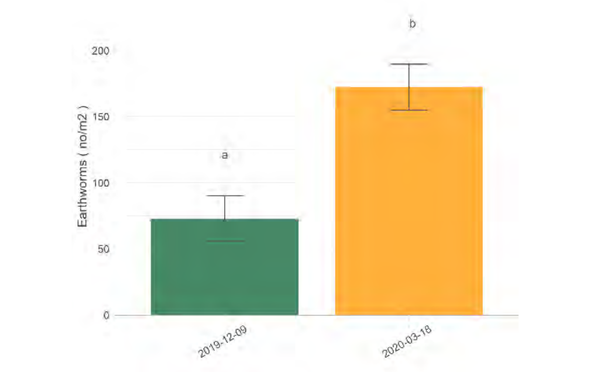

Figure 5: BDB_EX1_NSI_date_earthworm_no

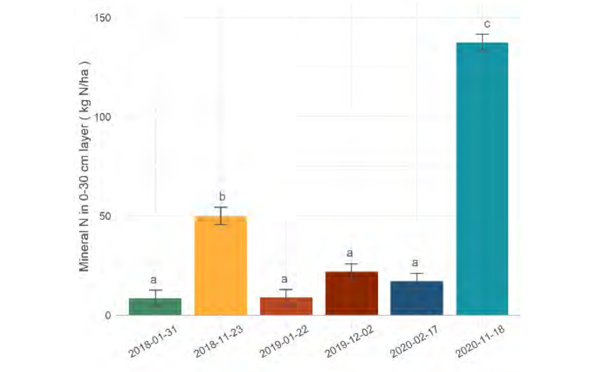

Figure 6: BDB_EX1_NSI_date_Nmin1

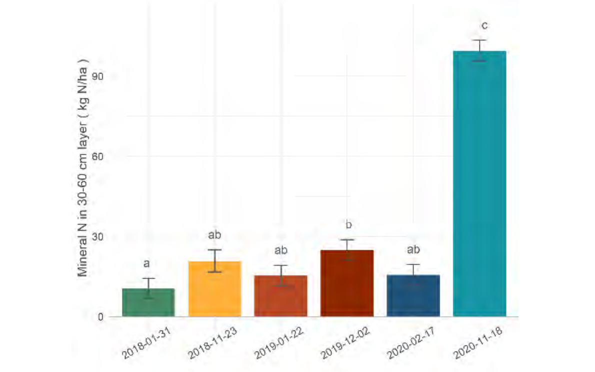

Figure 7: BDB_EX1_NSI_date_Nmin2

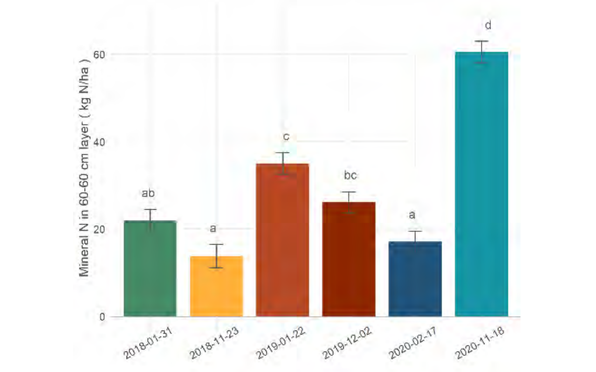

Figure 8: BDB_EX1_NSI_date_Nmin3

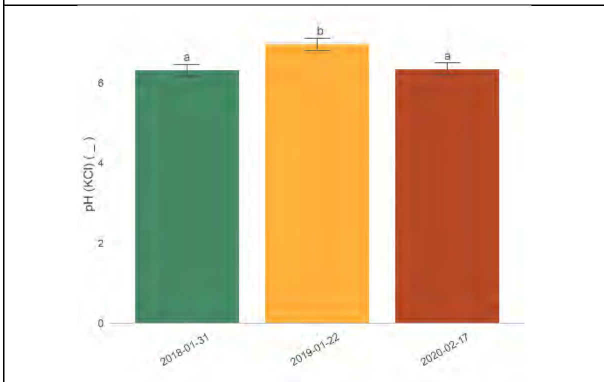

Figure 9: BDB_EX1_NSI_date_ph_kcl

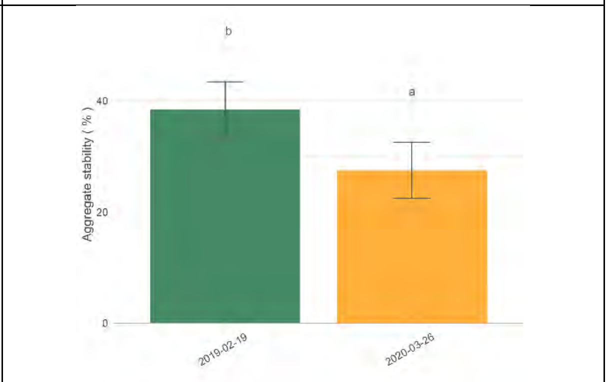

Figure 10: BDB_EX1_NSI_date_wsa

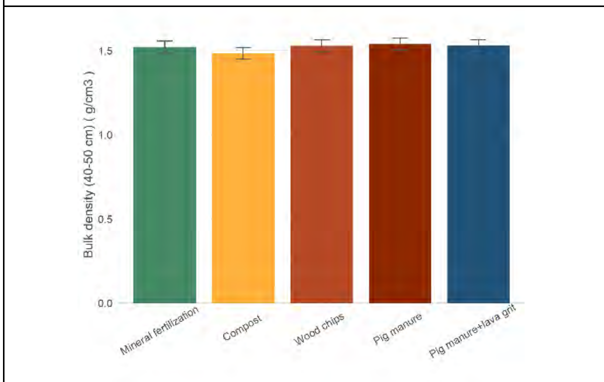

Figure 11: BDB_EX1_NSI_treat_bd_bot

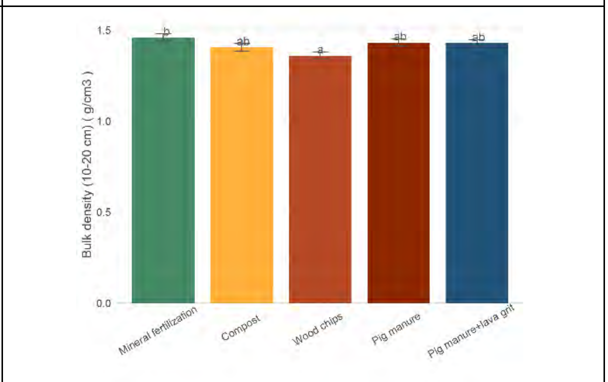

Figure 12: BDB_EX1_NSI_treat_bd_top

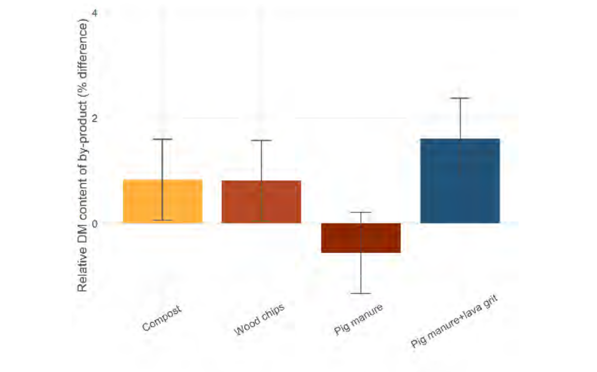

Figure 13: BDB_EX1_NSI_treat_byproduct_DMcontent

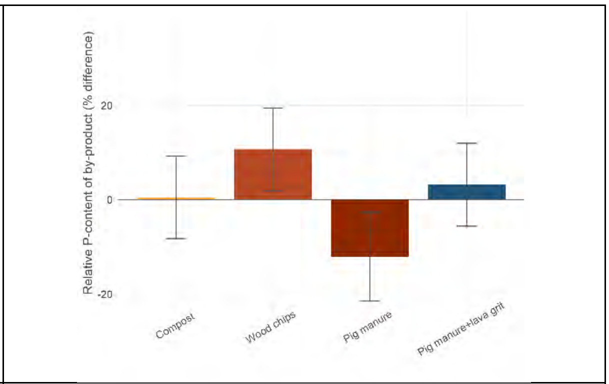

Figure 14: BDB_EX1_NSI_treat_byproduct_Pcontent

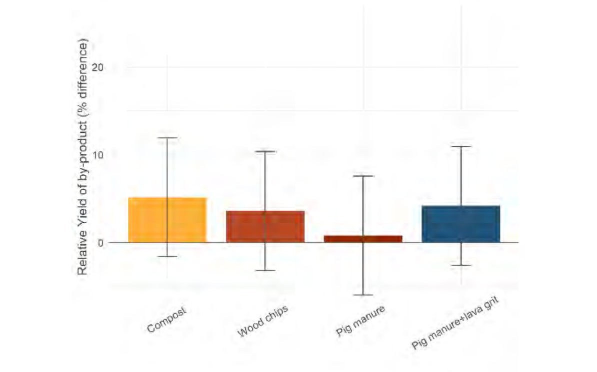

Figure 15: BDB_EX1_NSI_treat_byproduct_yield_ha

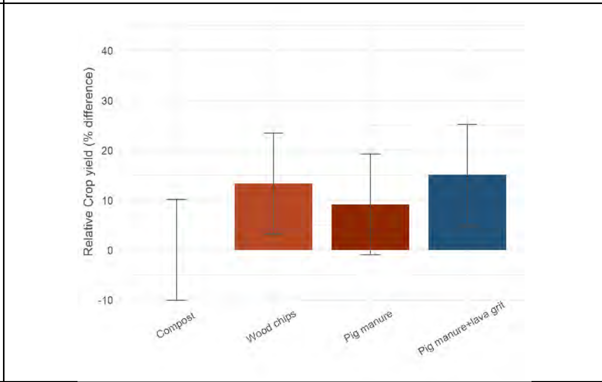

Figure 16: BDB_EX1_NSI_treat_crop_yield_ha

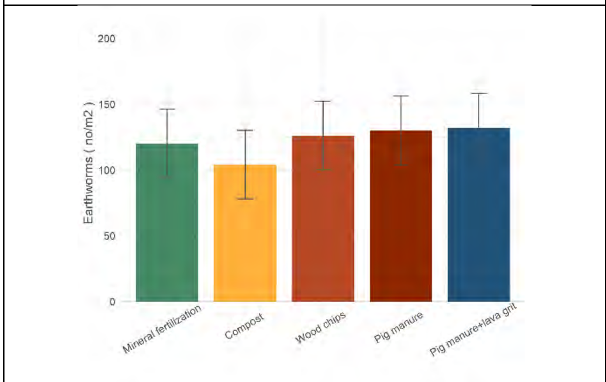

Figure 17: BDB_EX1_NSI_treat_earthworm_no

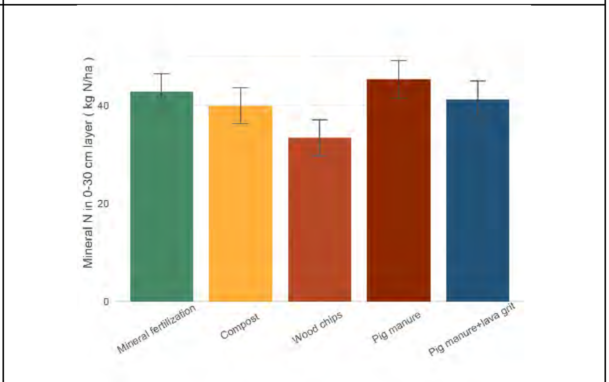

Figure 18: BDB_EX1_NSI_treat_Nmin1

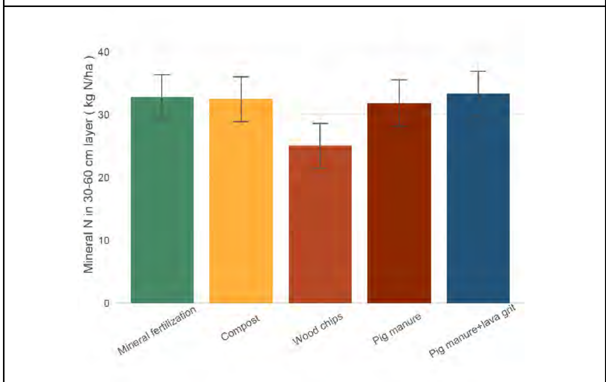

Figure 19: BDB_EX1_NSI_treat_Nmin2

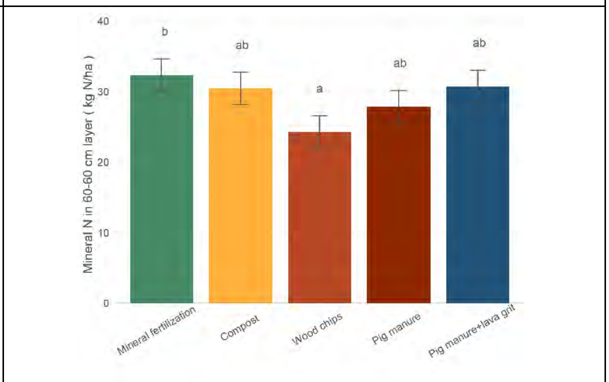

Figure 20: BDB_EX1_NSI_treat_Nmin3

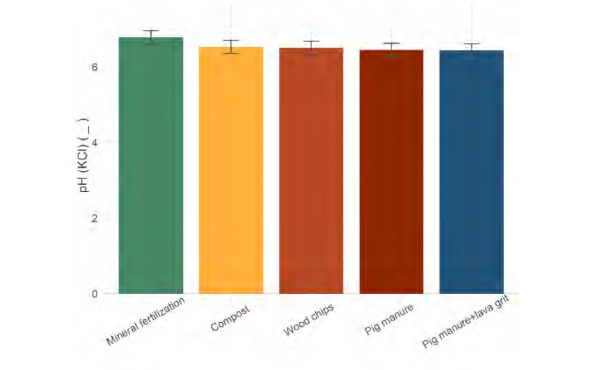

Figure 21: BDB_EX1_NSI_treat_ph_kcl

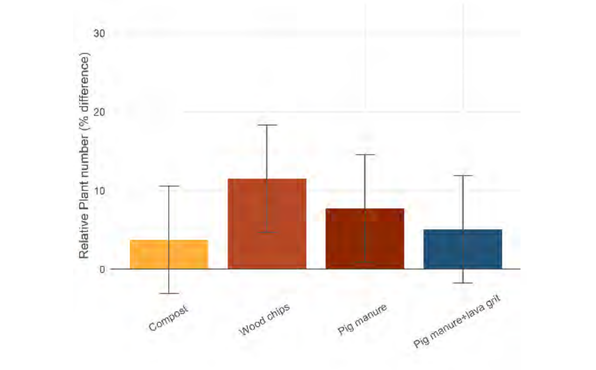

Figure 22: BDB_EX1_NSI_treat_plant_number

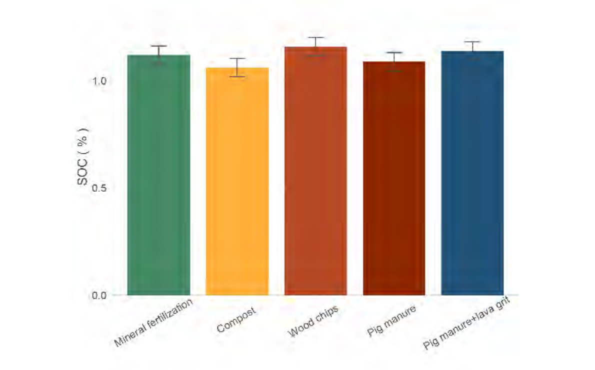

Figure 23: BDB_EX1_NSI_treat_soc

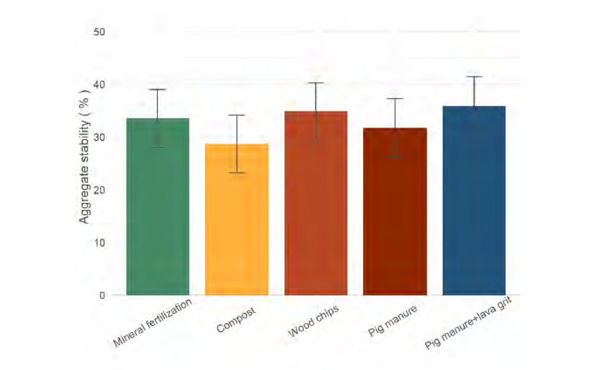

Figure 24: BDB_EX1_NSI_treat_wsa

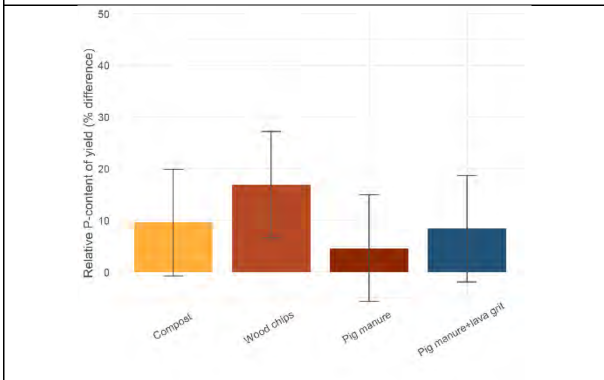

Figure 25: BDB_EX1_NSI_treat_yield_Pcontent

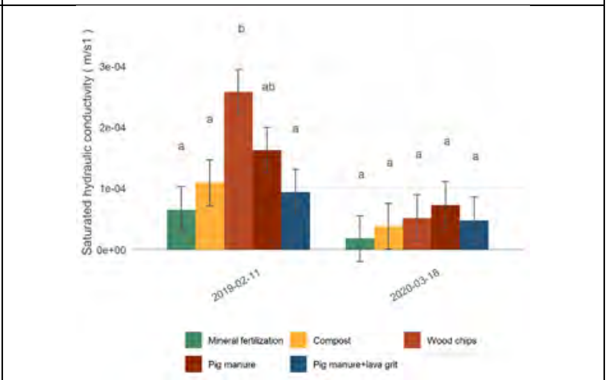

Figure 26: BDB_EX1_SI_ksat

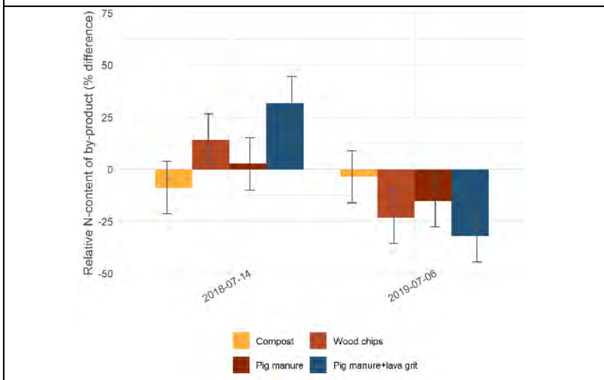

Figure 27: BDB_EX1SI_byproduct_Ncontent

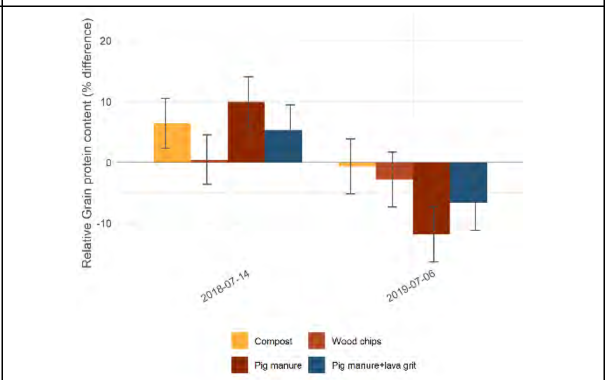

Figure 28: BDB_EX1SI_grain_proteincontent

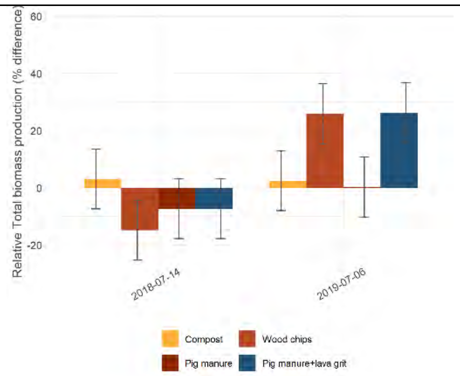

Figure 29: BDB_EX1SI_totalbiomass_production_ha

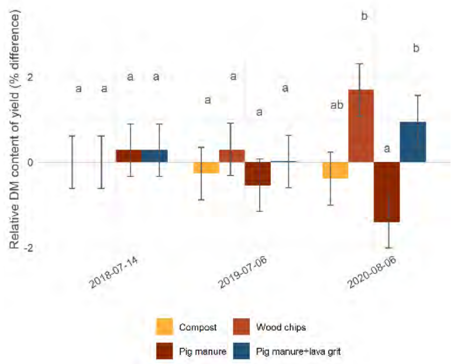

Figure 30: BDB_EX1SI_yield_DMcontent

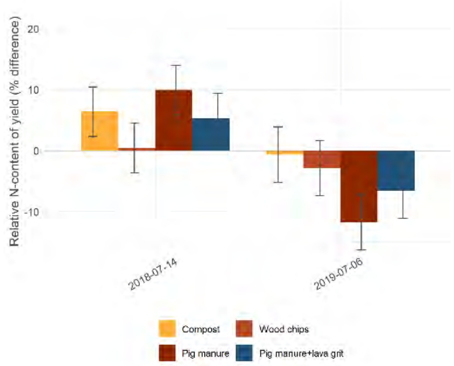

Figure 31: BDB_EX1SI_yield_Ncontent

Experiment 2:

Table 2: Indicators measured in the SS

Observation code	**Unit**	**Description in the Y-axis**
ksat	m s^{-1}	Saturated hydraulic conductivity
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
soc	%	SOC
ph_kcl	_	pH (KCl)
crop_yield_ha	kg/ha	Crop yield
totalbiomass_production_ha	kg DM/ha	Total biomass production
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
plant_number	no/ha	Plant number
crop_height	cm	Crop height
Nmin1	kg N/ha	Mineral N in 0-30 cm layer
Nmin2	kg N/ha	Mineral N in 30-60 cm layer
Nmin3	kg N/ha	Mineral N in 60-90 cm layer
pest_infestation	%	Infected plants

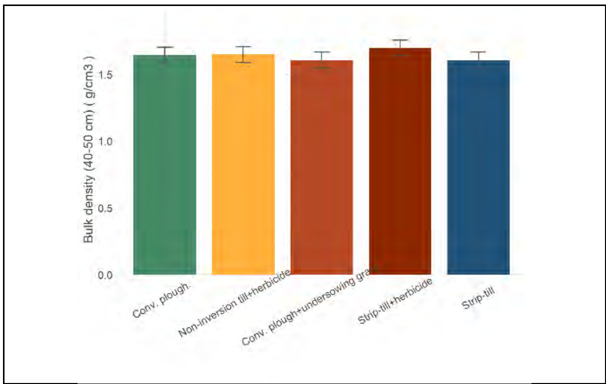

Figure 32: BDB_EX2_NR_bd_bot

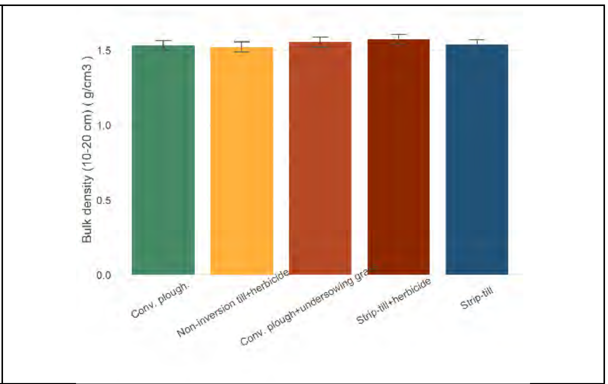

Figure 33: BDB_EX2_NR_bd_top

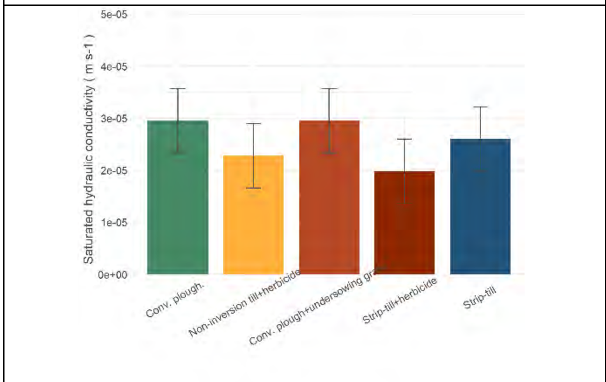

Figure 34: BDB_EX2_NR_ksat

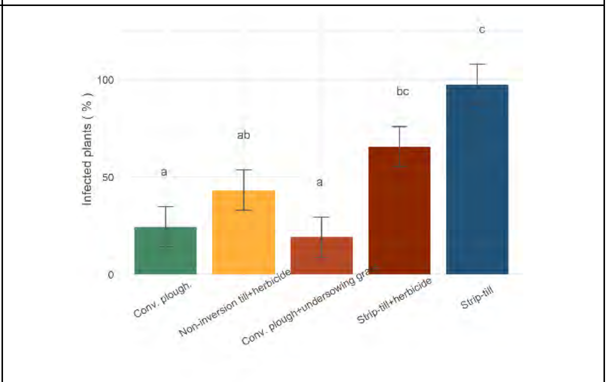

Figure 35: BDB_EX2_NR_pest_infestation

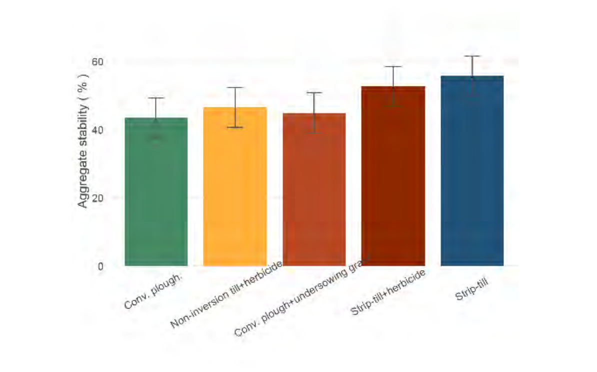

Figure 36: BDB_EX2_NR_wsa

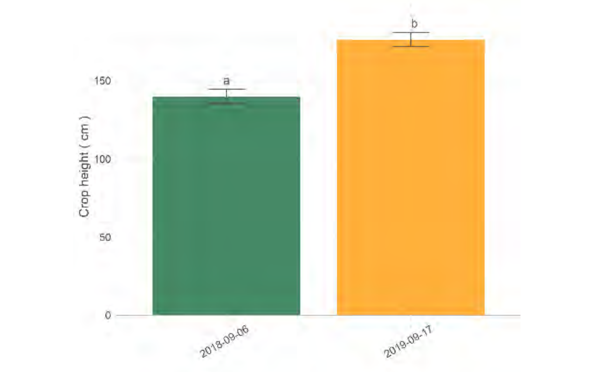

Figure 37: BDB_EX2_NSI_date_crop_height

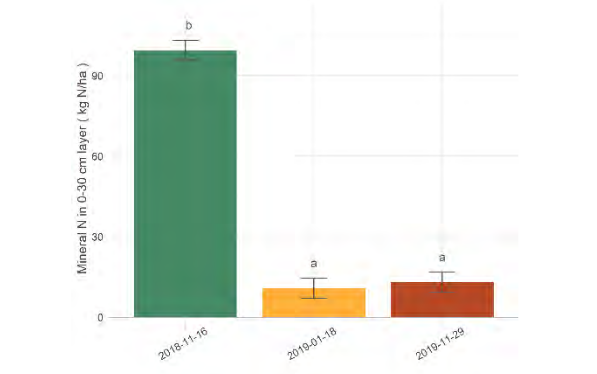

Figure 38: BDB_EX2_NSI_date_Nmin1

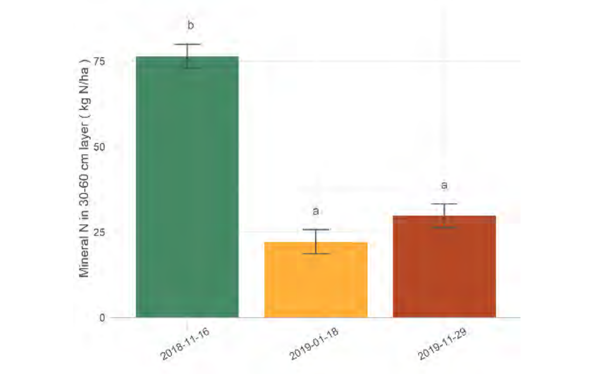

Figure 39: BDB_EX2_NSI_date_Nmin2

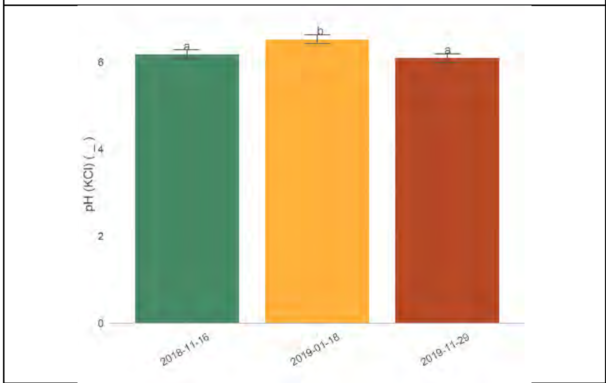

Figure 40: BDB_EX2_NSI_date_ph_kcl

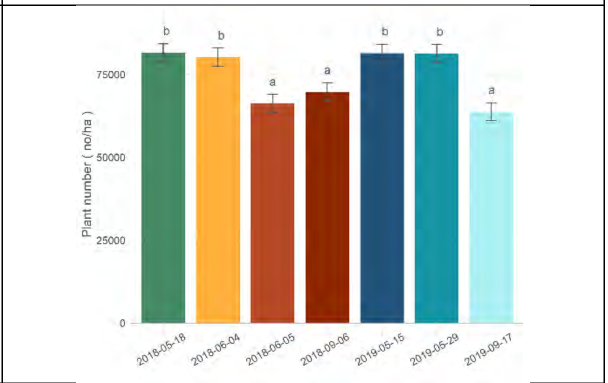

Figure 41: BDB_EX2_NSI_date_plant_number

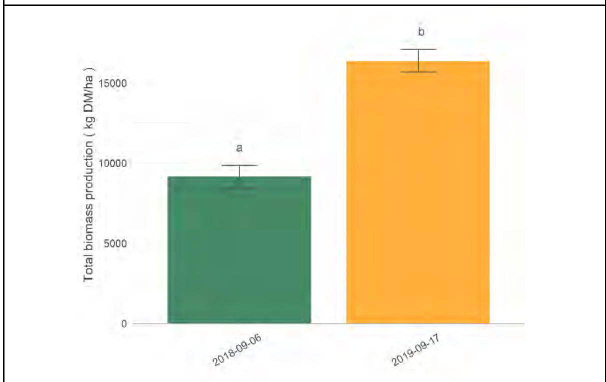

Figure 42: BDB_EX2_NSI_date_totalbiomass_production_ha

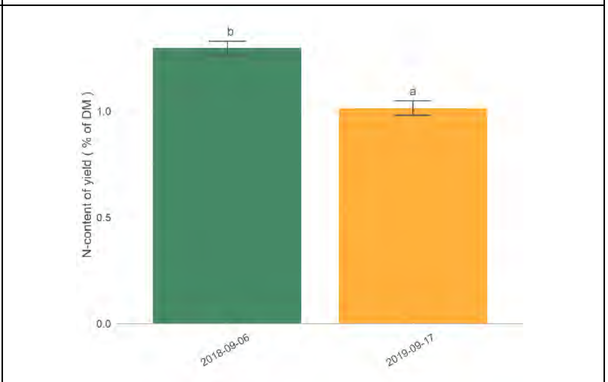

Figure 43: BDB_EX2_NSI_date_yield_Ncontent

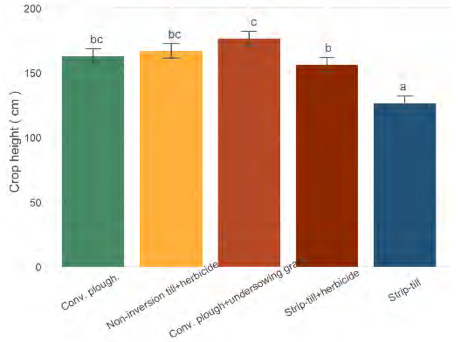

Figure 44: BDB_EX2_NSI_treat_crop_height

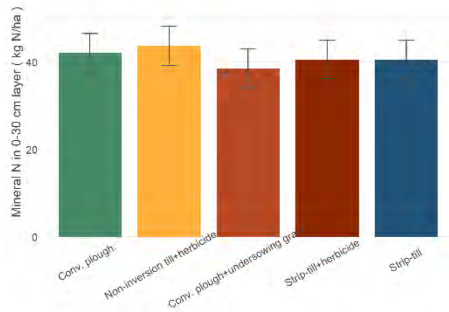

Figure 45: BDB_EX2_NSI_treat_Nmin1

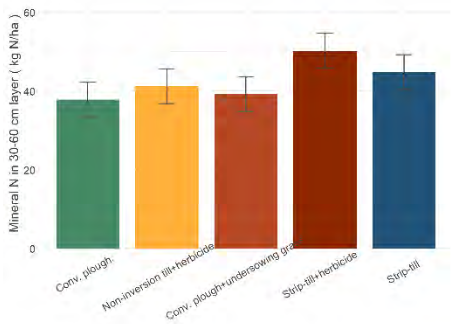

Figure 46: BDB_EX2_NSI_treat_Nmin2

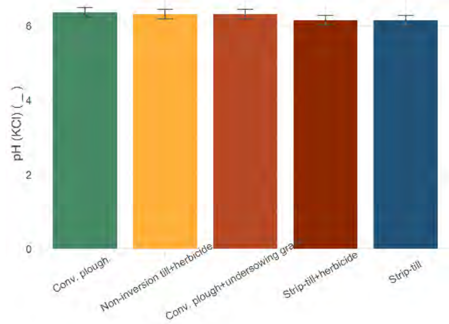

Figure 47: BDB_EX2_NSI_treat_ph_kcl

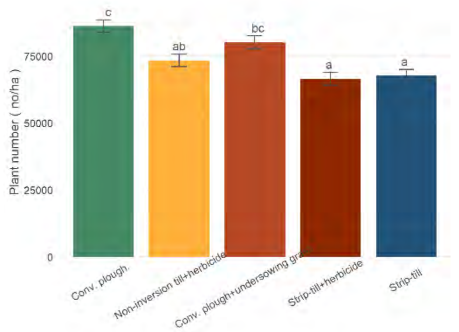

Figure 48: BDB_EX2_NSI_treat_plant_number

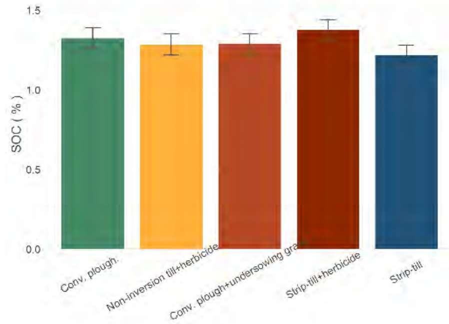

Figure 49: BDB_EX2_NSI_treat_soc

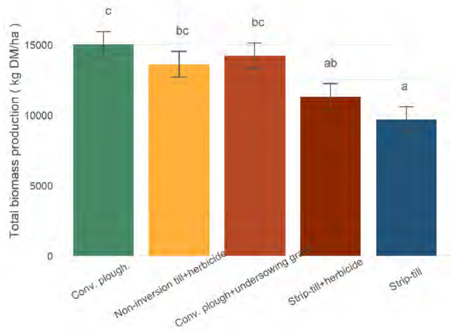

Figure 50: BDB_EX2_NSI_treat_totalbiomass_production_ha

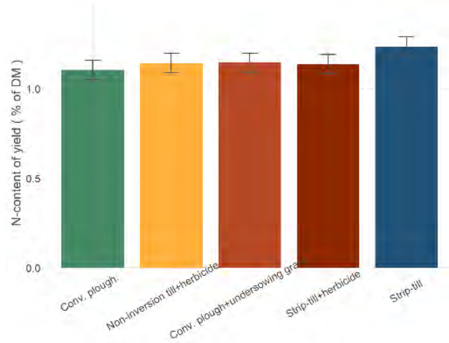

Figure 51: BDB_EX2_NSI_treat_yield_Ncontent

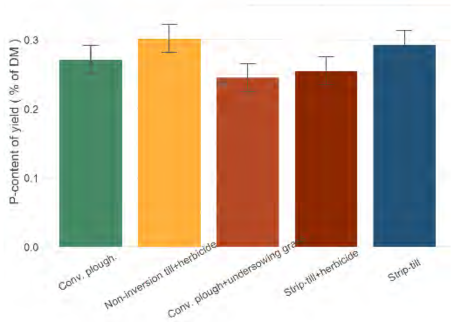

Figure 52: BDB_EX2_NSI_treat_yield_Pcontent

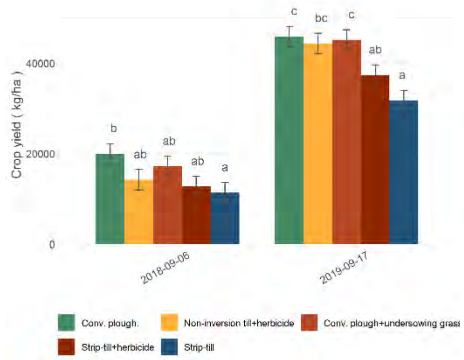

Figure 53: BDB_EX2_SI_crop_yield_ha

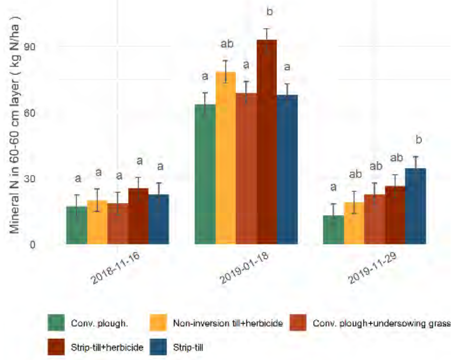

Figure 54: BDB_EX2_SI_Nmin3

Experiment 3:

Table 3: Indicators measured in the SS

Observation code	Unit	Description in the Y-axis
ksat	$m\ s^{-1}$	Saturated hydraulic conductivity
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
crop_yield_ha	kg/ha	Crop yield
totalbiomass_production_ha	kg DM/ha	Total biomass production
yield_DMcontent	%	DM content of the yield
yield_Ncontent	% of DM	N-content of yield
yield_Pcontent	% of DM	P-content of yield
plant_number	number/ha	Plant number
crop_height	cm	Crop height

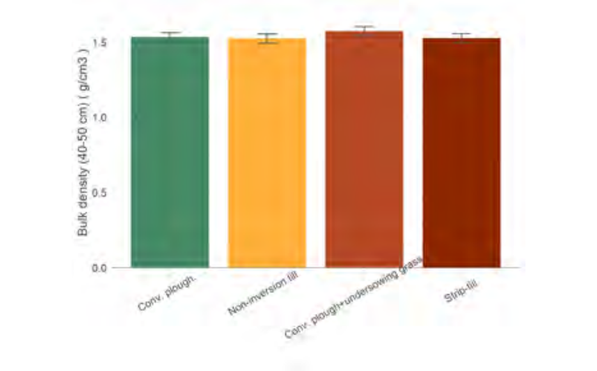

Figure 55: BDB_EX3_NR_bd_bot

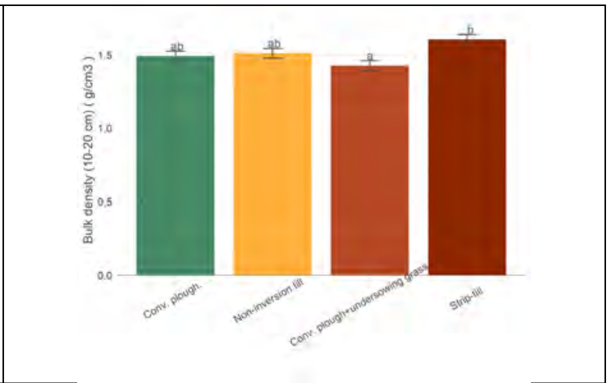

Figure 56: BDB_EX3_NR_bd_top

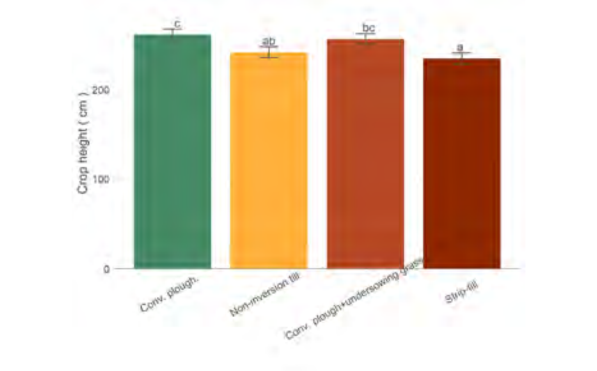

Figure 57: BDB_EX3_NR_crop_height

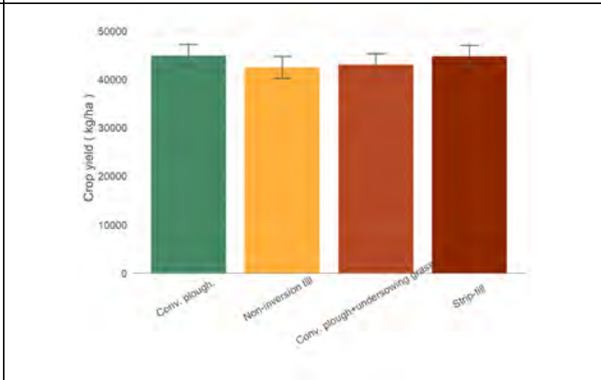

Figure 58: BDB_EX3_NR_crop_yield_ha

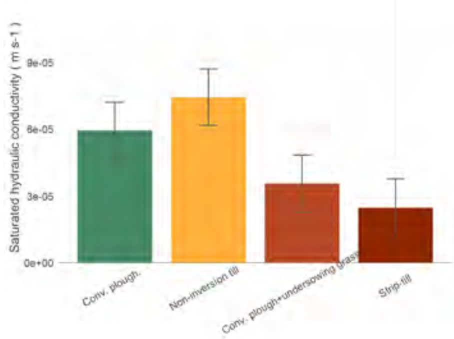

Figure 59: BDB_EX3_NR_ksat

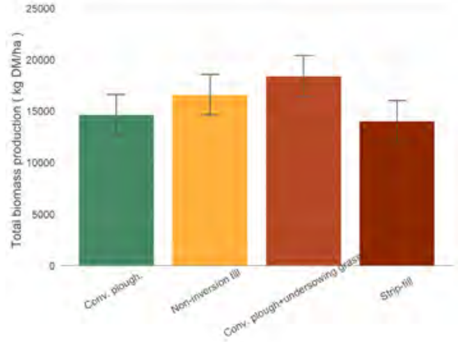

Figure 60: BDB_EX3_NR_totalbiomass_production_ha

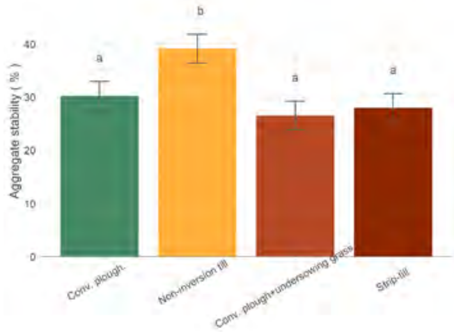

Figure 61: BDB_EX3_NR_wsa

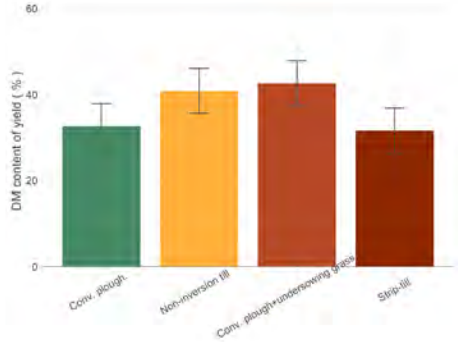

Figure 62: BDB_EX3_NR_yield_DMcontent

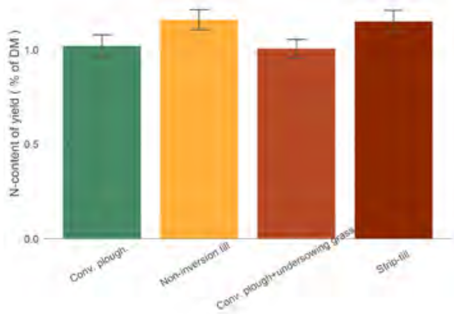

Figure 63: BDB_EX3_NR_yield_Ncontent

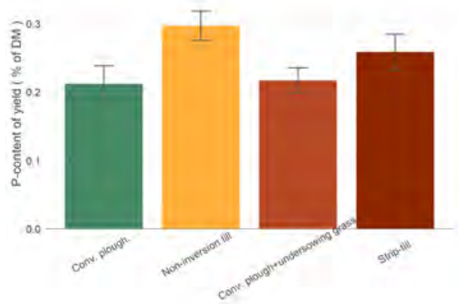

Figure 64: BDB_EX3_NR_yield_Pcontent

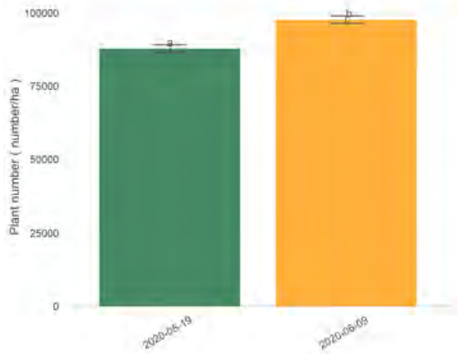

Figure 65: BDB_EX3_NSI_date_plant_number

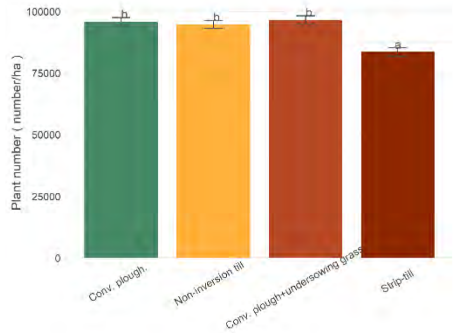

Figure 66: BDB_EX3_NSI_treat_plant_number

1. Belgium: Figures from the analysis of the meteorological data

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See the general introduction to D5.3 for the explanation.

Table of Figures

1E Ukkel (ECAD17)

The main meteorological station in Belgium; which started 1833/01/01 but series used van 1947 till now.

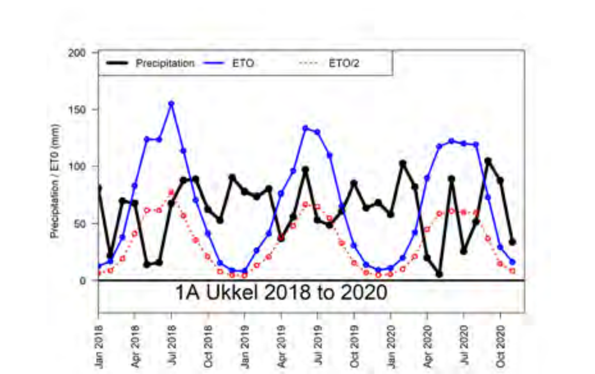

Figure 1: 1A Ukkel 00aFAOgrow

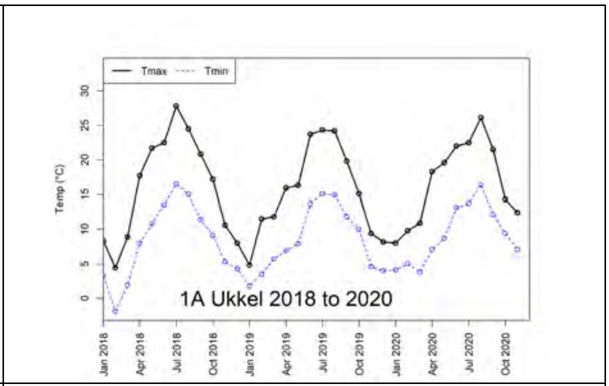

Figure 2: 1A Ukkel 00b TnTx

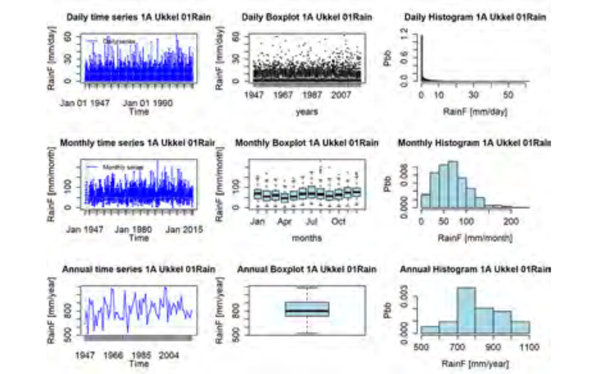

Figure 3: 1A Ukkel 01Rainhyplo

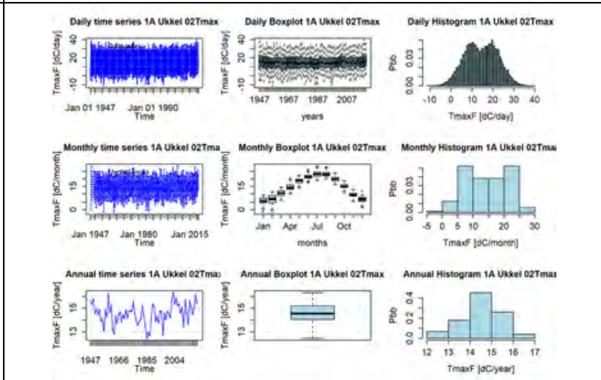

Figure 4: 1A Ukkel 02Tmaxhyplo

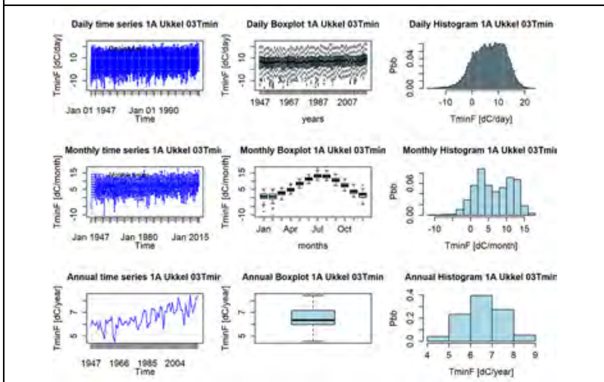

Figure 5: 1A Ukkel 03Tminhyplo

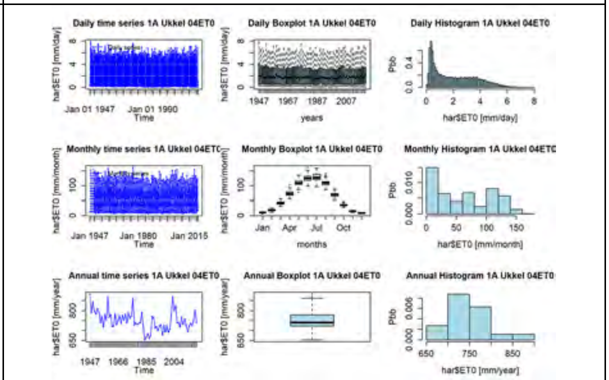

Figure 6: 1A Ukkel 04ET0hyplo

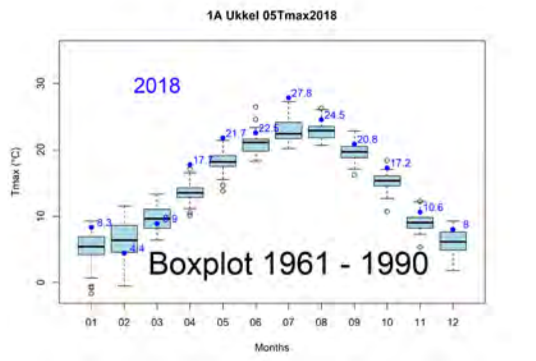

Figure 7: 1A Ukkel 05Tmax2018box

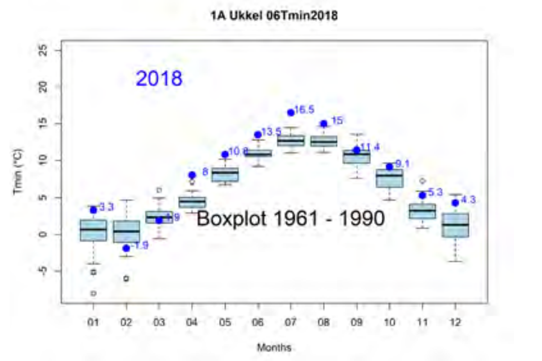

Figure 8: 1A Ukkel 06Tmin2018box

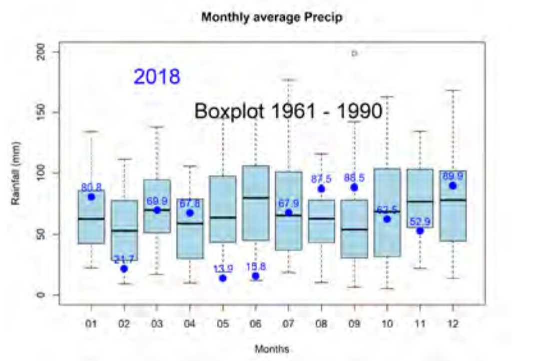

Figure 9: 1A Ukkel 07Precip2018box

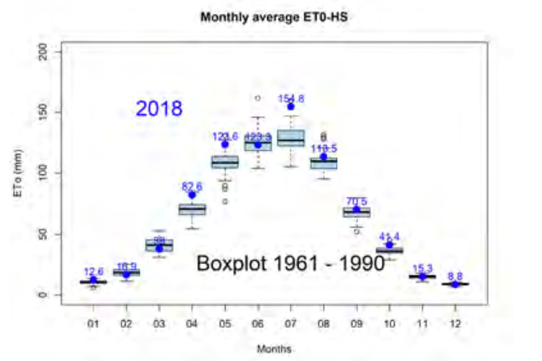

Figure 10: 1A Ukkel 08ET02018box

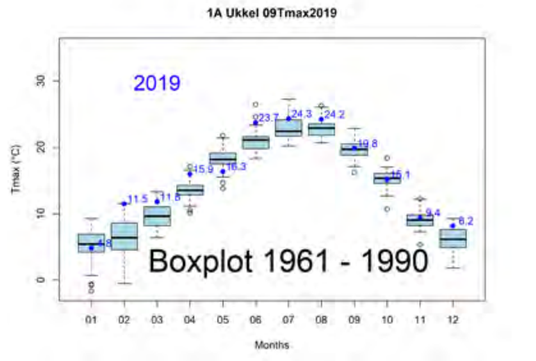

Figure 11: 1A Ukkel 09Tmax2019box

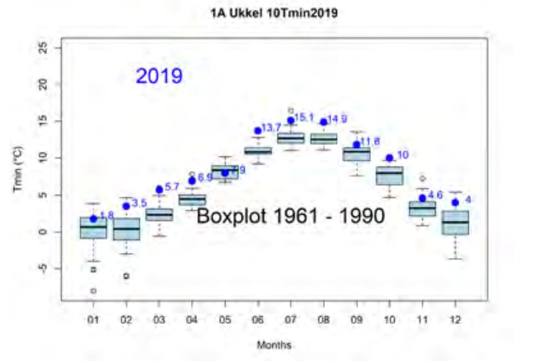

Figure 12: 1A Ukkel 10Tmin2019box

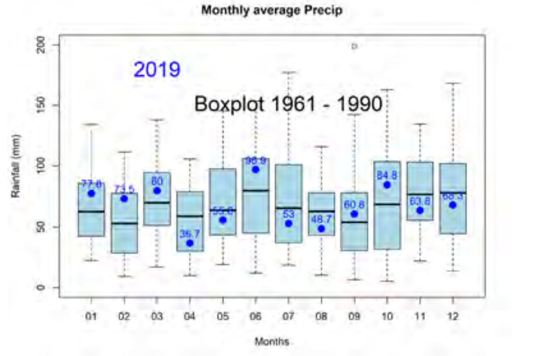

Figure 13: 1A Ukkel 11Precip2019box

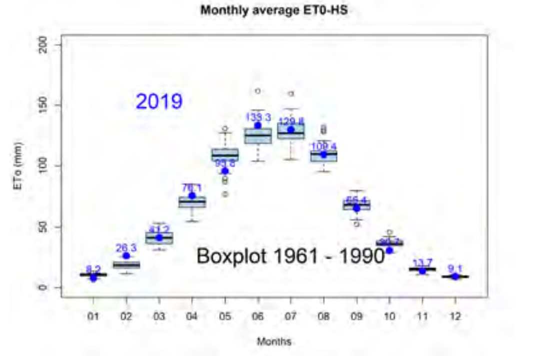

Figure 14: 1A Ukkel 12ET02019box

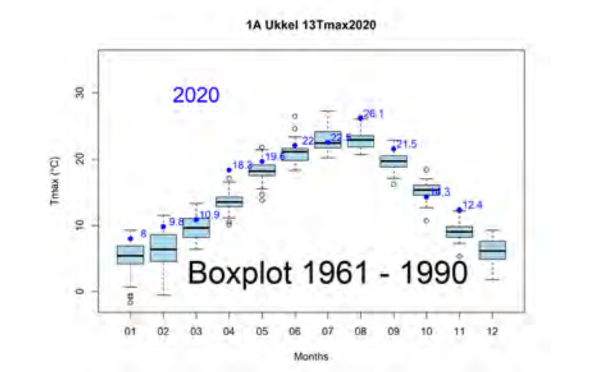

Figure 15: 1A Ukkel 13Tmax2020box

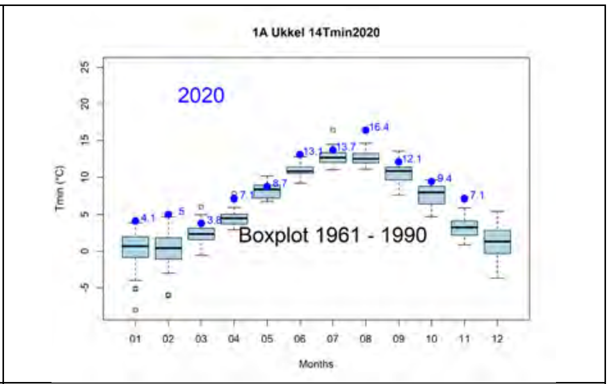

Figure 16: 1A Ukkel 14Tmin2020box

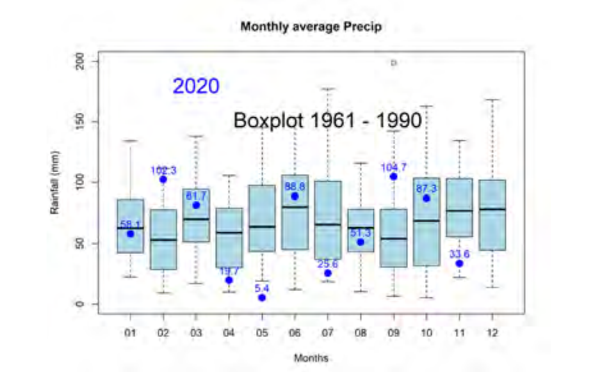

Figure 17: 1A Ukkel 15Precip2020box

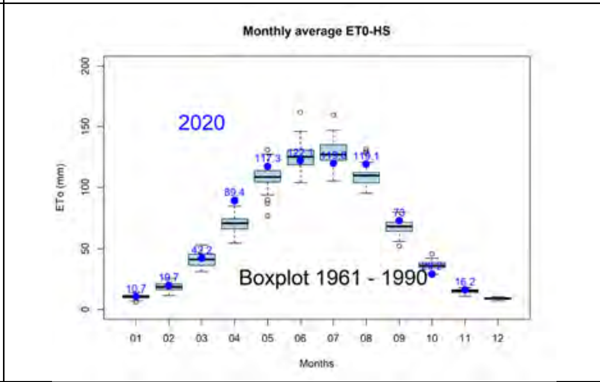

Figure 18: 1A Ukkel 16ET02020box

2. Norway: Figures from the analysis

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The general explanation of the filenames for the figures for experiment 1

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1: Indicators measured and analysed for the SS

Observation code	Unit	Description
wsa	%	Aggregate stability
bd_top	g/cm3	Bulk density
nmin_top	mg-N/Kg soil	Mineral N
k_plus	cmol+/kg	Exchangeble K
ca2_plus	cmol+/kg	Exchangeble Ca
na_plus	cmol+/kg	Exchangeble Na
mg2plus	cmol+/kg	Exchangeble Mg
soc	%	SOC
ph_kcl	_	pH
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
pavail2	P mg PO4/kg	Olsen P
crop_protein	%	Crop protein
crop_fat	%	Crop fat

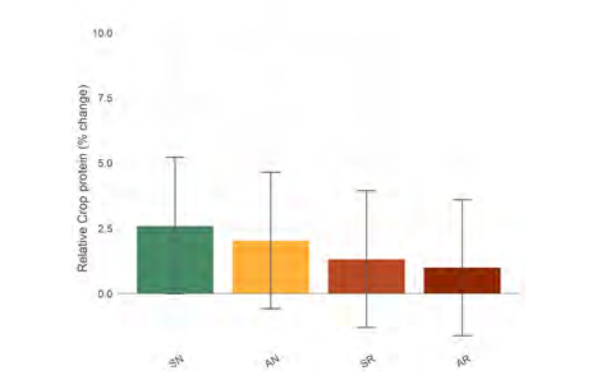

Figure 1: NIBIO_EX1_NSI_treat_crop_protein

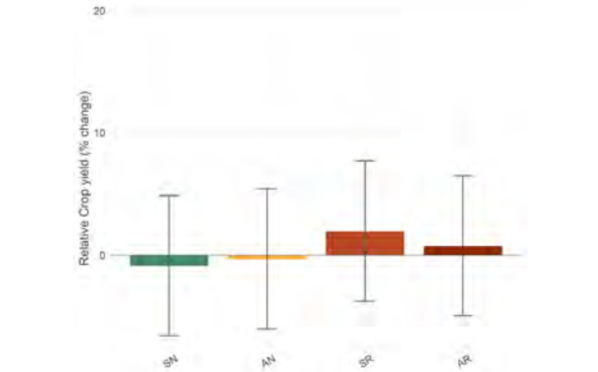

Figure 2: NIBIO_EX1_NSI_treat_crop_yield_ha

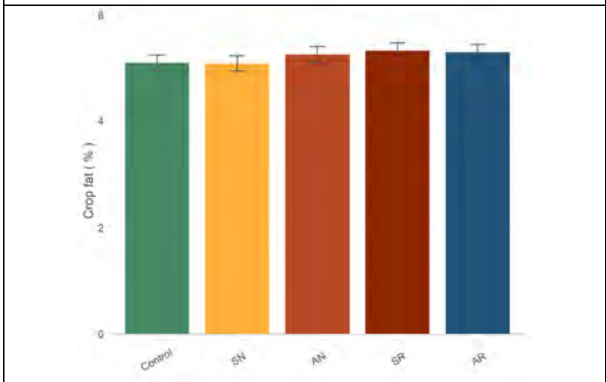

Figure 3: NIBIO_EX1_NR_crop_fat

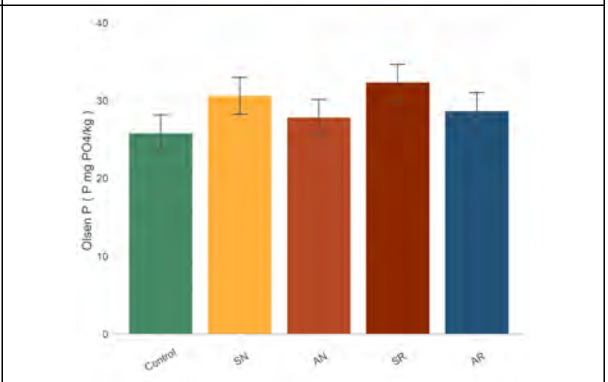

Figure 4: NIBIO_EX1_NR_pavail2

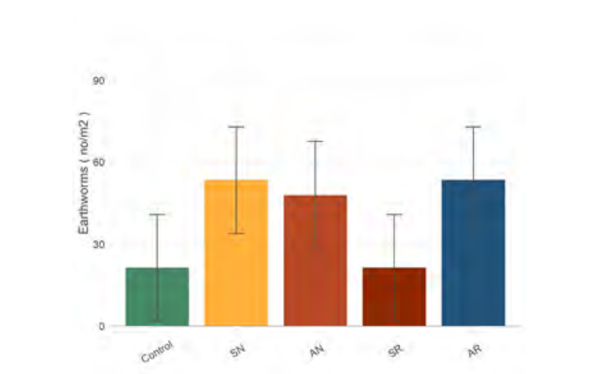

Figure 5: NIBIO_EX1_NR_earthworm_no

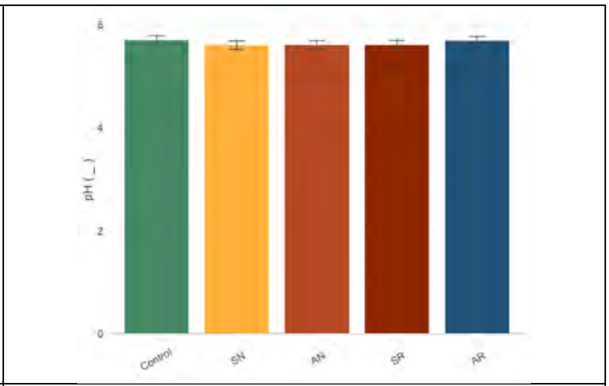

Figure 6: NIBIO_EX1_NR_ph_kcl

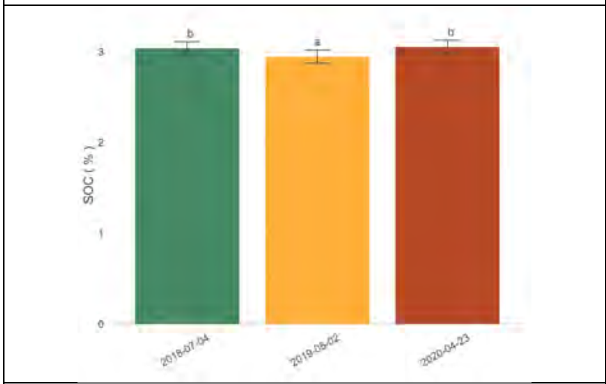

Figure 7: NIBIO_EX1_NSI_date_soc

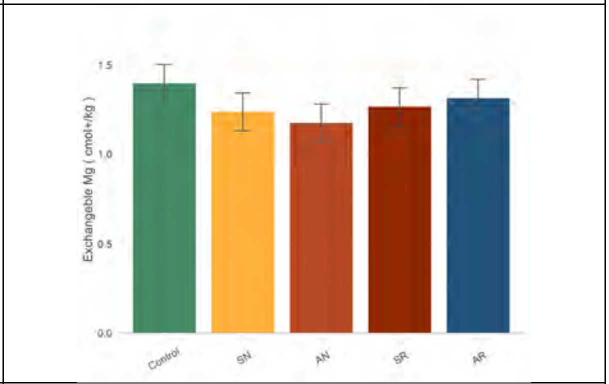

Figure 8: NIBIO_EX1_NR_mg2plus

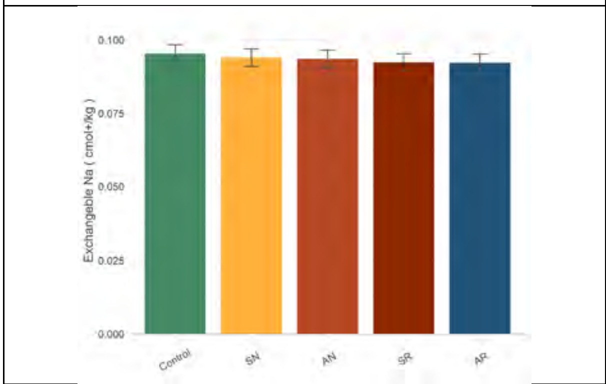

Figure 9: NIBIO_EX1_NR_na_plus

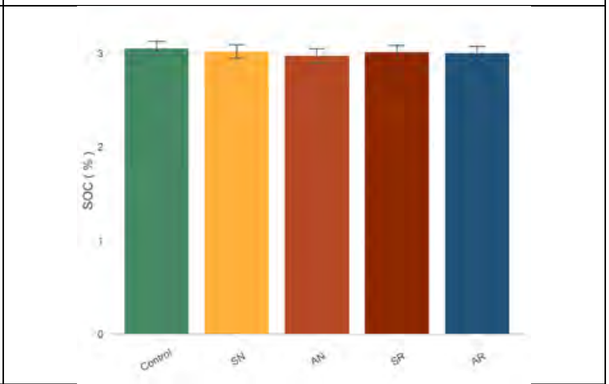

Figure 10: NIBIO_EX1_NSI_treat_soc

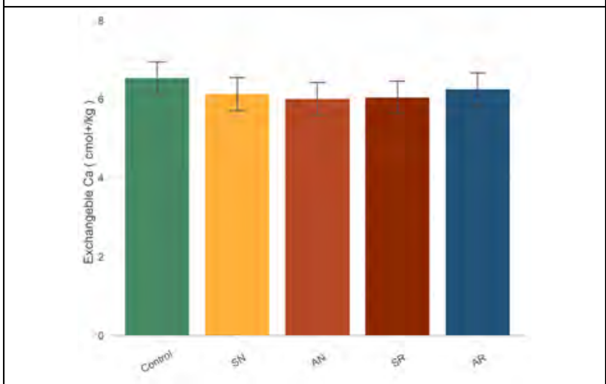

Figure 11: NIBIO_EX1_NR_ca2_plus

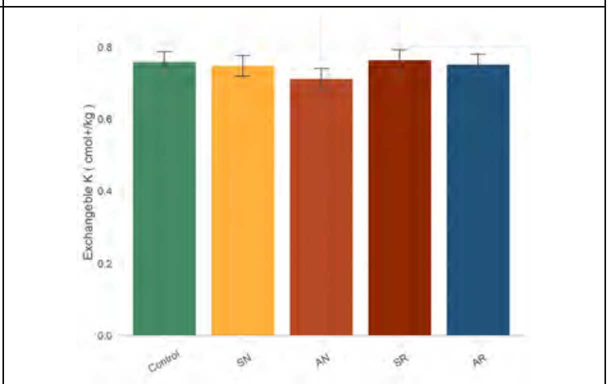

Figure 12: NIBIO_EX1_NR_k_plus

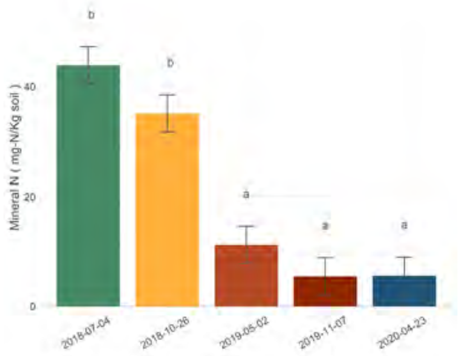 	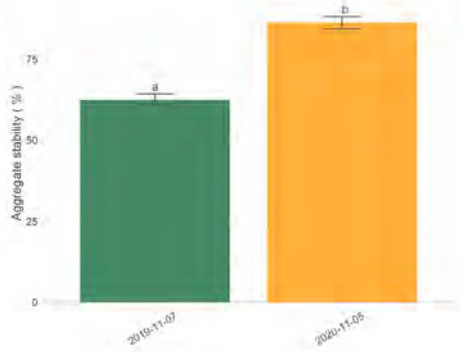
Figure 13: NIBIO_EX1_NSI_date_nmin_top	*Figure 14: NIBIO_EX1_NSI_date_wsa*
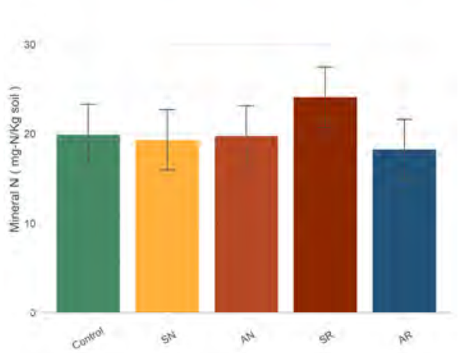 	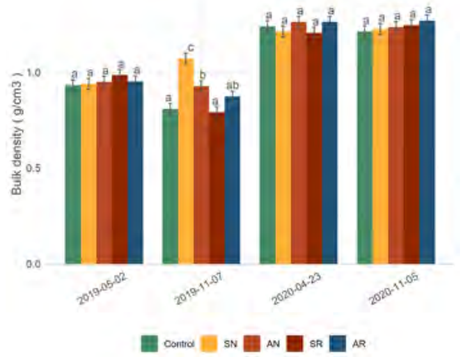
Figure 15: NIBIO_EX1_NSI_treat_nmin_top	*Figure 16: NIBIO_EX1_SI_bd_top*
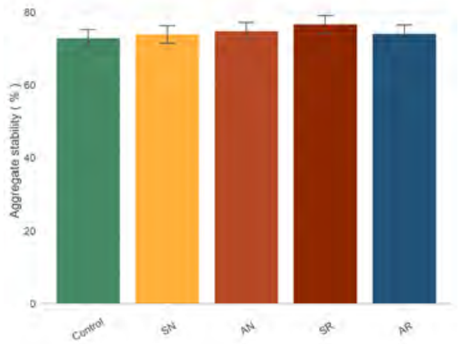 	
Figure 17: NIBIO_EX1_NSI_treat_wsa	

Experiment 2

The main plots have not been replicated and therefore the standard deviation is indicated by dashed lines and **cannot** be used for group comparison between treatments. The histograms represent one plot only.

Table 2:Indicators measured and analysed for the SS

Observation code	Unit	Description
nmin_top	mg-N/Kg soil	Mineral N (0-10 cm)
nmin_10_20	mg-N/Kg soil	Mineral N (10-20 cm)
nmin_20_30	mg-N/Kg soil	Mineral N (20-30 cm)
soc_top	%	SOC (0-10 cm)
soc_10_20	%	SOC (10-20 cm)
soc_20_30	%	SOC (20-30 cm)
crop_yield_ha	kg/ha	Barley yield

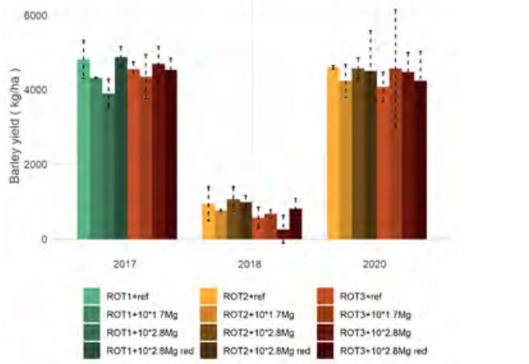

Figure 18: NIBIO_EX2_crop_yield_ha

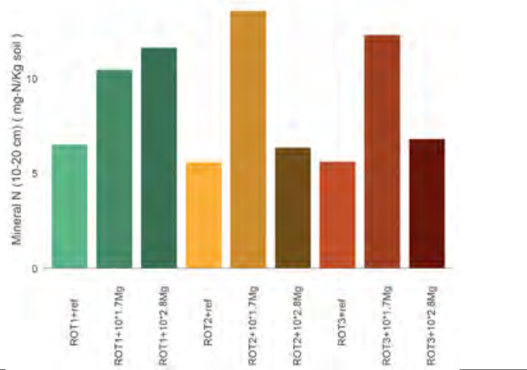

Figure 19: NIBIO_EX2_nmin_10_20

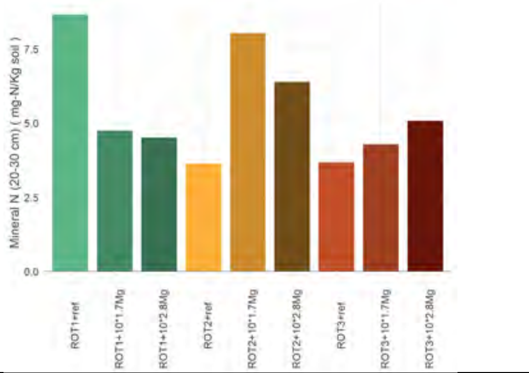

Figure 20: NIBIO_EX2_nmin_20_30

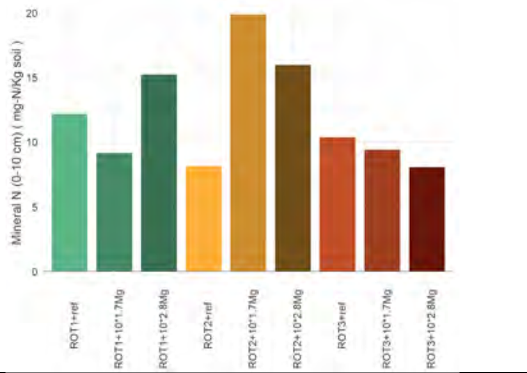

Figure 21: NIBIO_EX2_nmin_top

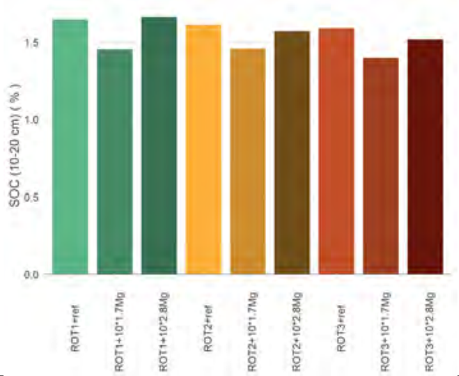

Figure 22: NIBIO_EX2_soc_10_20

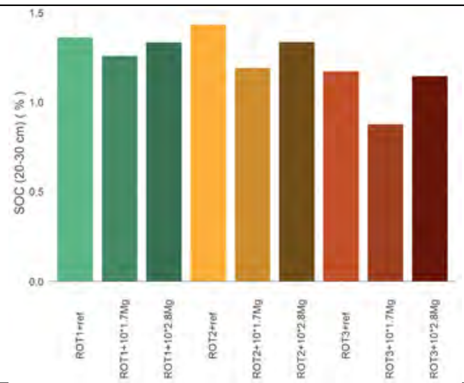

Figure 23: NIBIO_EX2_soc_20_30

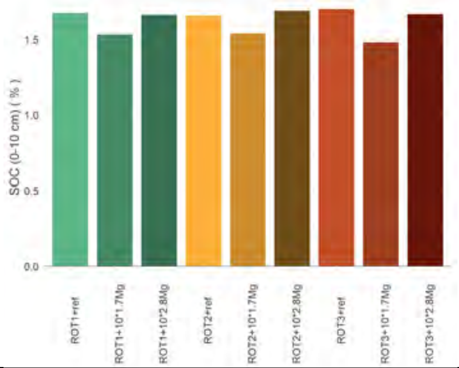

Figure 24: NIBIO_EX2_soc_top

2. Norway: Figures from the analysis

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For explanation of the graphs consult the introduction to D5.3

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2Ea Osaker (ECAD18010)

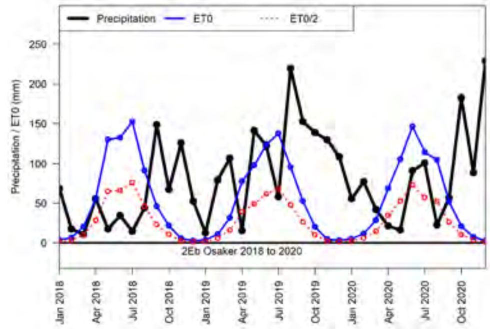


Figure 1: 2Eb Osaker 00aFAOgrow

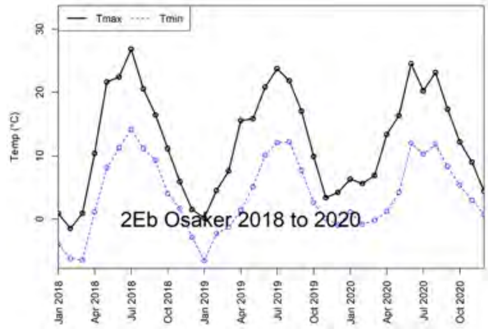


Figure 2: 2Eb Osaker 00b TnTx

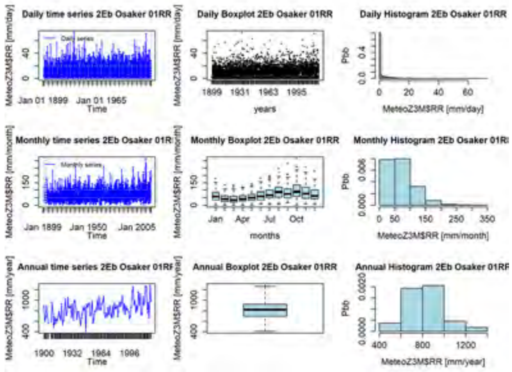


Figure 3: 2Eb Osaker 01RRhyplo

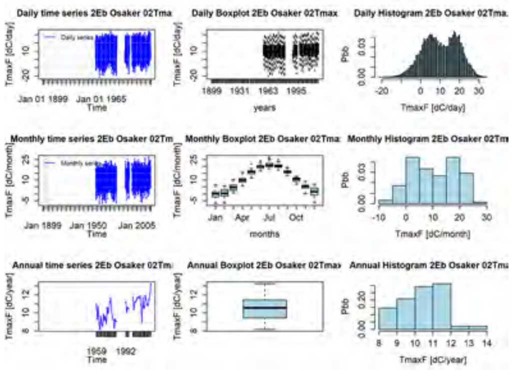


Figure 4: 2Eb Osaker 02Tmaxhyplo

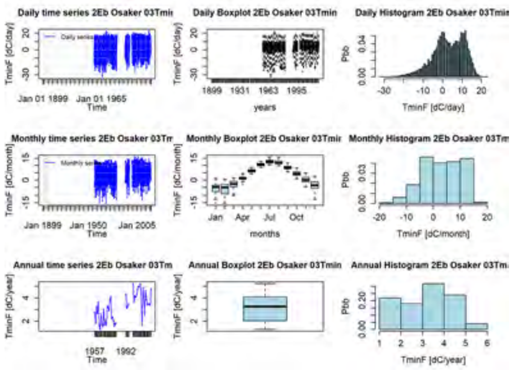


Figure 5: 2Eb Osaker 03Tminhyplo

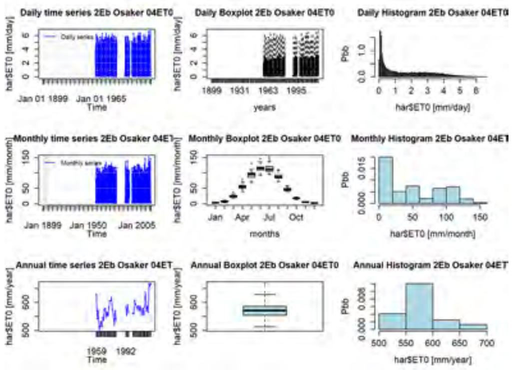


Figure 6: 2Eb Osaker 04ET0hyplo

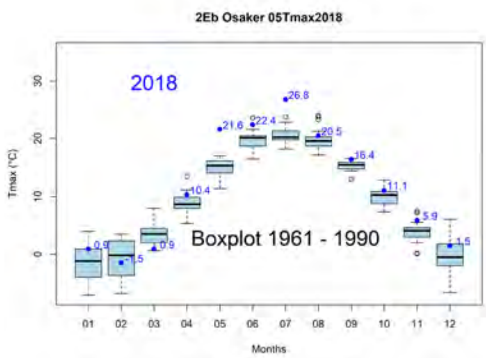


Figure 7: 2Eb Osaker 05Tmax2018box

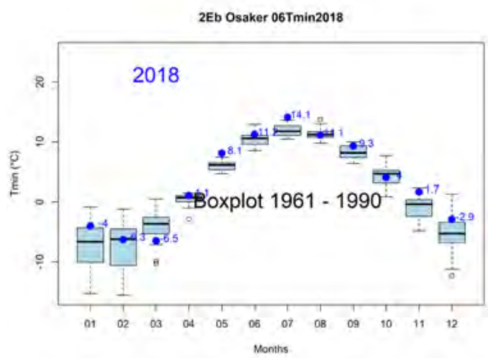


Figure 8: 2Eb Osaker 06Tmin2018box

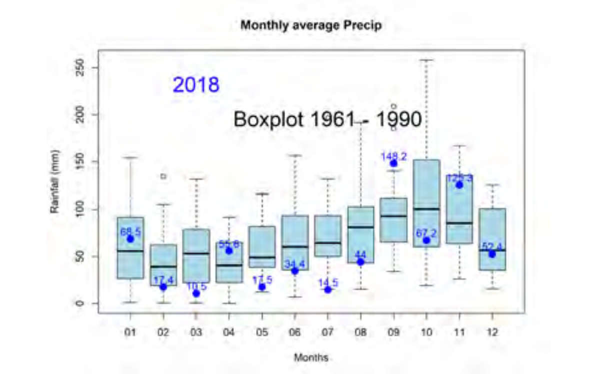


Figure 9: 2Eb Osaker 07Precip2018box

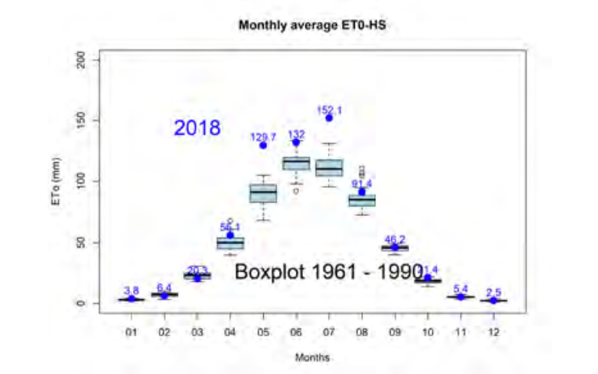
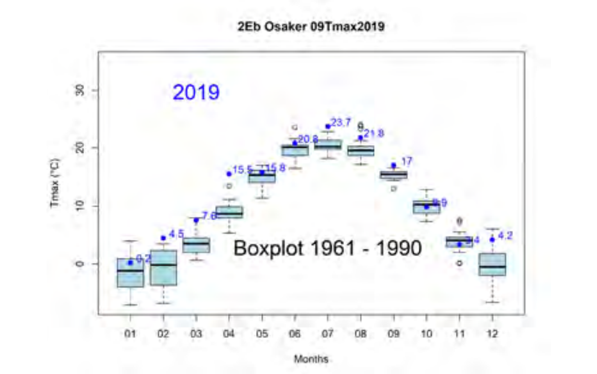


Figure 10: 2Eb Osaker 08ET02018box



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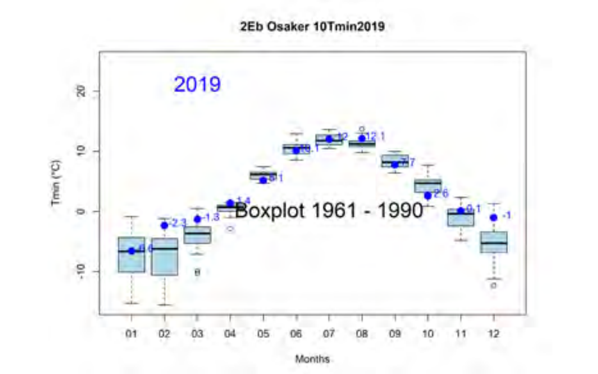


Figure 12: 2Eb Osaker 10Tmin2019box

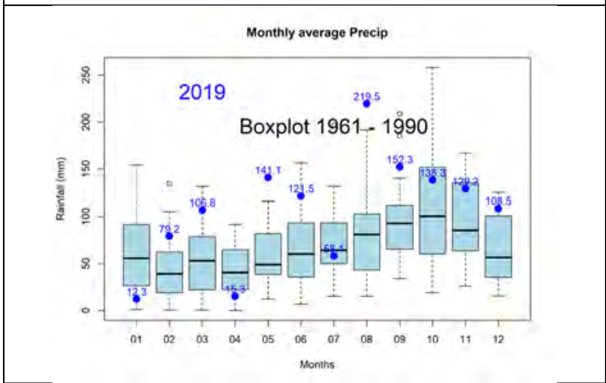
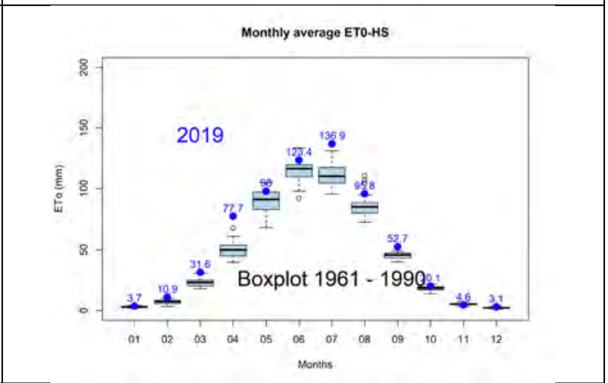


Figure 13: 2Eb Osaker 11Precip2019box



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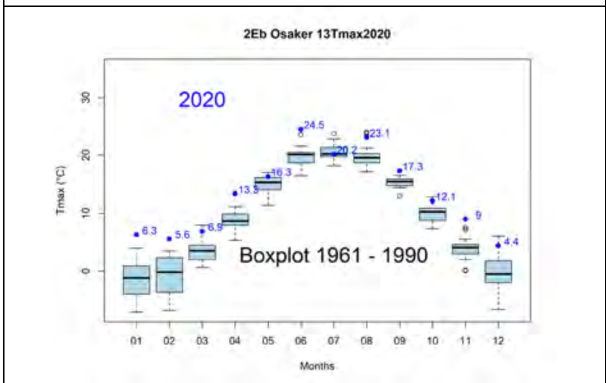


Figure 15: 2Eb Osaker 13Tmax2020box

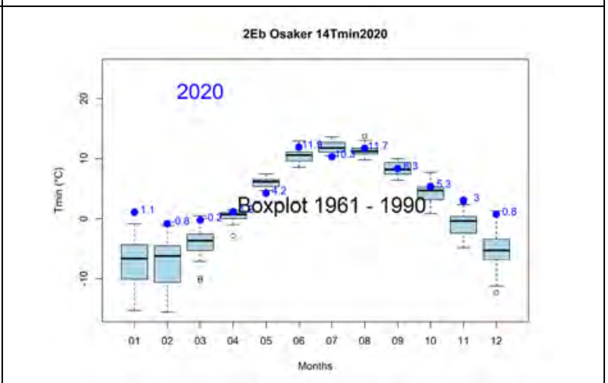


Figure 16: 2Eb Osaker 14Tmin2020box

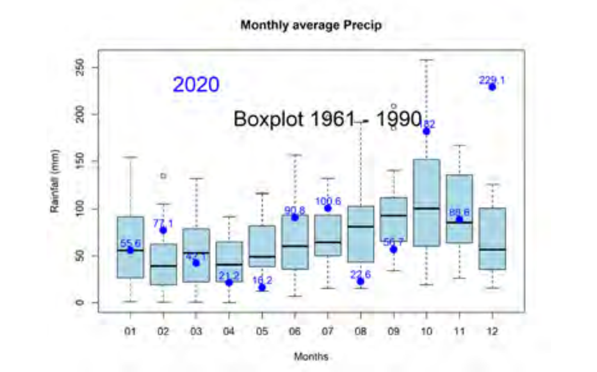


Figure 17: 2Eb Osaker 15Precip2020box

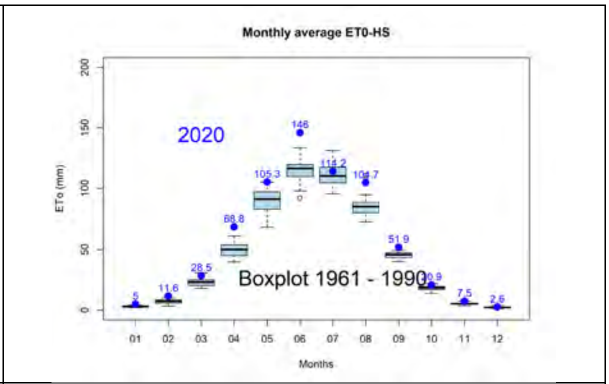


Figure 18: 2Eb Osaker 16ET02020box

2Eb Sarpsborg (ECAD2590)

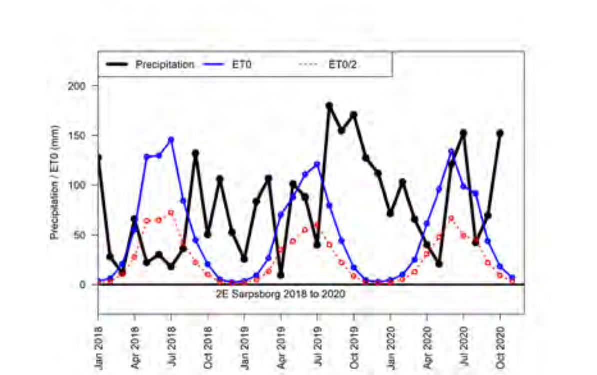
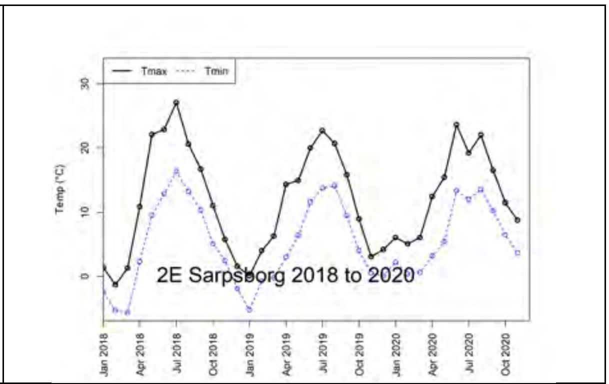


Figure 19: 2E Sarpsborg 00aFAOgrow



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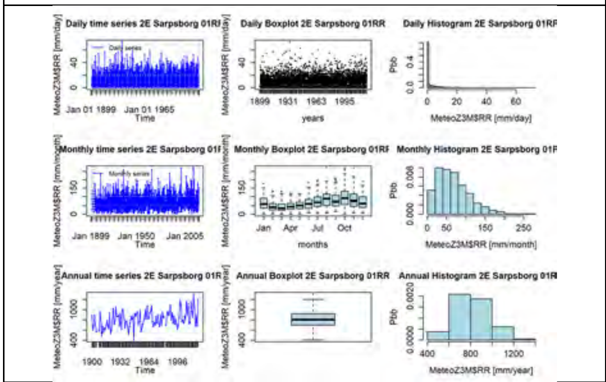
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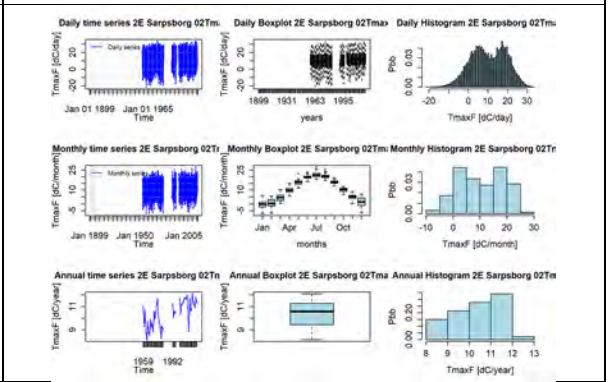
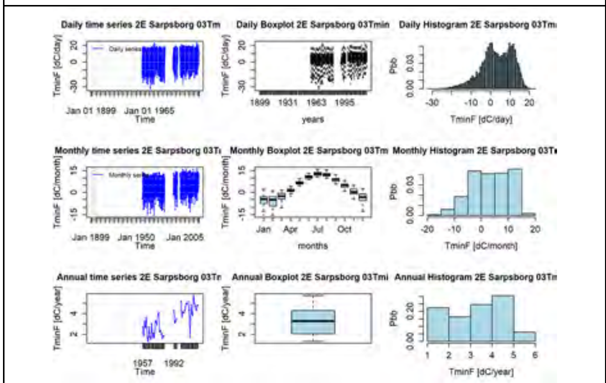


Figure 22: 2E Sarpsborg 02Tmaxhyplo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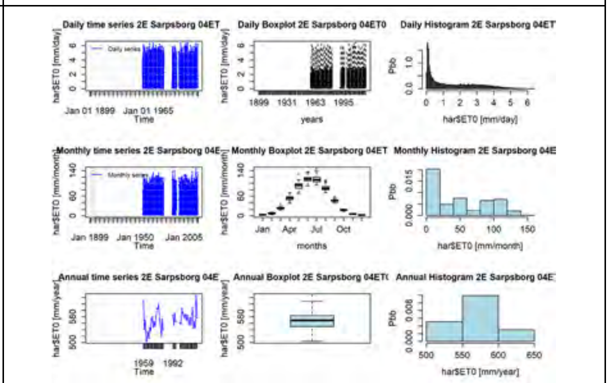
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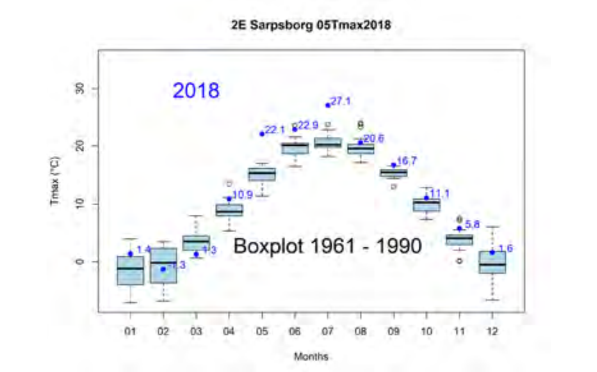


Figure 25: 2E Sarpsborg 05Tmax2018box

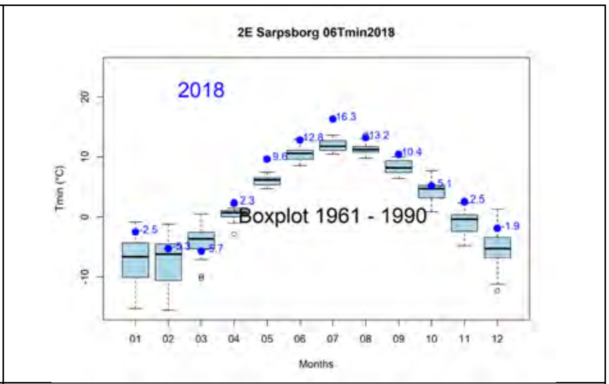


Figure 26: 2E Sarpsborg 06Tmin2018box

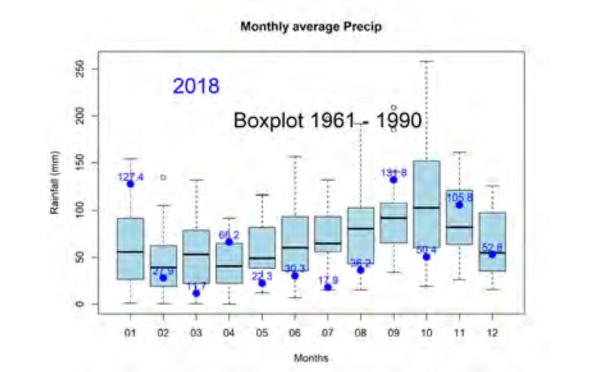
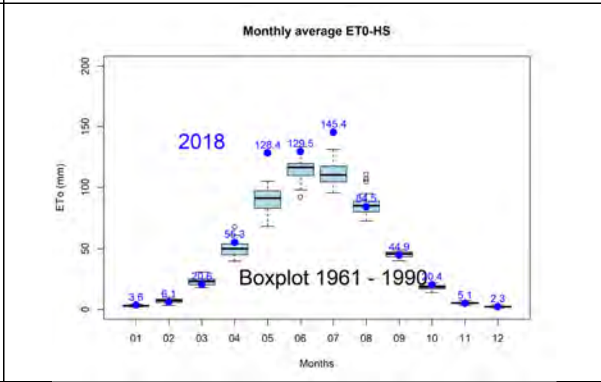


Figure 27: 2E Sarpsborg 07Precip2018box



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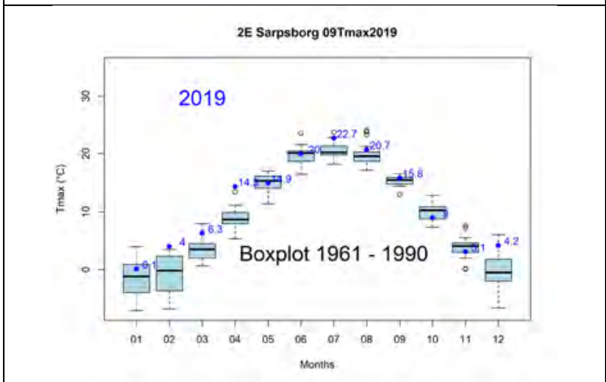

Figure 29: 2E Sarpsborg 09Tmax2019box

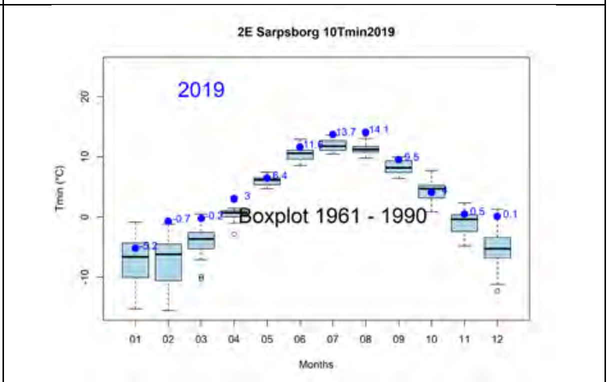

Figure 30: 2E Sarpsborg 10Tmin2019box

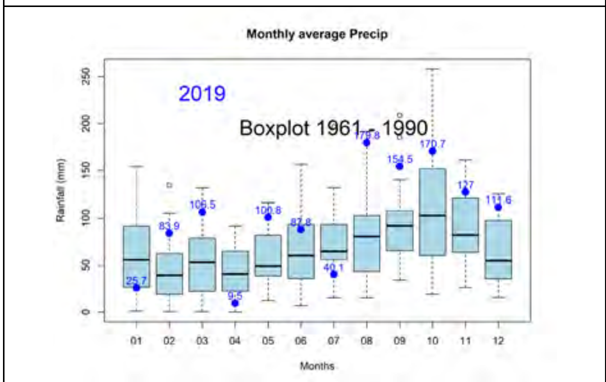

Figure 31: 2E Sarpsborg 11Precip2019box

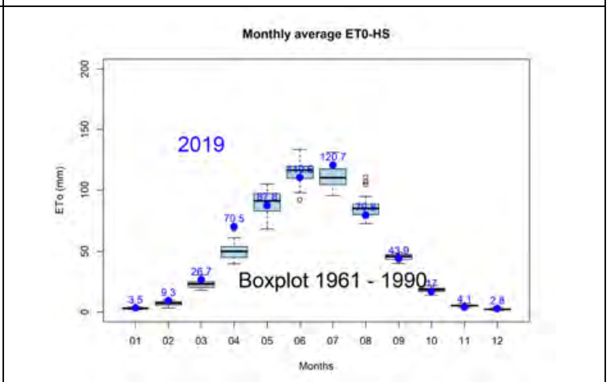

Figure 32: 2E Sarpsborg 12ET02019box

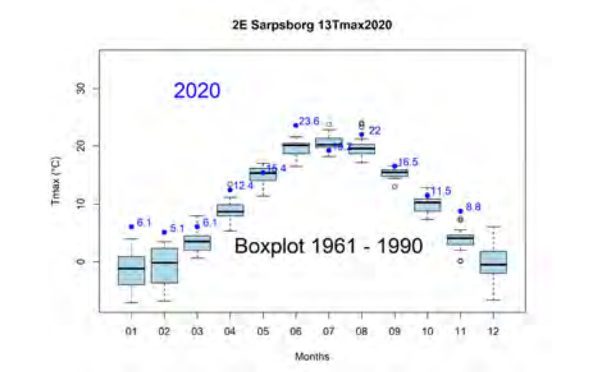

Figure 33: 2E Sarpsborg 13Tmax2020box

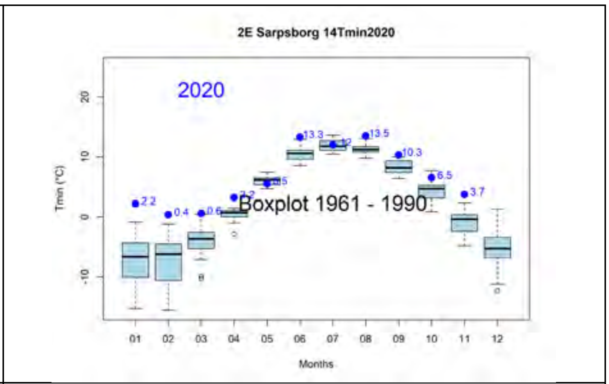

Figure 34: 2E Sarpsborg 14Tmin2020box

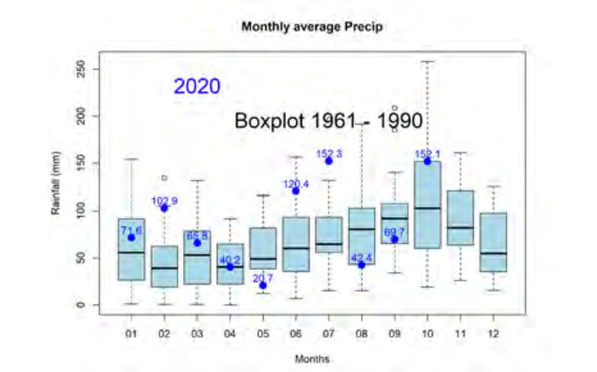

Figure 35: 2E Sarpsborg 15Precip2020box

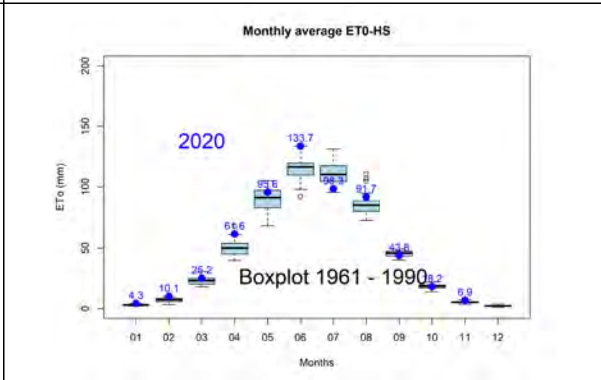

Figure 36: 2E Sarpsborg 16ET02020box

2Ec Roverud (ECAD 18033)

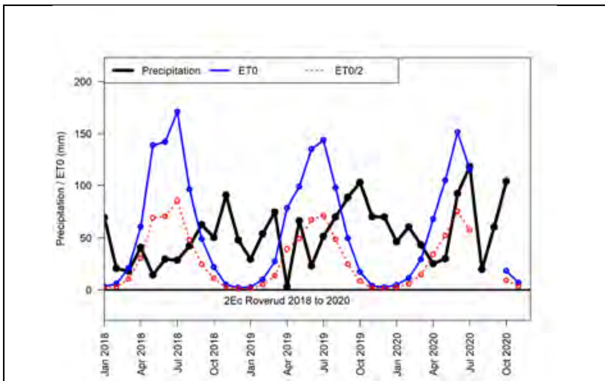

Figure 37: 2Ec Roverud 00aFAOgrow

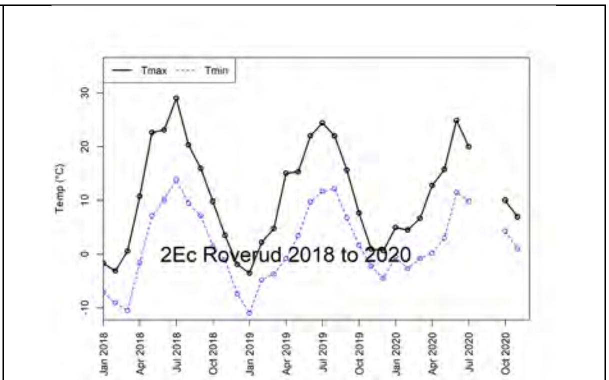

Figure 38: 2Ec Roverud 00b TnTx

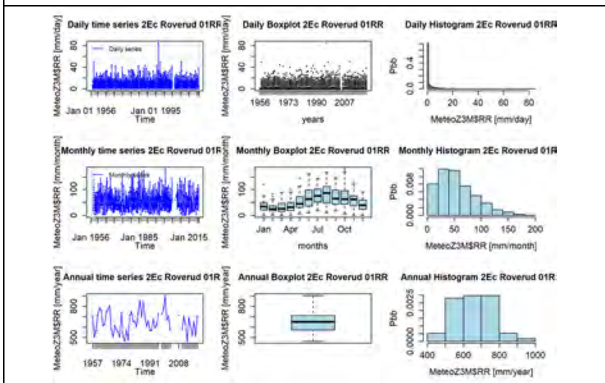

Figure 39: 2Ec Roverud 01RRhyplo

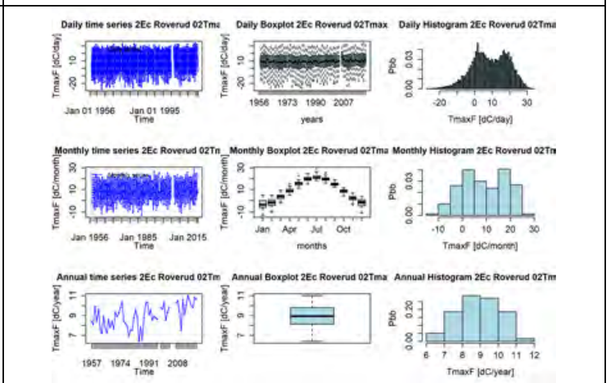

Figure 40: 2Ec Roverud 02Tmaxhyplo

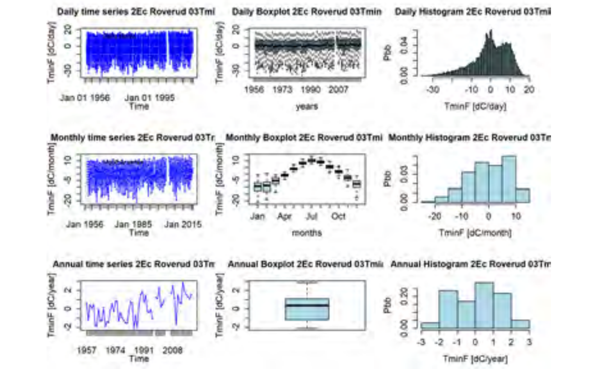

Figure 41: 2Ec Roverud 03Tminhyplo

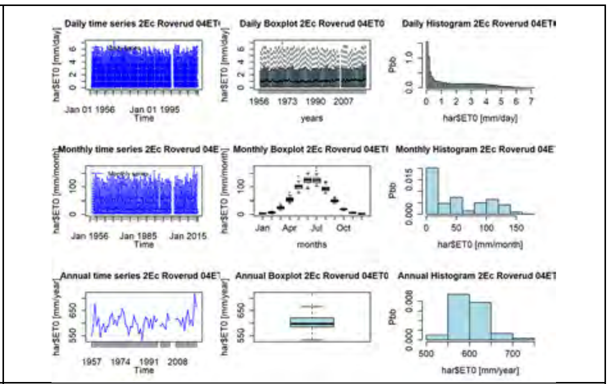

Figure 42: 2Ec Roverud 04ET0hyplo

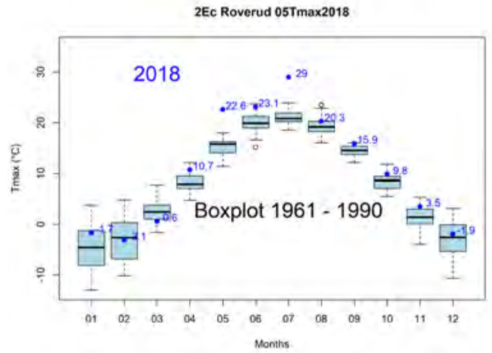

Figure 43: 2Ec Roverud 05Tmax2018box

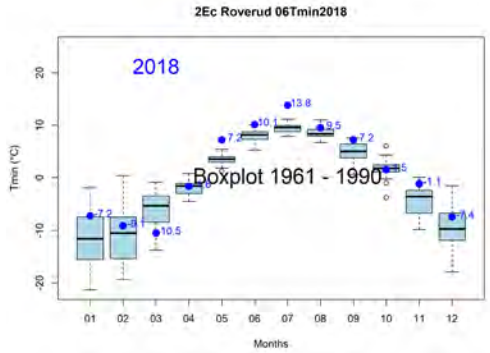

Figure 44: 2Ec Roverud 06Tmin2018box

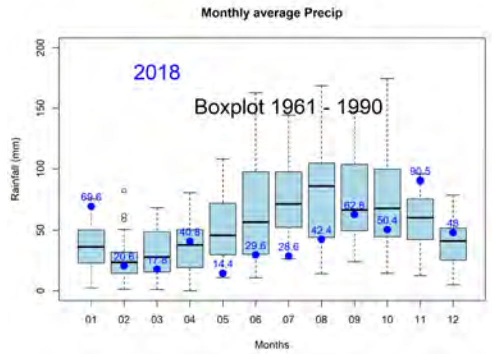

Figure 45: 2Ec Roverud 07Precip2018box

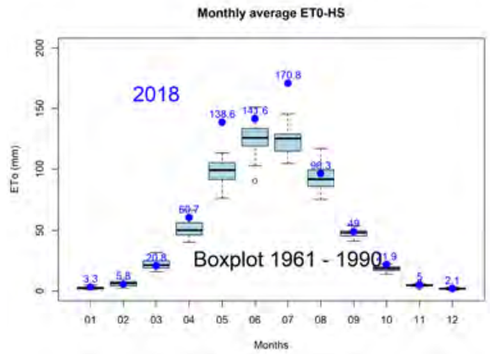

Figure 46: 2Ec Roverud 08ET02018box

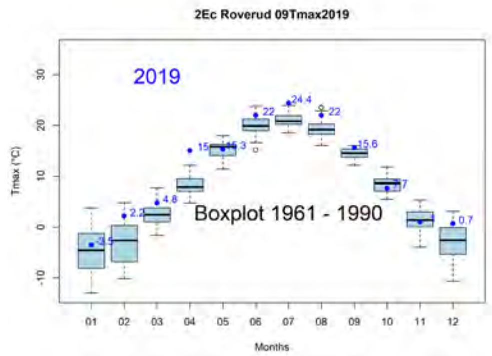

Figure 47: 2Ec Roverud 09Tmax2019box

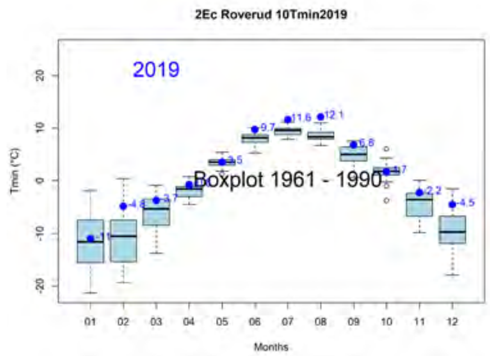

Figure 48: 2Ec Roverud 10Tmin2019box

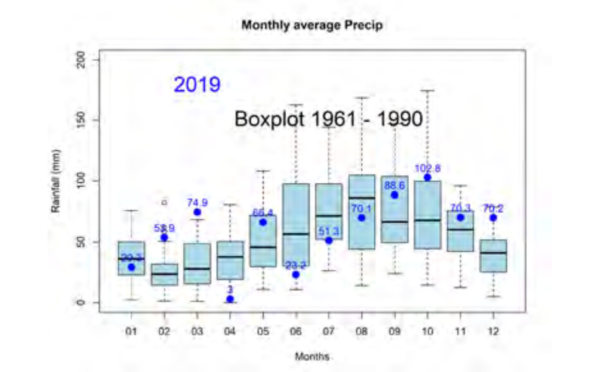

Figure 49: 2Ec Roverud 11Precip2019box

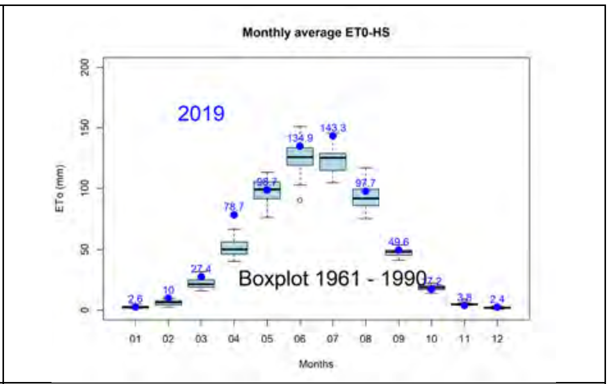

Figure 50: 2Ec Roverud 12ET02019box

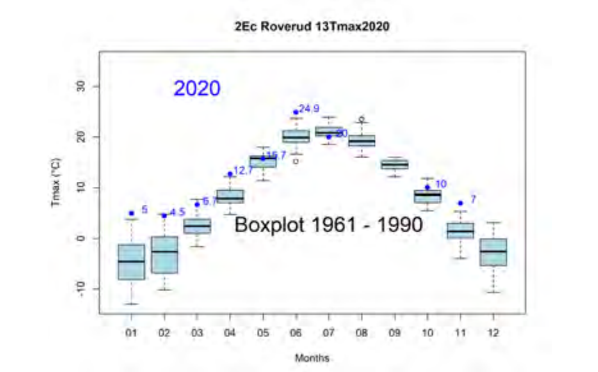

Figure 51: 2Ec Roverud 13Tmax2020box

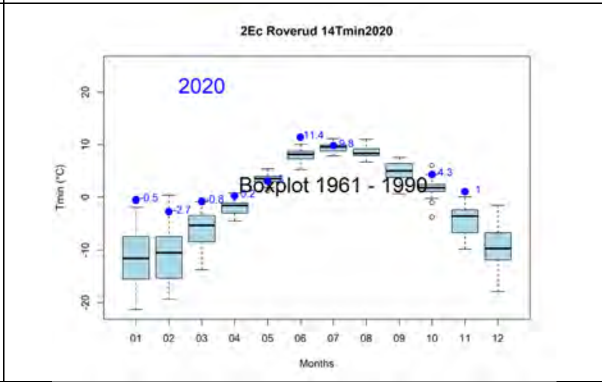

Figure 52: 2Ec Roverud 14Tmin2020box

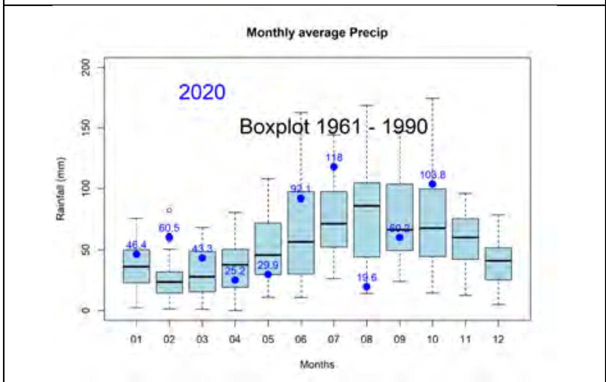

Figure 53: 2Ec Roverud 15Precip2020box

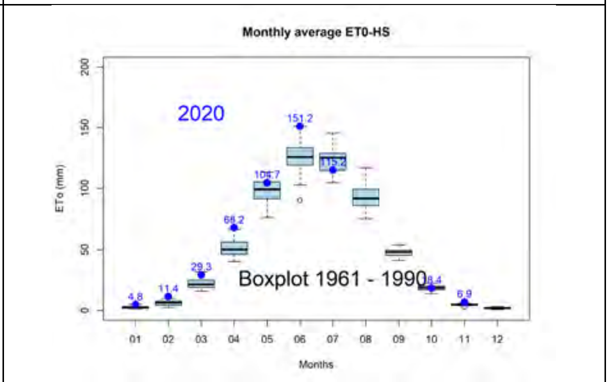

Figure 54: 2Ec Roverud 16ET02020box

3. Hungary: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1: The names for the indicators in the figures with their units and the description

Observation code	Unit	Description
ksat	cm/h	Saturated hydraulic conductivity
wsa		Water stable aggregates
bd_top	g/cm^3	Bulk density top
bd_bot	g/cm^3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorus
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in water
earthworm_no	no/m^2	Earthworm number
microb_biom_c	µgC_micg^{-1}DM	Microbial biomass carbon
crop_yield_ha	kg/ha	Crop yield
CEC	cmol+/kg	Cation Exchange Capacity

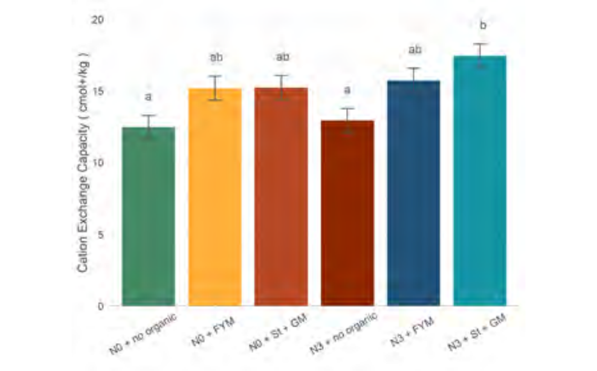

Figure 1: UP_EX1_NR_CEC

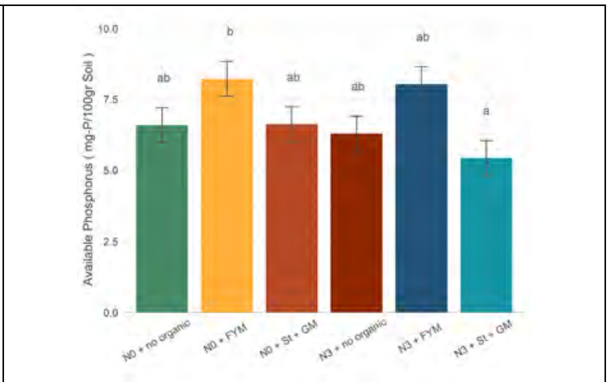

Figure 2: UP_EX1_NR_p_avail

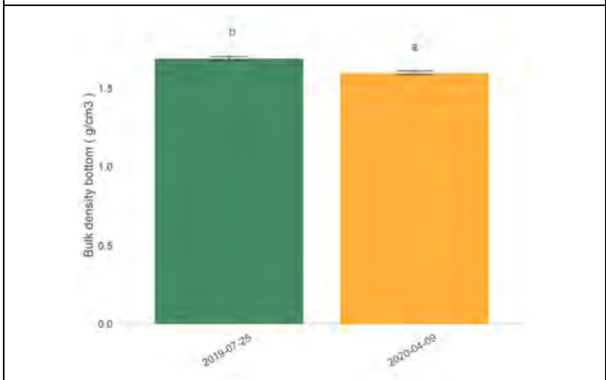

Figure 3: UP_EX1_NSI_date_bd_bot

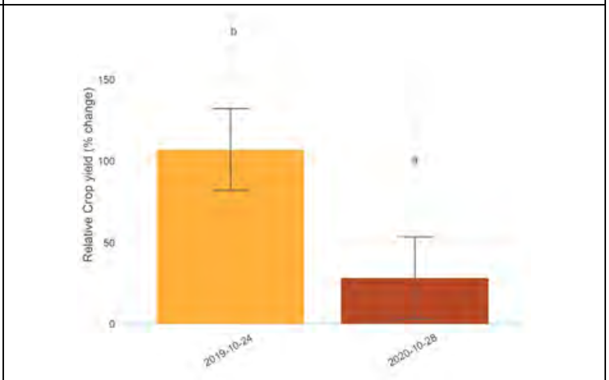

Figure 4: UP_EX1_NSI_date_crop_yield_ha

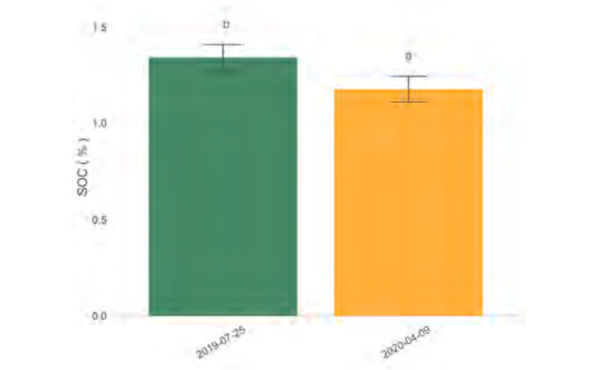

Figure 5: UP_EX1_NSI_date_soc

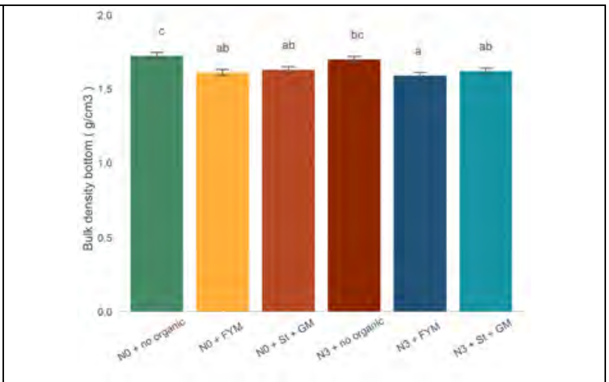

Figure 6: UP_EX1_NSI_treat_bd_bot

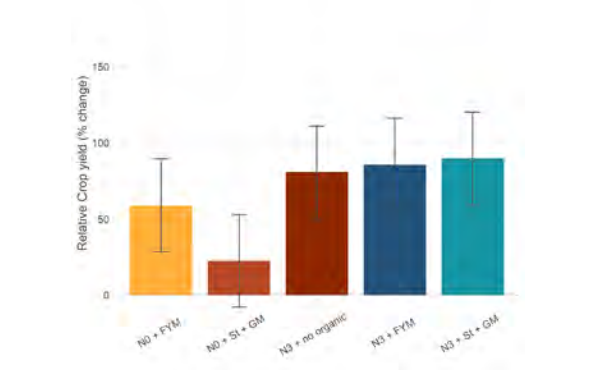

Figure 7: UP_EX1_NSI_treat_crop_yield_ha

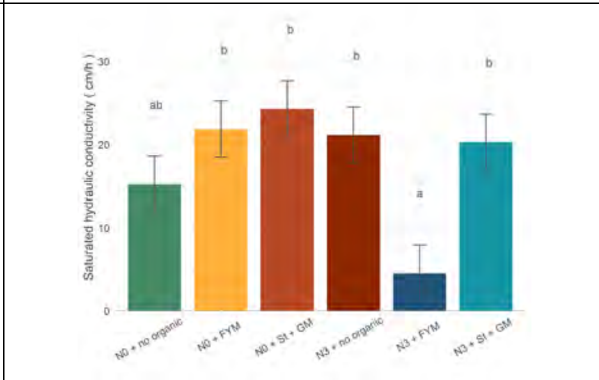

Figure 8: UP_EX1_NSI_treat_ksat

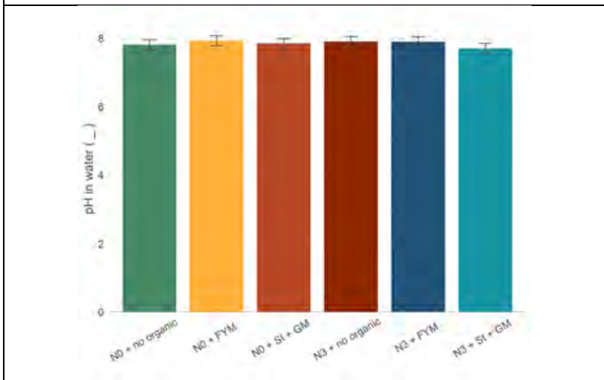

Figure 9: UP_EX1_NSI_treat_ph_h2o

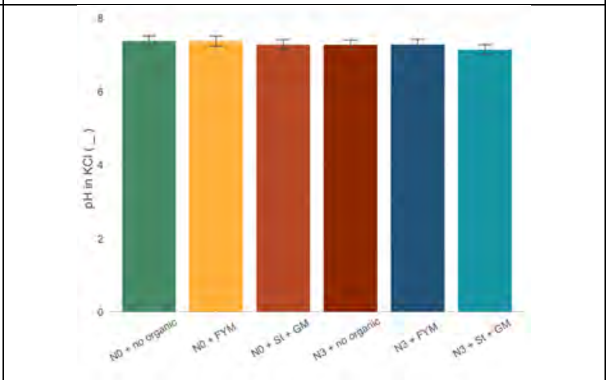

Figure 10: UP_EX1_NSI_treat_ph_kcl

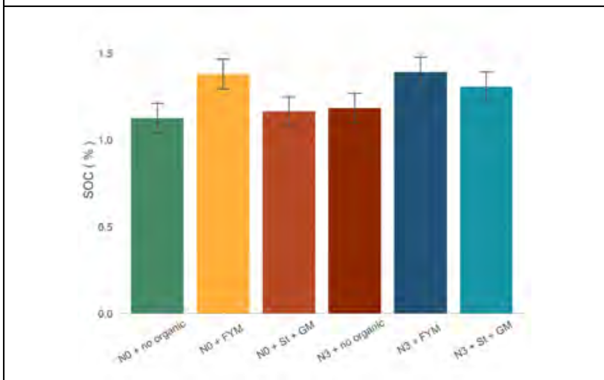

Figure 11: UP_EX1_NSI_treat_soc

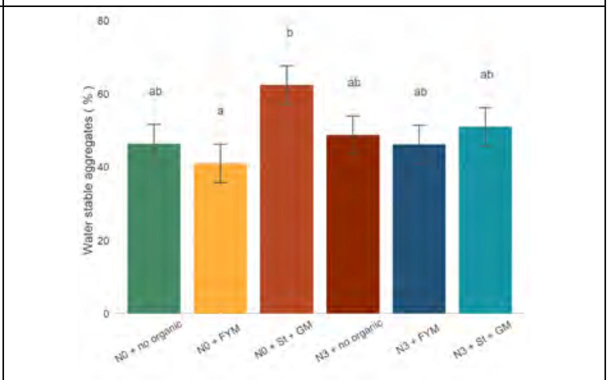

Figure 12: UP_EX1_NSI_treat_wsa

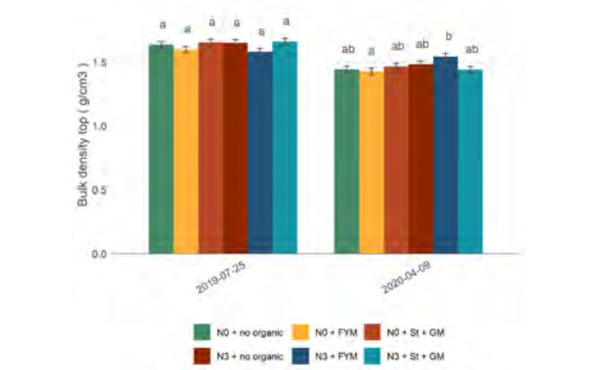

Figure 13: UP_EX1_SI_bd_top

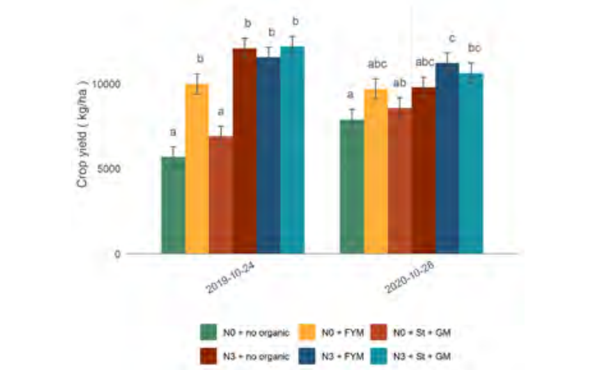

Figure 14: UP_EX1_SI_crop_yield_ha

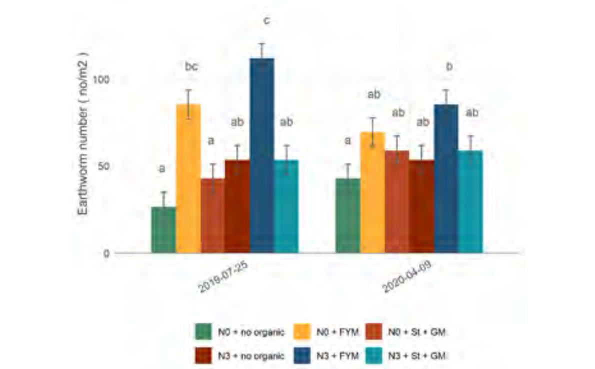

Figure 15: UP_EX1_SI_earthworm_no

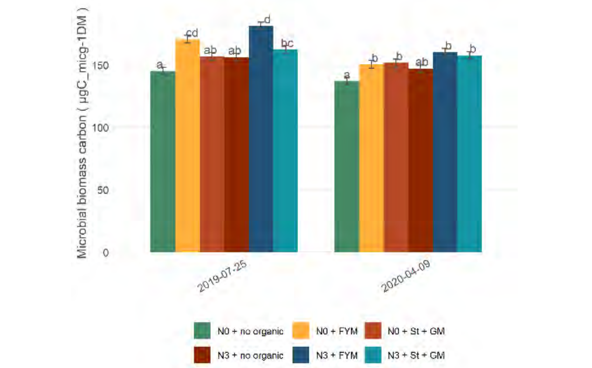

Figure 16: UP_EX1_SI_microb_biom_c

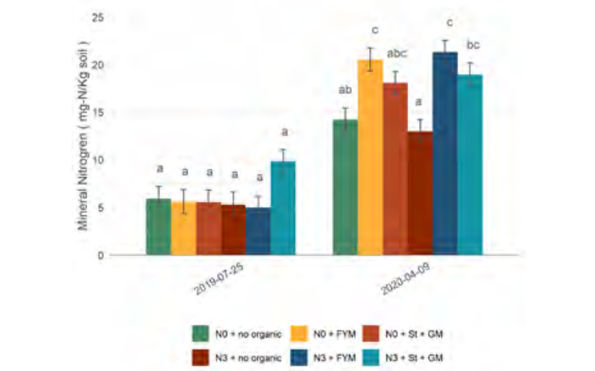

Figure 17: UP_EX1_SI_nmin_top

3. Hungary: Figures from the analysis

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For the interpretation please read the introduction to D5.3

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4E Szombathely (ECAD 2042)

The meteorological station Szombathely has data starting in 1900 till now. Unfortunately the temperature appear to be erroneous and are likely a mixture of average, maximum and minimum temperature in the series.

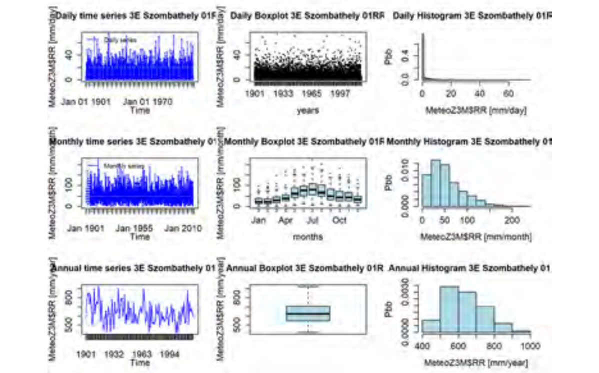

Figure 1: 3E Szombathely 01RRhyplo

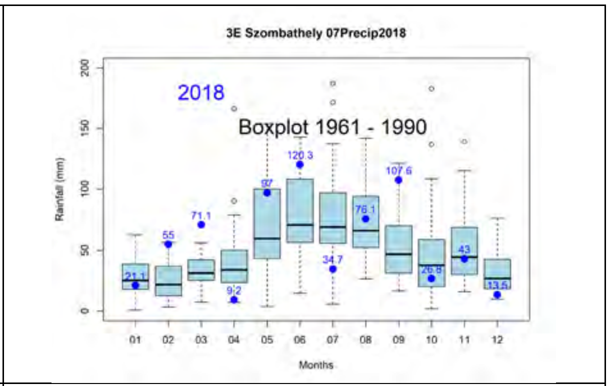

Figure 2: 3E Szombathely 07Precip2018box

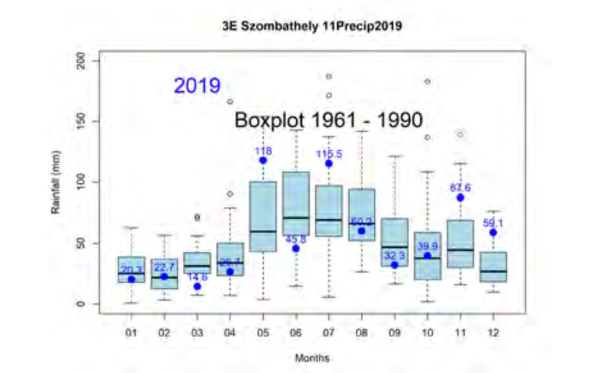

Figure 3: 3E Szombathely 11Precip2019box

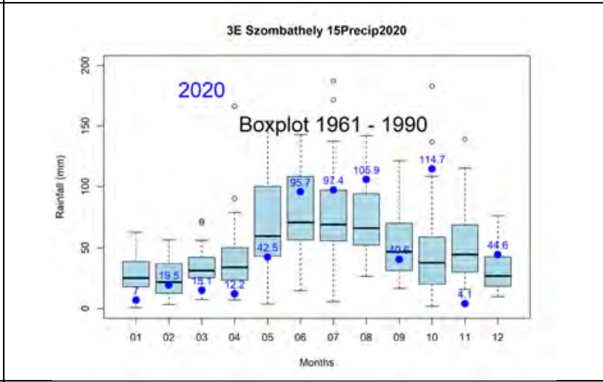

Figure 4: 3E Szombathely 15Precip2020box

4a Keszthely

Local meteorological data close to the experimental fields have observations from 2006 till now.

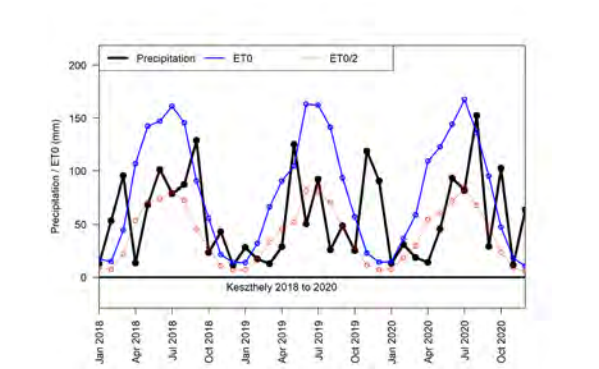

Figure 5: 3aKeszthely 00aFAOgrow

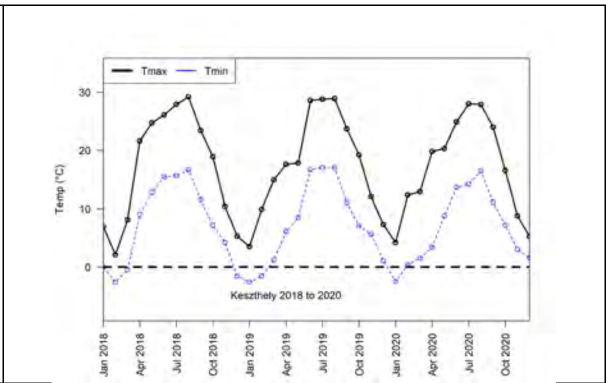

Figure 6: 3aKeszthely 00bTnTx

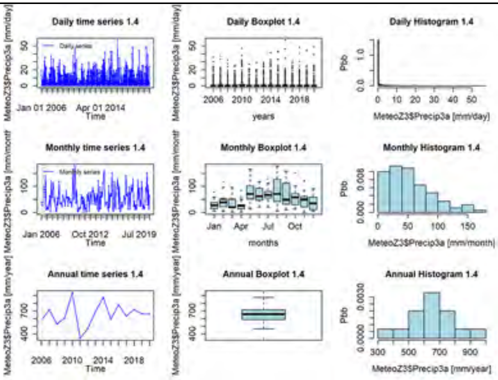

Figure 7: 3aKeszthely 01PrecHyplo

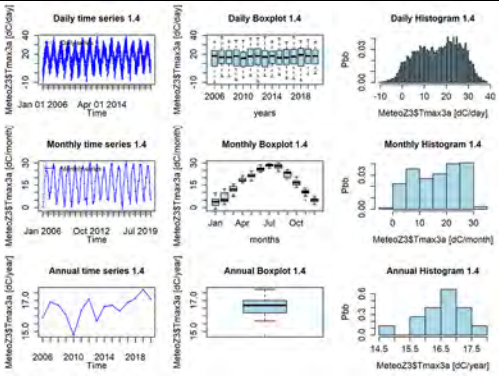

Figure 8: 3aKeszthely 02TmaxHyplo

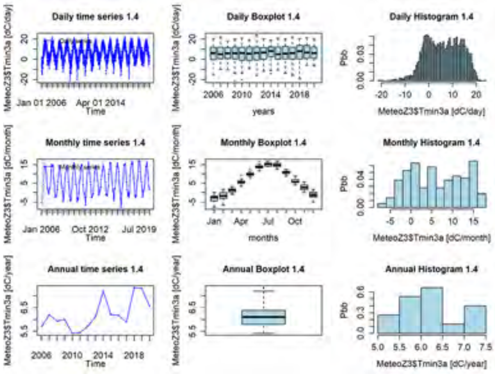

Figure 9: 3aKeszthely 03TminHyplo

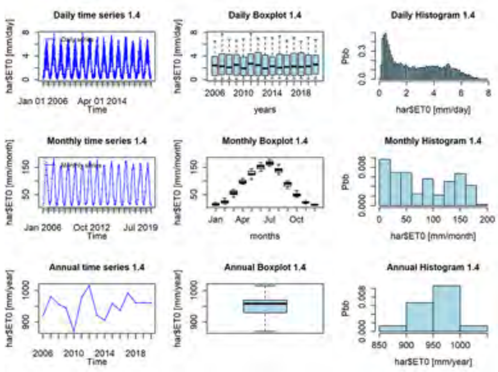

Figure 10: 3aKeszthely 04ET0Hyplo

4.Switzerland: Figures from the analysis

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For experiments without replicated treatments, the **dashed lines** mean the standard deviation of the measurements within the same plot. Those can not be used for Groupwise comparison of treatments.

Table of Figures

Experiment 2:

Observation code	Unit	Description
ksat	cm s^{-1}	Ksat
top_wc_pf2_0	m3m-3	Water content-FC
top_wc_pf4_2	m3m-3	Water content-PWP
top_wc_pf2_7	m3m-3	Water content-pF2.7
top_wc_pf_1_8	m3m-3	Water content-pF1.8
top_satur_wc	m3m-3	Water content-Saturation
wsa	%	Water Stable Aggregates
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
weed_infestation	%	Weed infestation
crop_yield_ha	kg/ha	Crop yield

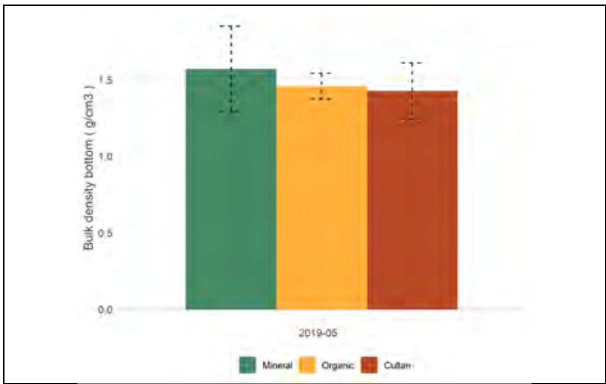

Figure 1: UNIBE_EX2_FD3_bd_bot

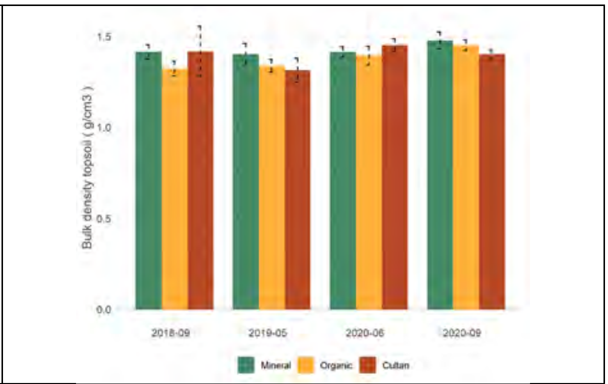

Figure 2: UNIBE_EX2_FD3_bd_top

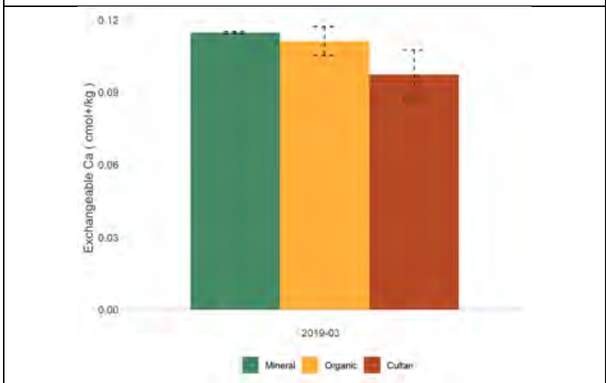

Figure 3: UNIBE_EX2_FD3_ca2_plus

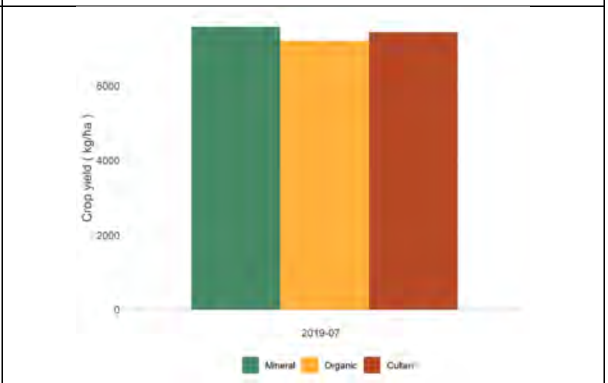

Figure 4: UNIBE_EX2_FD3_crop_yield_ha

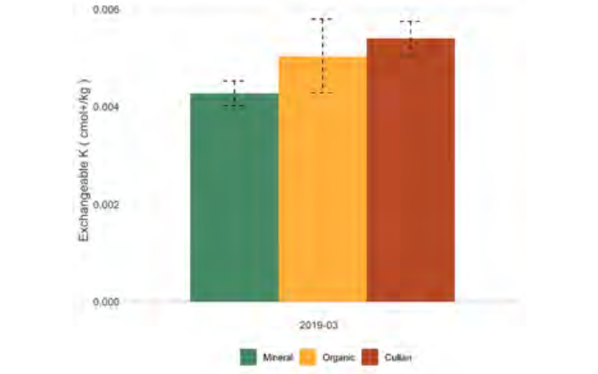

Figure 5: UNIBE_EX2_FD3_k_plus

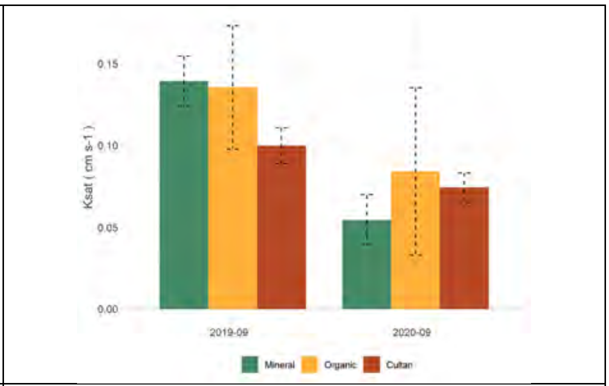

Figure 6: UNIBE_EX2_FD3_ksat

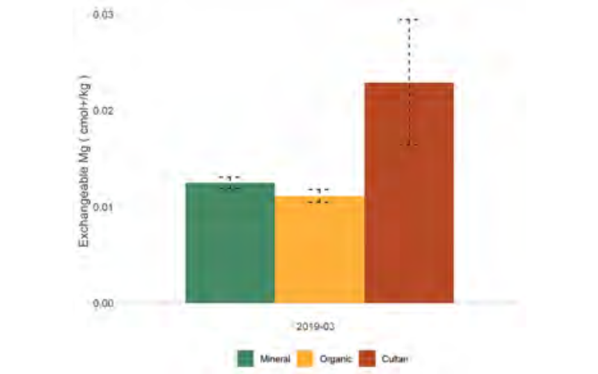

Figure 7: UNIBE_EX2_FD3_mg2plus

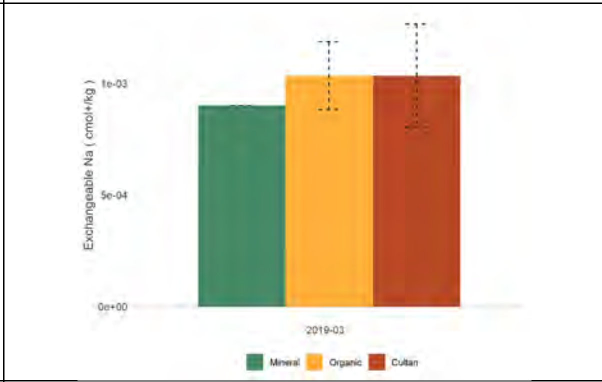

Figure 8: UNIBE_EX2_FD3_na_plus

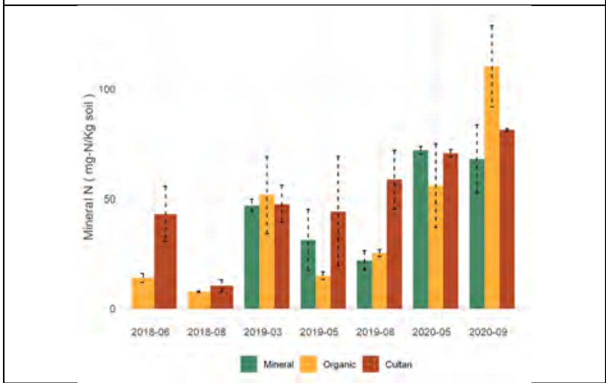

Figure 9: UNIBE_EX2_FD3_nmin_top

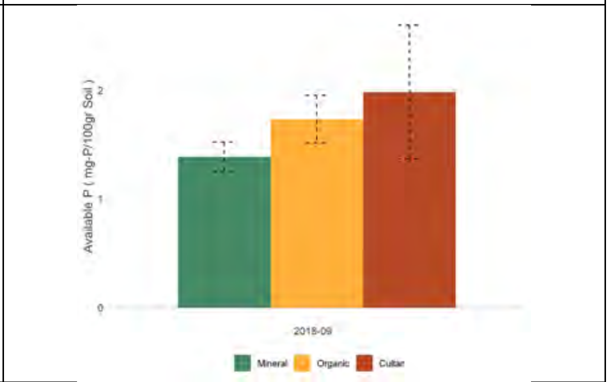

Figure 10: UNIBE_EX2_FD3_p_avail

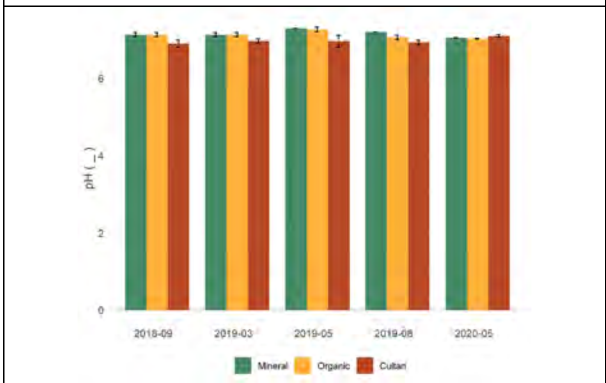

Figure 11: UNIBE_EX2_FD3_ph_h2o

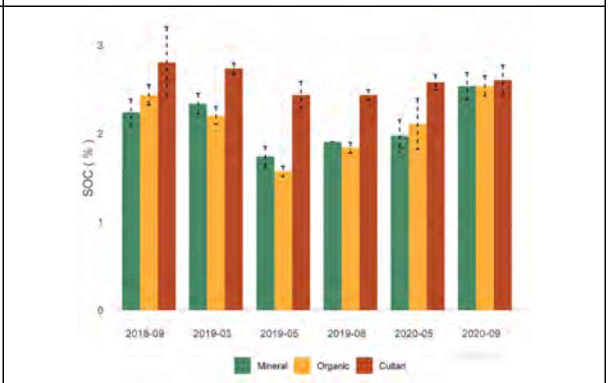

Figure 12: UNIBE_EX2_FD3_soc

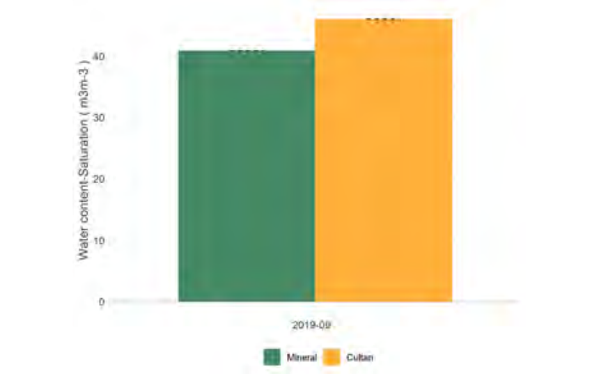

Figure 13: UNIBE_EX2_FD3_top_satur_wc

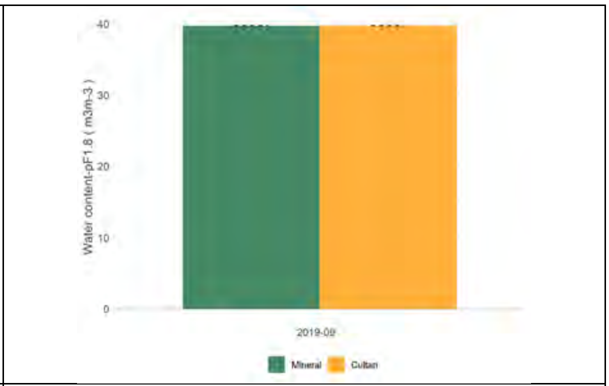

Figure 14: UNIBE_EX2_FD3_top_wc_pf_1_8

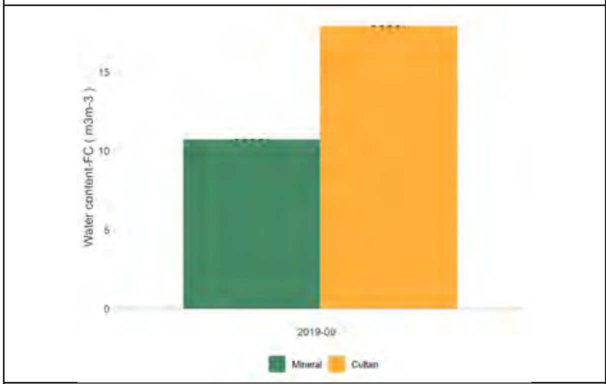

Figure 15: UNIBE_EX2_FD3_top_wc_pf2_0

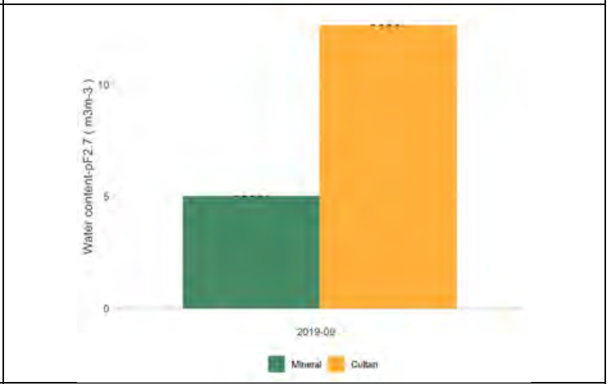

Figure 16: UNIBE_EX2_FD3_top_wc_pf2_7

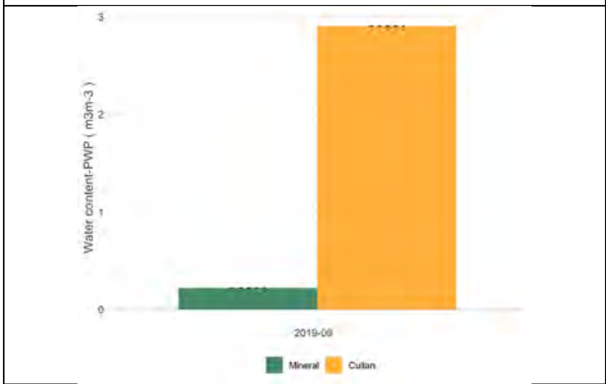

Figure 17: UNIBE_EX2_FD3_top_wc_pf4_2

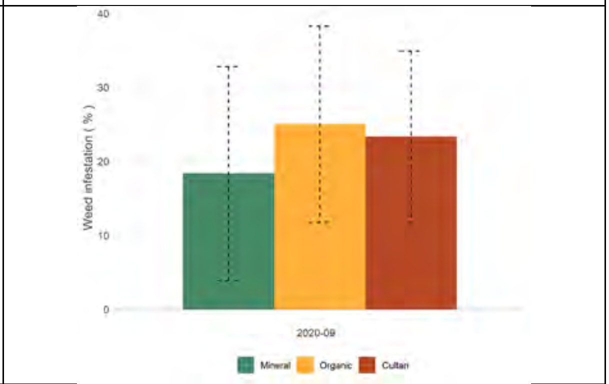

Figure 18: UNIBE_EX2_FD3_weed_infestation

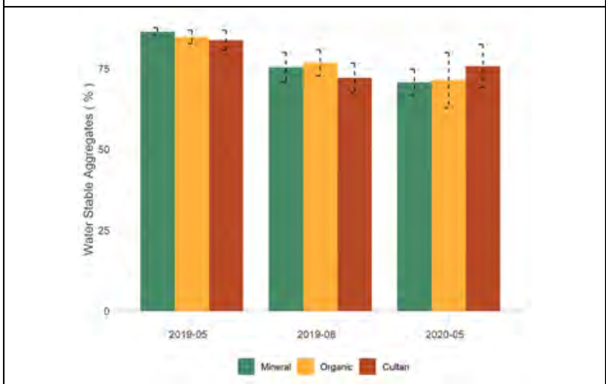

Figure 19: UNIBE_EX2_FD3_wsa

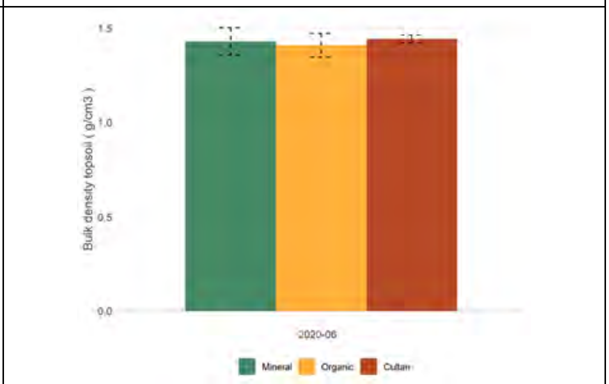

Figure 20: UNIBE_EX2_FD4_bd_top

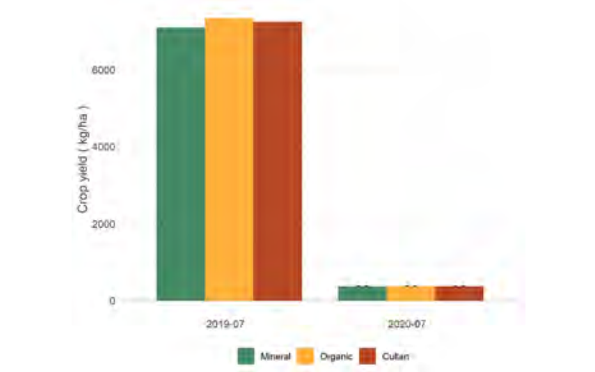

Figure 21: UNIBE_EX2_FD4_crop_yield_ha

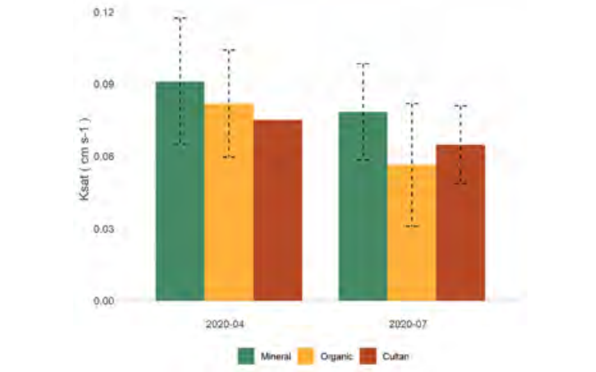

Figure 22: UNIBE_EX2_FD4_ksat

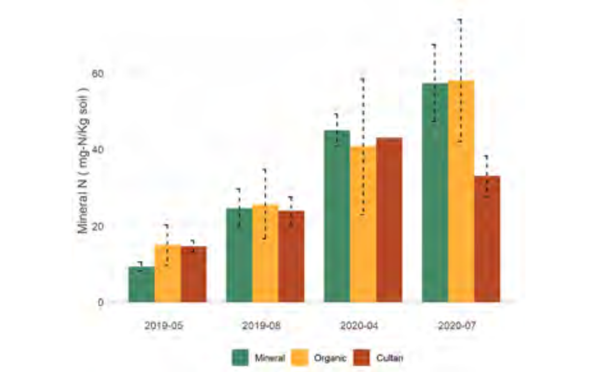

Figure 23: UNIBE_EX2_FD4_nmin_top

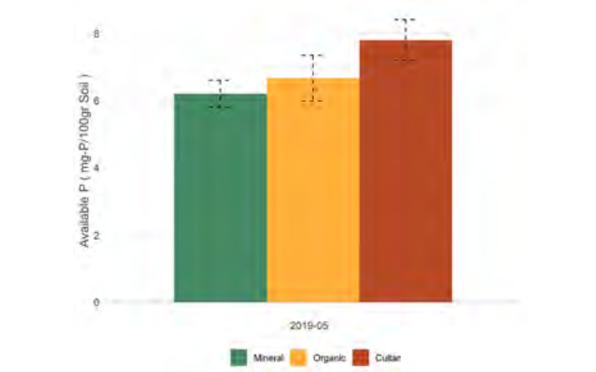

Figure 24: UNIBE_EX2_FD4_p_avail

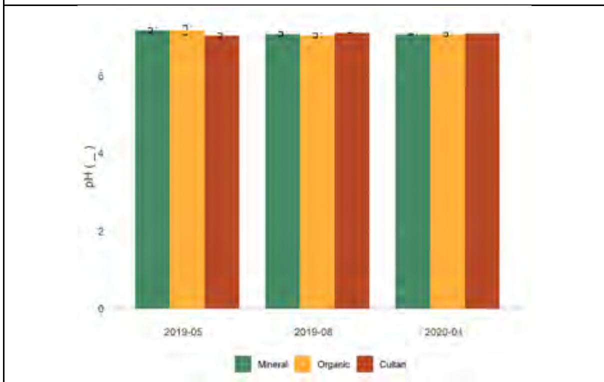

Figure 25: UNIBE_EX2_FD4_ph_h2o

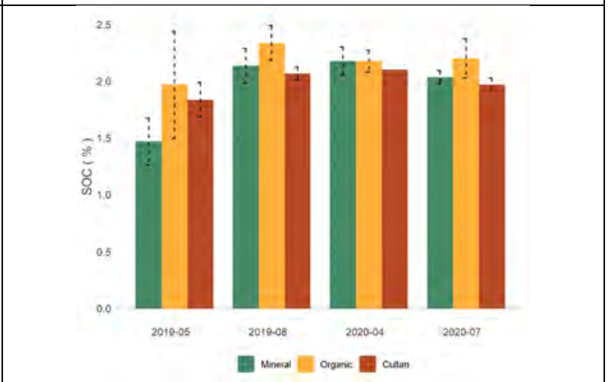

Figure 26: UNIBE_EX2_FD4_soc

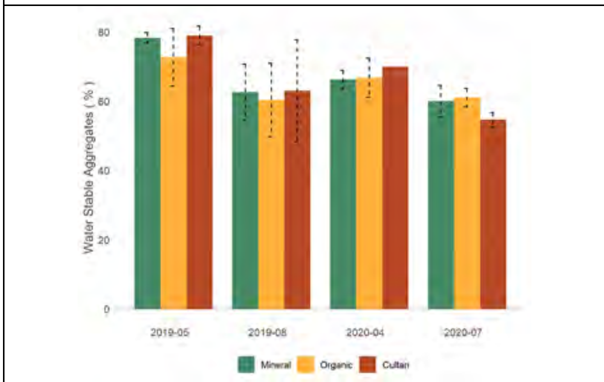

Figure 27: UNIBE_EX2_FD4_wsa

Experiment 3

Observation code	Unit	Description
ksat	cm s^{-1}	Ksat
top_wc_pf2_0	m3m-3	Water content-FC
top_wc_pf4_2	m3m-3	Water content-PWP
top_wc_pf2_7	m3m-3	Water content-pF2.7
top_wc_pf_1_8	m3m-3	Water content-pF1.8
top_satur_wc	m3m-3	Water content-Saturation
wsa	%	Water Stable Aggregates
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
weed_infestation	%	Weed infestation
crop_yield_ha	kg/ha	Crop yield

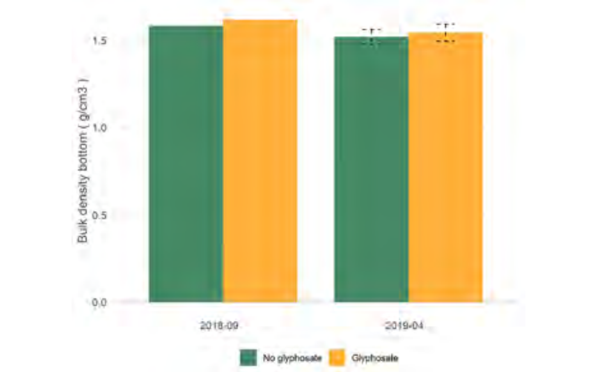

Figure 28: UNIBE_EX3_FD5_bd_bot

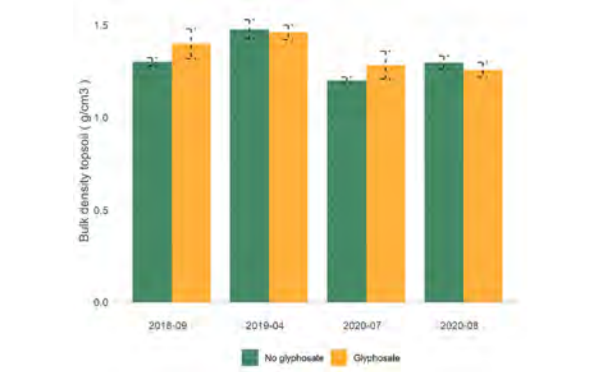

Figure 29: UNIBE_EX3_FD5_bd_top

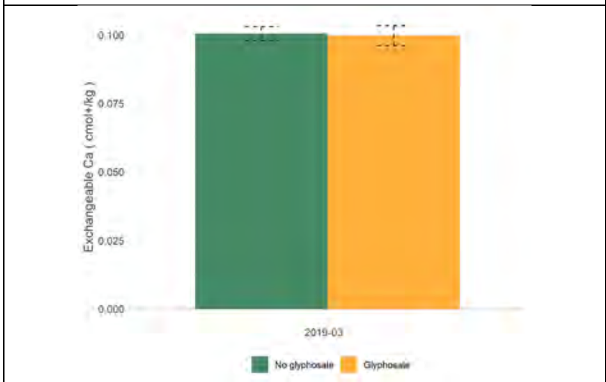

Figure 30: UNIBE_EX3_FD5_ca2_plus

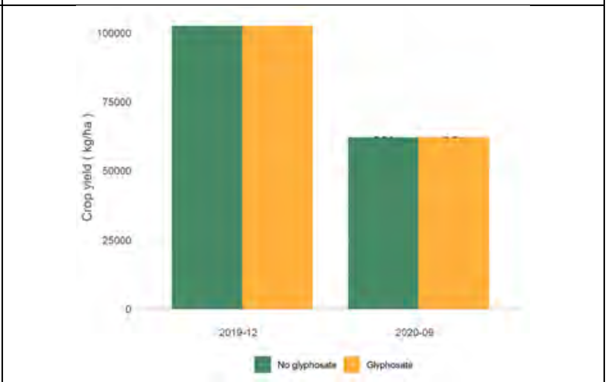

Figure 31: UNIBE_EX3_FD5_crop_yield_ha

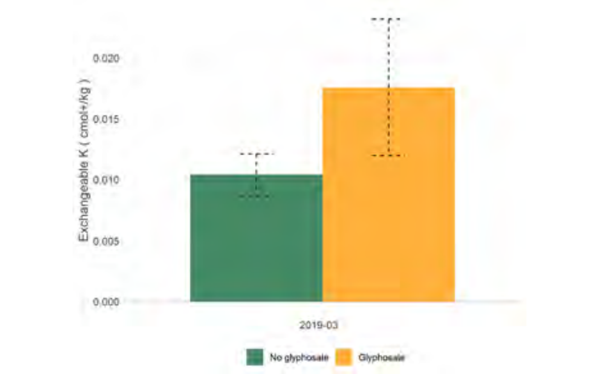

Figure 32: UNIBE_EX3_FD5_k_plus

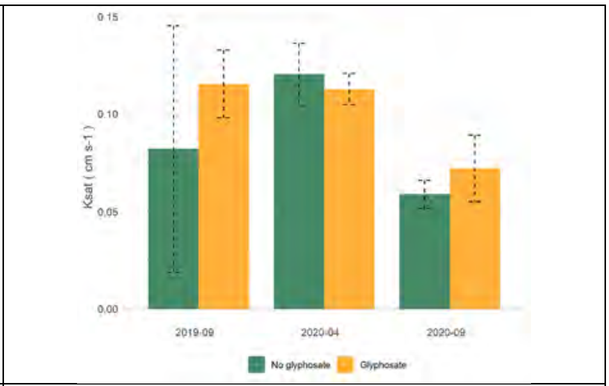

Figure 33: UNIBE_EX3_FD5_ksat

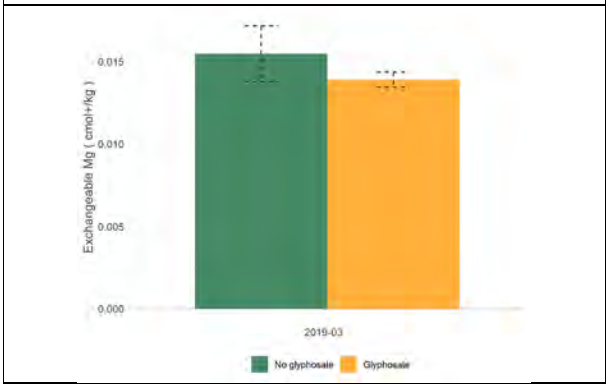

Figure 34: UNIBE_EX3_FD5_mg2plus

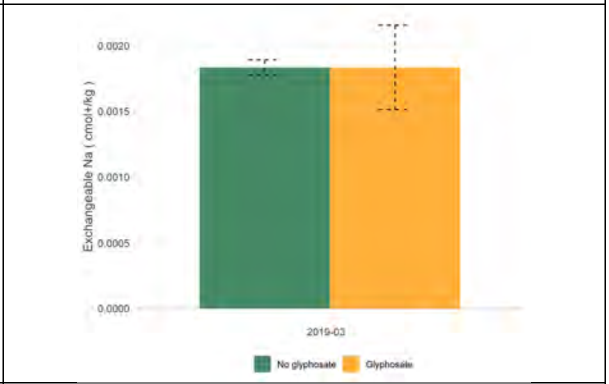

Figure 35: UNIBE_EX3_FD5_na_plus

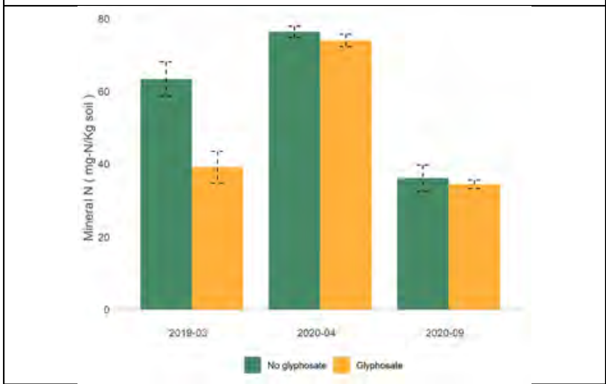

Figure 36: UNIBE_EX3_FD5_nmin_top

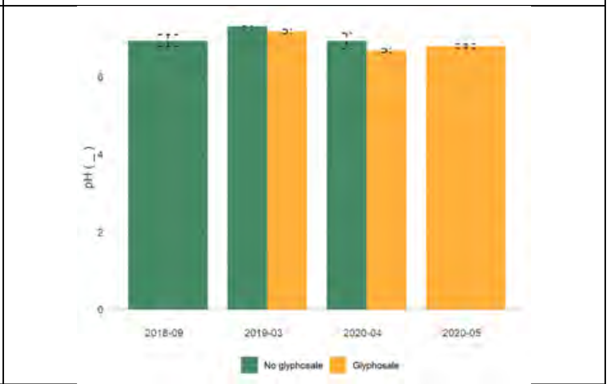

Figure 37: UNIBE_EX3_FD5_ph_h2o

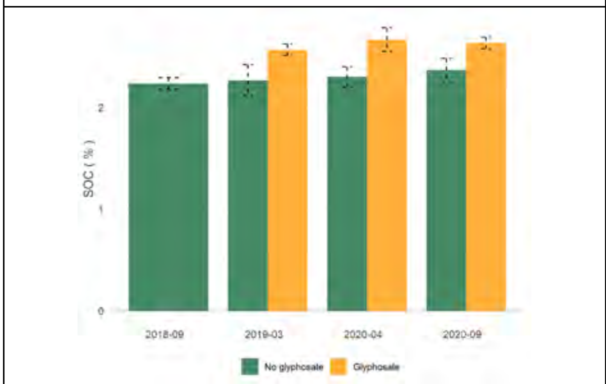

Figure 38: UNIBE_EX3_FD5_soc

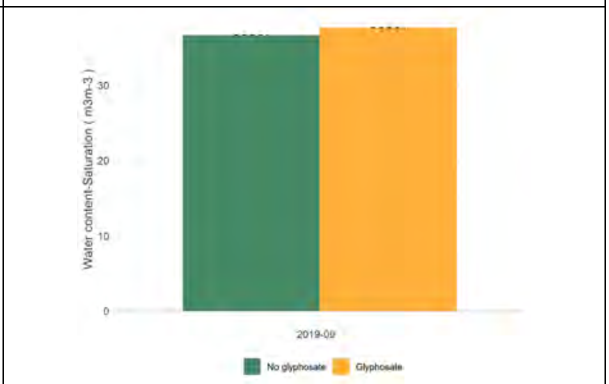

Figure 39: UNIBE_EX3_FD5_top_satur_wc

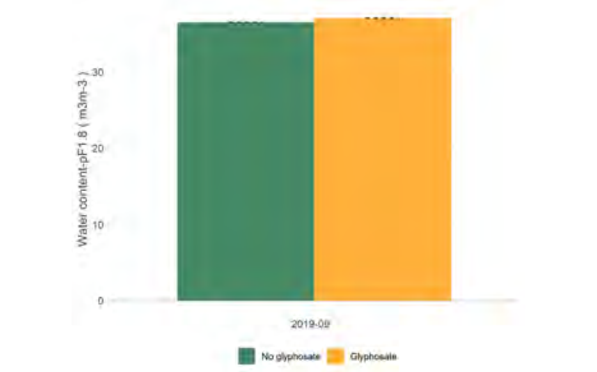

Figure 40: UNIBE_EX3_FD5_top_wc_pf_1_8

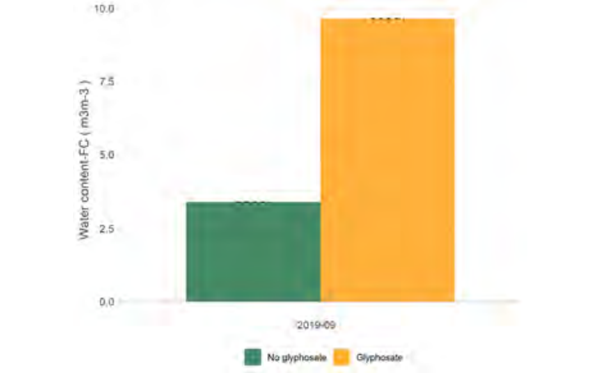

Figure 41: UNIBE_EX3_FD5_top_wc_pf2_0

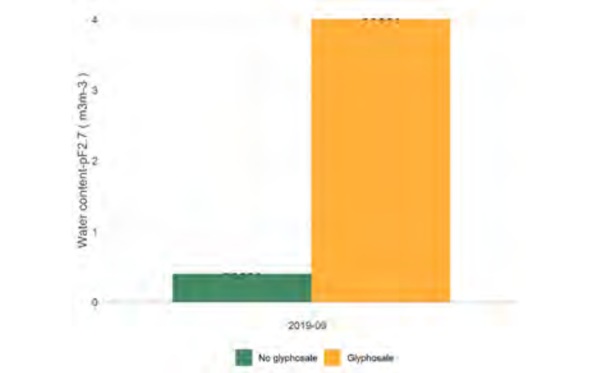

Figure 42: UNIBE_EX3_FD5_top_wc_pf2_7

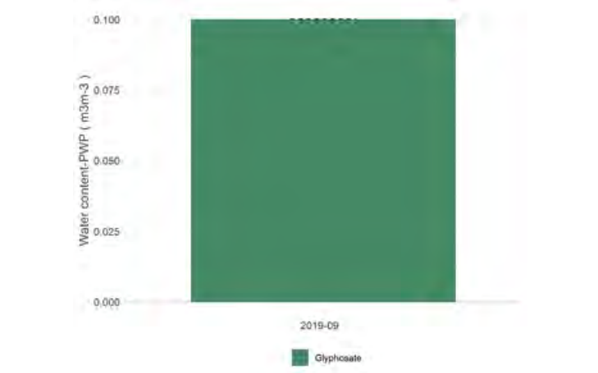

Figure 43: UNIBE_EX3_FD5_top_wc_pf4_2

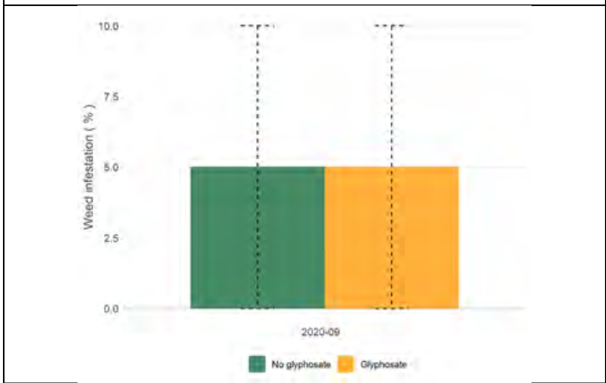

Figure 44: UNIBE_EX3_FD5_weed_infestation

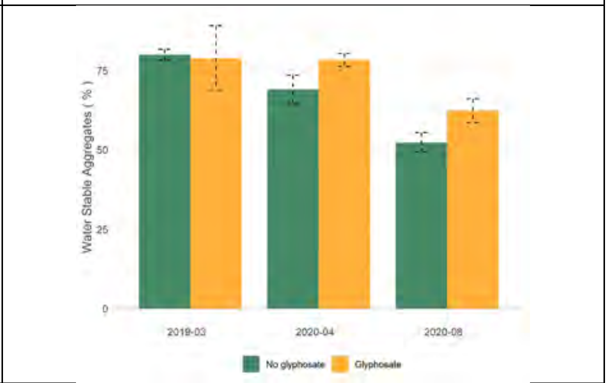

Figure 45: UNIBE_EX3_FD5_wsa

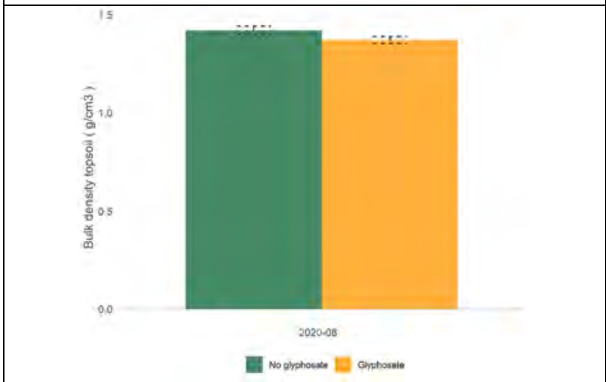

Figure 46: UNIBE_EX3_FD6_bd_top

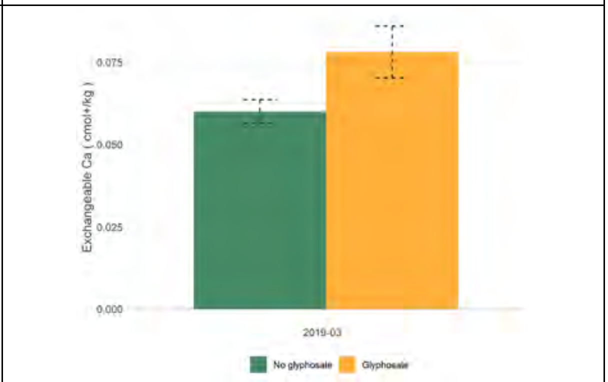

Figure 47: UNIBE_EX3_FD6_ca2_plus

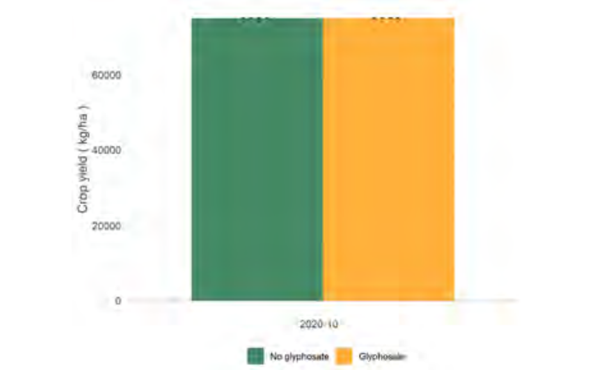

Figure 48: UNIBE_EX3_FD6_crop_yield_ha

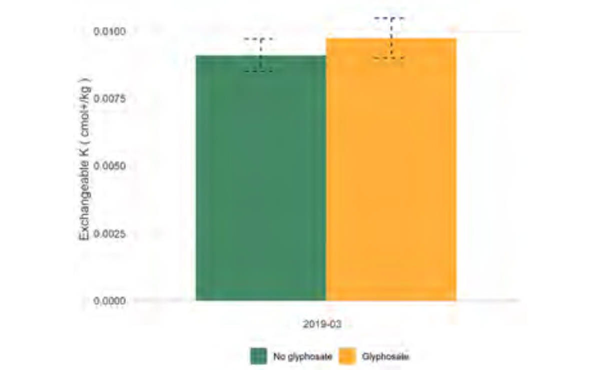

Figure 49: UNIBE_EX3_FD6_k_plus

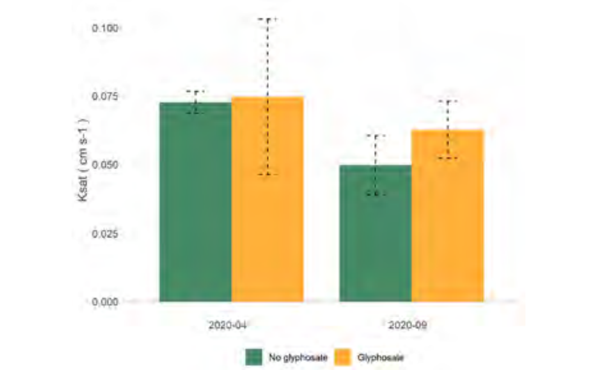

Figure 50: UNIBE_EX3_FD6_ksat

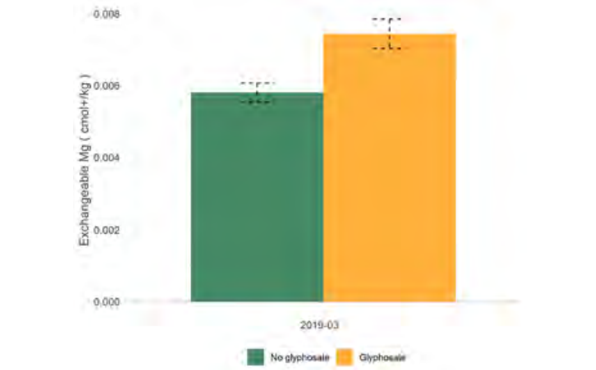

Figure 51: UNIBE_EX3_FD6_mg2plus

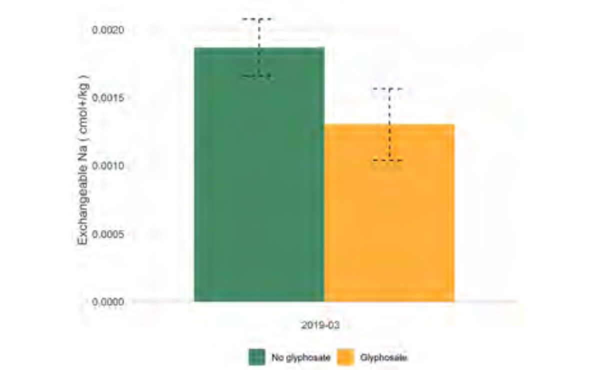

Figure 52: UNIBE_EX3_FD6_na_plus

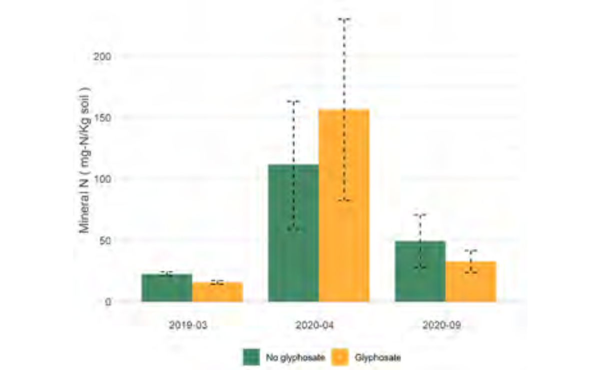

Figure 53: UNIBE_EX3_FD6_nmin_top

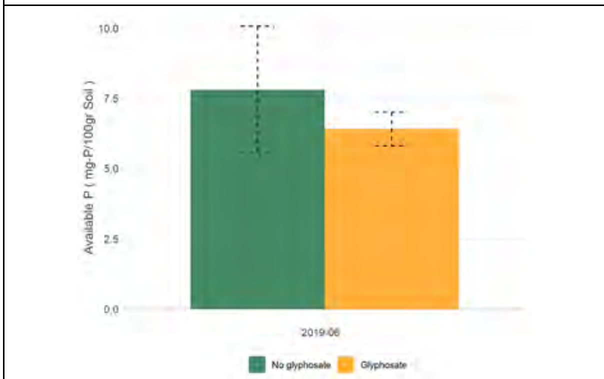

Figure 54: UNIBE_EX3_FD6_p_avail

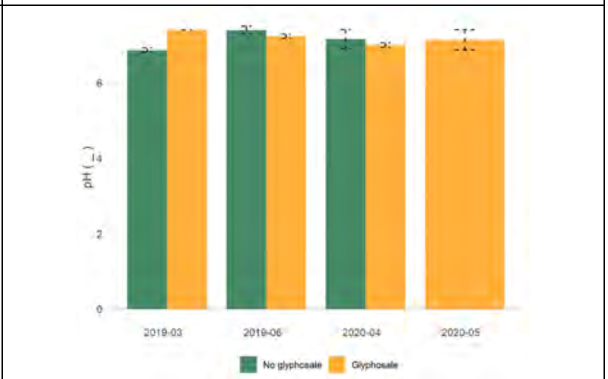

Figure 55: UNIBE_EX3_FD6_ph_h2o

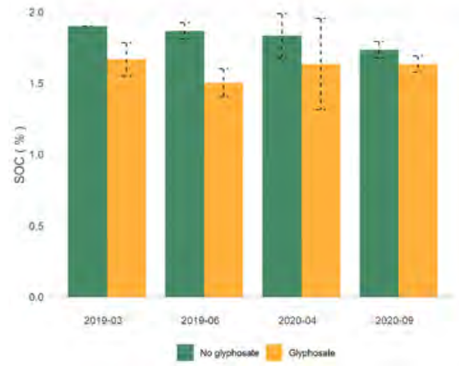	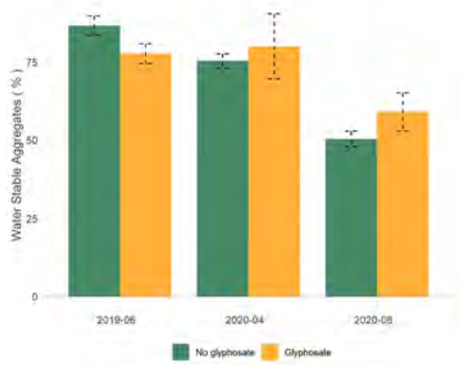
Figure 56: UNIBE_EX3_FD6_soc	*Figure 57: UNIBE_EX3_FD6_wsa*

4. Switzerland: Figures from the meteorological analysis

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For the interpretation of the meteorological figures please consult the introduction to D5.3.

Table of Figures

4E Konstanz (ECAD 495)

This German station is at 25 km from Frauenfeld and has measurements in ECAD starting in 1947 until 30 November 2020. Most Swiss stations in ECAD are at a larger distance. The station is situated at 443 m ASL near the Bodensee which has a level around 395m.

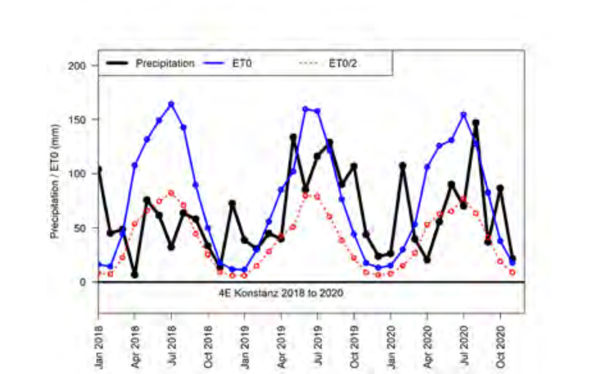

Figure 1: 4E Konstanz 00aFAOgrow

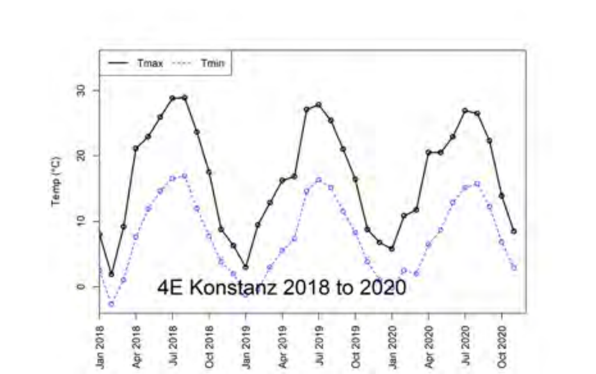

Figure 2: 4E Konstanz 00b TnTx

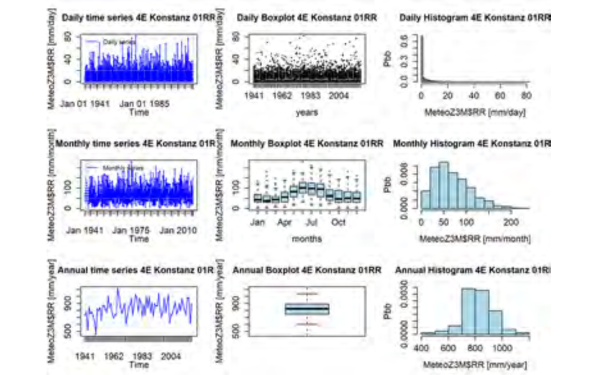

Figure 3: 4E Konstanz 01RRhyplo

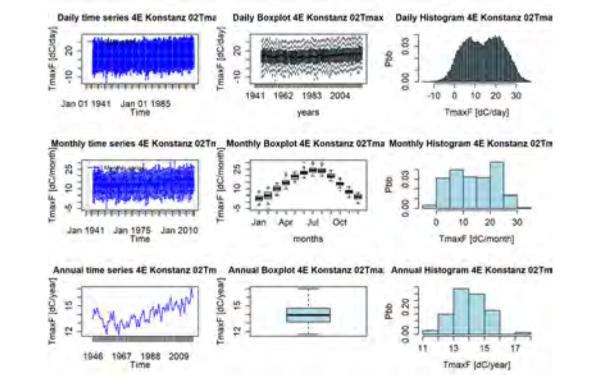

Figure 4: 4E Konstanz 02Tmaxhyplo

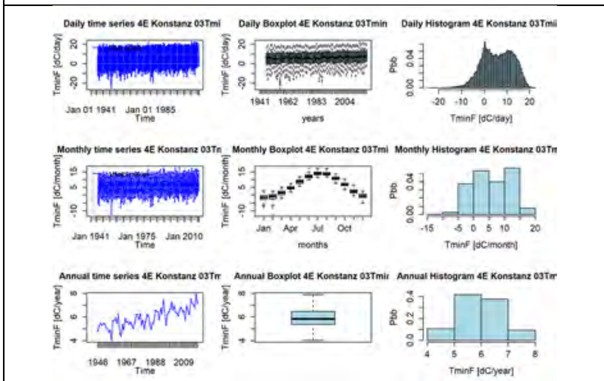

Figure 5: 4E Konstanz 03Tminhyplo

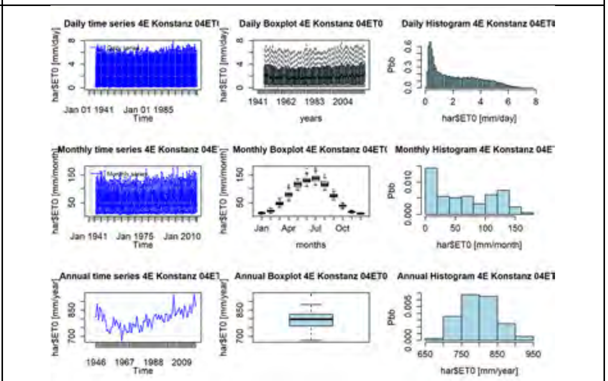

Figure 6: 4E Konstanz 04ET0hyplo

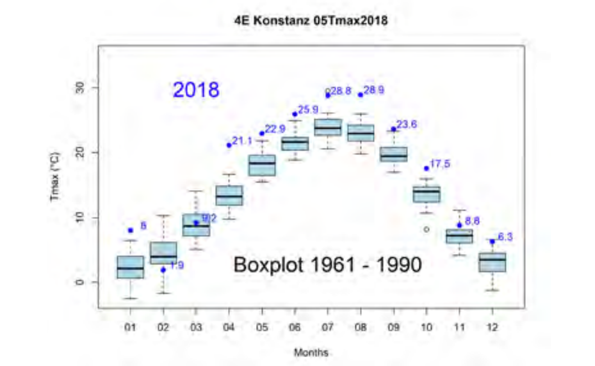

Figure 7: 4E Konstanz 05Tmax2018box

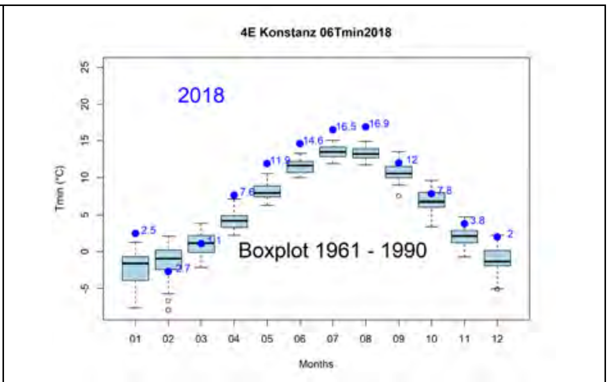

Figure 8: 4E Konstanz 06Tmin2018box

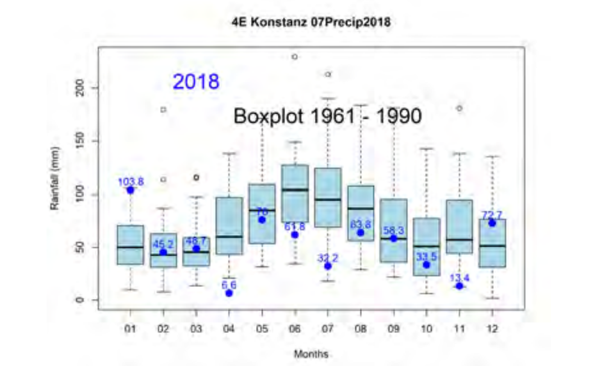

Figure 9: 4E Konstanz 07Precip2018box

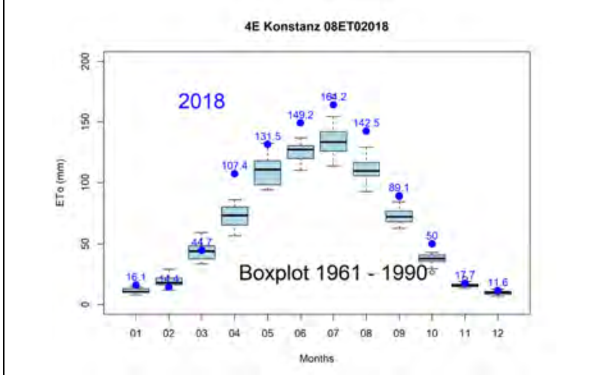

Figure 10: 4E Konstanz 08ET02018box

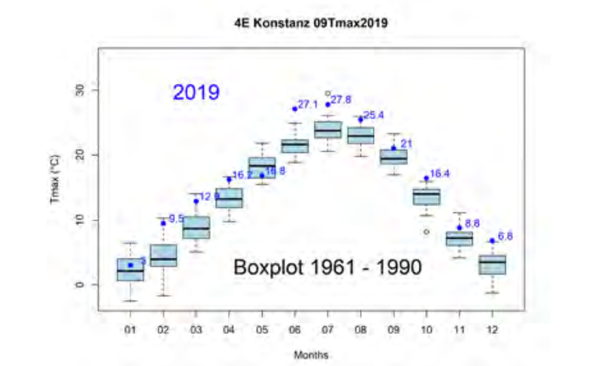

Figure 11: 4E Konstanz 09Tmax2019box

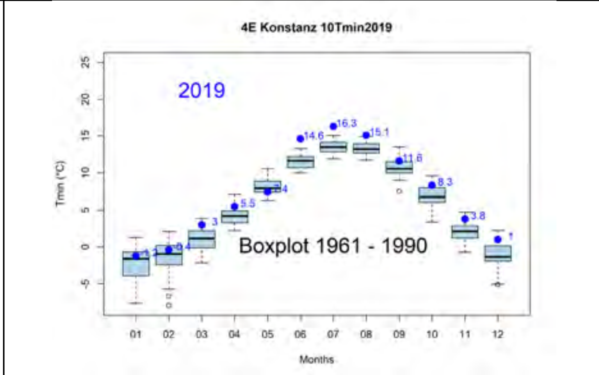

Figure 12: 4E Konstanz 10Tmin2019box

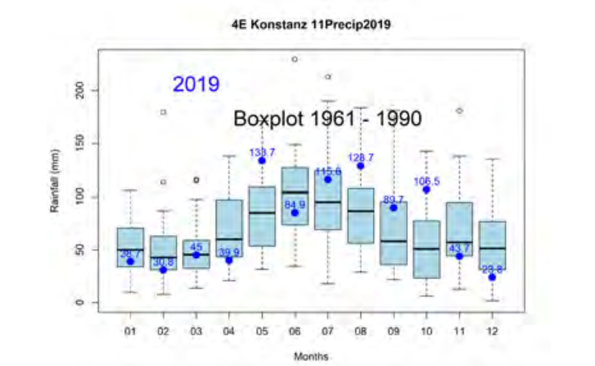

Figure 13: 4E Konstanz 11Precip2019box

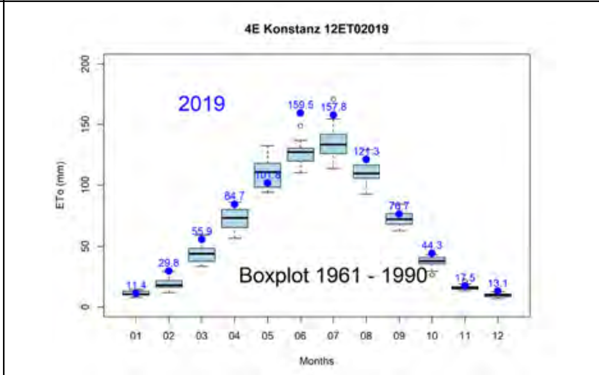

Figure 14: 4E Konstanz 12ET02019box

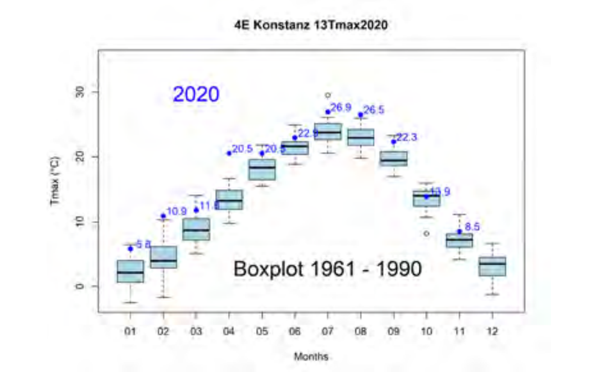

Figure 15: 4E Konstanz 13Tmax2020box

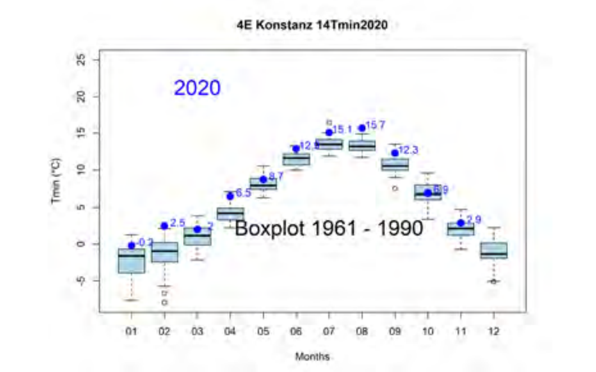

Figure 16: 4E Konstanz 14Tmin2020box

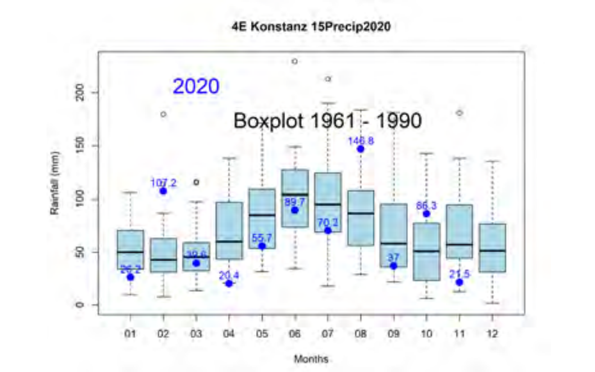

Figure 17: 4E Konstanz 15Precip2020box

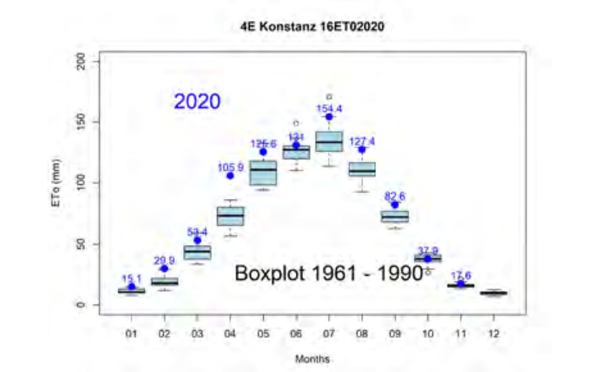

Figure 18: 4E Konstanz 16ET02020box

4a Frauenfeld

Meteo data from the Swiss Meteo service. Unfortunately no recent data for temperature but long series for rainfall. Station at 393 m ASL.

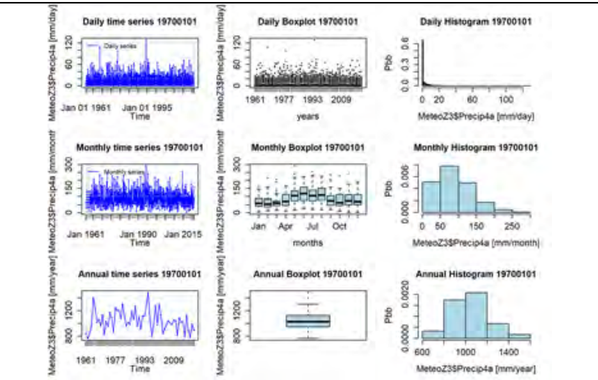

Figure 19: 4aFrauenfeld 01PrecHyplo

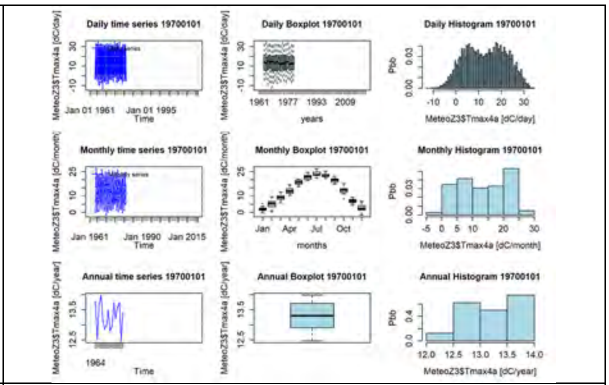

Figure 20: 4aFrauenfeld 02TmaxHyplo

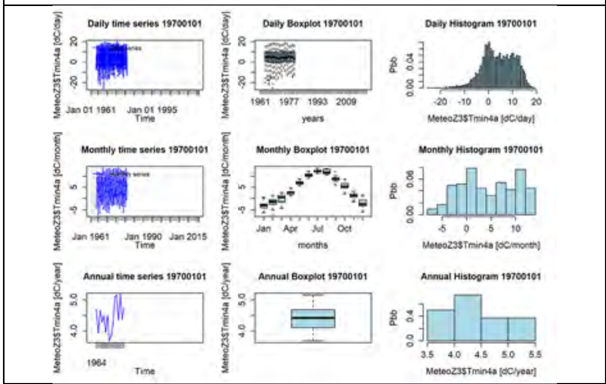

Figure 21: 4aFrauenfeld 03TminHyplo

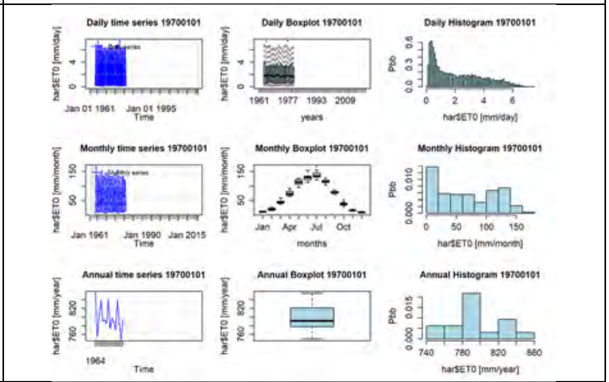

Figure 22: 4aFrauenfeld 04ET0Hyplo

4.b Aadorf Tanikon

Recent data for 2018 to 2020. Station at 539 mASL.

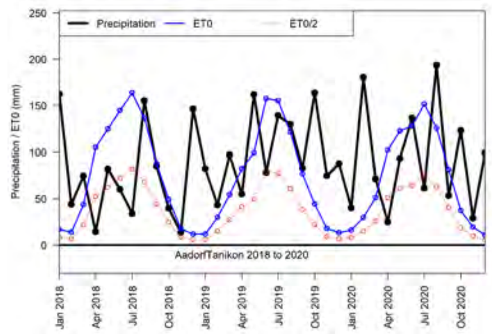

Figure 23: 4bAadorfTanikon 00aFAOgrow

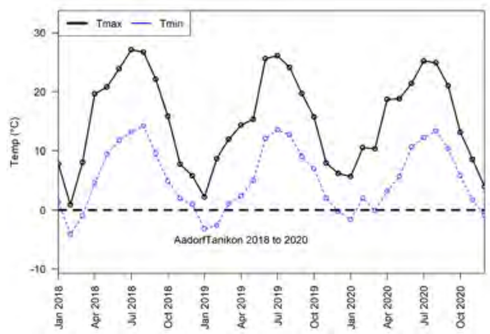

Figure 24: 4bAadorfTanikon 00bTnTx

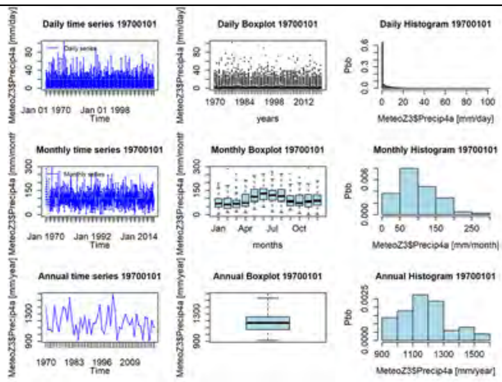

Figure 25: 4bAadorfTanikon 01PrecHyplo

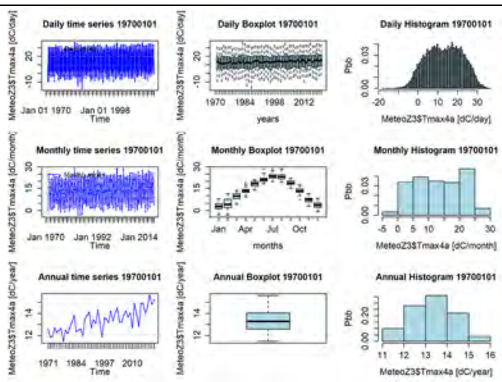

Figure 26: 4bAadorfTanikon 02TmaxHyplo

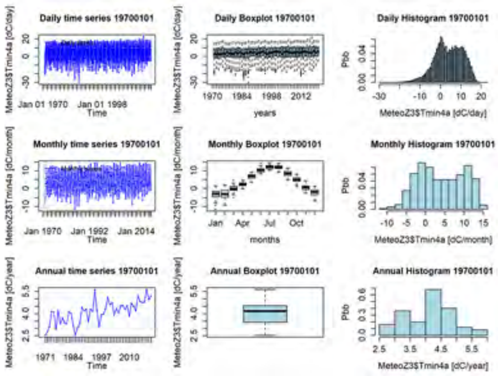

Figure 27: 4bAadorfTanikon 03TminHyplo

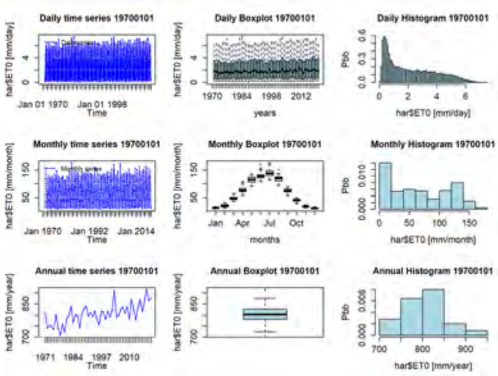

Figure 28: 4bAadorfTanikon 04ET0Hyplo

4c Salen Reutenen

Meteostation at 718m ASL.

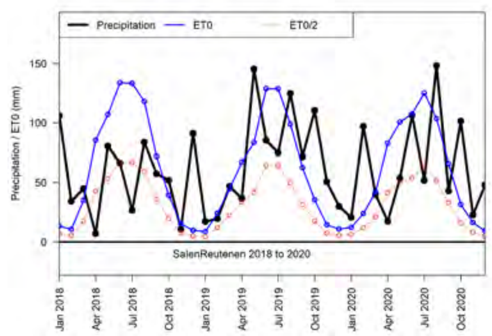

Figure 29: 4cSalenReutenen 00aFAOgrow

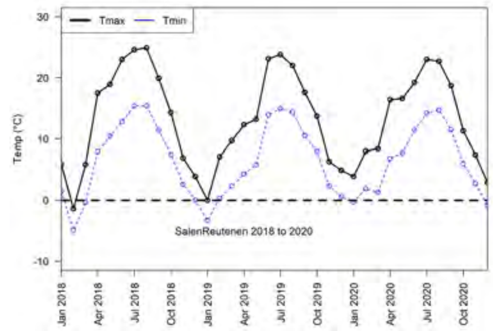

Figure 30: 4cSalenReutenen 00bTnTx

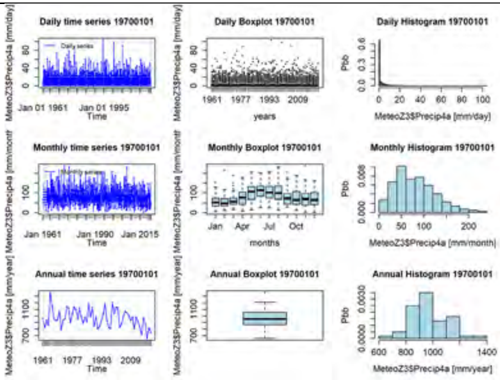

Figure 31: 4cSalenReutenen 01PrecHyplo

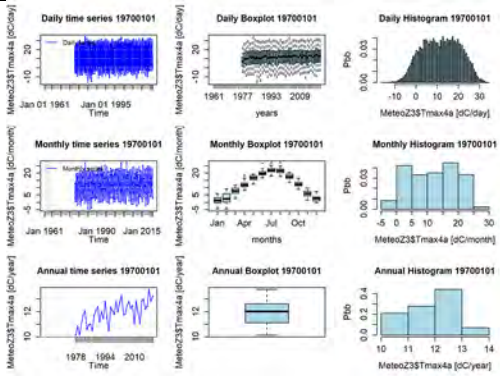

Figure 32: 4cSalenReutenen 02TmaxHyplo

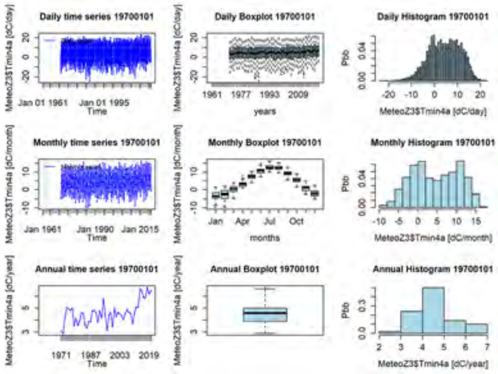

Figure 33: 4cSalenReutenen 03TminHyplo

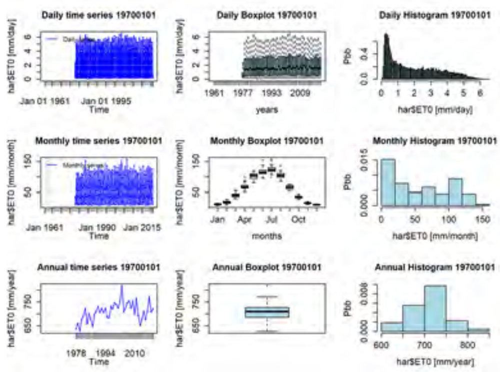

Figure 34: 4cSalenReutenen 04ET0Hyplo

5. Denmark: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1:Indicators measures and analysed

Observation code	Unit	Description
top_wc_pf2_0	m3m-3	Water content at FC
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
p_avail	mg-P/100gr Soil	Available P
soc	%	SOC
ph_kcl	_	pH
earthworm_no	no/m2	Earthworms
tot_N	%	Total N
air_perm	um2	Air permeability
pore_org	um2	Specific permeability
k_avail	mg K/100 gr soil	Available K
mg_avail	mg Mg/100 gr soil	Available Mg
extr_c	g C/kg soil	Extractable C
crop_yield_ha	kg/ha	Crop yield
crop_N	%	N content-harvest material
covercrop_DM	kg/ha	Cover crop aboveground biomass
covercrop_N	%	N content-aboveground biomass

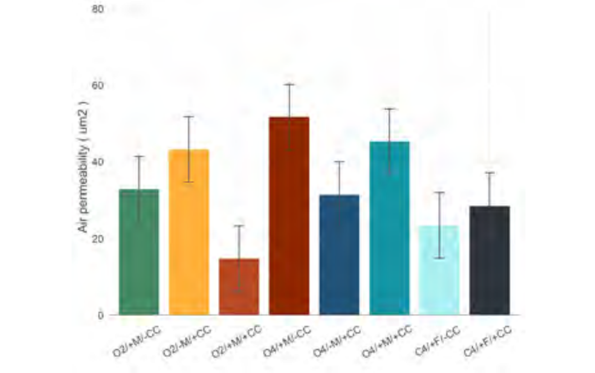

Figure 1: AU_EX1_NR_air_perm

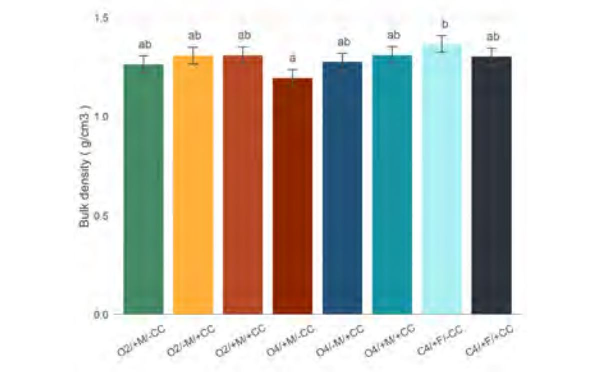

Figure 2: AU_EX1_NR_bd_top

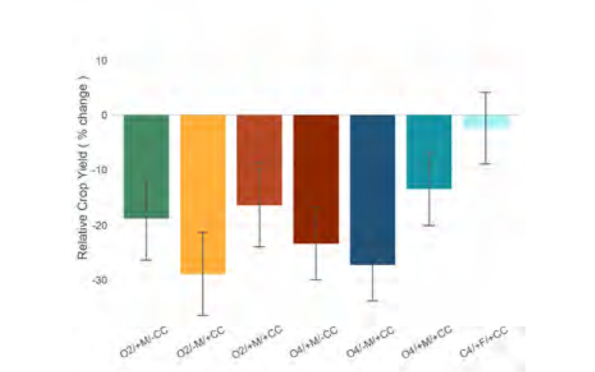

Figure 3: AU_EX1_NR_crop_yield_change

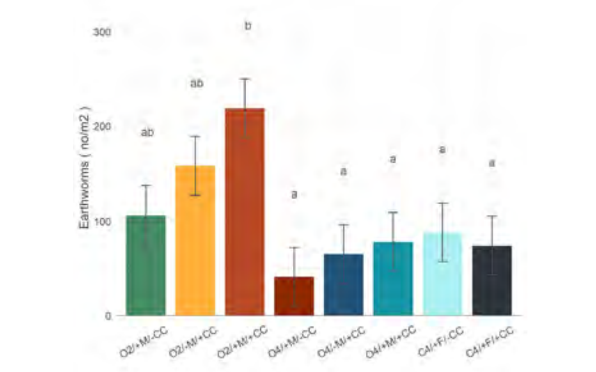

Figure 4: AU_EX1_NR_earthworm_no

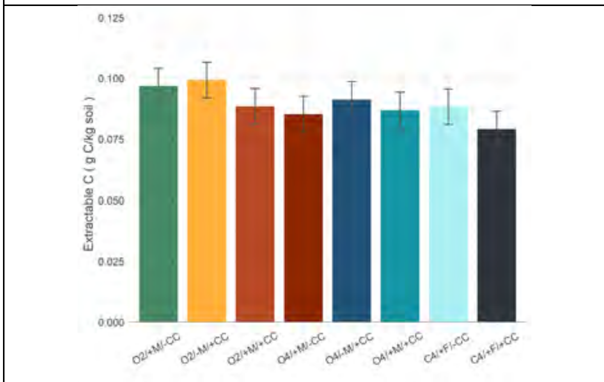

Figure 5: AU_EX1_NR_extr_c

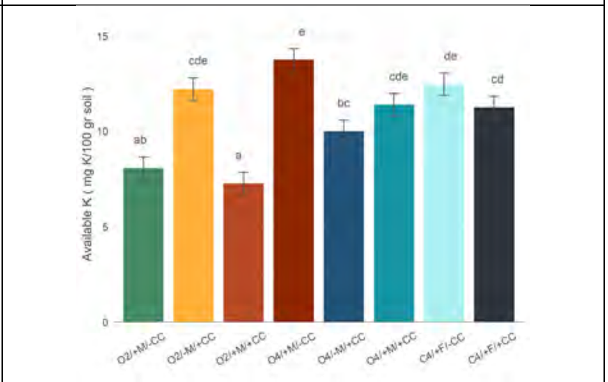

Figure 6: AU_EX1_NR_k_avail

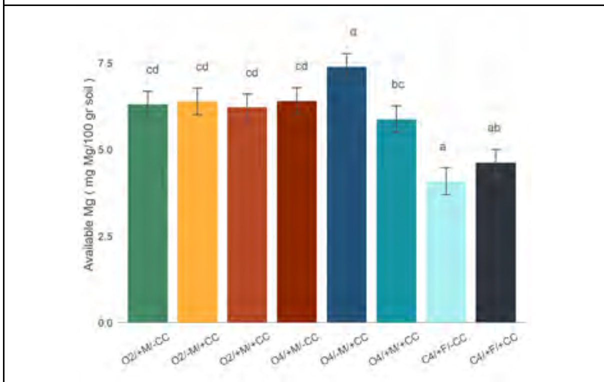

Figure 7: AU_EX1_NR_mg_avail

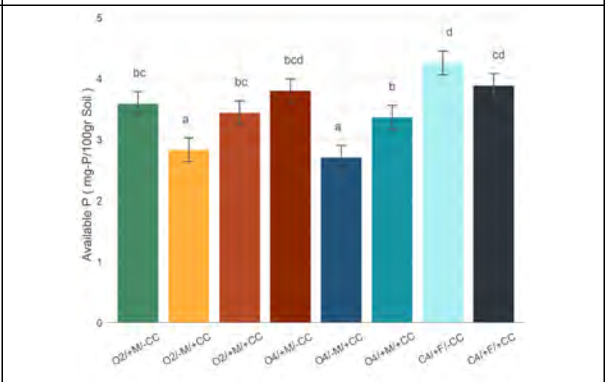

Figure 8: AU_EX1_NR_p_avail

SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

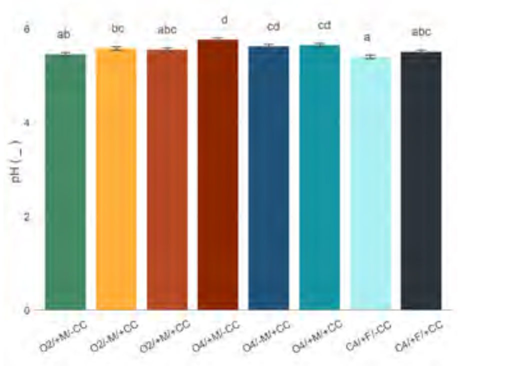

Figure 9: AU_EX1_NR_ph_kcl

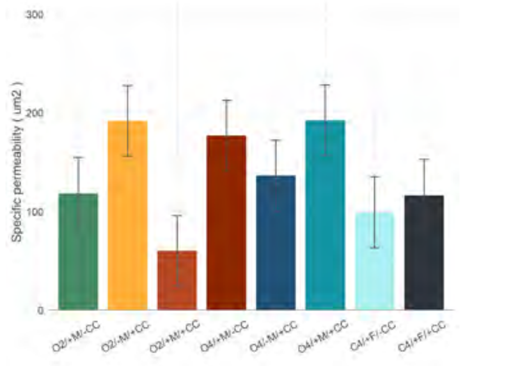

Figure 10: AU_EX1_NR_pore_org

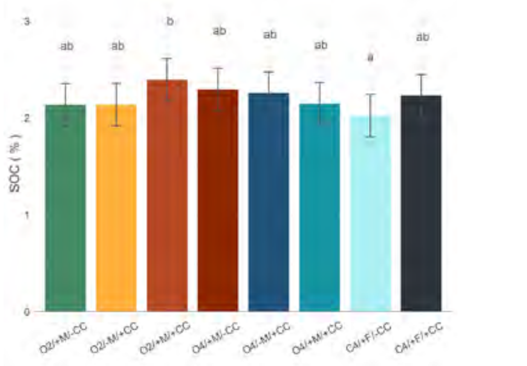

Figure 11: AU_EX1_NR_soc

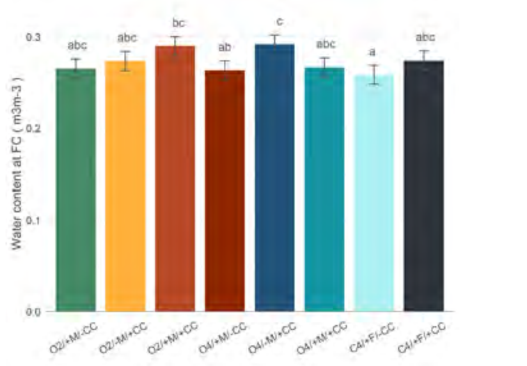

Figure 12: AU_EX1_NR_top_wc_pf2_0

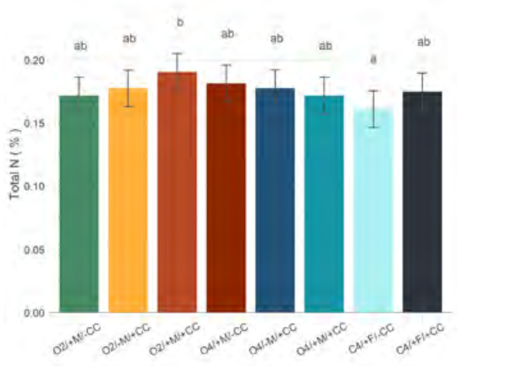

Figure 13: AU_EX1_NR_tot_N

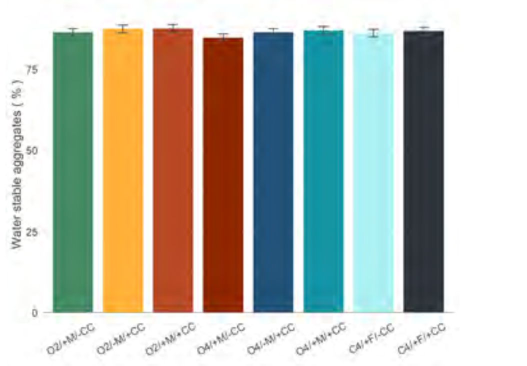

Figure 14: AU_EX1_NR_wsa

5. Denmark: Meteo Figures

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For the interpretation of the meteorological figures please see the introduction in D5.3

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Foulum meteorogical station at the study site

Foulum is a meteorological station with data available from 01/01/2014 till now. This station characterizes the climate at the experimental station.

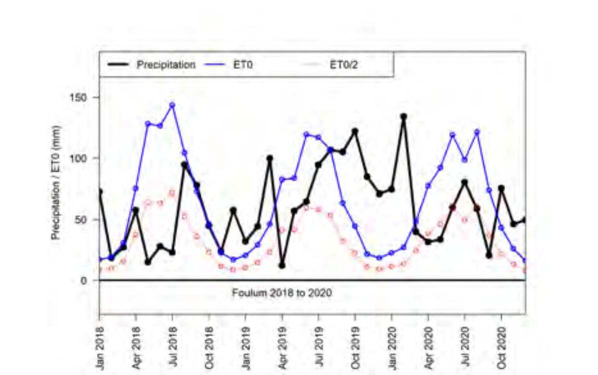

Figure 1: 5aFoulum 00aFAOgrow

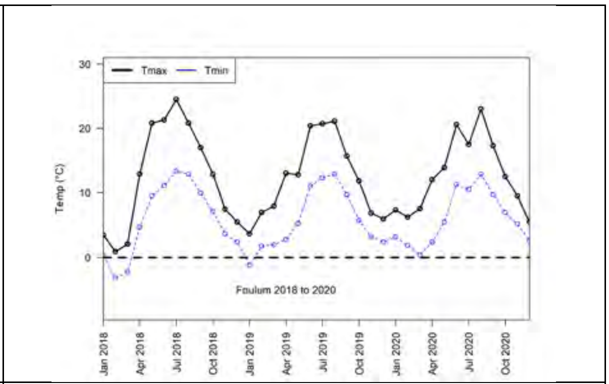

Figure 2: 5aFoulum 00bTnTx

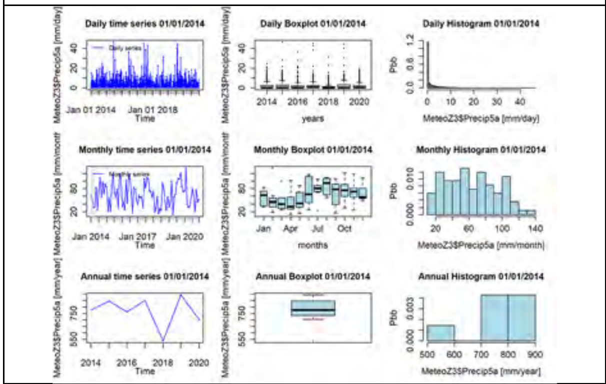

Figure 3: 5aFoulum 01PrecHyplo

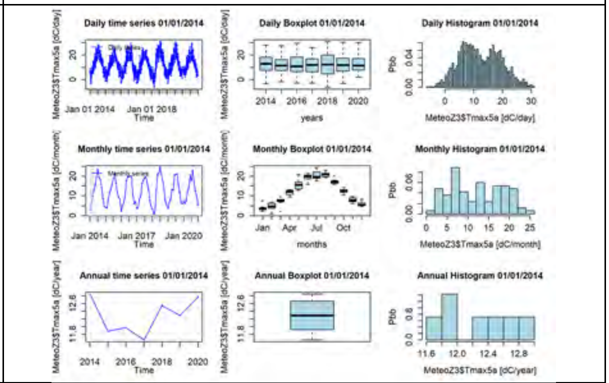

Figure 4: 5aFoulum 02TmaxHyplo

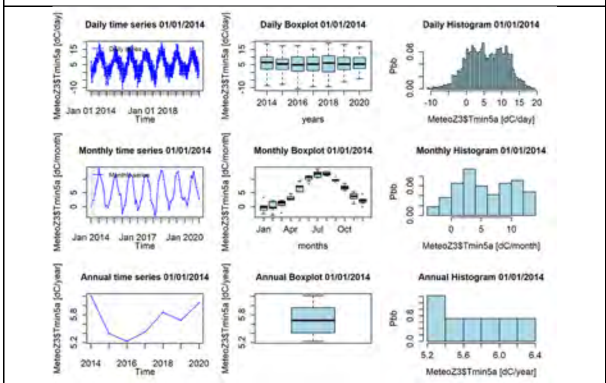

Figure 5: 5aFoulum 03TminHyplo

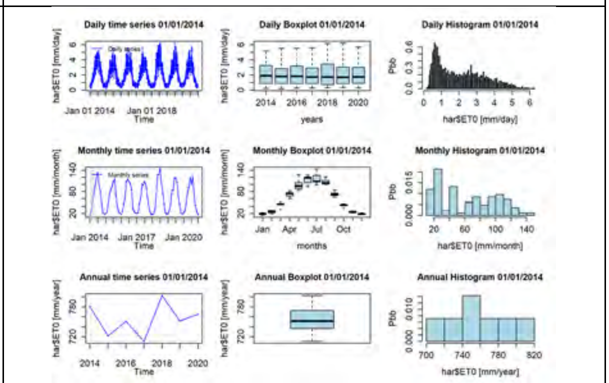

Figure 6: 5aFoulum 04ET0Hyplo

Gronbaek-Allingskovgard (ECAD 108)

Unfortunately Denmark provides a very limited amount of stations to ECAD and very little at the mainland. The station Gronbaek-Allingskovgard only contains Precipitation and does not include 2020. This series started in 1872 with precipitation and it is strange that no temperature are available in ECAD for this station. Therefore this station was used for the Precipitation normal 1961-90 and compared to that of Foulum. The nearest temperature data in ECAD are at 80 km from Foulum, are often along the coast and cannot be used.

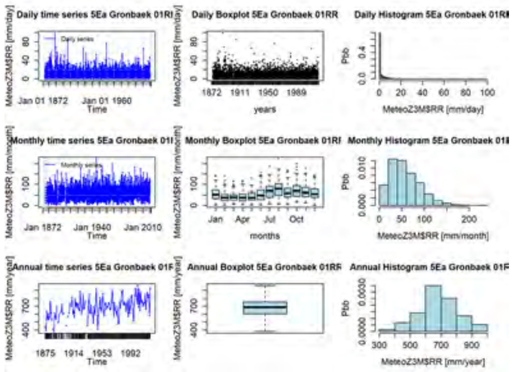

Figure 7: 5Ea Gronbaek 01RRhyplo

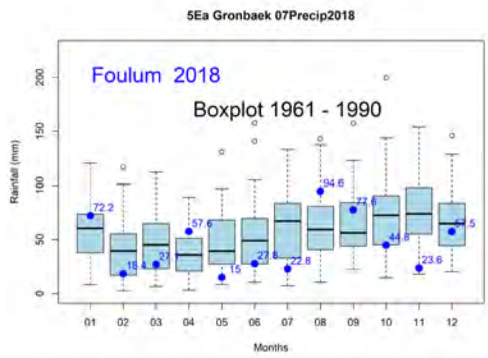

Figure 8: 5Ea Gronbaek 07Precip2018box

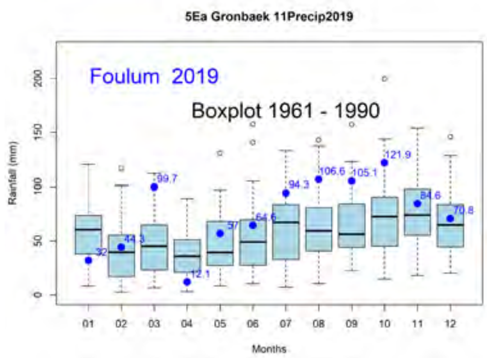

Figure 9: 5Ea Gronbaek 11Precip2019box

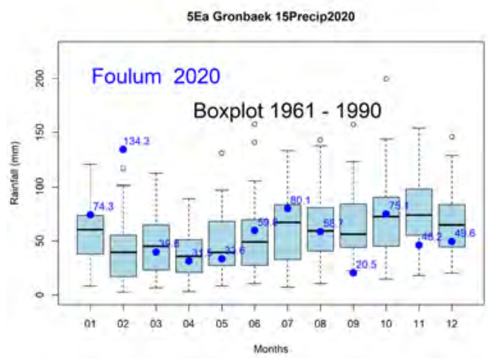

Figure 10: 5Ea Gronbaek 15Precip2020box

6. UK: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement “Treatment*Date”, and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1: Indicators measured and analysed

Observation code	Unit	Description
top_wc_pf2_0	m^3 water/m^3soil	Water content-Field capacity
top_wc_pf4_2	m^3 water/m^3soil	Water content-PWP
top_wc_pf2_7	m^3 water/m^3soil	Water content-Stress point
top_wc_pf_1_8	m^3 water/m^3soil	Water content at pF1.8
top_satur_wc	m^3 water/m^3soil	Water content at Saturation
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density in topsoil
penetration_score	kPa	Penetration resistance
top_clay	%	Clay content
top_silt	%	Silt content
top_sand	%	Sand content
nmin_top	mg N/kg soil	Mineral nitrogen
p_avail	mg P/100 g Soil	Phosphorus
k_plus	cmol+/kg	Potassium
ca2_plus	cmol+/kg	Calcium
mg2plus	cmol+/kg	Magnesium
soc	%	Soil organic carbon
ph_kcl	_	pH
ph_h2o	_	pH
earthworm_no	Earthworms/m^2	Earthworm number
crop_yield	kg/m^2	Crop yield of the plot
crop_yield_ha	kg/hectare	Crop yield
vess	_	Visual evaluation of soil structure
greenhouse_gas	$gCO^2/m^2/h$	Carbon dioxide flux
water_infiltration	m^3 water/m^3soil	Water infiltration

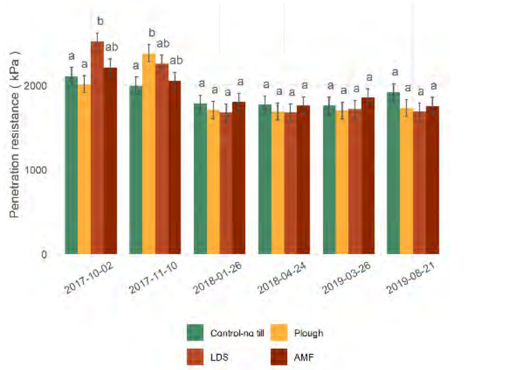

Figure 1: GWCT_EX1_SI_penetration_score

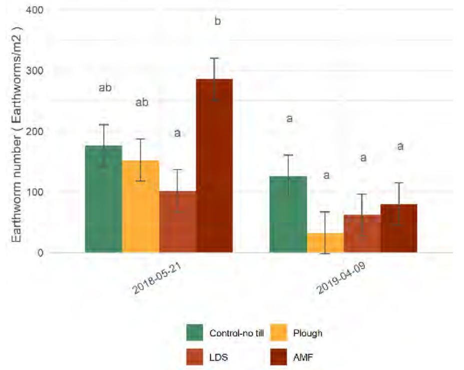

Figure 2: GWCT_EX1_SI_earthworm_no

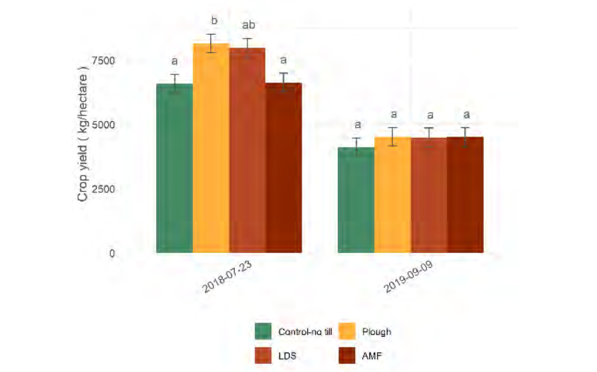

Figure 3: GWCT_EX1_SI_crop_yield_ha

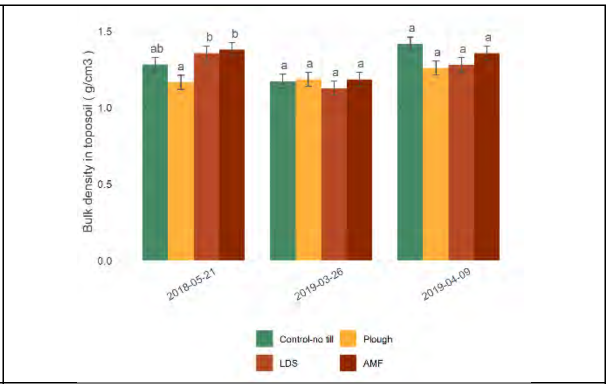

Figure 4: GWCT_EX1_SI_bd_top

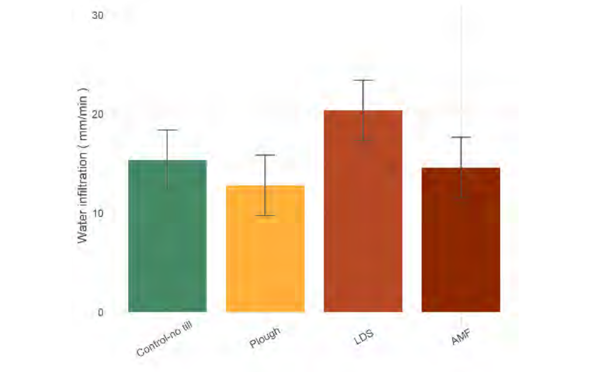

Figure 5: GWCT_EX1_NSI_treat_water_infiltration

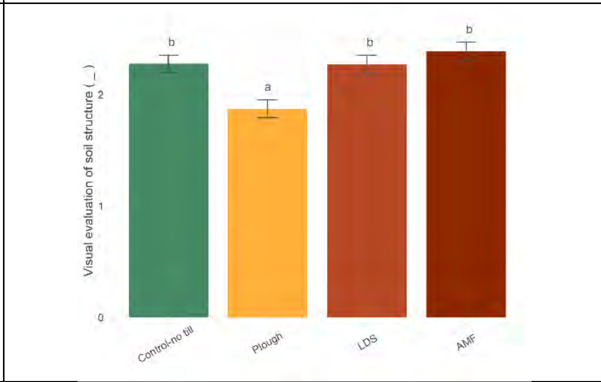

Figure 6: GWCT_EX1_NSI_treat_vess

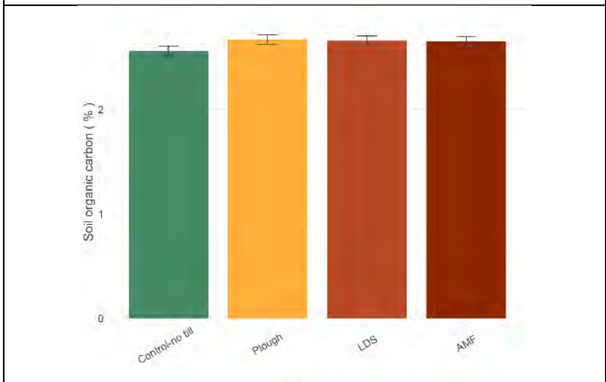

Figure 7: GWCT_EX1_NSI_treat_soc

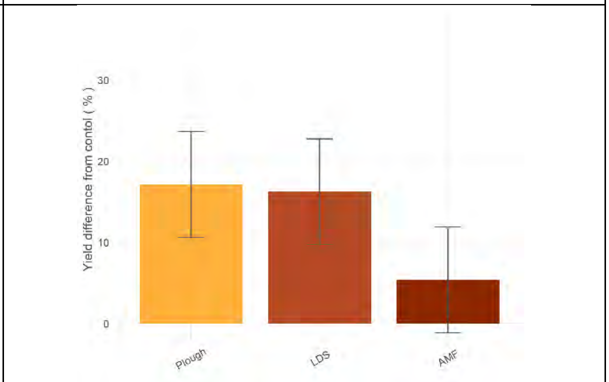

Figure 8: GWCT_EX1_NSI_treat_relative_yield_ha

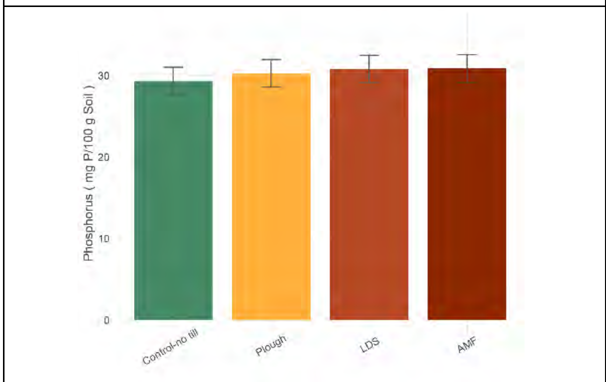

Figure 9: GWCT_EX1_NSI_treat_p_avail

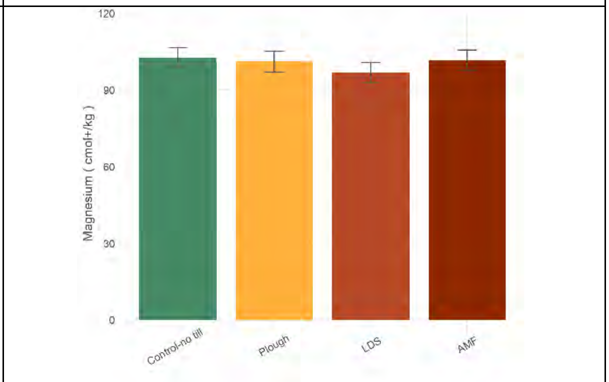

Figure 10: GWCT_EX1_NSI_treat_mg2plus

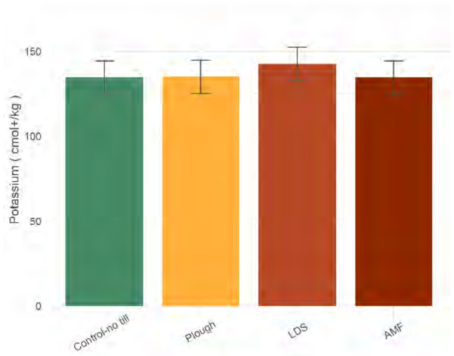

Figure 11: GWCT_EX1_NSI_treat_k_plus

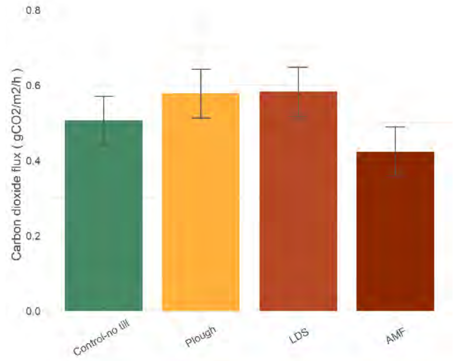

Figure 12: GWCT_EX1_NSI_treat_greenhouse_gas

Figure 13: GWCT_EX1_NSI_date_soc

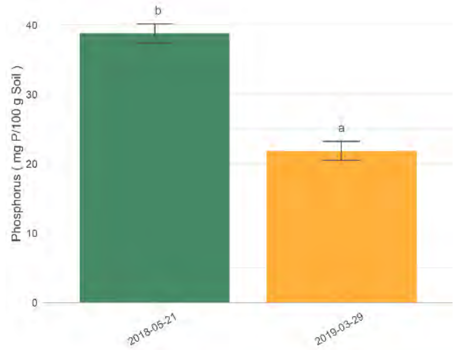

Figure 14: GWCT_EX1_NSI_date_p_avail

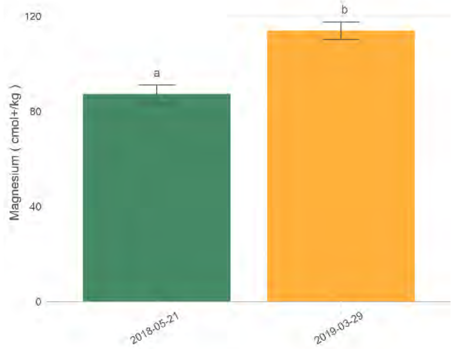

Figure 15: GWCT_EX1_NSI_date_mg2plus

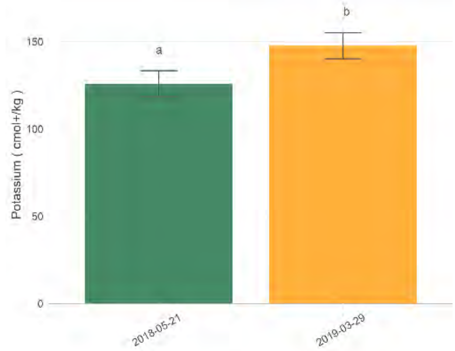

Figure 16: GWCT_EX1_NSI_date_k_plus

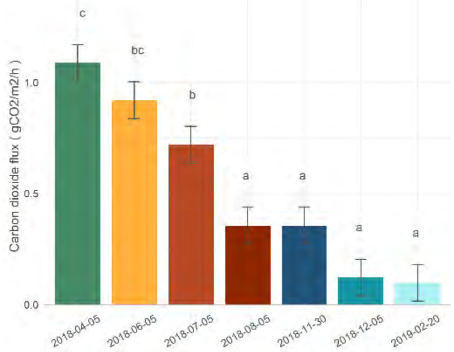

Figure 17: GWCT_EX1_NSI_date_greenhouse_gas

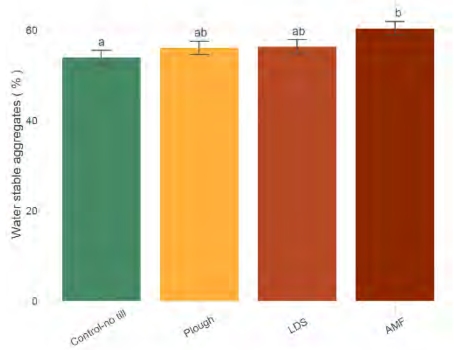

Figure 18: GWCT_EX1_NR_wsa

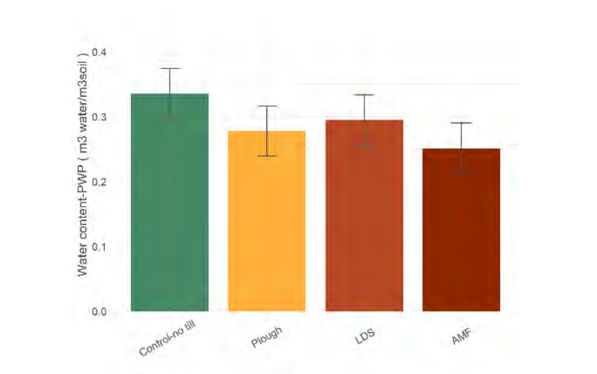

Figure 19: GWCT_EX1_NR_top_wc_pf4_2

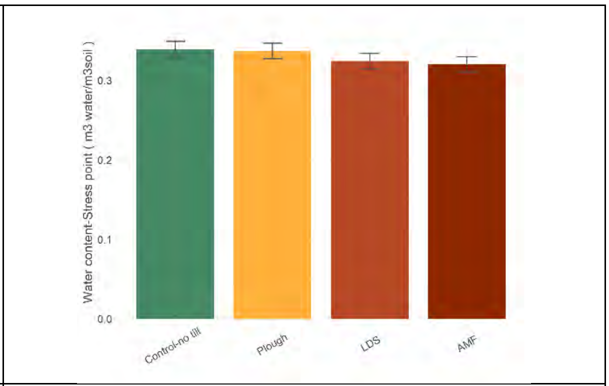

Figure 20: GWCT_EX1_NR_top_wc_pf2_7

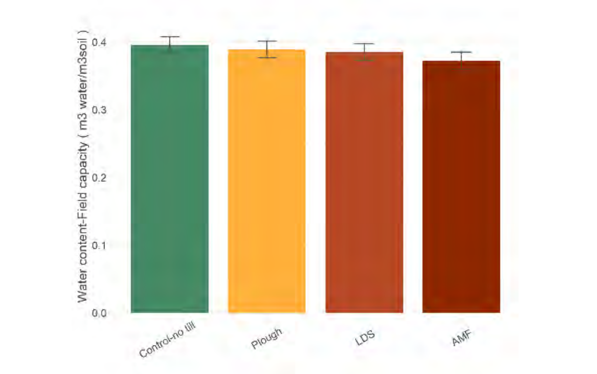

Figure 21: GWCT_EX1_NR_top_wc_pf2_0

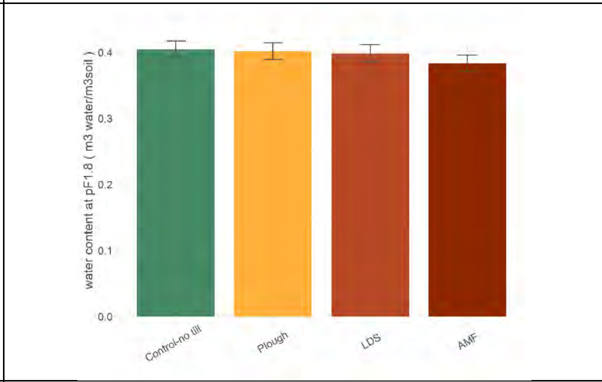

Figure 22: GWCT_EX1_NR_top_wc_pf_1_8

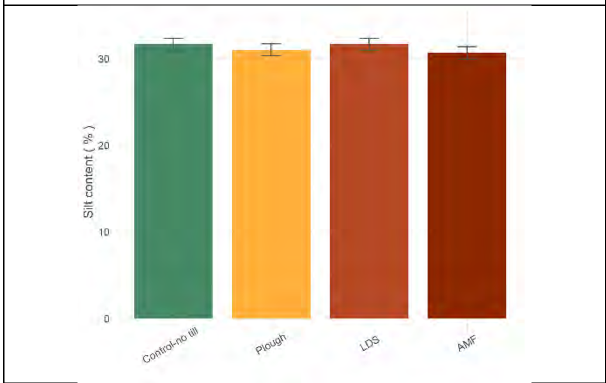

Figure 23: GWCT_EX1_NR_top_silt

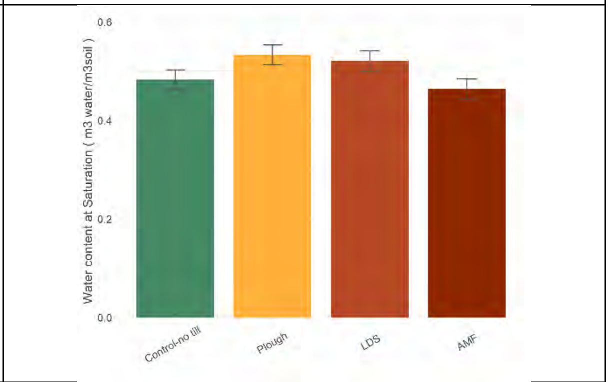

Figure 24: GWCT_EX1_NR_top_satur_wc

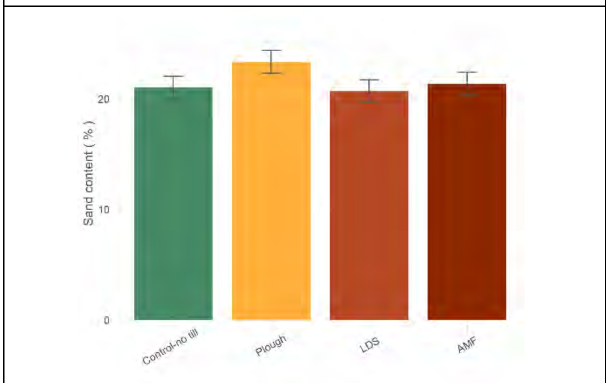

Figure 25: GWCT_EX1_NR_top_sand

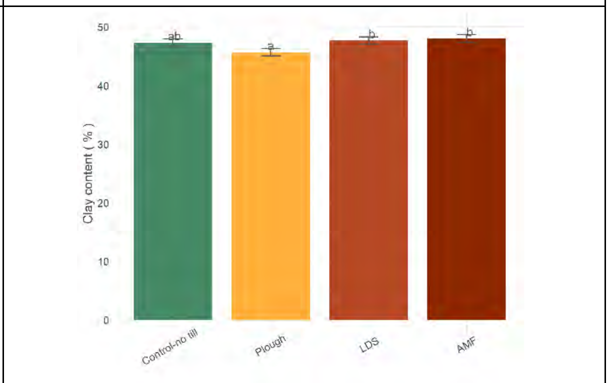

Figure 26: GWCT_EX1_NR_top_clay

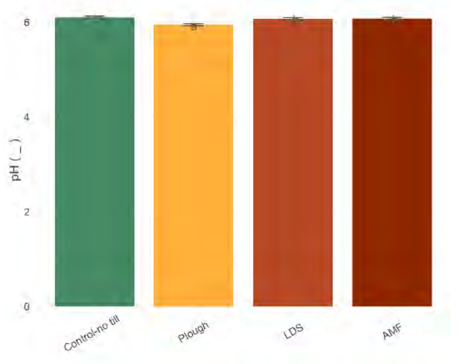

Figure 27: GWCT_EX1_NR_ph_kcl

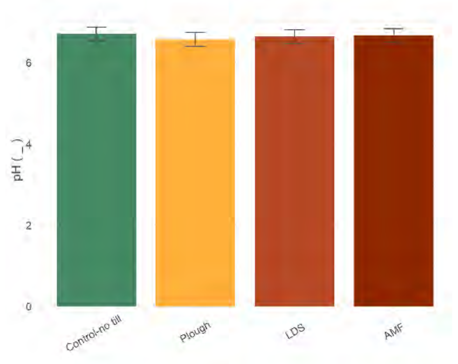

Figure 28: GWCT_EX1_NR_ph_h2o

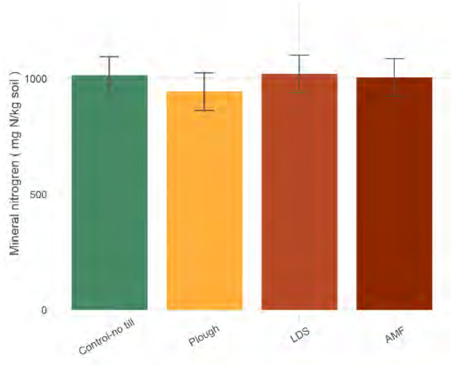

Figure 29: GWCT_EX1_NR_nmin_top

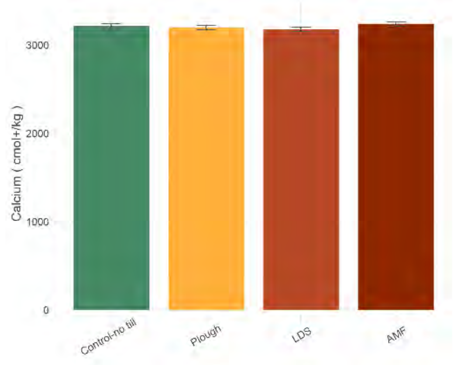

Figure 30: GWCT_EX1_NR_ca2_plus

SoilCare
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Experiment 2

Table 2: Indicators measured and analysed

Observation code	Unit	Description
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density in topsoil
bd_bot	g/cm^3	Bulk density below the plough layer
penetration_score	kPa	Penetration resistance
p_avail	mg P/100 g Soil	Phosphorus
k_plus	cmol+/kg	Potassium
ca2_plus	cmol+/kg	Calcium
na_plus	cmol+/kg	Sodium
mg2plus	cmol+/kg	Magnesium
soc	%	Soil organic carbon
ph_kcl	_	pH
earthworm_no	$Earthworms/m^2$	Earthworm number
vess	_	Visual evaluation of soil structure
greenhouse_gas	gCO2/m2/h	Carbon dioxide flux
water_infiltration	mm/min	Water infiltration
soc_2	%	Soil organic carbon
earthworm_no_2	$Earthworms/m^2$	Earthworm number
water_infiltration_2	mm/min	Water infiltration

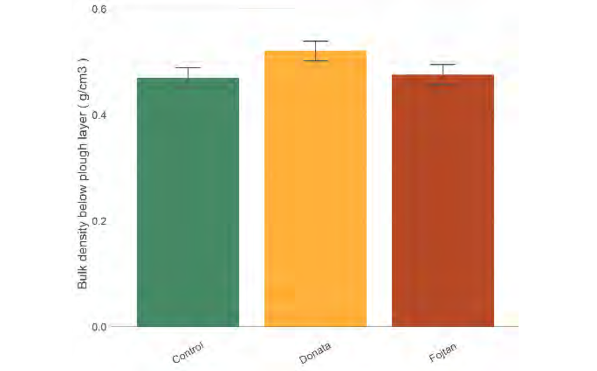

Figure 31: GWCT_EX2_NR_bd_bot

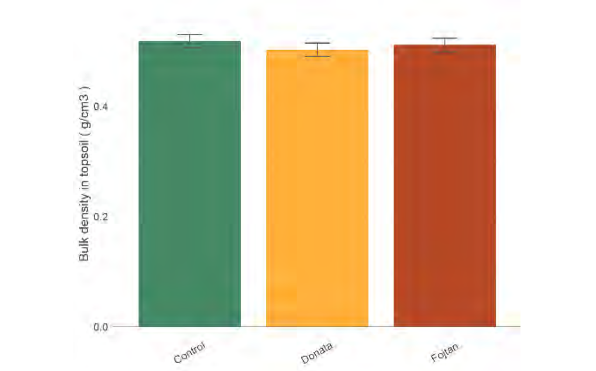

Figure 32: GWCT_EX2_NR_bd_top

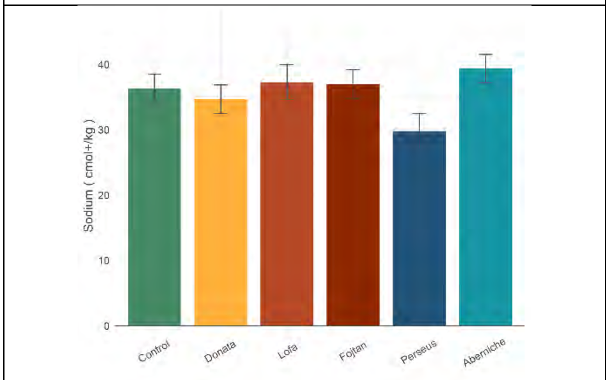

Figure 33: GWCT_EX2_NR_na_plus

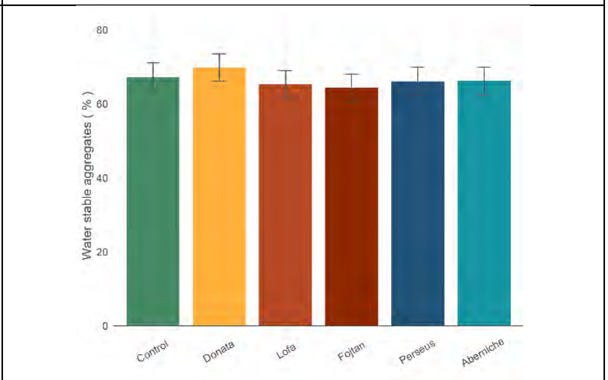

Figure 34: GWCT_EX2_NR_wsa

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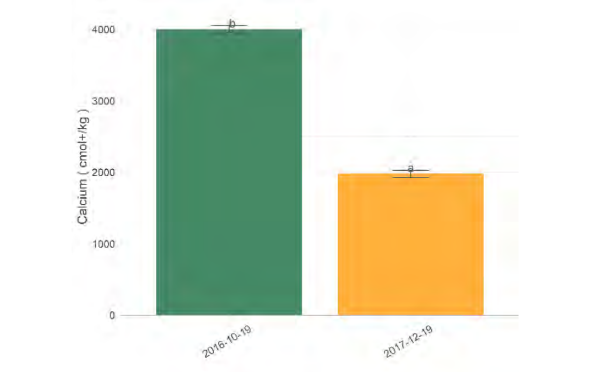


Figure 35: GWCT_EX2_NSI_date_ca2_plus

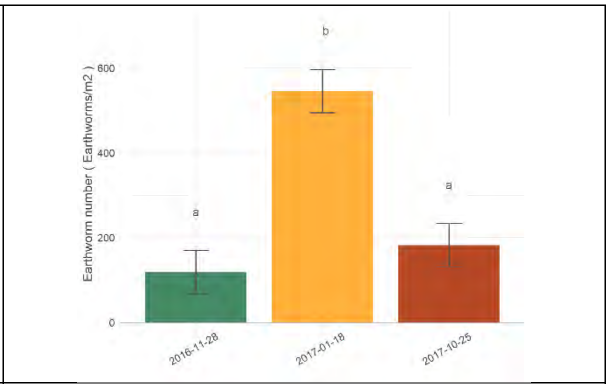


Figure 36: GWCT_EX2_NSI_date_earthworm_no

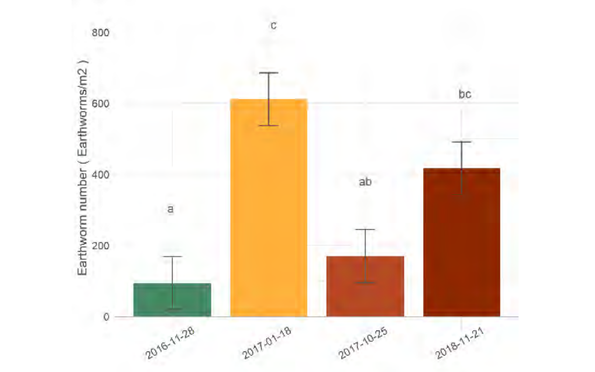


Figure 37: GWCT_EX2_NSI_date_earthworm_no_2

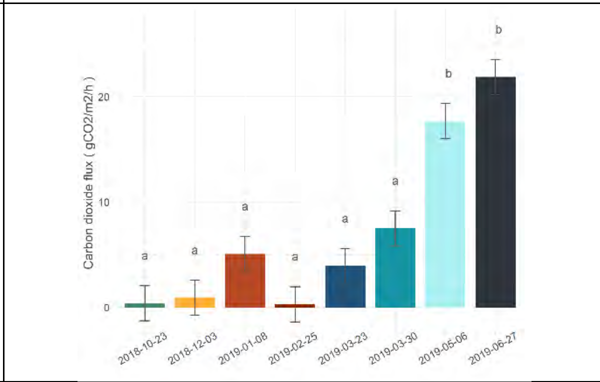


Figure 38: GWCT_EX2_NSI_date_greenhouse_gas

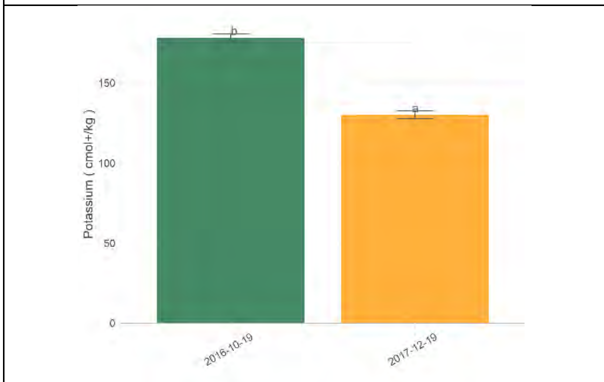


Figure 39: GWCT_EX2_NSI_date_k_plus

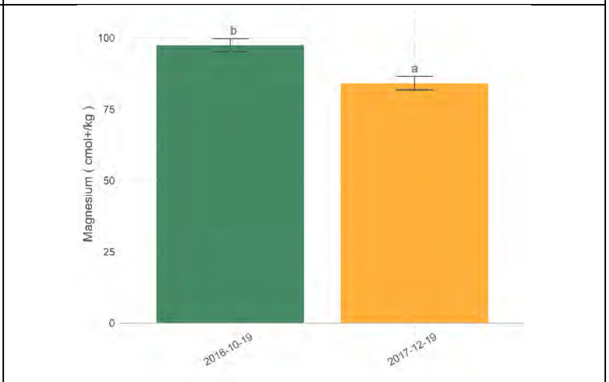


Figure 40: GWCT_EX2_NSI_date_mg2plus

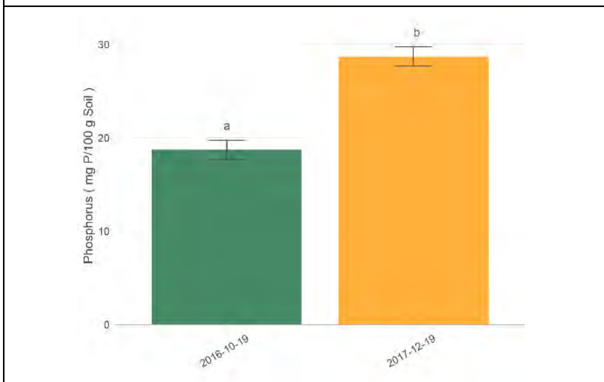


Figure 41: GWCT_EX2_NSI_date_p_avail

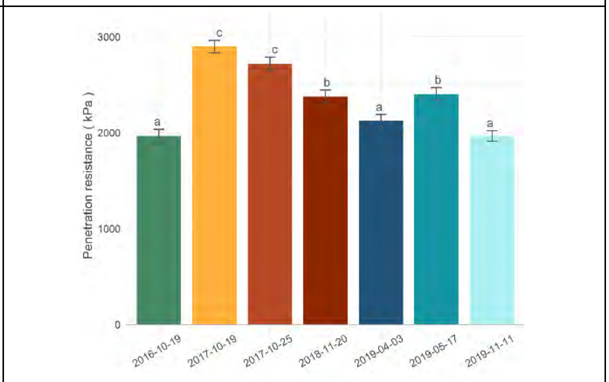


Figure 42: GWCT_EX2_NSI_date_penetration_score

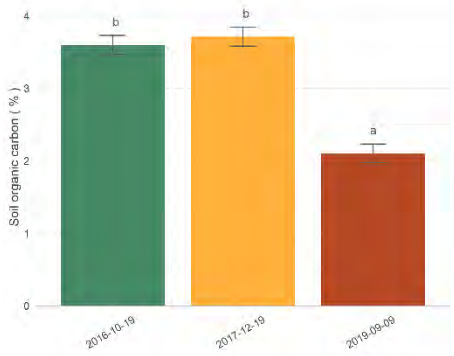
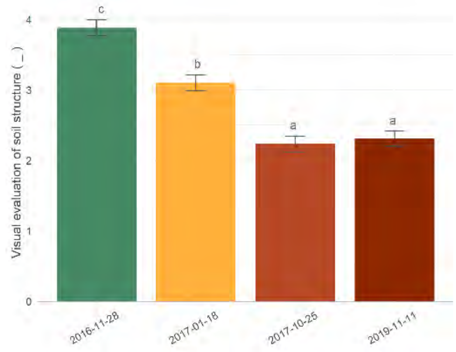
	

Figure 43: GWCT_EX2_NSI_date_soc_2	*Figure 44: GWCT_EX2_NSI_date_vess*

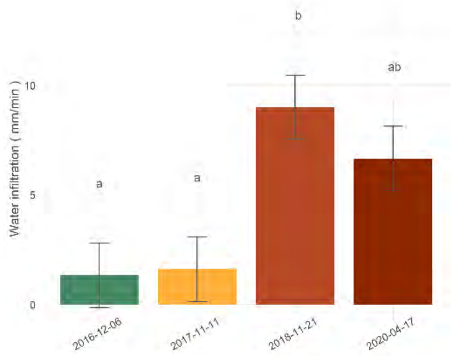
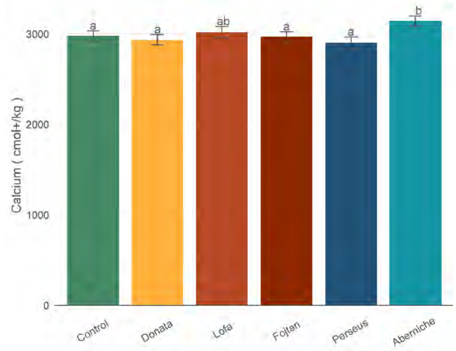

	

Figure 45: GWCT_EX2_NSI_date_water_infiltration_2	*Figure 46: GWCT_EX2_NSI_treat_ca2_plus*

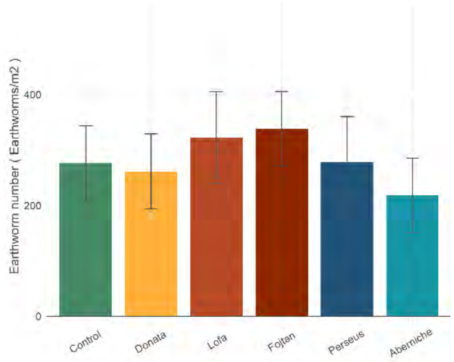
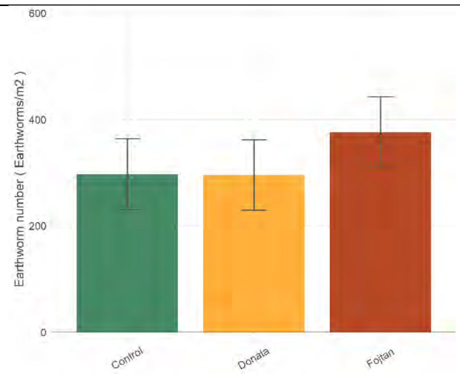

	

Figure 47: GWCT_EX2_NSI_treat_earthworm_no	*Figure 48: GWCT_EX2_NSI_treat_earthworm_no_2*

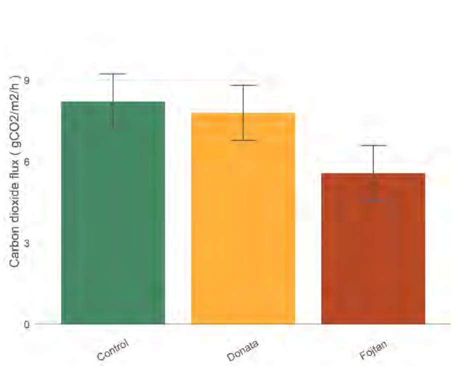
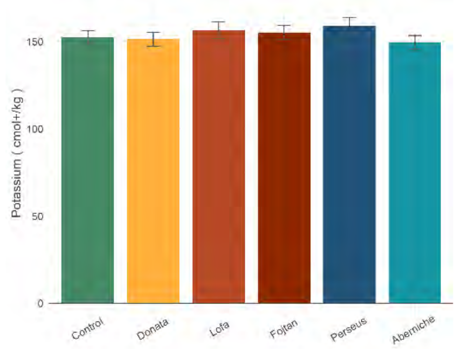
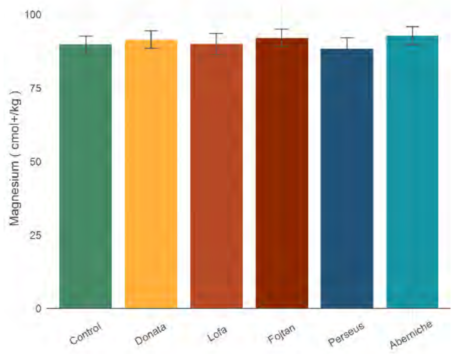

	

Figure 49: GWCT_EX2_NSI_treat_greenhouse_gas	*Figure 50: GWCT_EX2_NSI_treat_k_plus*



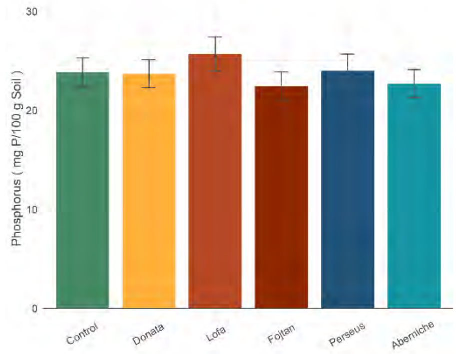
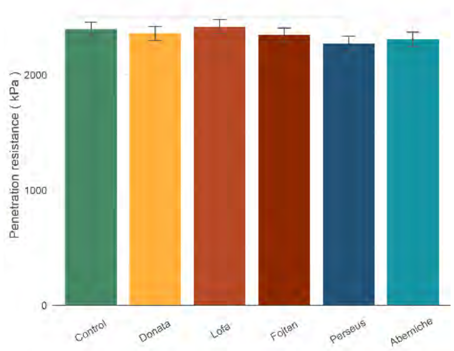


Figure 51: GWCT_EX2_NSI_treat_mg2plus

Figure 52: GWCT_EX2_NSI_treat_p_avail



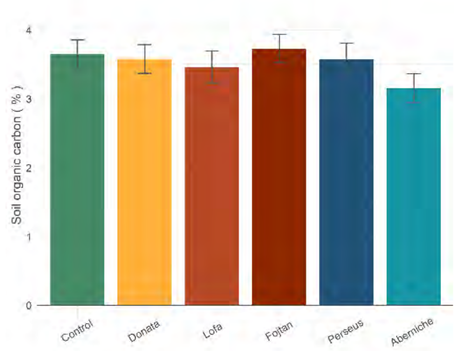


Figure 53: GWCT_EX2_NSI_treat_penetration_score

Figure 54: GWCT_EX2_NSI_treat_soc

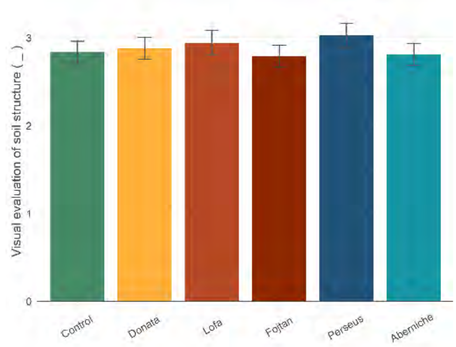
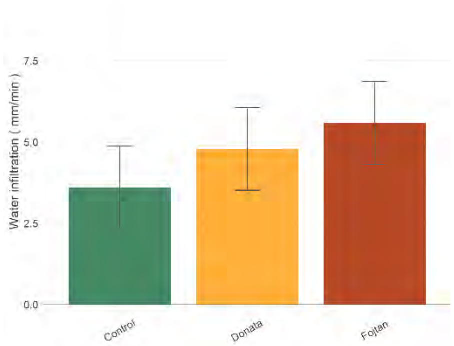


Figure 55: GWCT_EX2_NSI_treat_soc_2

Figure 56: GWCT_EX2_NSI_treat_vess



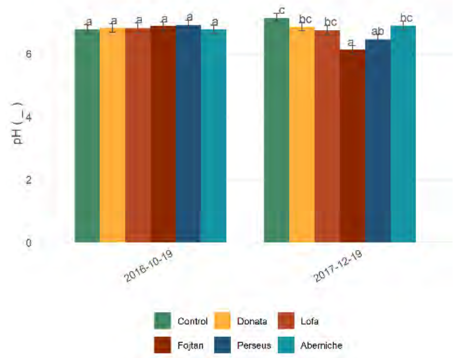
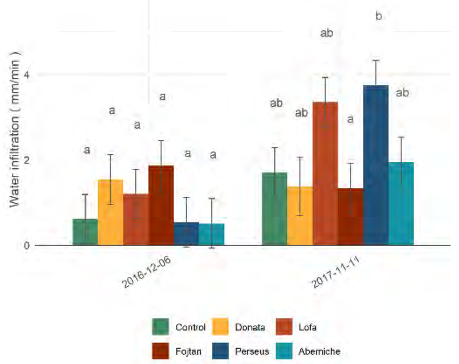


Figure 57: GWCT_EX2_NSI_treat_water_infiltration_2

Figure 58: GWCT_EX2_SI_ph_kcl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6. UK: Figures from the analysis

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For the interpretation of these figures see the general introduction to D5.3.

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6E Nottingham (ECAD1850)

This meteorological station is at 50 km from the experimental site.

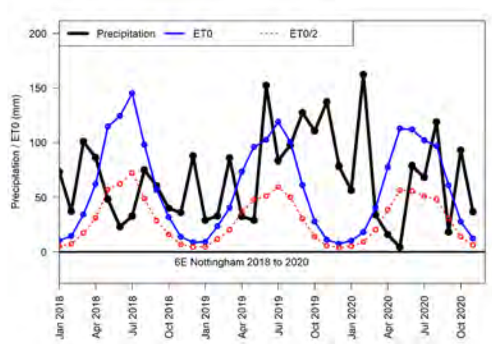

Figure 1: 6E Nottingham 00aFAOgrow

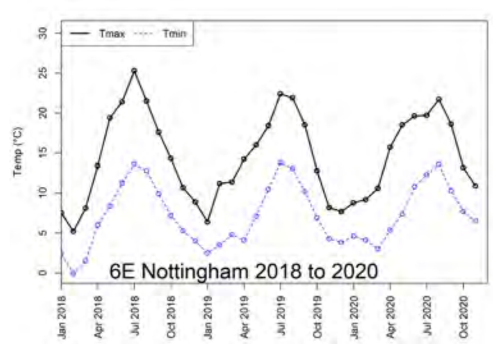

Figure 2: 6E Nottingham 00b TnTx

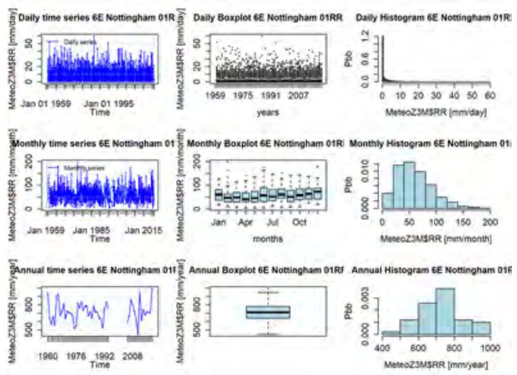

Figure 3: 6E Nottingham 01RRhyplo

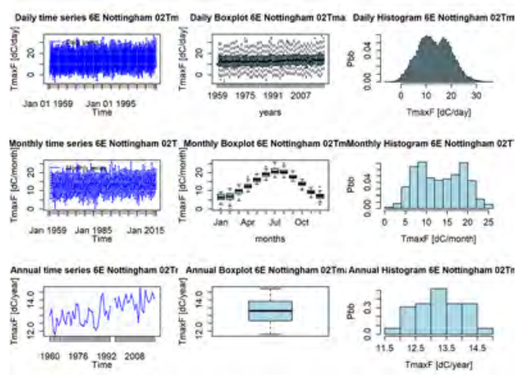

Figure 4: 6E Nottingham 02Tmaxhyplo

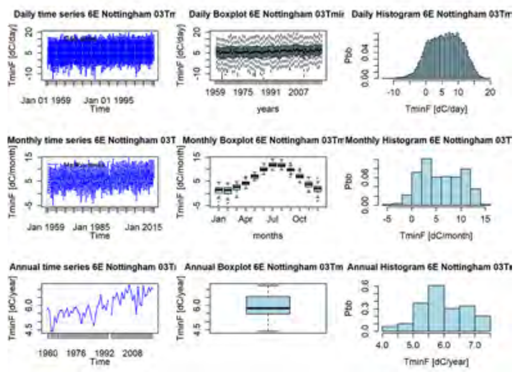

Figure 5: 6E Nottingham 03Tminhyplo

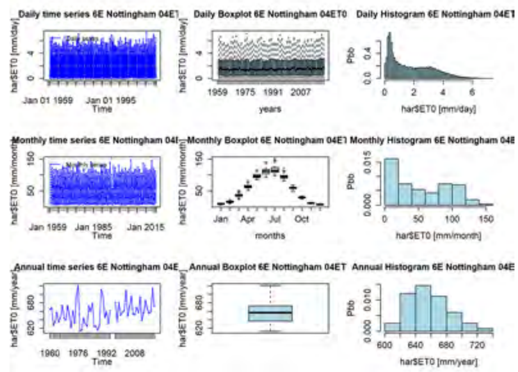

Figure 6: 6E Nottingham 04ET0hyplo

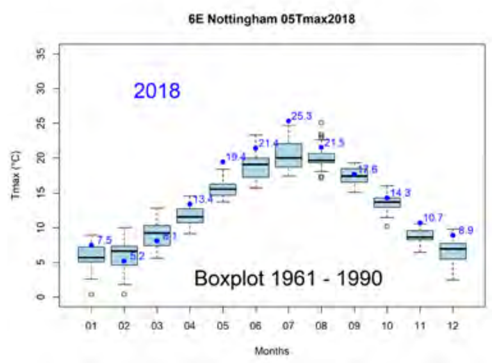

Figure 7: 6E Nottingham 05Tmax2018box

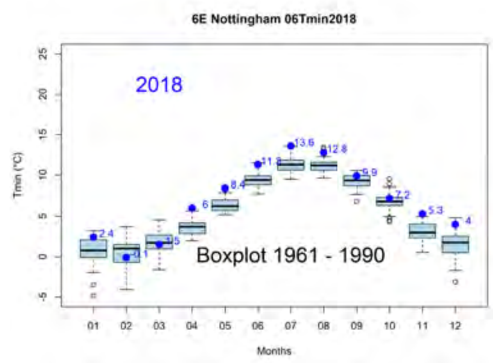

Figure 8: 6E Nottingham 06Tmin2018box

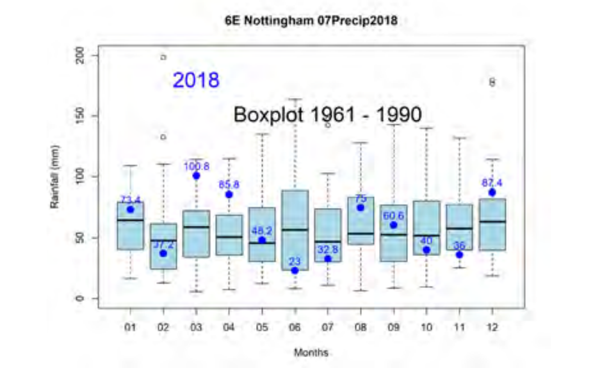

Figure 9: 6E Nottingham 07Precip2018box

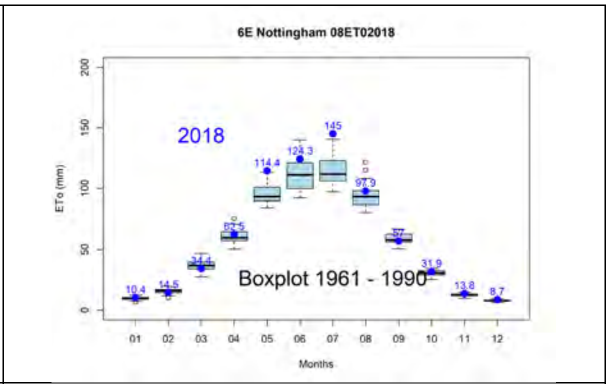

Figure 10: 6E Nottingham 08ETO2018box

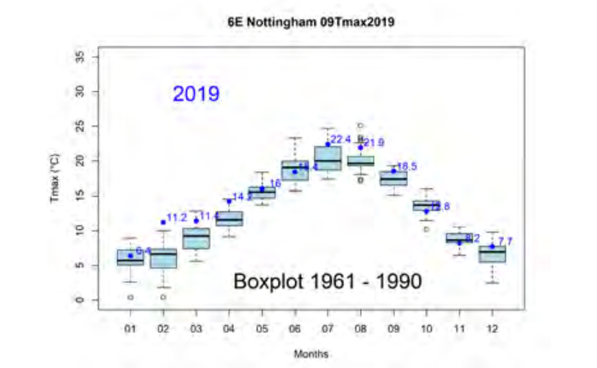

Figure 11: 6E Nottingham 09Tmax2019box

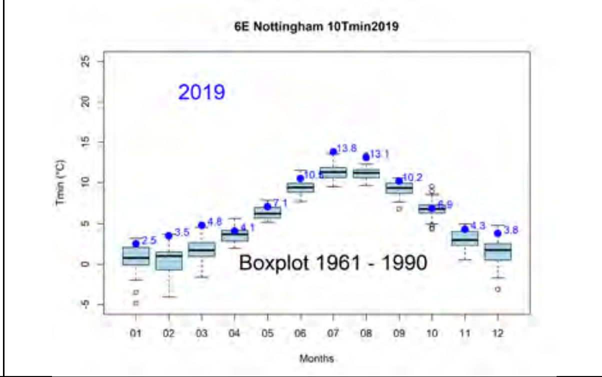

Figure 12: 6E Nottingham 10Tmin2019box

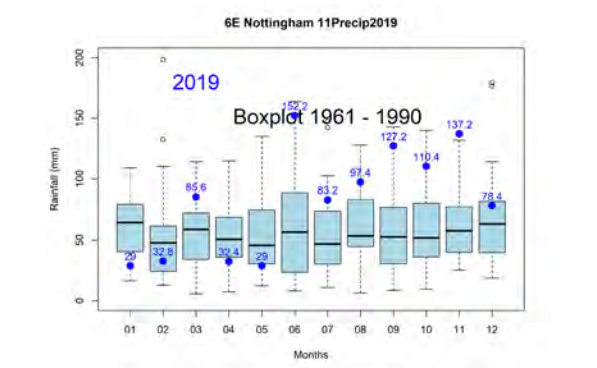

Figure 13: 6E Nottingham 11Precip2019box

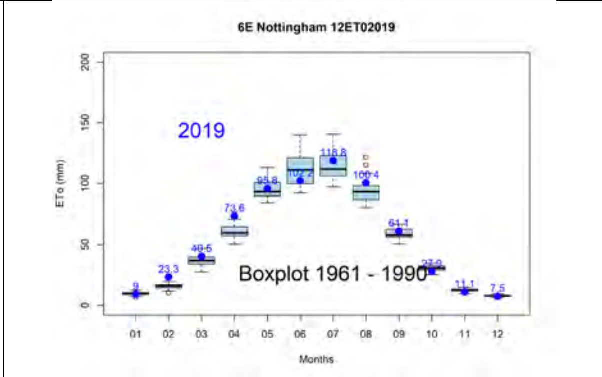

Figure 14: 6E Nottingham 12ETO2019box

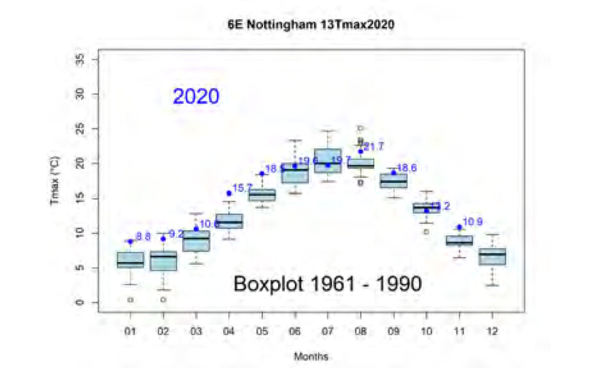

Figure 15: 6E Nottingham 13Tmax2020box

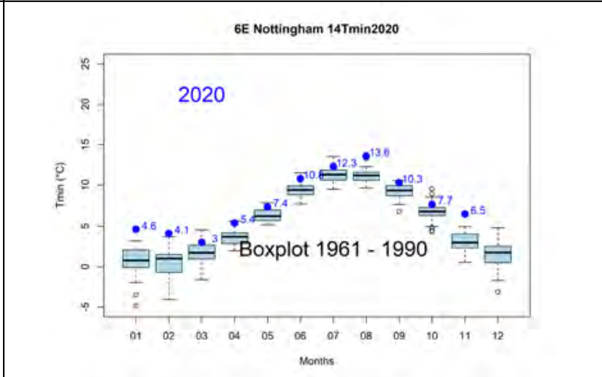

Figure 16: 6E Nottingham 14Tmin2020box

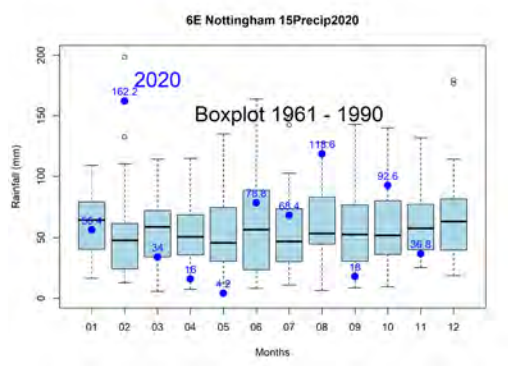

Figure 17: 6E Nottingham 15Precip2020box

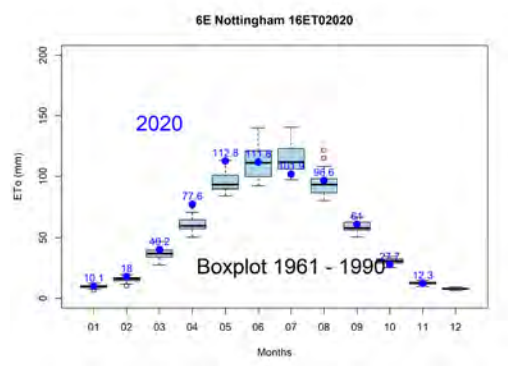

Figure 18: 6E Nottingham 16ET02020box

1. Germany: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment 1:

Table 1: Soil physical, chemical and biological properties analysed in the experiment

Observation code	Unit	Description
top_wc_pf1.08	m3m-3	Water content at pF1.08
top_wc_pf2.0	m3m-3	Water content at Field capacity (pF=2.0)
top_wc_pf2.5	m3m-3	Water content at Stress point (pF=2.5)
top_wc_pf4.2	m3m-3	Water content at Permanent wilting point (pF=4.2)
top_satur_wc	m3m-3	Water content at Saturation
Wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
top_clay	%	Percentage of clay fraction
top_silt	%	Percentage of silt fraction
top_sand	%	Percentage of the sand fraction
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorus
k+	cmol+/kg	Exchangeable Potassium
ca2+	cmol+/kg	Exchangeable Calcium
na+	cmol+/kg	Exchangeable Sodium (units of charge)
mg2+	cmol+/kg	Exchangeable Magnesium
Soc	%	SOC
ph_kcl	Unitless	pH in KCl
weed_infestation	%	Weed infestation (soil cover by weeds)
earthworm_no	No/m2	Earthworms
microb_biom_c	µgC_micg-1DM	Microbial biomass carbon
microb_biom_n	µgN_micg-1DM	Microbial biomass nitrogen
disolved_c	µgC_micg-1DM	Dissolved carbon of C extractable with 0.5 M K2SO4.
soil_cover	%	Soil cover
crop_yield	kg FS/plot	Crop yield of the plot- Fresh substance
crop_yield_ha	kg DS/hectare	Crop yield- Oven-dried substance
ß-Glu_activity	nmol/g/h	ß-Glucosidase
Xyl_activity	nmol/g/h	ß-Xylosidase
N-Ac_activity	nmol/g/h	N-Acetyl-ß-Glucosaminidase
Phos_activity	nmol/g/h	Phosphomonoesterase
K_avail	mg-K/100gr Soil	Available Potassium
Infiltration	mm/h	Infiltration rate
crop_protein_content	% DS	Crop protein content in grain
crop_full_barley_share	% of harvested grains	Crop grain size >2.5 mm

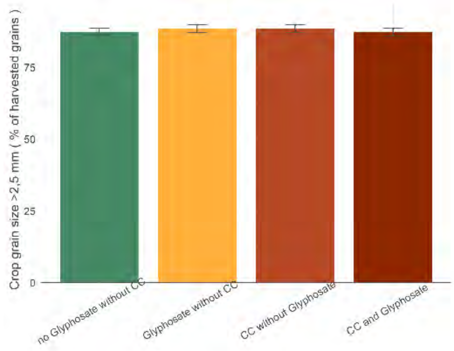

Figure 1: UH_EX1_NR_crop_full_barley_share

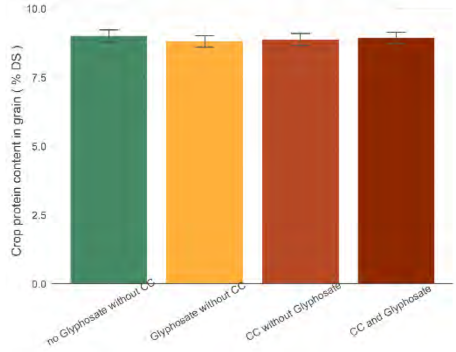

Figure 2: UH_EX1_NR_crop_protein_content

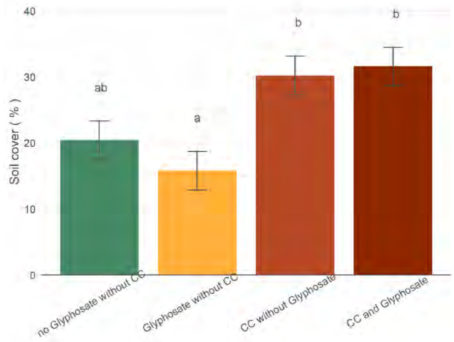

Figure 3: UH_EX1_NR_soil_cover

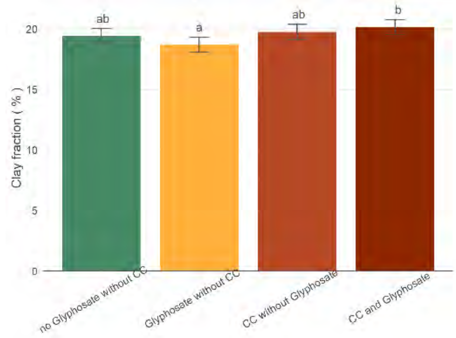

Figure 4: UH_EX1_NR_top_clay

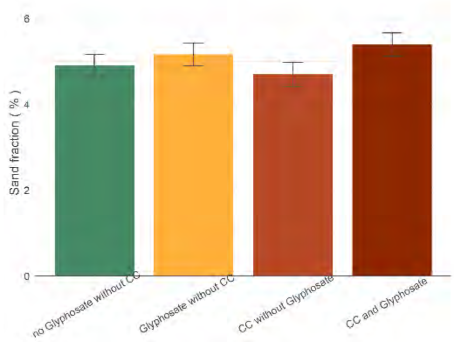

Figure 5: UH_EX1_NR_top_sand

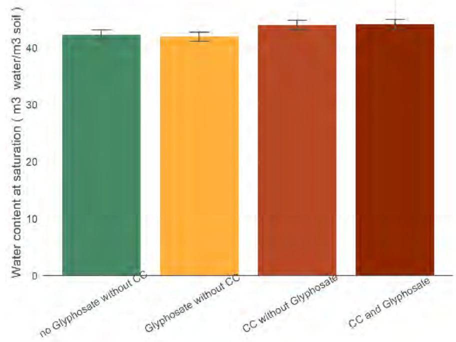

Figure 6: UH_EX1_NR_top_satur_wc

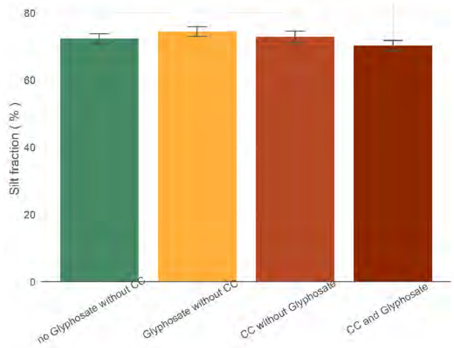

Figure 7: UH_EX1_NR_top_silt

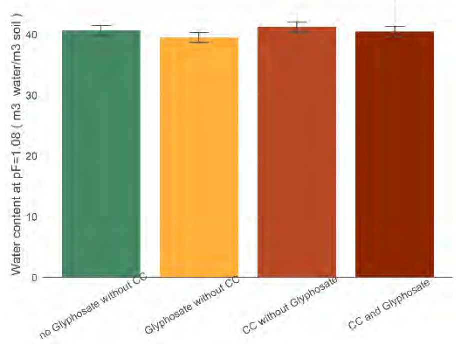

Figure 8: UH_EX1_NR_top_wc_pf_1_8

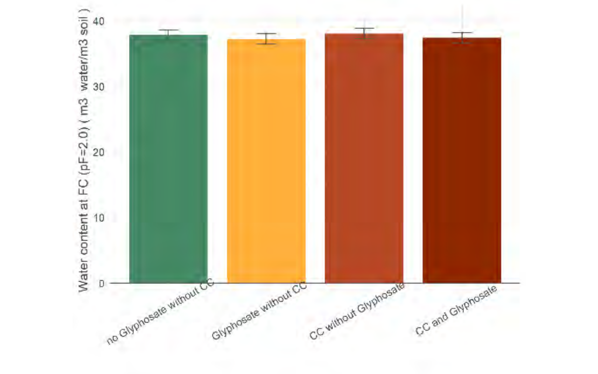

Figure 9: UH_EX1_NR_top_wc_pf2_0

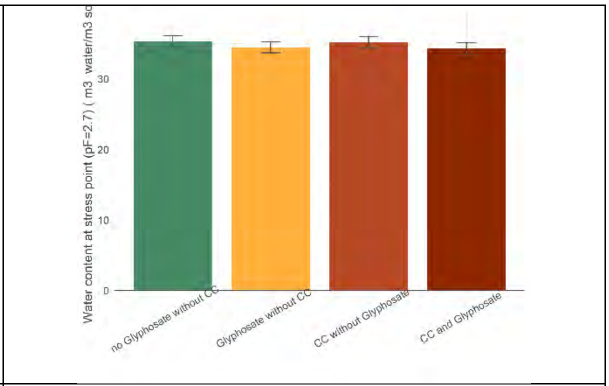

Figure 10: UH_EX1_NR_top_wc_pf2_7

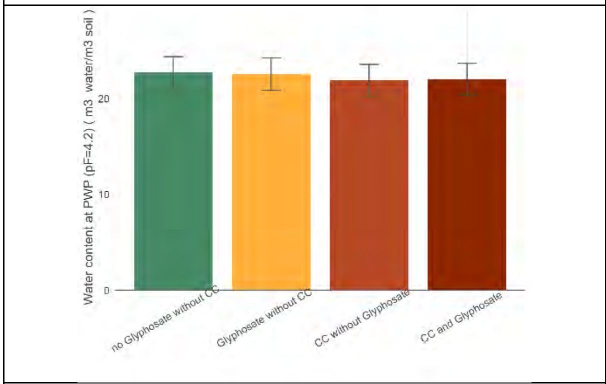

Figure 11: UH_EX1_NR_top_wc_pf4_2

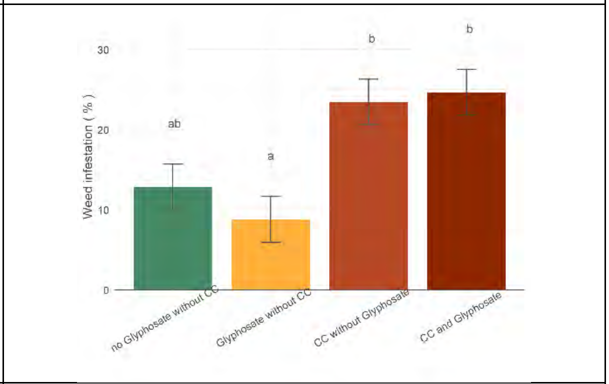

Figure 12: UH_EX1_NR_weed_infestation

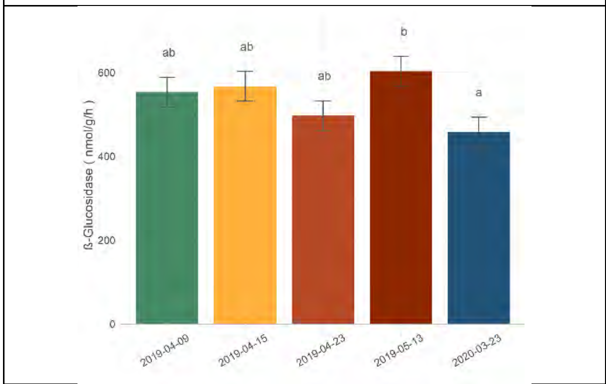

Figure 13: UH_EX1_NSI_date_B_Glu_activity

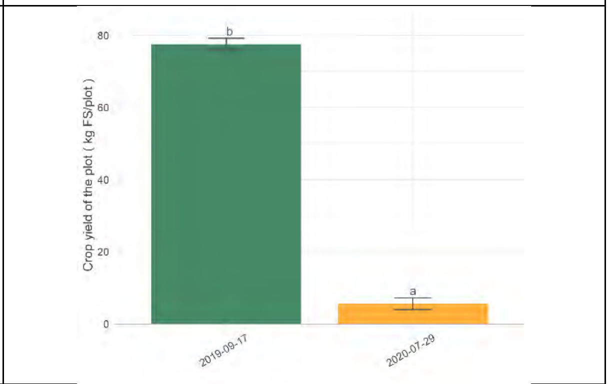

Figure 14: UH_EX1_NSI_date_crop_yield

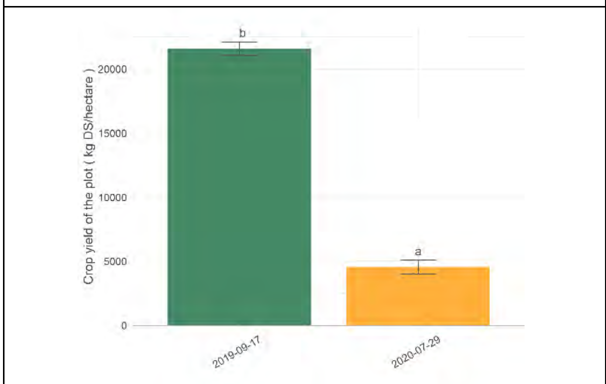

Figure 15: UH_EX1_NSI_date_crop_yield_ha

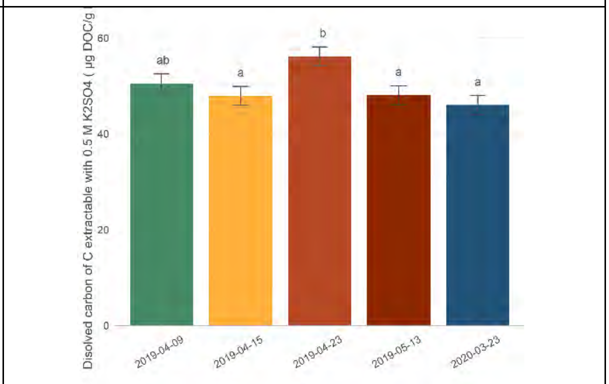

Figure 16: UH_EX1_NSI_date_disolved_c

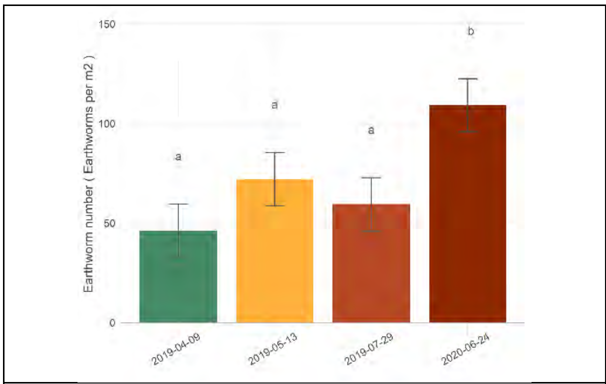

Figure 17: UH_EX1_NSI_date_earthworm_no

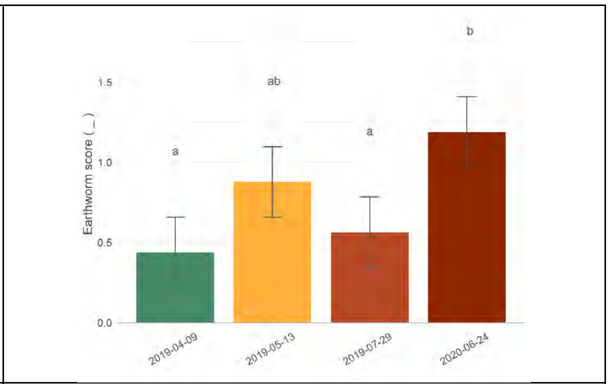

Figure 18: UH_EX1_NSI_date_earthworm_score

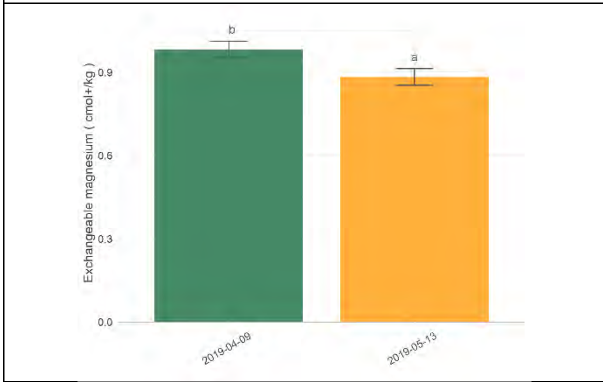

Figure 19: UH_EX1_NSI_date_mg2plus

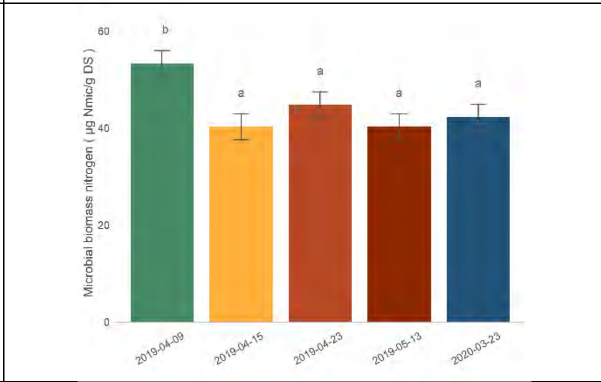

Figure 20: UH_EX1_NSI_date_microb_biom_n

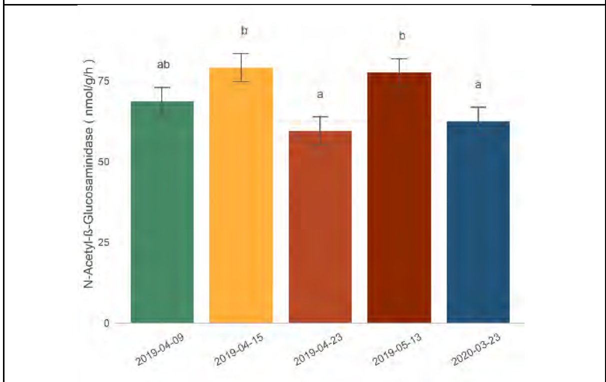

Figure 21: UH_EX1_NSI_date_N_Ac_activity

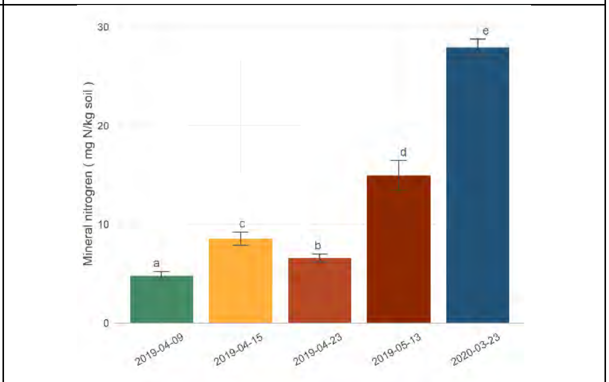

Figure 22: UH_EX1_NSI_date_nmin_top

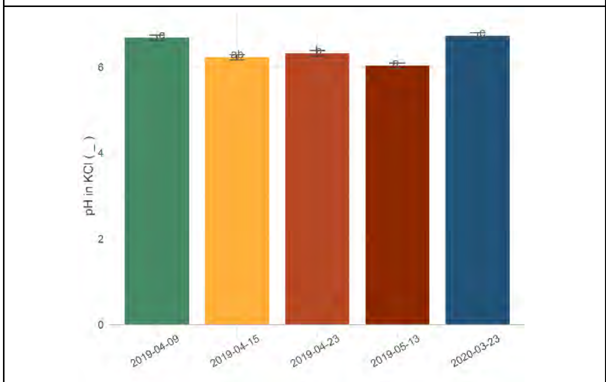

Figure 23: UH_EX1_NSI_date_ph_kcl

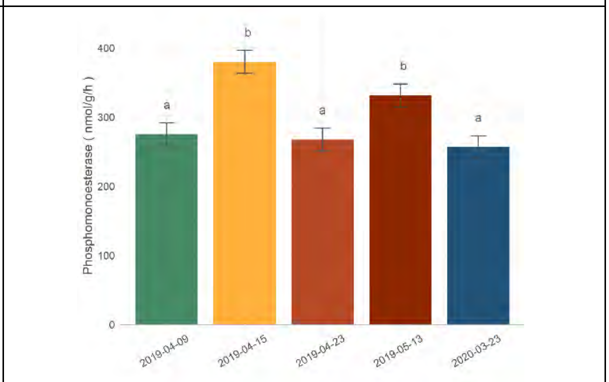

Figure 24: UH_EX1_NSI_date_Phos_activity

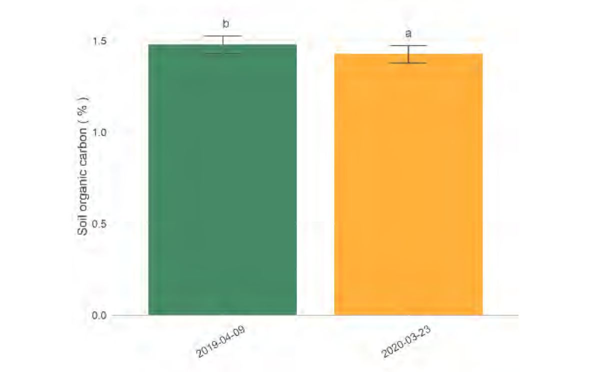

Figure 25: UH_EX1_NSI_date_soc

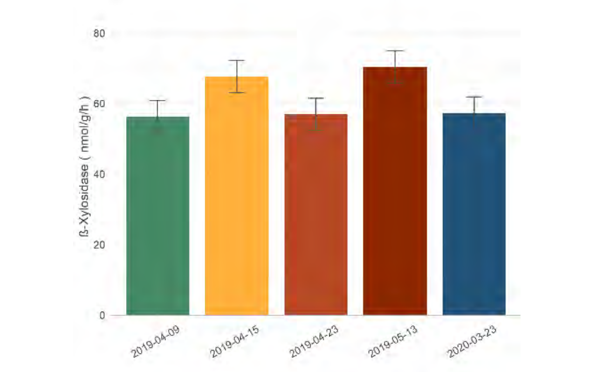

Figure 26: UH_EX1_NSI_date_Xyl_activity

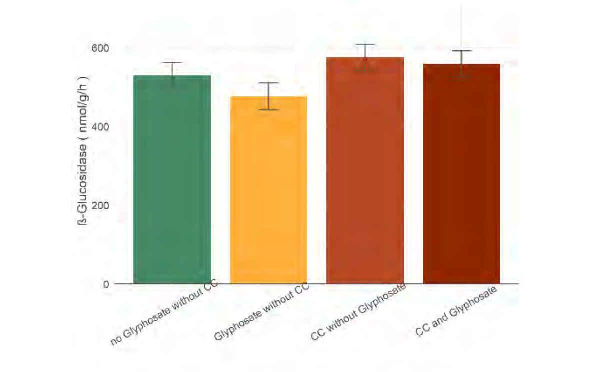

Figure 27: UH_EX1_NSI_treat_B_Glu_activity

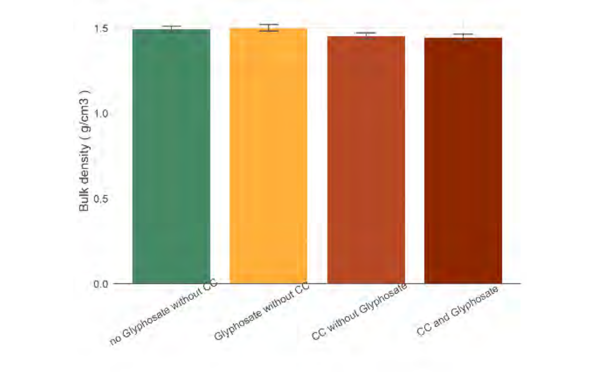

Figure 28: UH_EX1_NSI_treat_bd_top

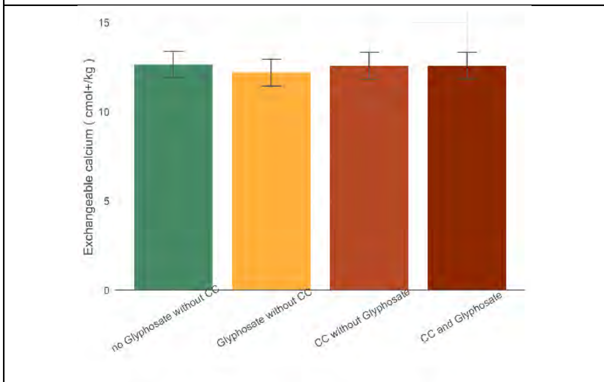

Figure 29: UH_EX1_NSI_treat_ca2_plus

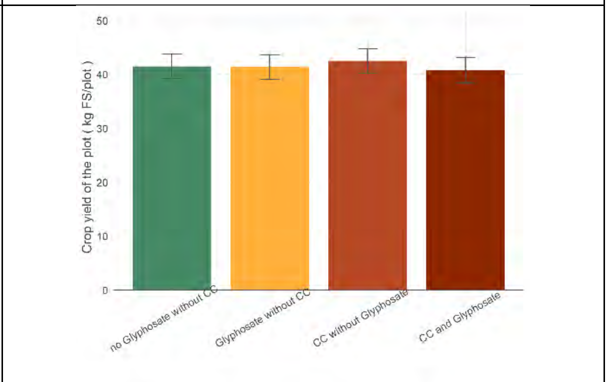

Figure 30: UH_EX1_NSI_treat_crop_yield

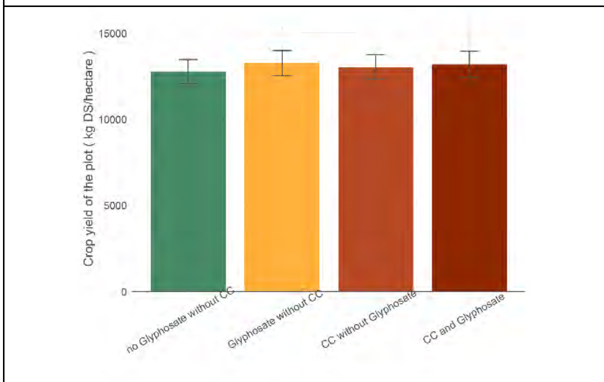

Figure 31: UH_EX1_NSI_treat_crop_yield_ha

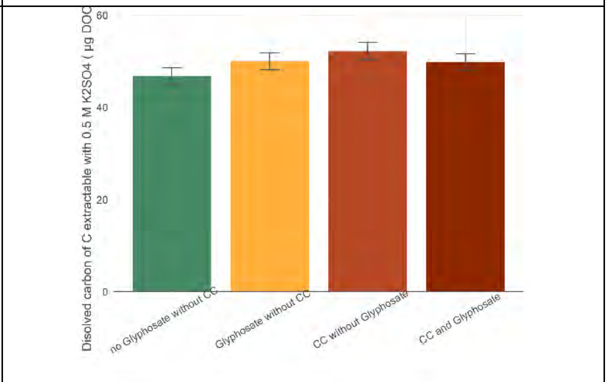

Figure 32: UH_EX1_NSI_treat_disolved_c

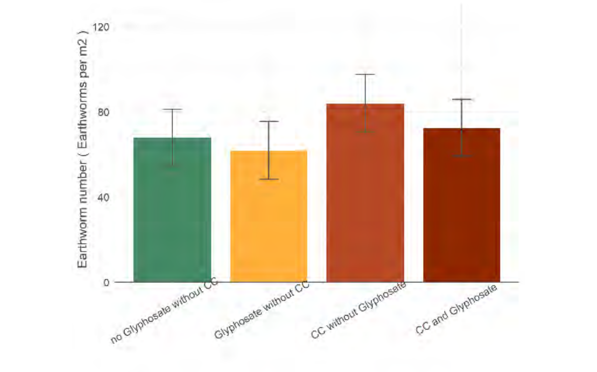

Figure 33: UH_EX1_NSI_treat_earthworm_no

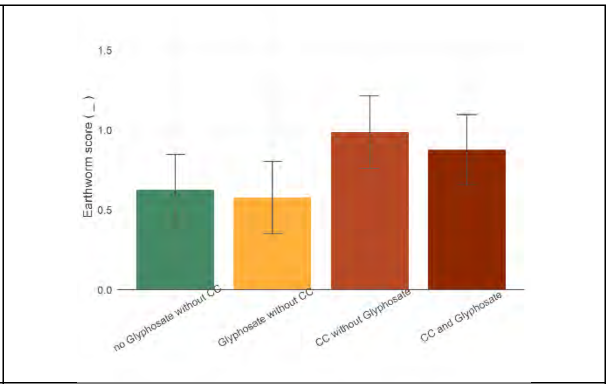

Figure 34: UH_EX1_NSI_treat_earthworm_score

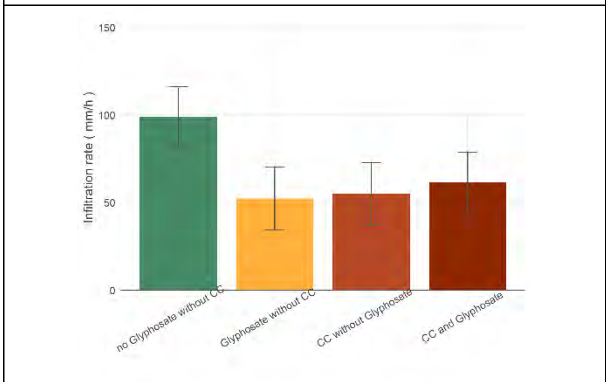

Figure 35: UH_EX1_NSI_treat_Infiltration

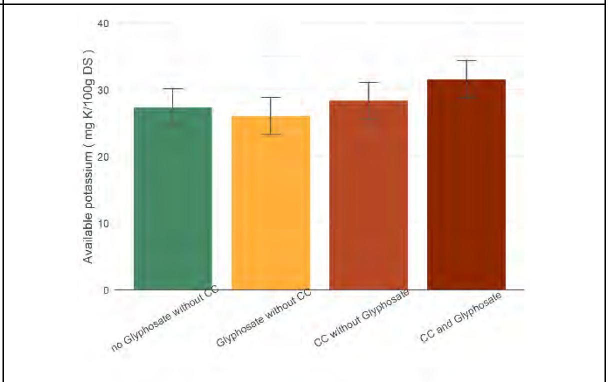

Figure 36: UH_EX1_NSI_treat_K_avail

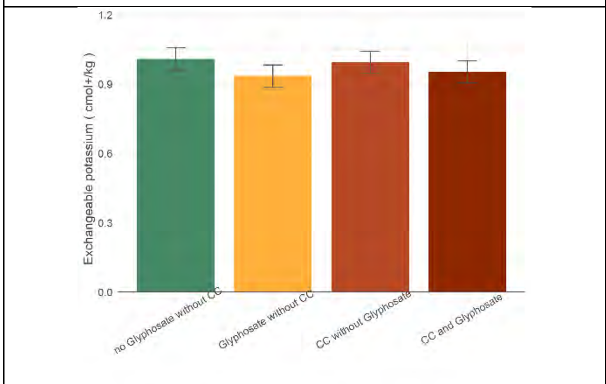

Figure 37: UH_EX1_NSI_treat_k_plus

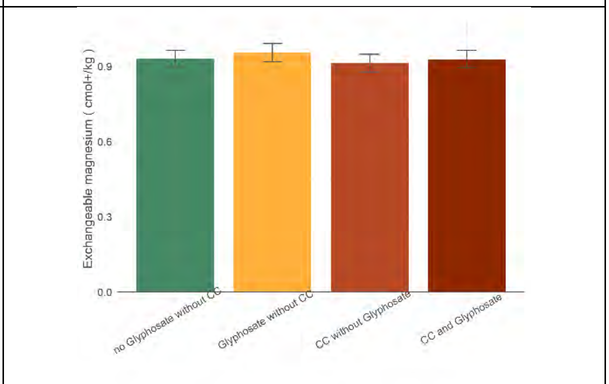

Figure 38: UH_EX1_NSI_treat_mg2plus

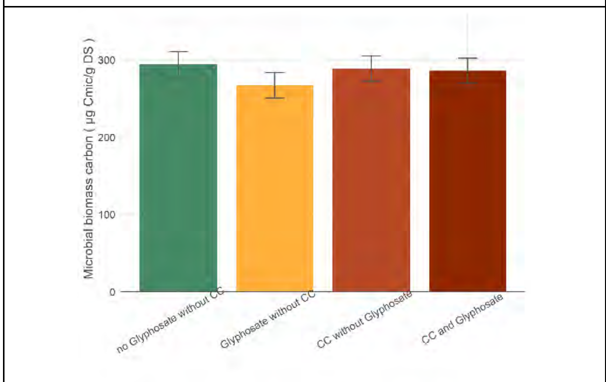

Figure 39: UH_EX1_NSI_treat_microb_biom_c

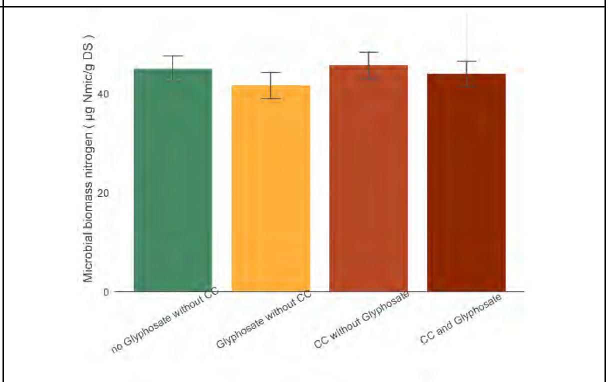

Figure 40: UH_EX1_NSI_treat_microb_biom_n

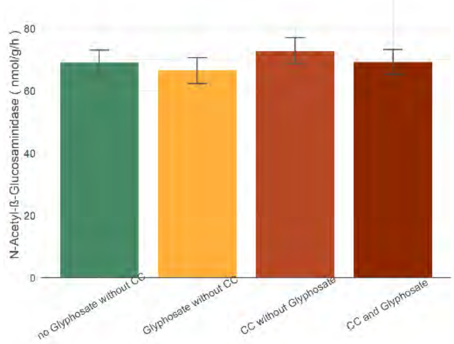

Figure 41: UH_EX1_NSI_treat_N_Ac_activity

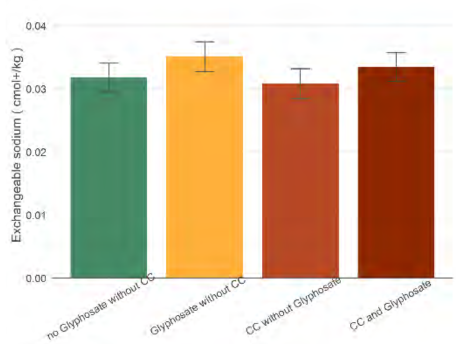

Figure 42: UH_EX1_NSI_treat_na_plus

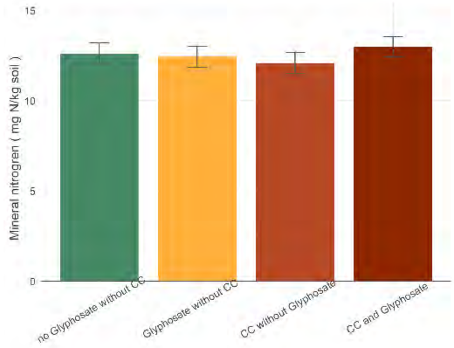

Figure 43: UH_EX1_NSI_treat_nmin_top

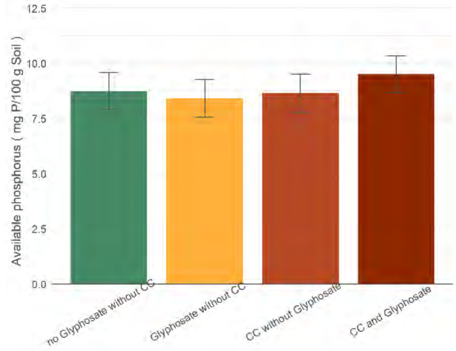

Figure 44: UH_EX1_NSI_treat_p_avail

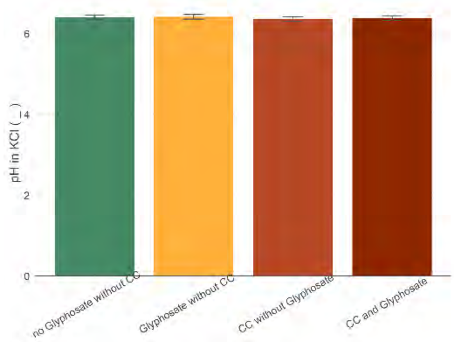

Figure 45: UH_EX1_NSI_treat_ph_kcl

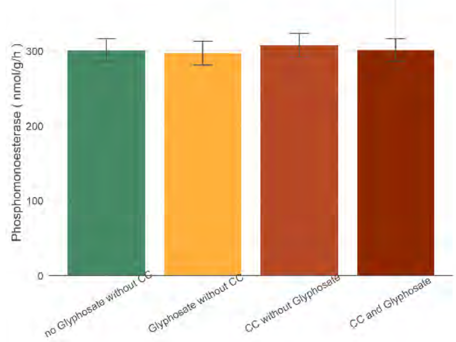

Figure 46: UH_EX1_NSI_treat_Phos_activity

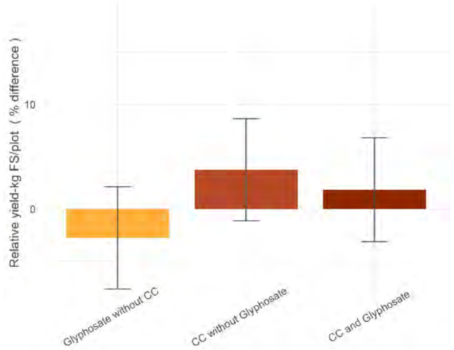

Figure 47: UH_EX1_NSI_treat_relative_yield

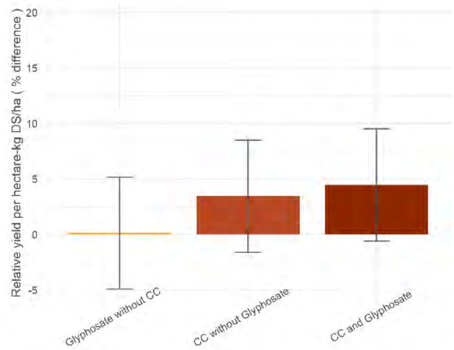

Figure 48: UH_EX1_NSI_treat_relative_yield_ha

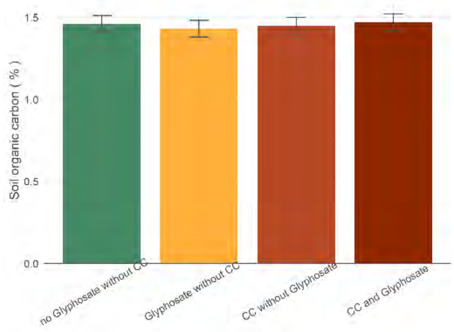	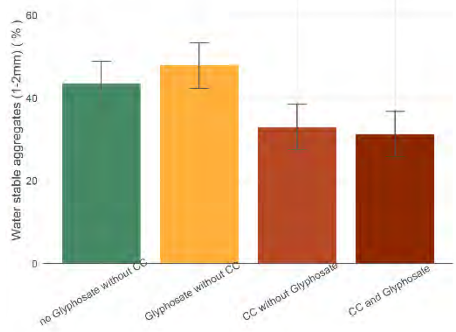
Figure 49: UH_EX1_NSI_treat_soc	*Figure 50: UH_EX1_NSI_treat_wsa*
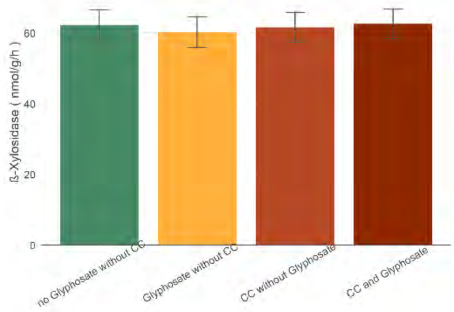	
Figure 51: UH_EX1_NSI_treat_Xyl_activity	

7. Germany: Figures Meteorological data

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For explanation of the figures please read the introduction to D5.3

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7E Stuttgart/Echterdingen. (ECAD 2763).

This station, listed in ECAD, covers 1953 until now and the station is located at 13 km from the experiments.

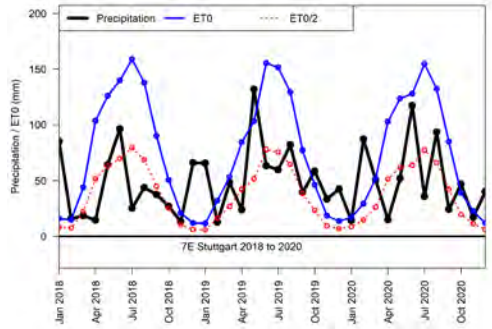

Figure 1: 7E Stuttgart 00aFAOgrow

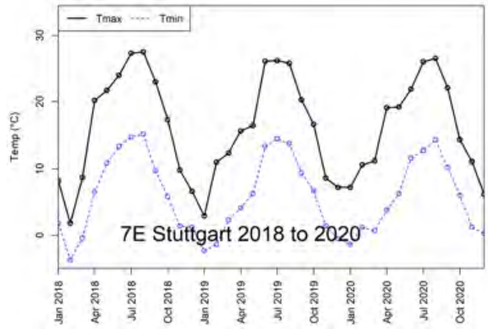

Figure 2: 7E Stuttgart 00b TnTx

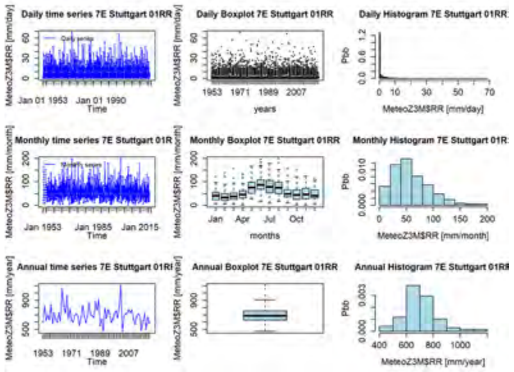

Figure 3: 7E Stuttgart 01RRhyplo

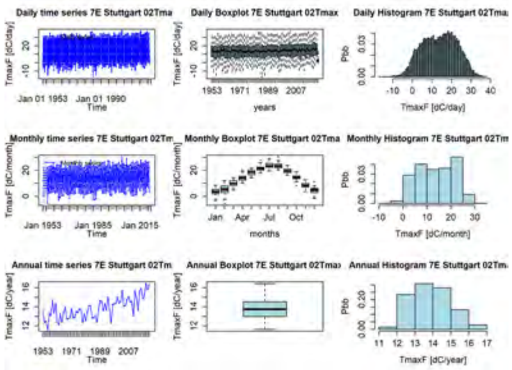

Figure 4: 7E Stuttgart 02Tmaxhyplo

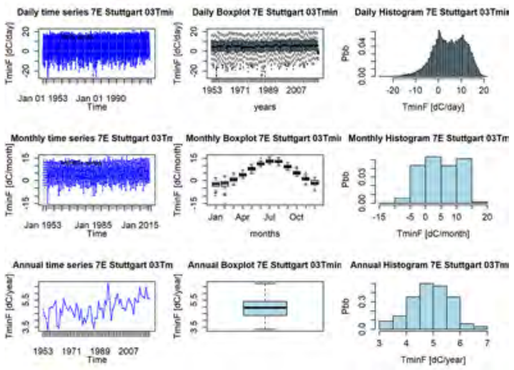

Figure 5: 7E Stuttgart 03Tminhyplo

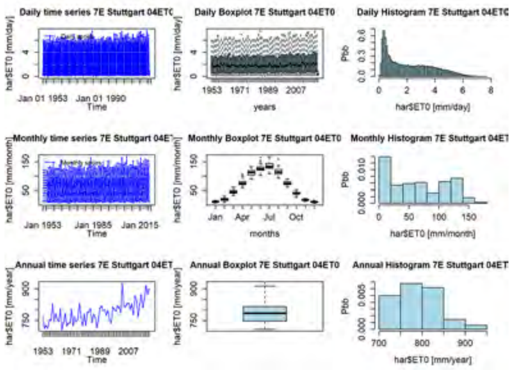

Figure 6: 7E Stuttgart 04ET0hyplo

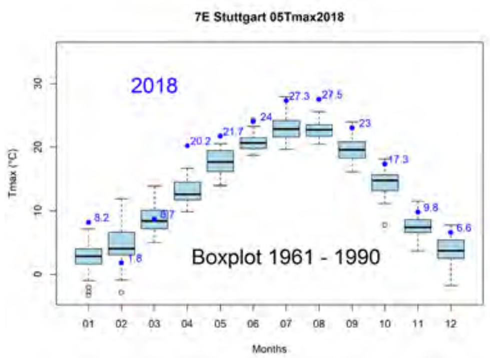

Figure 7: 7E Stuttgart 05Tmax2018box

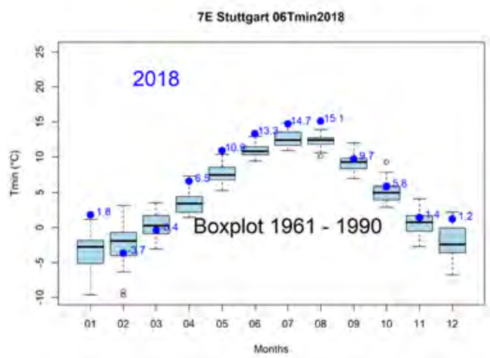

Figure 8: 7E Stuttgart 06Tmin2018box

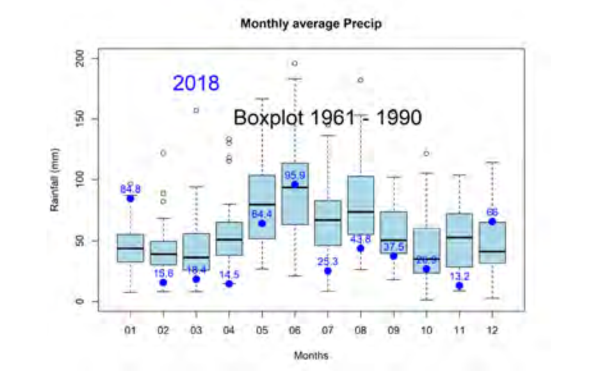

Figure 9: 7E Stuttgart 07Precip2018box

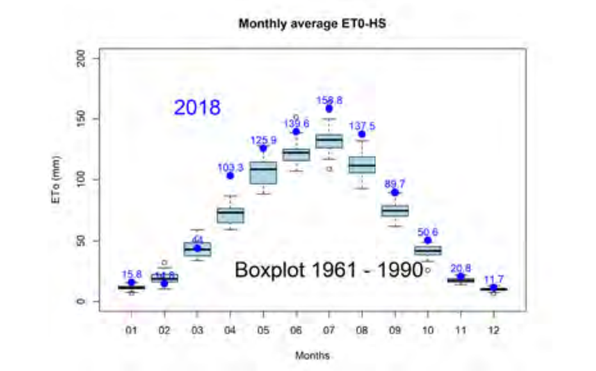

Figure 10: 7E Stuttgart 08ET02018box

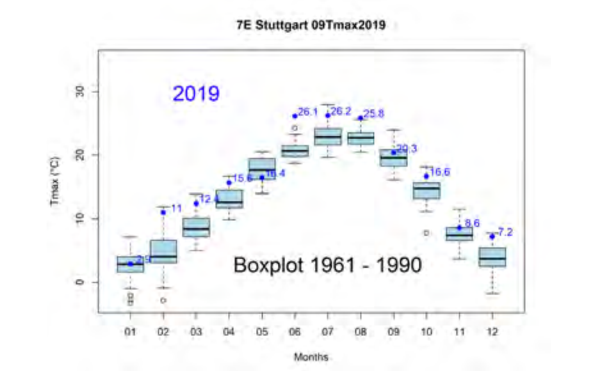

Figure 11: 7E Stuttgart 09Tmax2019box

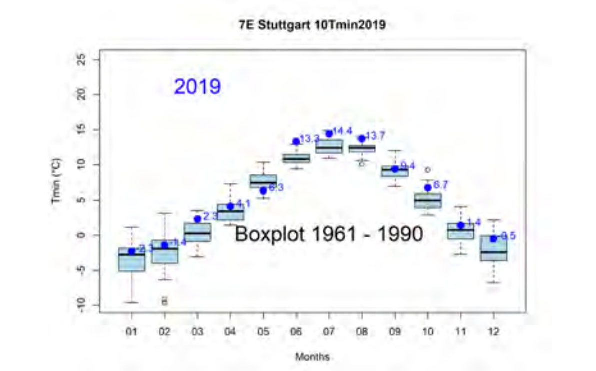

Figure 12: 7E Stuttgart 10Tmin2019box

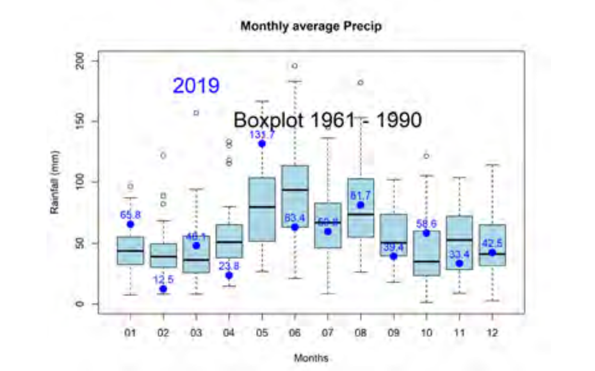

Figure 13: 7E Stuttgart 11Precip2019box

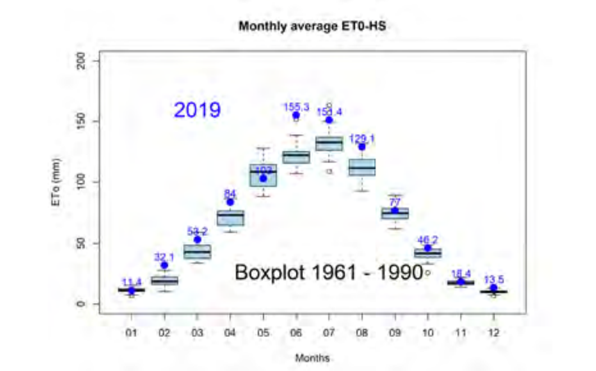

Figure 14: 7E Stuttgart 12ET02019box

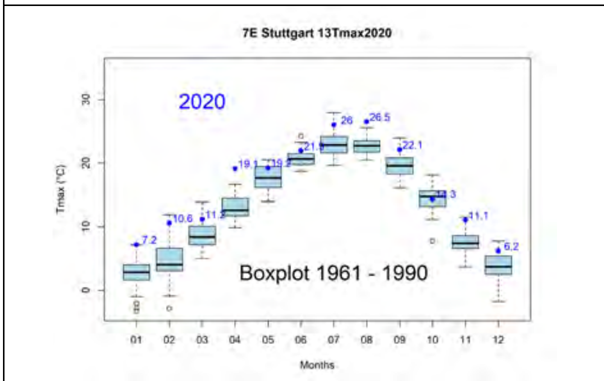

Figure 15: 7E Stuttgart 13Tmax2020box

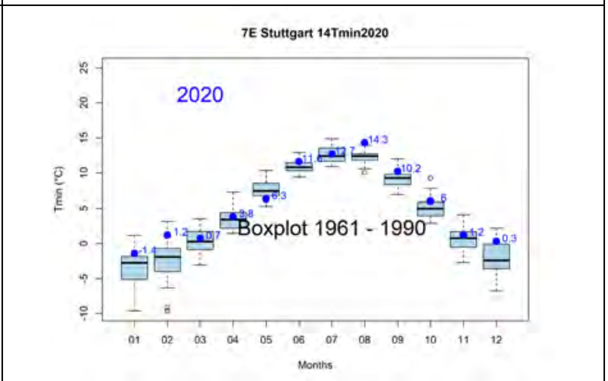

Figure 16: 7E Stuttgart 14Tmin2020box

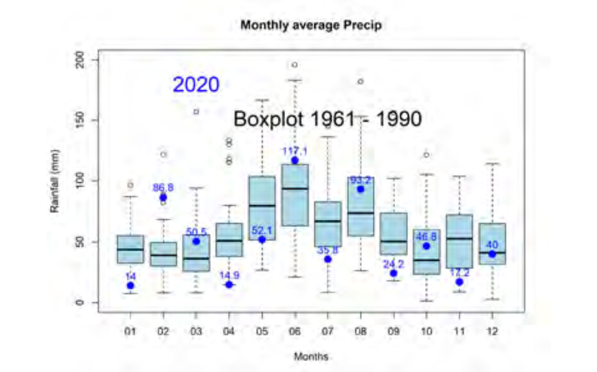

Figure 17: 7E Stuttgart 15Precip2020box

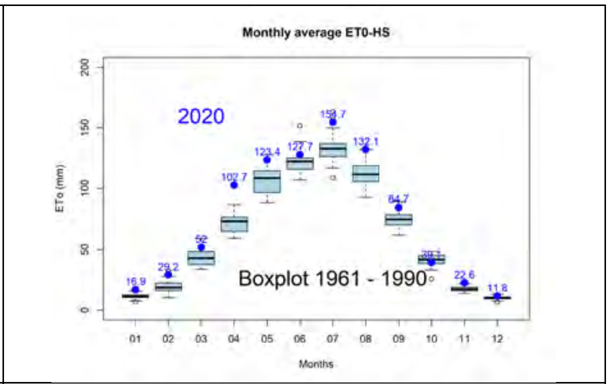

Figure 18: 7E Stuttgart 16ET02020box

7a Tachenhausen

This station is close to the experiments and can be download from the website of "*Agrar Meteo Baden Wurttemberg*" ([https://www.wetter-bw.de/)](https://www.wetter-bw.de/) starting from 1 August 2010 till now.

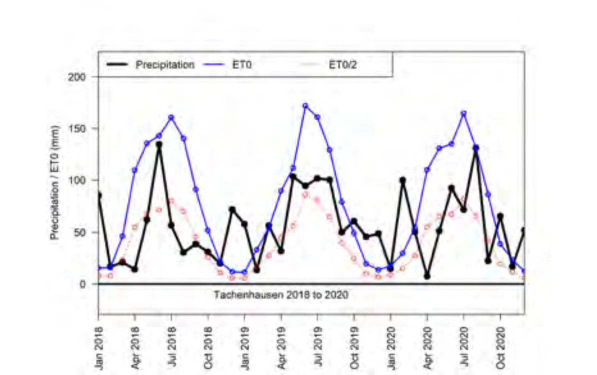

Figure 19: 7aTachenhausen 00aFAOgrow

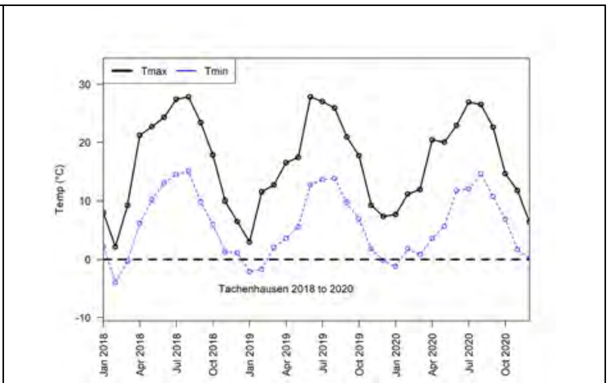

Figure 20: 7aTachenhausen 00bTnTx

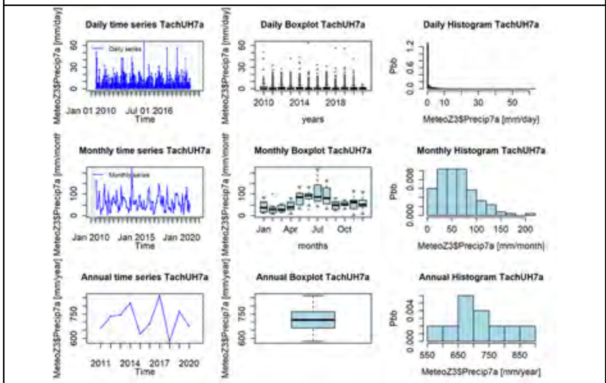

Figure 21: 7aTachenhausen 01PrecHyplo

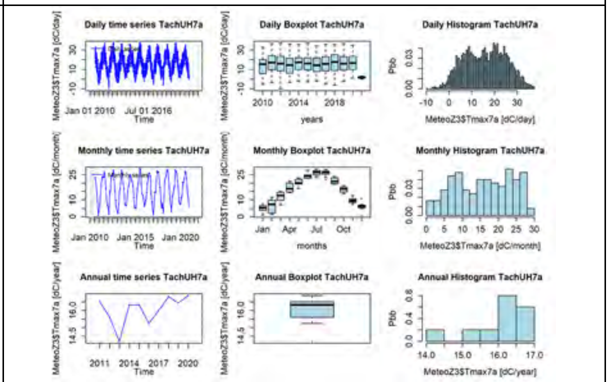

Figure 22: 7aTachenhausen 02TmaxHyplo

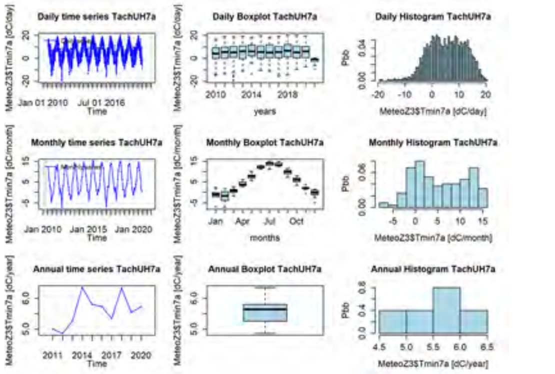

Figure 23: 7aTachenhausen 03TminHyplo

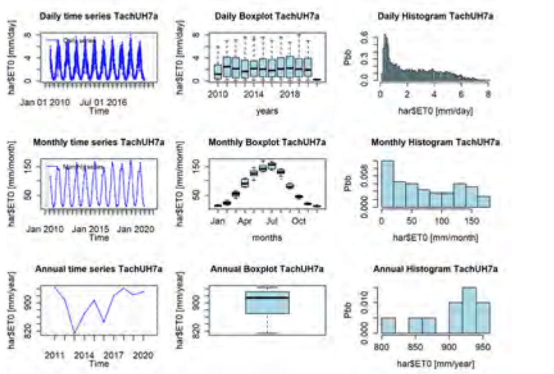

Figure 24: 7aTachenhausen 04ET0Hyplo

8. Romania: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table 1: Indicators measured and analyzed in the SS

Observation code	Unit	Description
ksat	cm/h	Saturated hydraulic conductivity
top_wc_pf2_0	m^3m^{-3}	Water content at FC
top_wc_pf4_2	m^3m^{-3}	Water content at PWP
top_wc_pf2_7	m^3m^{-3}	Water content at pF2.7
top_wc_pf_1_8	m^3m^{-3}	Water content at pF1.08
top_satur_wc	m^3m^{-3}	Water content at Saturation
wsa	%	Water stable aggregates
bd_top	g/cm^3	Bulk density (10-20 cm)
bd_bot	g/cm^3	Bulk density (40-50 cm)
top_clay	%	Clay content
top_silt	%	Silt content
top_sand	%	Sand content
p_avail	mg-P/100gr Soil	Available Phosphorus
k_plus	cmol+/kg	Exchangeable Potassium
ca2_plus	cmol+/kg	Exchangeable Calcium
na_plus	cmol+/kg	Exchangeable Sodium
mg2plus	cmol+/kg	Exchangeable Magnesium
soc	%	SOC
ph_h2o	_	pH
ec1_5	dS/m	EC
crop_yield	kg/plot	Crop yield of the plot
crop_yield_ha	kg/hectare	Crop yield

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Experiment 1:

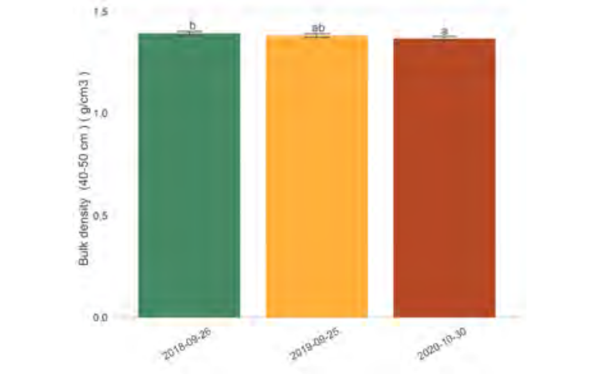

Figure 1: ICPA_EX1_NSI_date_bd_bot

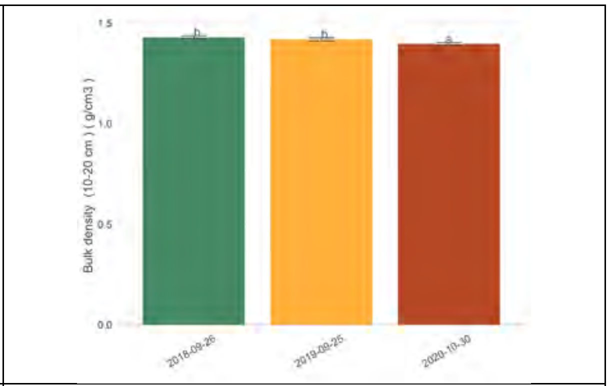

Figure 2: ICPA_EX1_NSI_date_bd_top

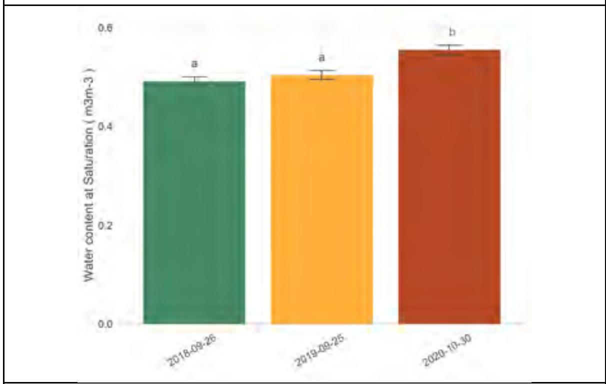

Figure 3: ICPA_EX1_NSI_date_top_satur_wc

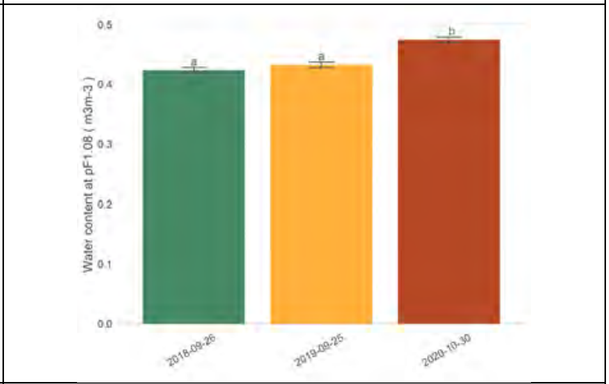

Figure 4: ICPA_EX1_NSI_date_top_wc_pf_1_8

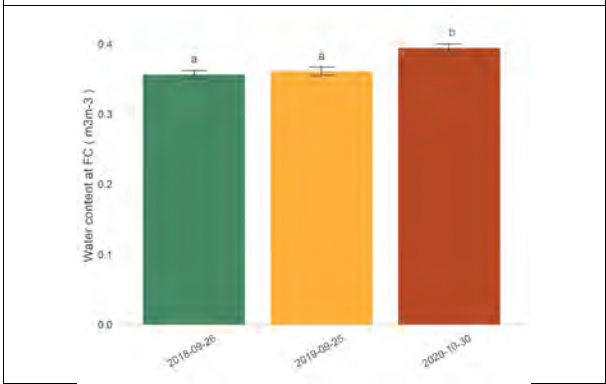

Figure 5: ICPA_EX1_NSI_date_top_wc_pf2_0

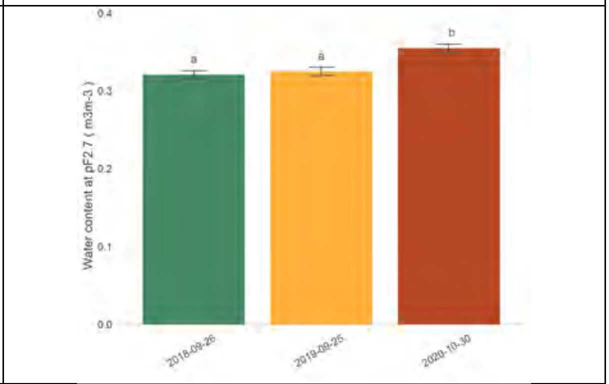

Figure 6: ICPA_EX1_NSI_date_top_wc_pf2_7

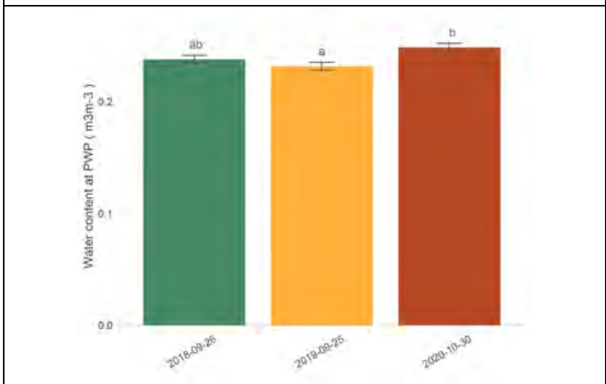

Figure 7: ICPA_EX1_NSI_date_top_wc_pf4_2

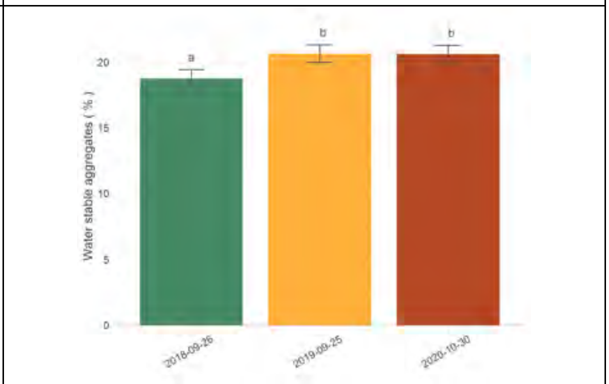

Figure 8: ICPA_EX1_NSI_date_wsa

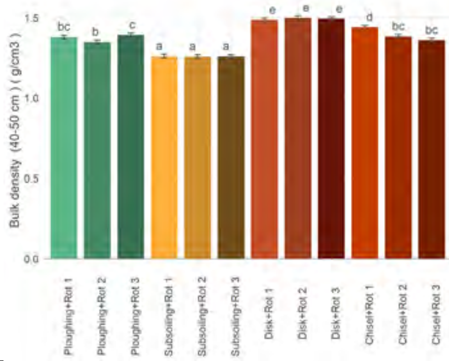

Figure 9: ICPA_EX1_NSI_treat_bd_bot

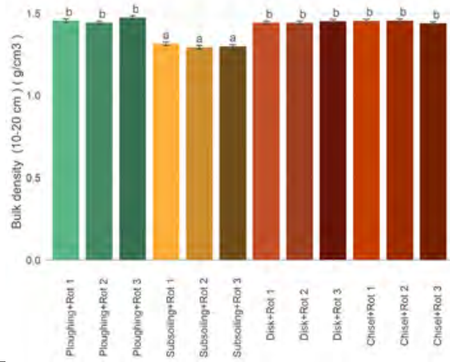

Figure 10: ICPA_EX1_NSI_treat_bd_top

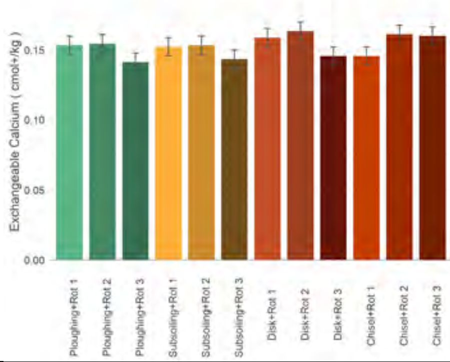

Figure 11: ICPA_EX1_NSI_treat_ca2_plus

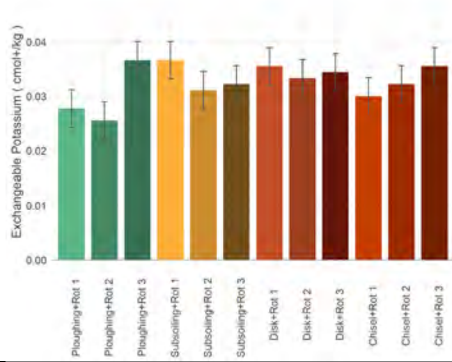

Figure 12: ICPA_EX1_NSI_treat_k_plus

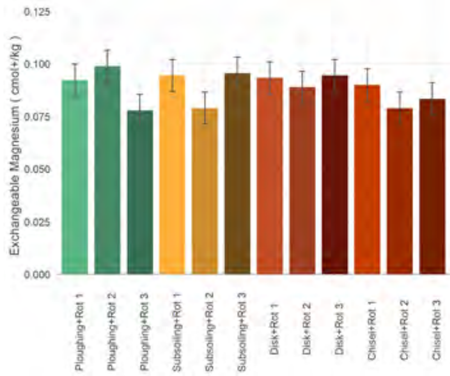

Figure 13: ICPA_EX1_NSI_treat_mg2plus

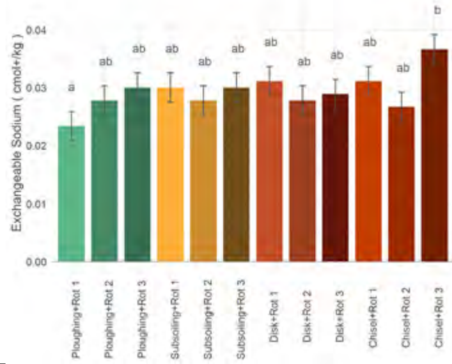

Figure 14: ICPA_EX1_NSI_treat_na_plus

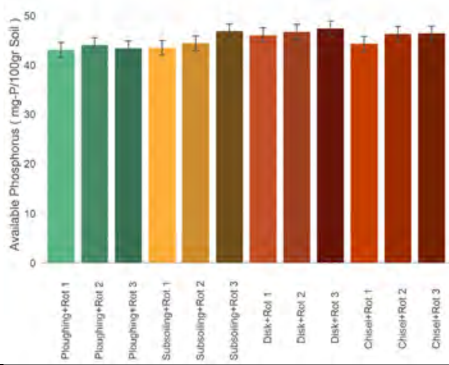

Figure 15: ICPA_EX1_NSI_treat_p_avail

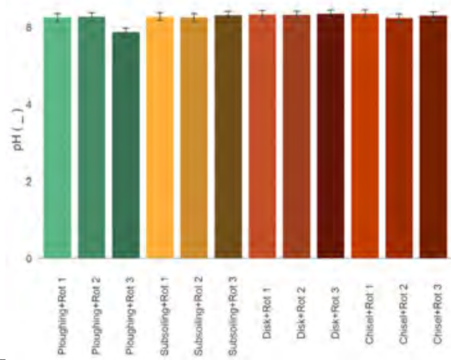

Figure 16: ICPA_EX1_NSI_treat_ph_h2o

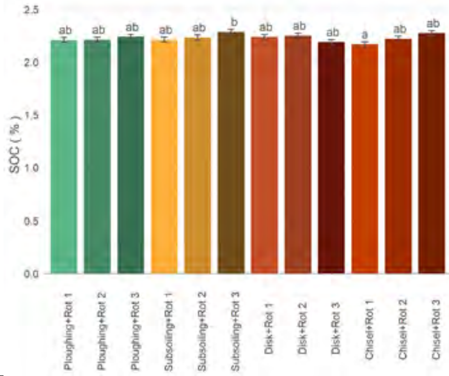

Figure 17: ICPA_EX1_NSI_treat_soc

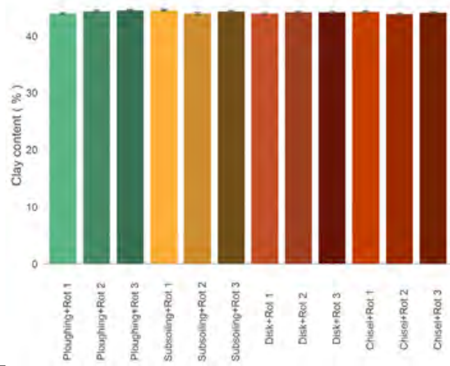

Figure 18: ICPA_EX1_NSI_treat_top_clay

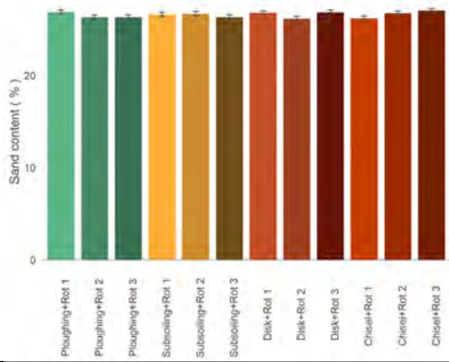

Figure 19: ICPA_EX1_NSI_treat_top_sand

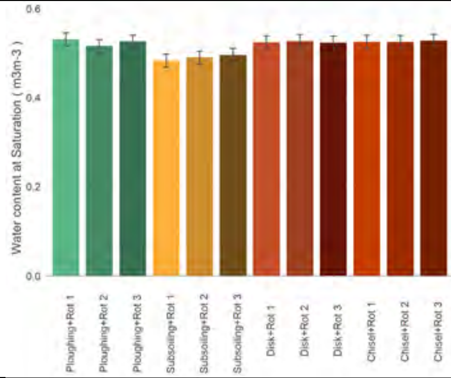

Figure 20: ICPA_EX1_NSI_treat_top_satur_wc

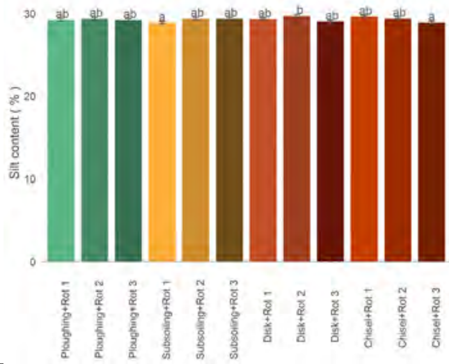

Figure 21: ICPA_EX1_NSI_treat_top_silt

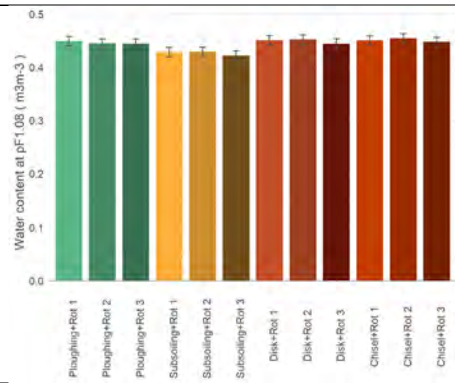

Figure 22: ICPA_EX1_NSI_treat_top_wc_pf_1_8

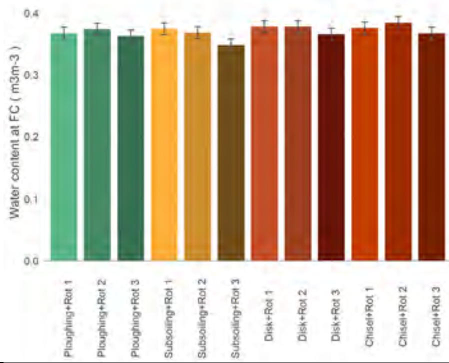

Figure 23: ICPA_EX1_NSI_treat_top_wc_pf2_0

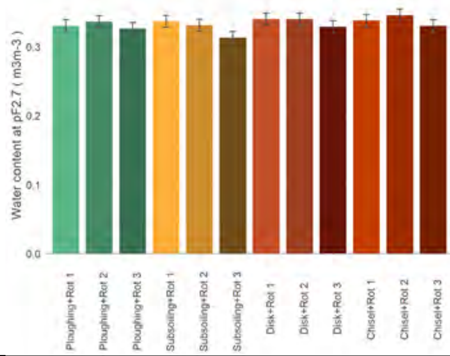

Figure 24: ICPA_EX1_NSI_treat_top_wc_pf2_7

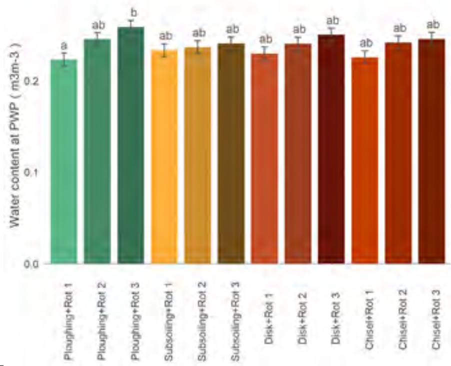

Figure 25: ICPA_EX1_NSI_treat_top_wc_pf4_2

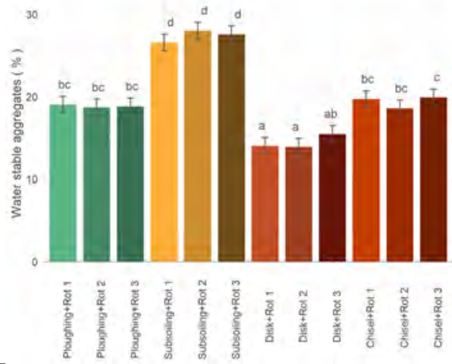

Figure 26: ICPA_EX1_NSI_treat_wsa

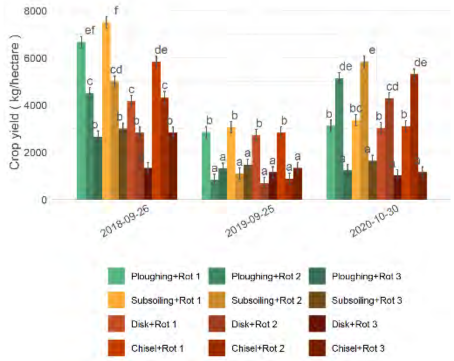

Figure 27: ICPA_EX1_SI_crop_yield_ha

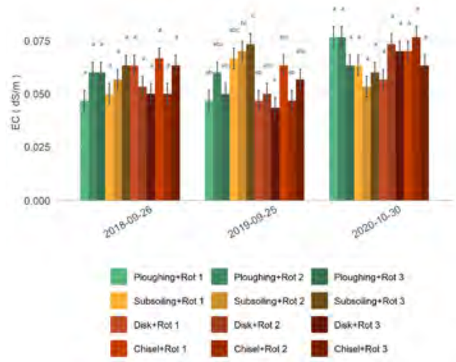

Figure 28: ICPA_EX1_SI_ec1_5

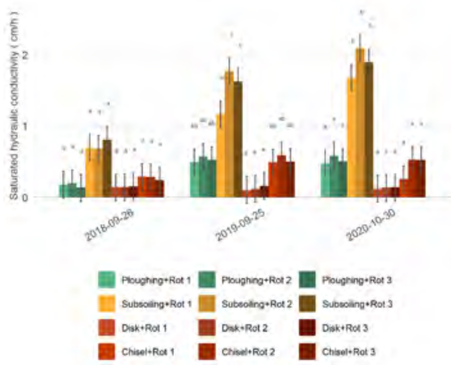

Figure 29: ICPA_EX1_SI_ksat

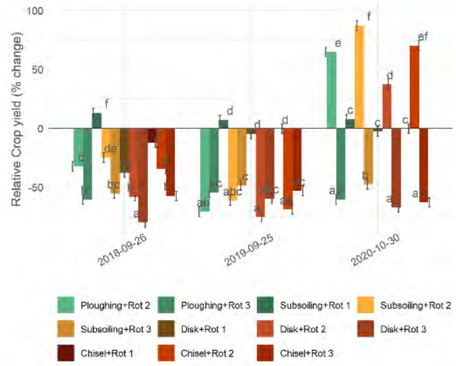

Figure 30: ICPA_EX1SI_rel_crop_yield_ha

8. Romania: Meteorological figures from the exploratory analysis

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For explanation of the figures for the meteorological analysis see the introductory part of D5.3

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8E Bucuresti (ECAD 219)

The meteorological station, Bucarest, is available as ECAD station 219. Measurement started in 1881 for rainfall up to November 2020, unfortunately, the station is at some distance km from the study site.

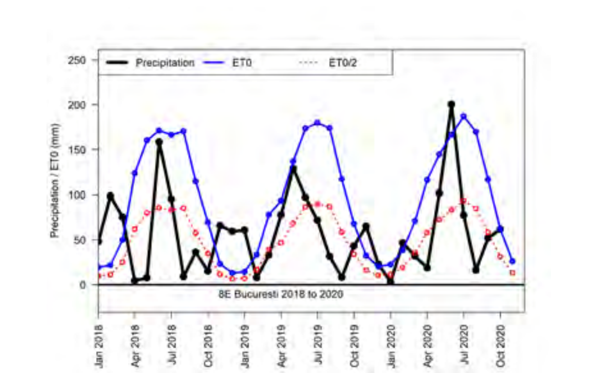


Figure 1: 8E Bucuresti 00aFAOgrow

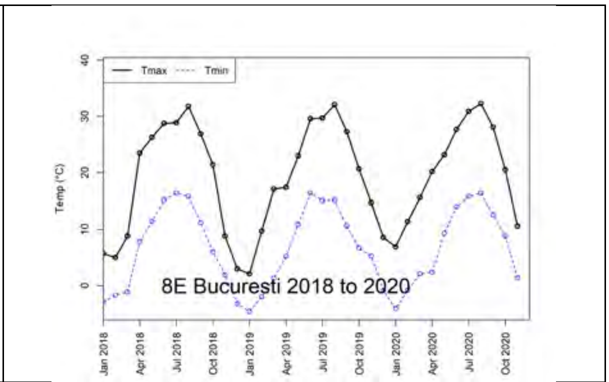


Figure 2: 8E Bucuresti 00b TnTx

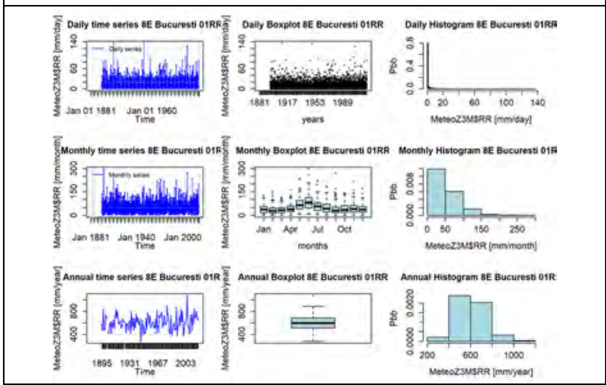


Figure 3: 8E Bucuresti 01RRhyplo

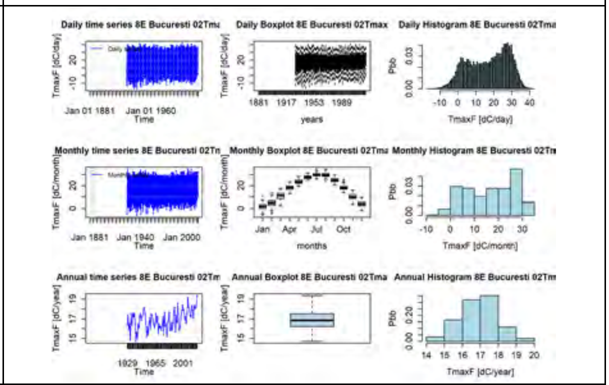


Figure 4: 8E Bucuresti 02Tmaxhyplo

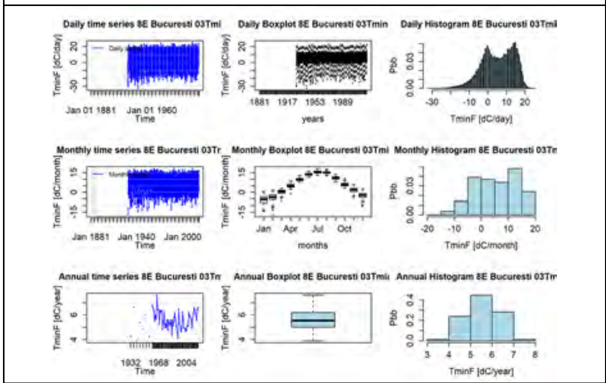


Figure 5: 8E Bucuresti 03Tminhyplo

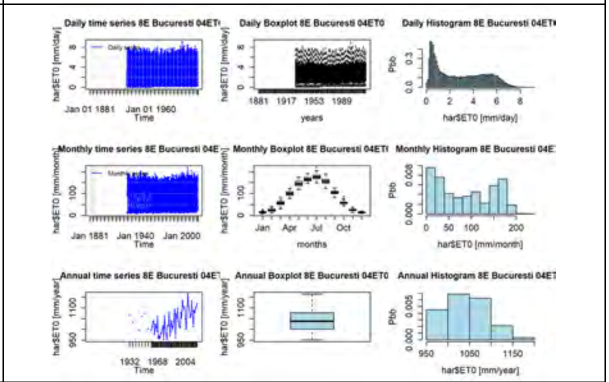


Figure 6: 8E Bucuresti 04ET0hyplo

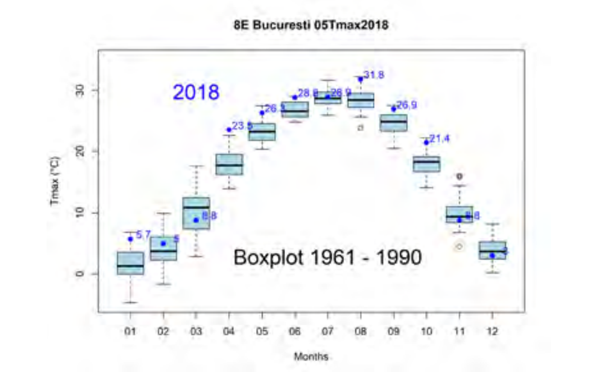


Figure 7: 8E Bucuresti 05Tmax2018box

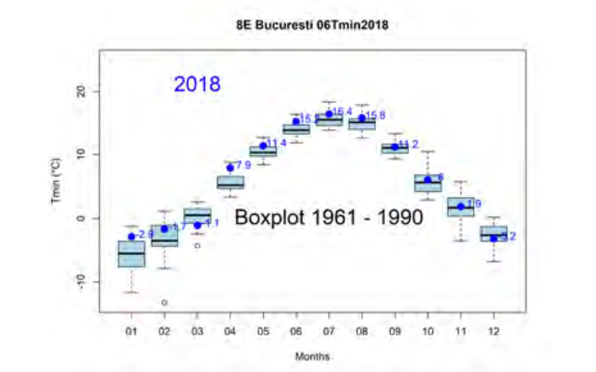


Figure 8: 8E Bucuresti 06Tmin2018box

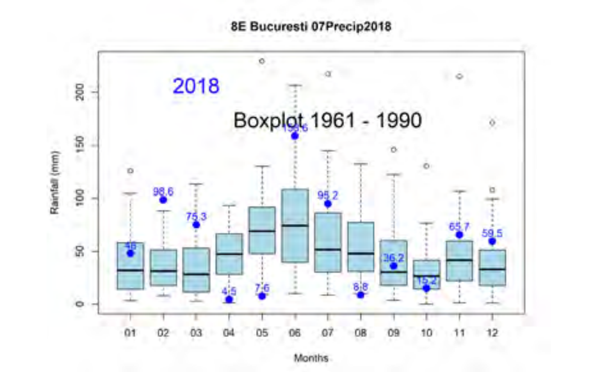


Figure 9: 8E Bucuresti 07Precip2018box

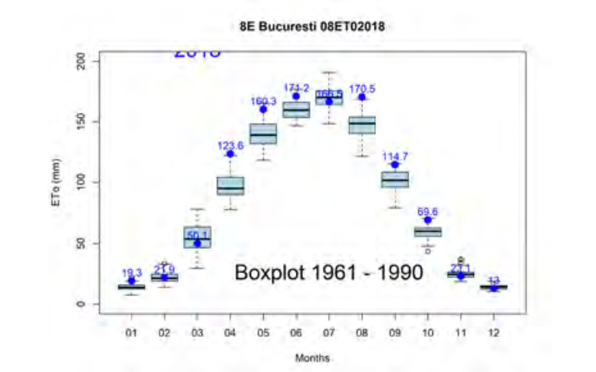


Figure 10: 8E Bucuresti 08ET02018box

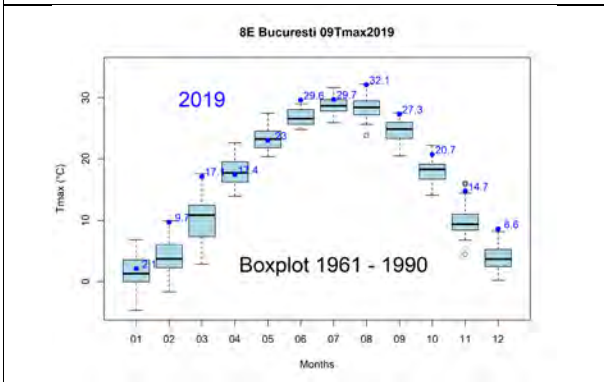


Figure 11: 8E Bucuresti 09Tmax2019box

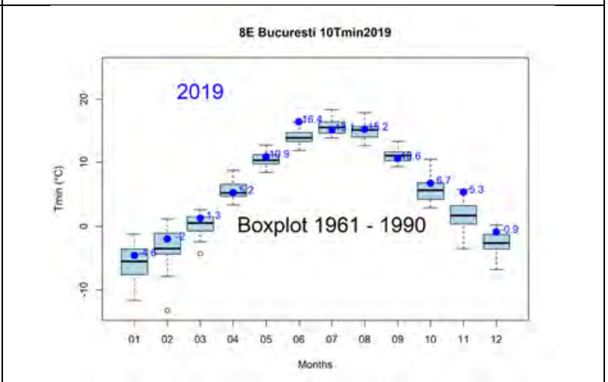


Figure 12: 8E Bucuresti 10Tmin2019box

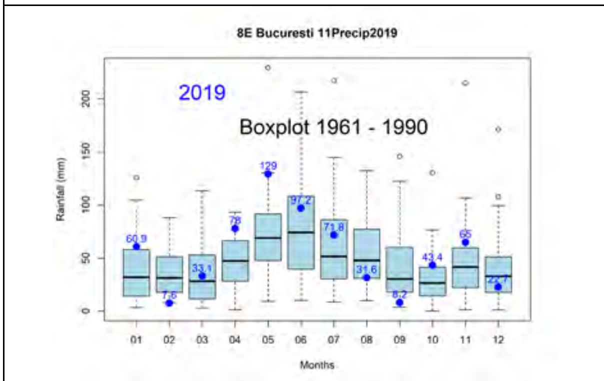


Figure 13: 8E Bucuresti 11Precip2019box

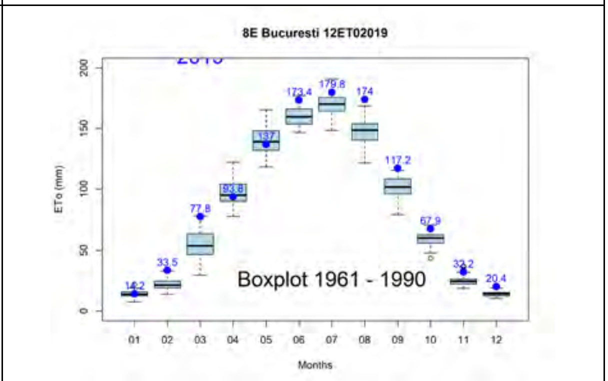


Figure 14: 8E Bucuresti 12ET02019box

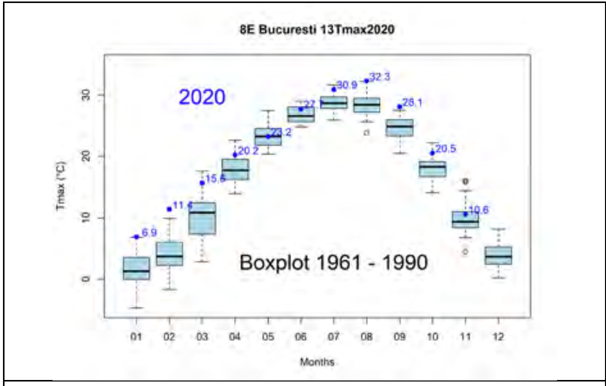


Figure 15: 8E Bucuresti 13Tmax2020box

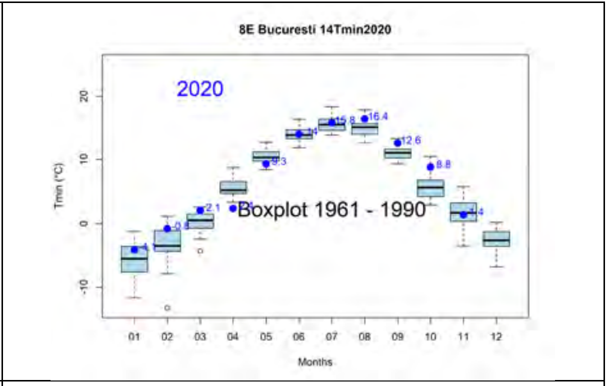


Figure 16: 8E Bucuresti 14Tmin2020box

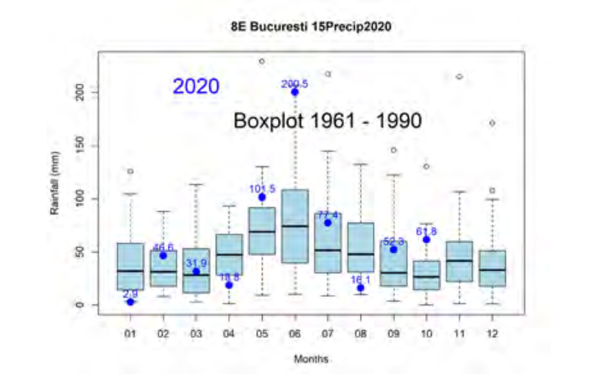


Figure 17: 8E Bucuresti 15Precip2020box

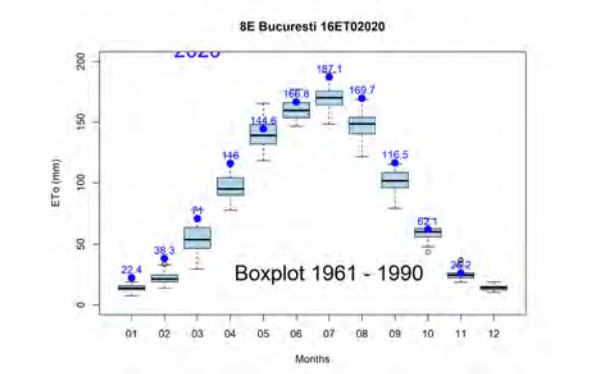


Figure 18: 8E Bucuresti 16ET02020box

8a Draganesti Vlasca

The station is close to the experiments but stopped in 2013.

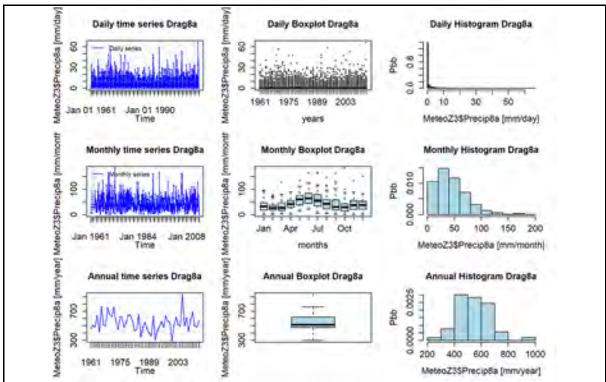


Figure 19: 8aDraganesti 01PrecHyplo

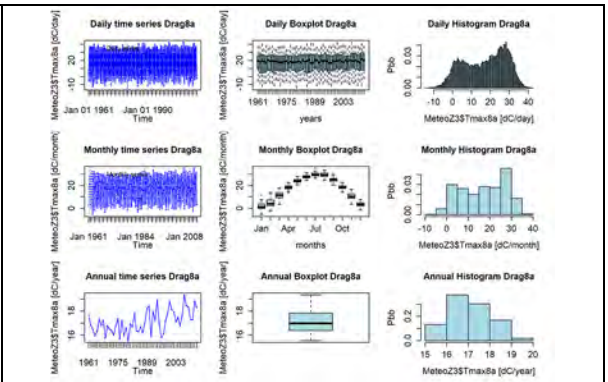


Figure 20: 8aDraganesti 02TmaxHyplo

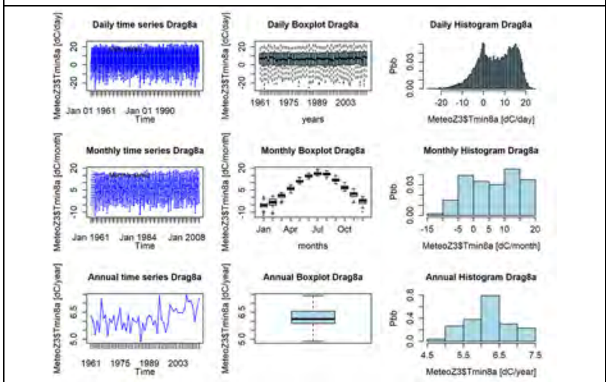


Figure 21: 8aDraganesti 03TminHyplo

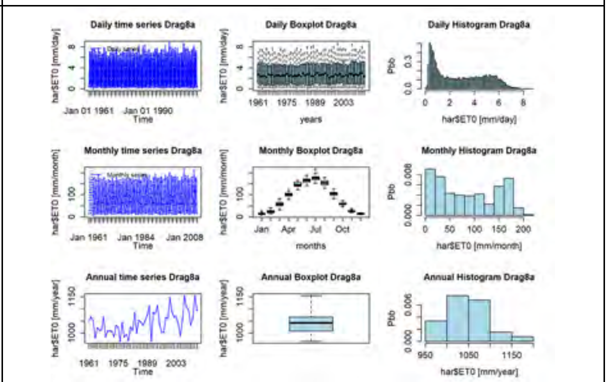


Figure 22: 8aDraganesti 04ET0Hyplo

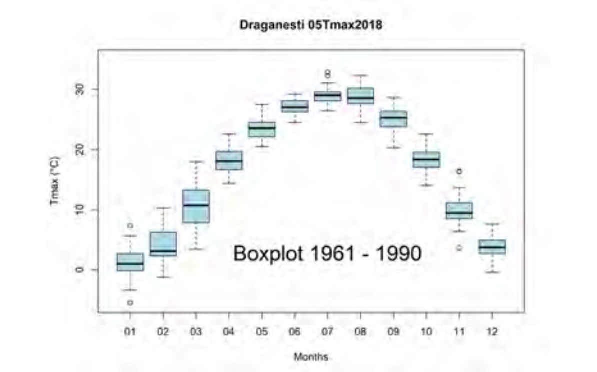
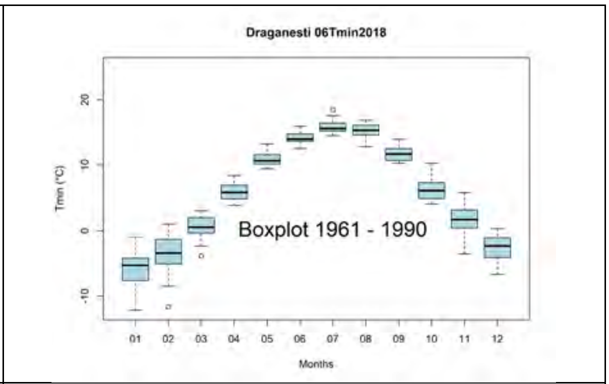


Figure 23: 8a Draganesti 05Tmaxbox



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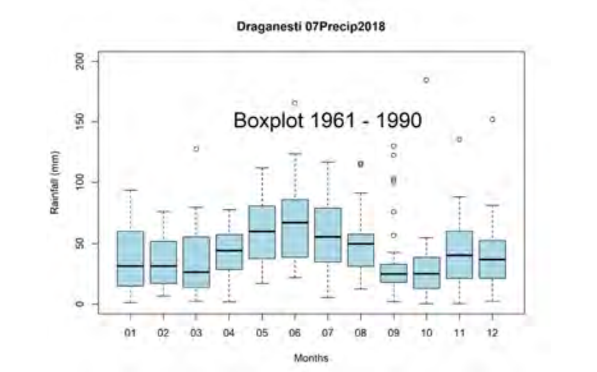

Figure 25: 8a Draganesti 07Precipbox

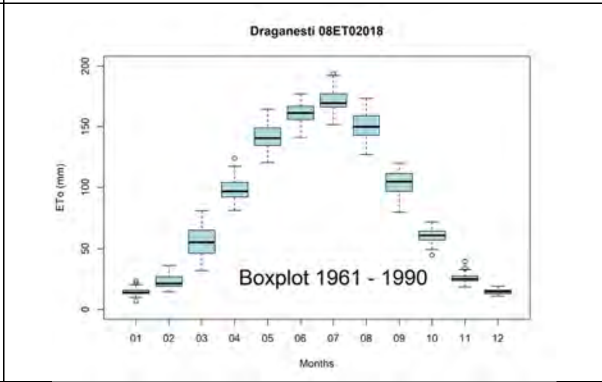

Figure 26: 8a Draganesti 08ET0box

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1. Italy: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment has an effect on the response variable all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table 1: Indicators measured and analysed

Observation code	**Unit**	**Description**
ksat	k_{sat}	m s^{-1}
top_wc_pf2_0	pF 2	m3m-3
top_wc_pf4_2	pF 4.2	m3m-3
top_wc_pf2_7	pF 2.7	m3m-3
top_wc_pf_1_8	pF 1.8	m3m-3
top_satur_wc	VWC_{sat}	m3m-3
wsa	Aggregate stability class	class
bd_top	BD_{10-20}	g/cm3
bd_bot	BD_{40-50}	g/cm3
top_clay	Clay	%
top_silt	Silt	%
top_sand	Sand	%
nmin_top	N_{min}	mg-N/Kg soil
p_avail	TP	mg-P/100gr Soil
k_plus	K^{+}	cmol+/kg
ca2_plus	CA^{2+}	cmol+/kg
na_plus	NA^{+}	cmol+/kg
mg2plus	MG^{+}	cmol+/kg
soc	SOC	%
ph_kcl	pH	unitless
weed_infestation	Weed infestation	%
earthworm_score	Earthworm score	unitless
earthworm_no	Earthworm no.	/m2
soil_cover	Soil cover	%
crop_yield	Yield	kg/plot
crop_yield_ha	Yield	kg/hectare

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Experiment 1:

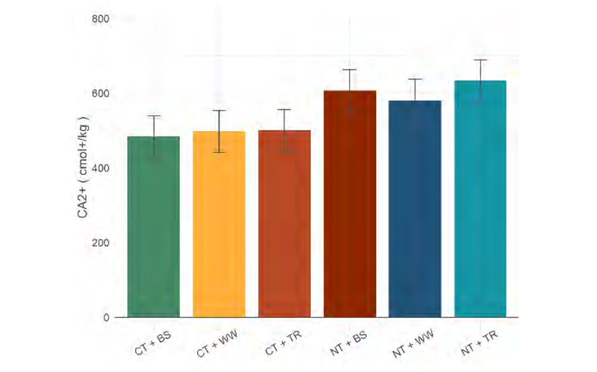

Figure 1: UNIPD_EX1_NR_ca2_plus

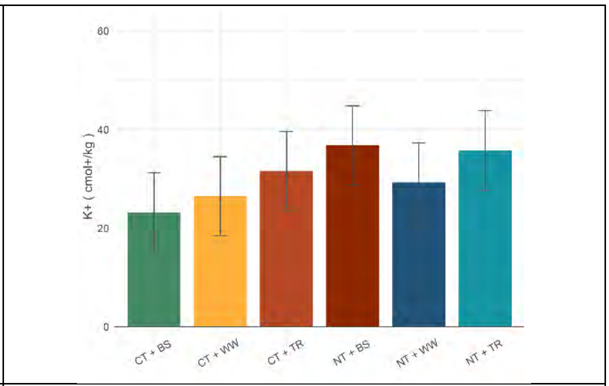

Figure 2: UNIPD_EX1_NR_k_plus

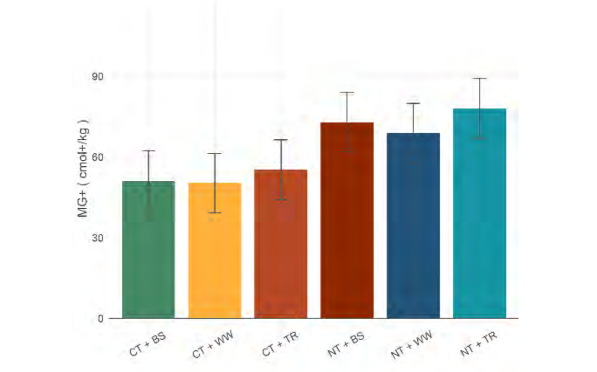

Figure 3: UNIPD_EX1_NR_mg2plus

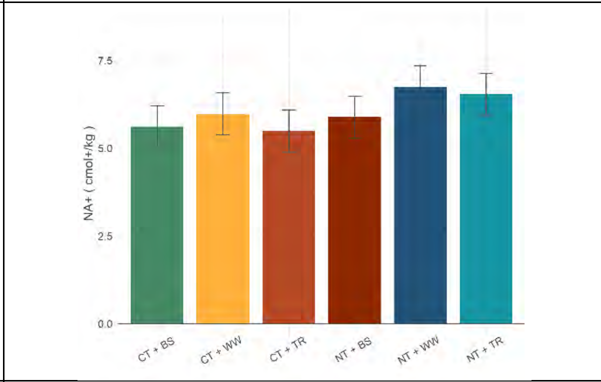

Figure 4: UNIPD_EX1_NR_na_plus

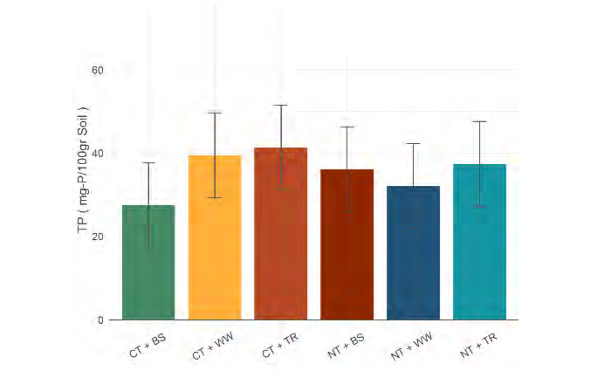

Figure 5: UNIPD_EX1_NR_p_avail

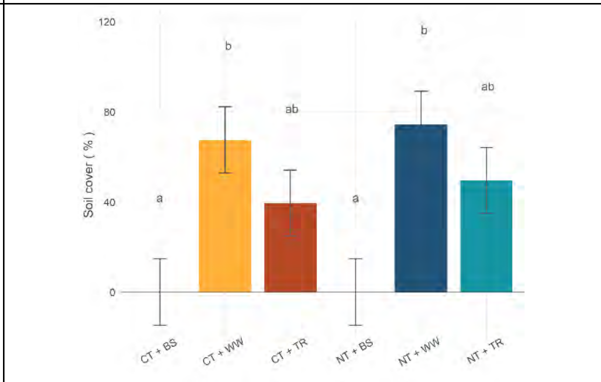

Figure 6: UNIPD_EX1_NR_soil_cover

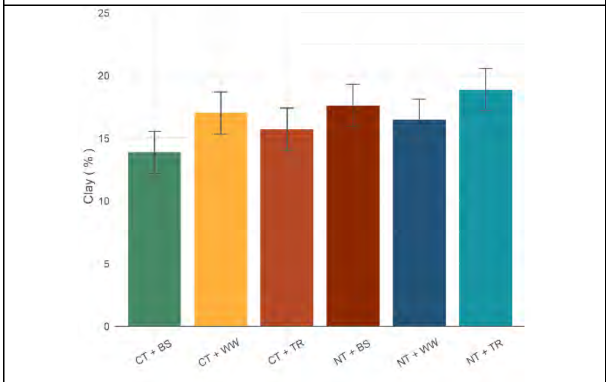

Figure 7: UNIPD_EX1_NR_top_clay

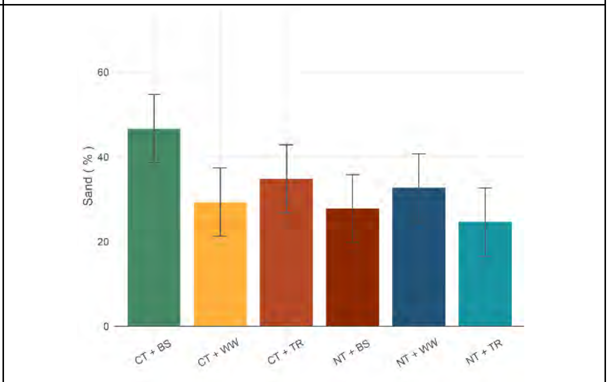

Figure 8: UNIPD_EX1_NR_top_sand

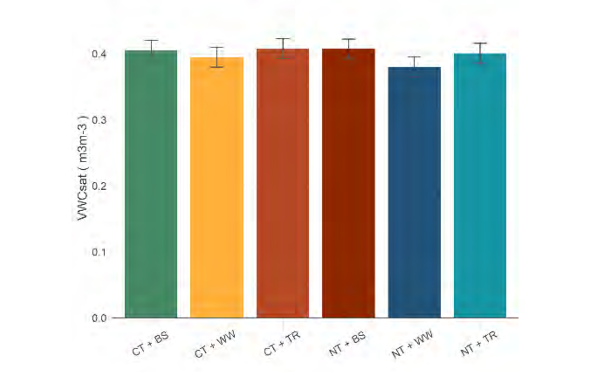

Figure 9: UNIPD_EX1_NR_top_satur_wc

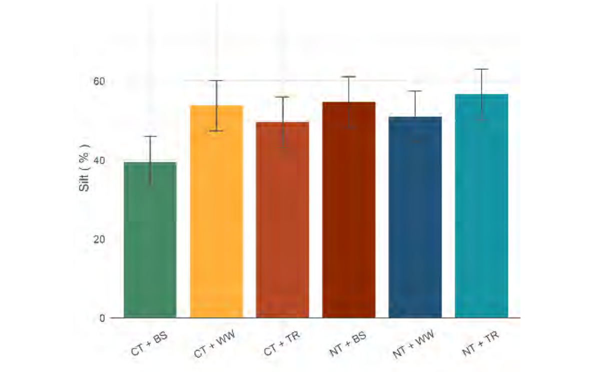

Figure 10: UNIPD_EX1_NR_top_silt

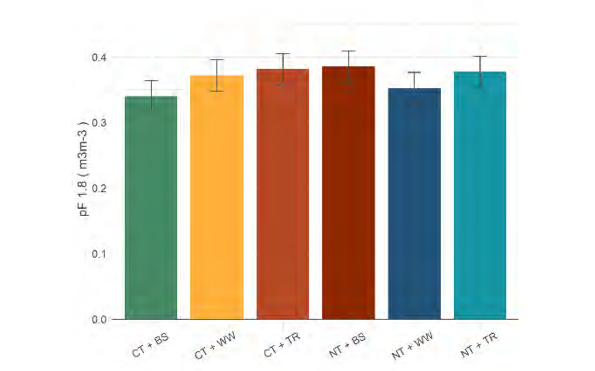

Figure 11: UNIPD_EX1_NR_top_wc_pf_1_8

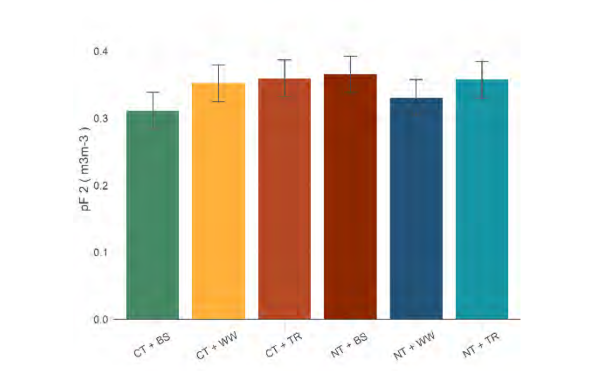

Figure 12: UNIPD_EX1_NR_top_wc_pf2_0

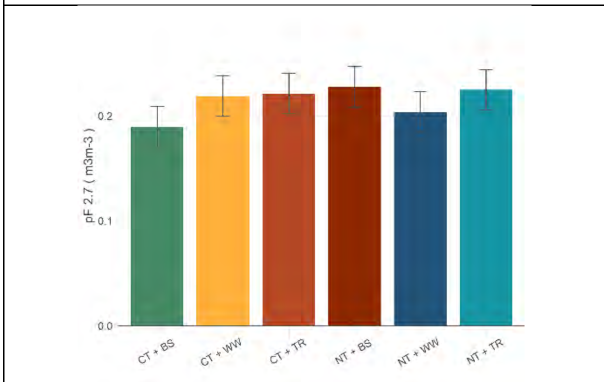

Figure 13: UNIPD_EX1_NR_top_wc_pf2_7

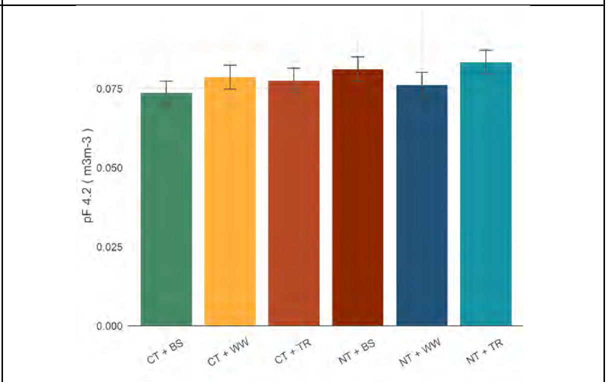

Figure 14: UNIPD_EX1_NR_top_wc_pf4_2

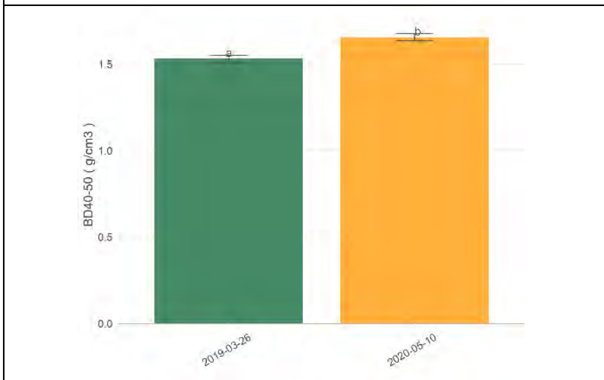

Figure 15: UNIPD_EX1_NSI_date_bd_bot

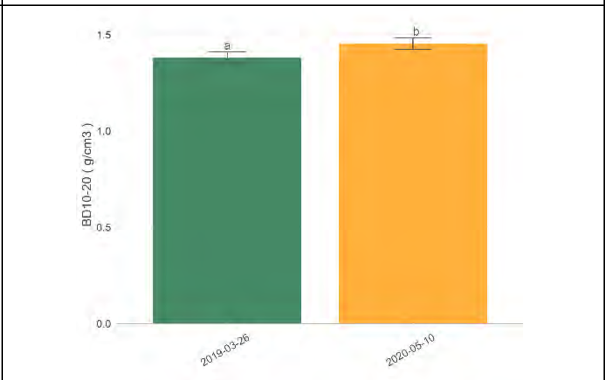

Figure 16: UNIPD_EX1_NSI_date_bd_top

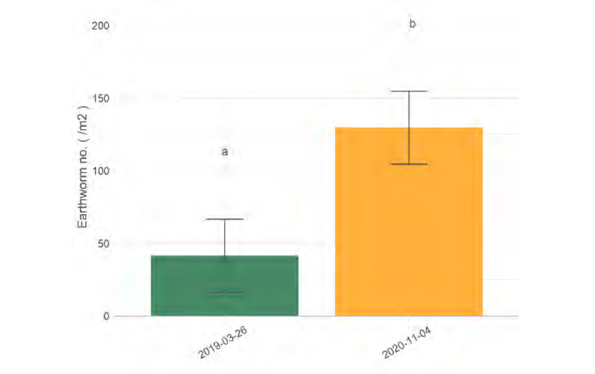

Figure 17: UNIPD_EX1_NSI_date_earthworm_no

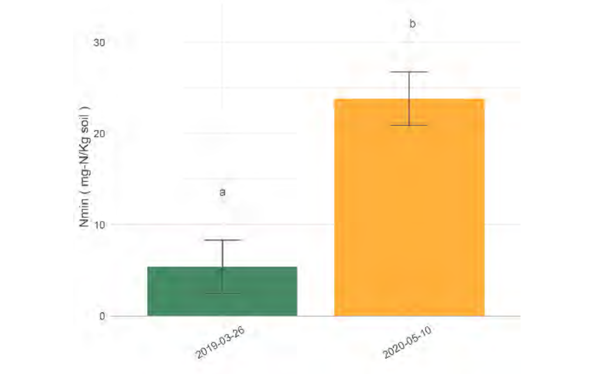

Figure 18: UNIPD_EX1_NSI_date_nmin_top

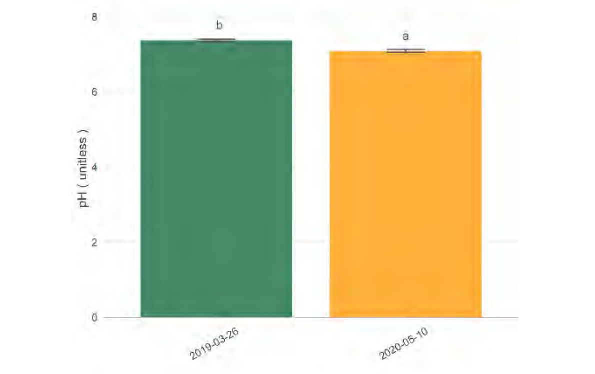

Figure 19: UNIPD_EX1_NSI_date_ph_kcl

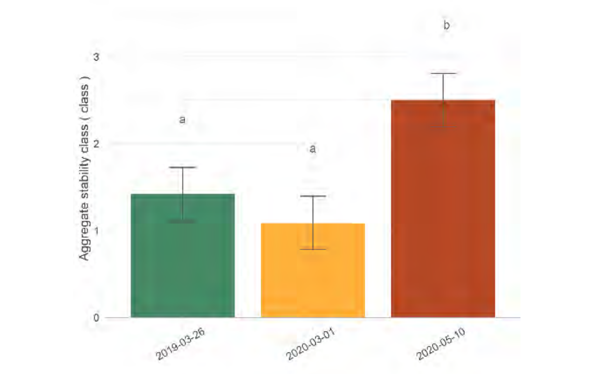

Figure 20: UNIPD_EX1_NSI_date_wsa

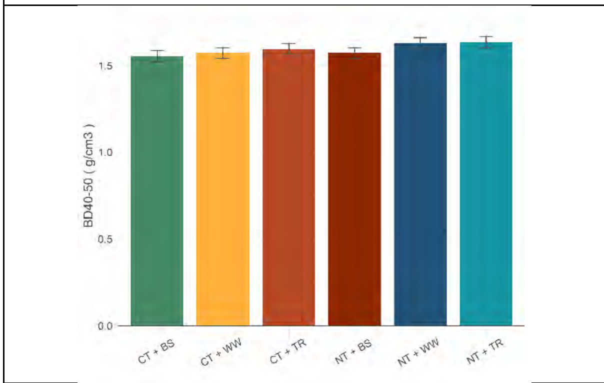

Figure 21: UNIPD_EX1_NSI_treat_bd_bot

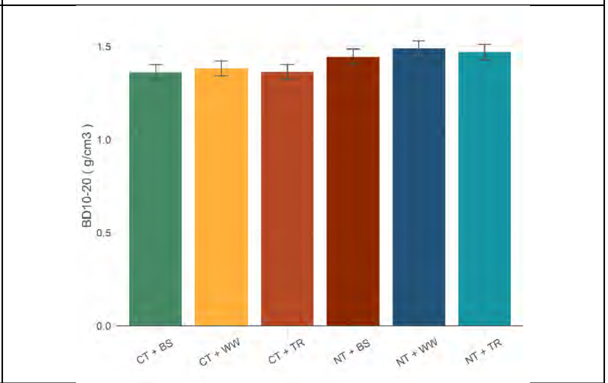

Figure 22: UNIPD_EX1_NSI_treat_bd_top

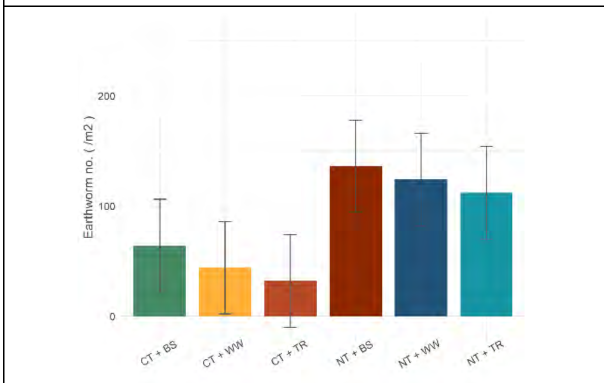

Figure 23: UNIPD_EX1_NSI_treat_earthworm_no

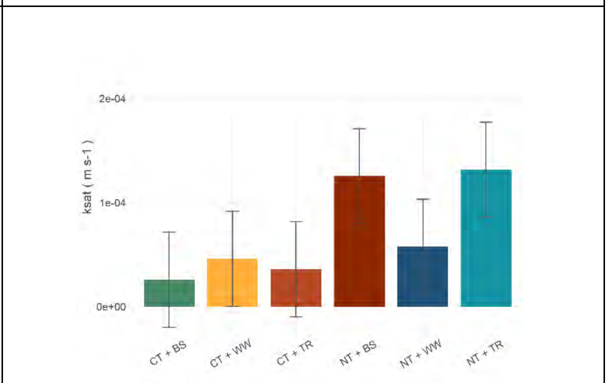

Figure 24: UNIPD_EX1_NSI_treat_ksat

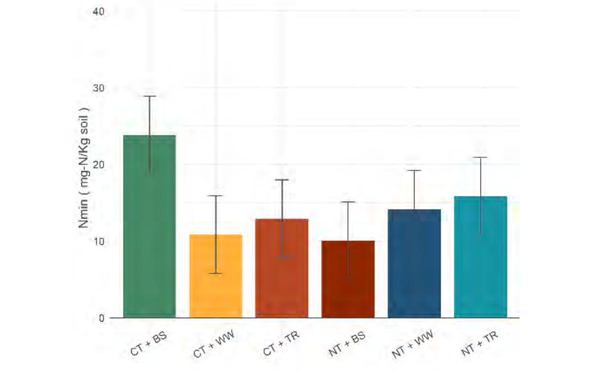

Figure 25: UNIPD_EX1_NSI_treat_nmin_top

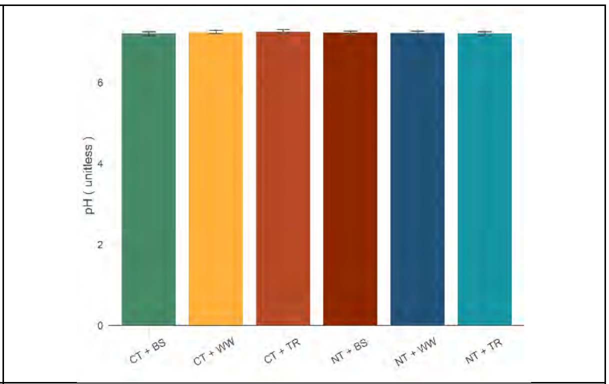

Figure 26: UNIPD_EX1_NSI_treat_ph_kcl

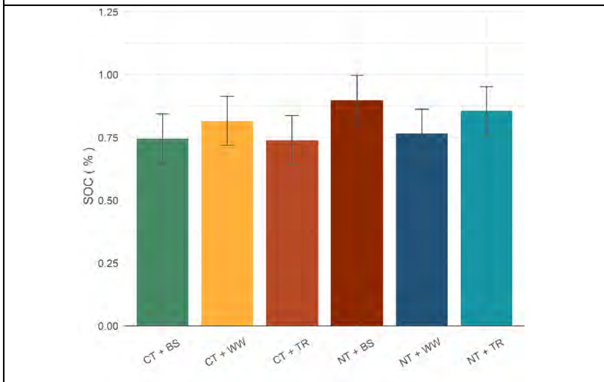

Figure 27: UNIPD_EX1_NSI_treat_soc

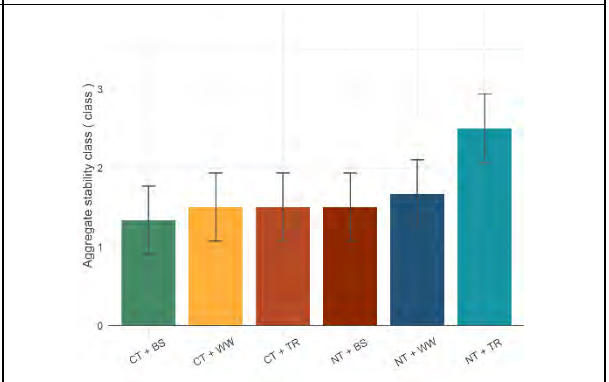

Figure 28: UNIPD_EX1_NSI_treat_wsa

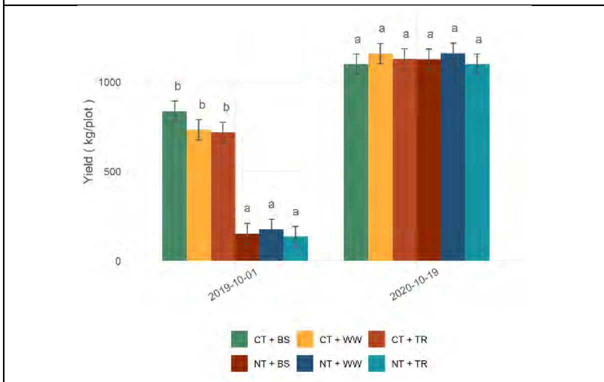

Figure 29: UNIPD_EX1_SI_crop_yield

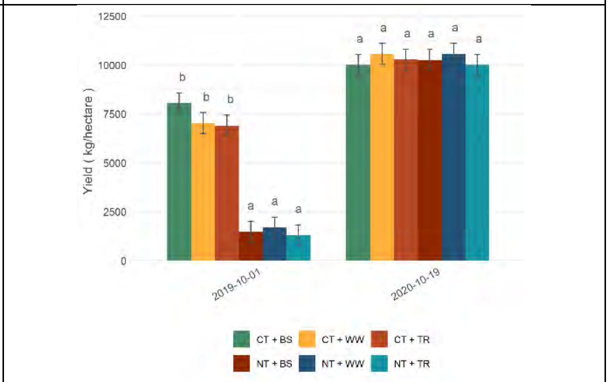

Figure 30: UNIPD_EX1_SI_crop_yield_ha

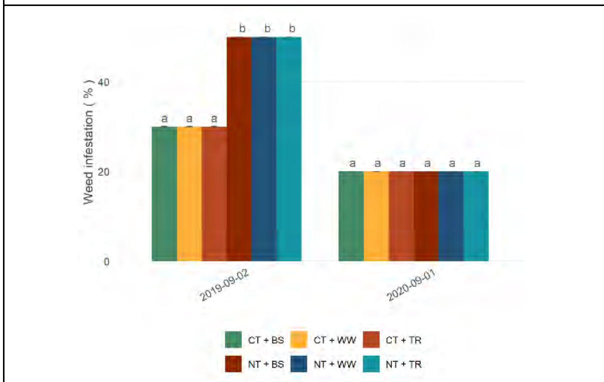

Figure 31: UNIPD_EX1_SI_weed_infestation

9. Italy: Figures from the meteorological analysis

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For the interpretation of the figures please read the introductory part of D5.3

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9a Legnaro

Meteorological station near the experimental site in Italy Measurement started 1963 and operates up to now.

Some short gaps in the temperature were filled up by interpolation.

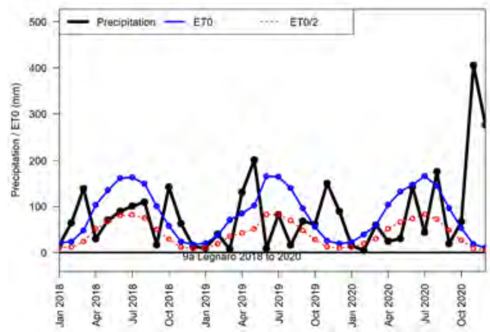

Figure 1: 9a Legnaro 00aFAOgrow

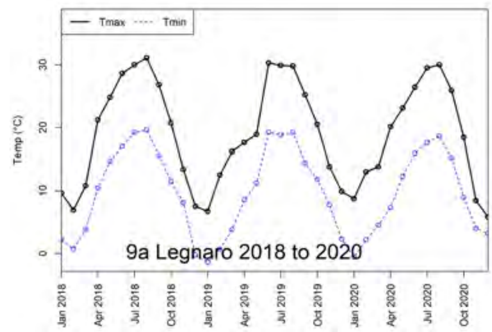

Figure 2: 9a Legnaro 00b TnTx

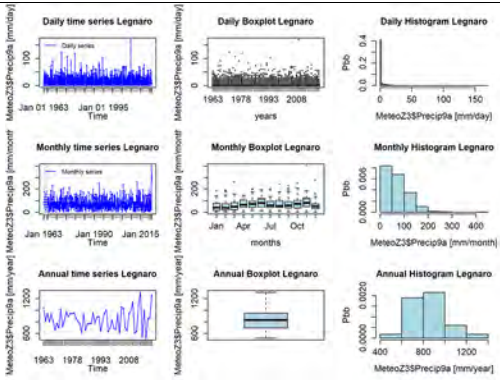

Figure 3: 9a Legnaro 01PrecHyplo

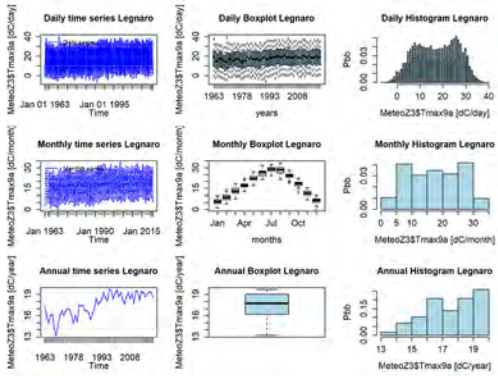

Figure 4: 9a Legnaro 02TmaxHyplo

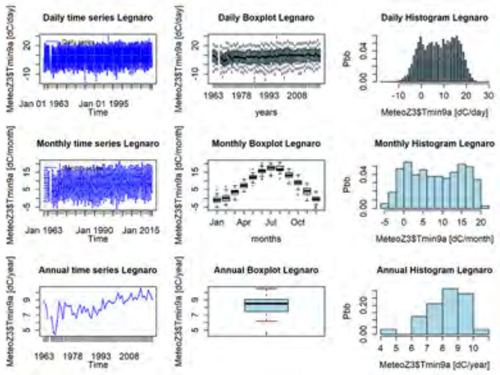

Figure 5: 9a Legnaro 03TminHyplo

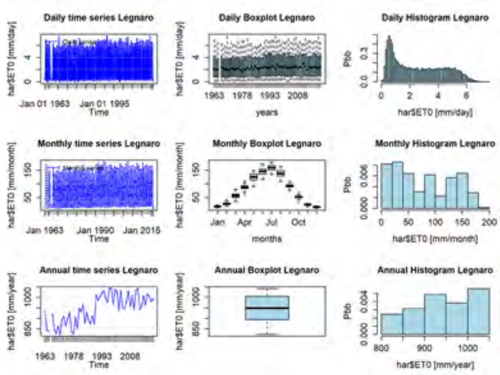

Figure 6: 9a Legnaro 04ET0Hyplo

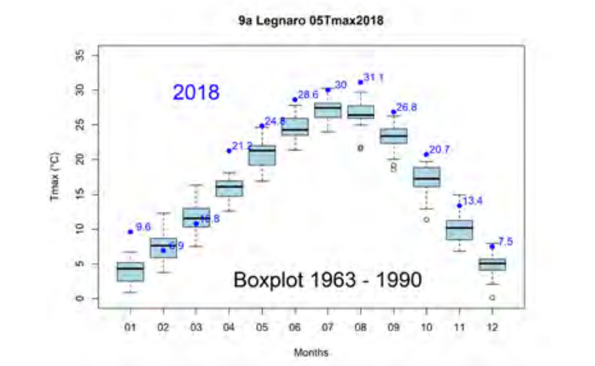

Figure 7: 9a Legnaro 05Tmax2018box

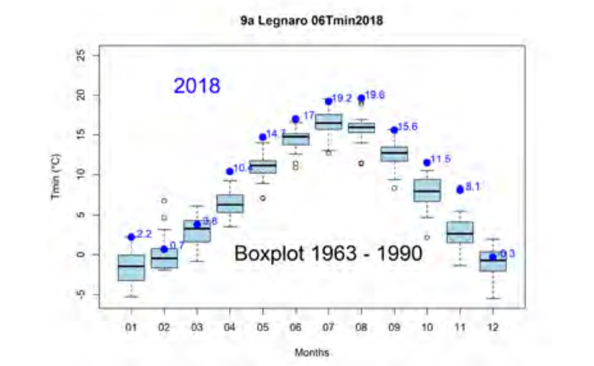

Figure 8: 9a Legnaro 06Tmin2018box

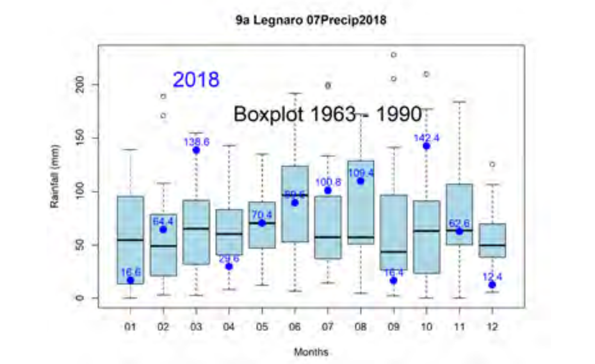

Figure 9: 9a Legnaro 07Precip2018box

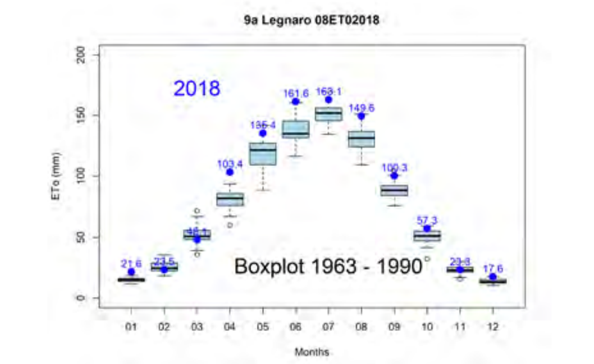

Figure 10: 9a Legnaro 08ET02018box

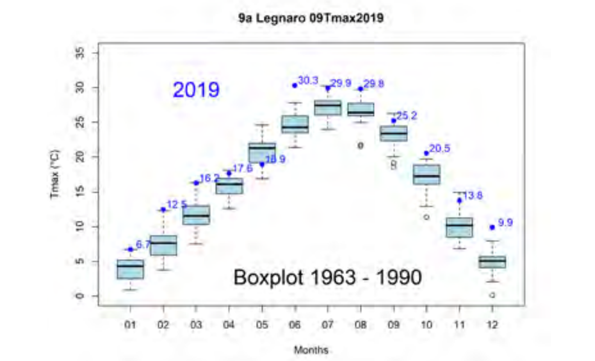

Figure 11: 9a Legnaro 09Tmax2019box

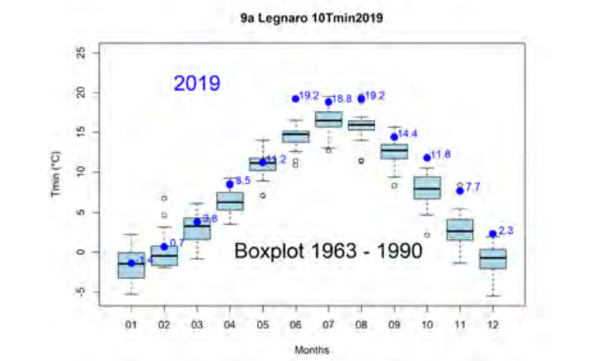

Figure 12: 9a Legnaro 10Tmin2019box

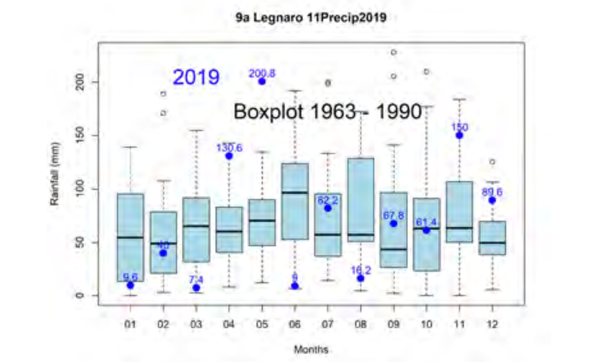

Figure 13: 9a Legnaro 11Precip2019box

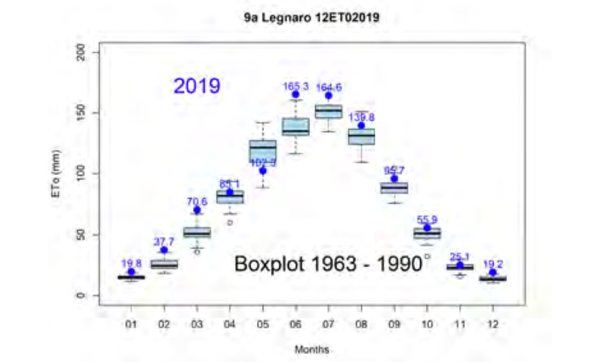

Figure 14: 9a Legnaro 12ET02019box

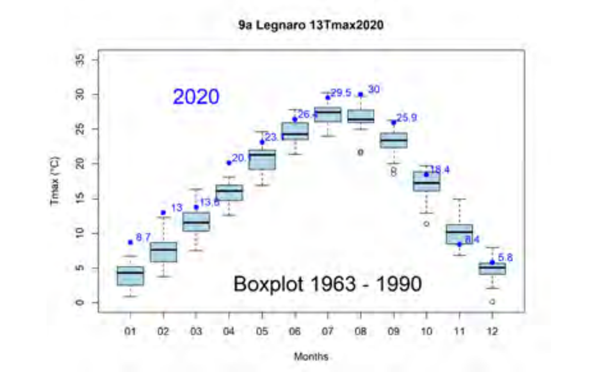

Figure 15: 9a Legnaro 13Tmax2020box

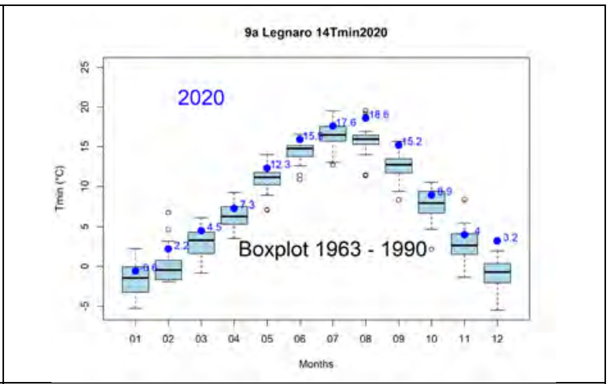

Figure 16: 9a Legnaro 14Tmin2020box

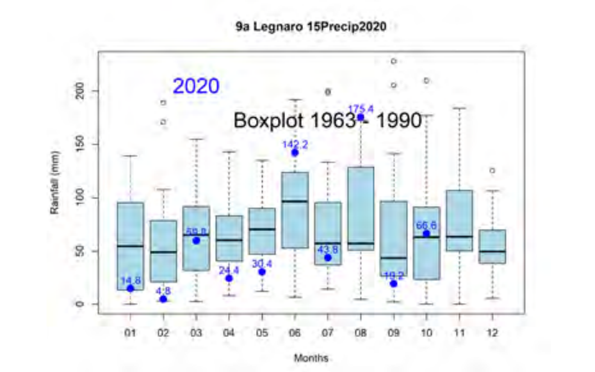

Figure 17: 9a Legnaro 15Precip2020box

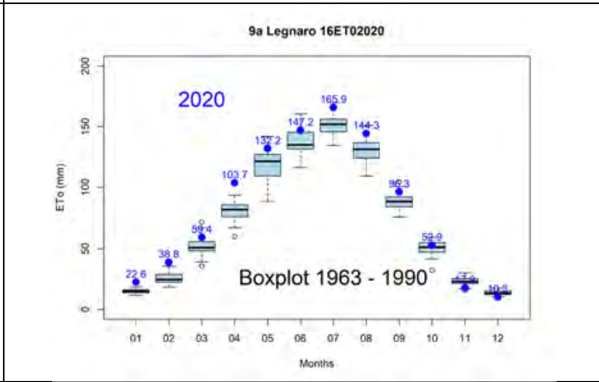

Figure 18: 9a Legnaro 16ET02020box

10. Poland: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table 1: Names of the measured indicators in the database, units and description

Observation code	**Unit**	**Description**
top_satur_wc	m^3m^{-3}	Saturated hydraulic conductivity
bd_top	g/cm^3	Bulk density (10-20 cm)
bd_bot	g/cm^3	Bulk density (40-50 cm)
top_clay	%	Clay fraction (topsoil)
top_silt	%	Silt fraction (topsoil)
top_sand	%	Sand fraction (topsoil)
nmin_top	mg-N/Kg soil	Mineral Nitrogen (topsoil)
p_avail	mg-P/100gr Soil	Available Phosphorus top (topsoil)
soc	%	SOC (topsoil)
ph_kcl	_	pH in KCl (topsoil)
ph_h2o	_	pH in water (topsoil)
thermal_conductivity	W/(m K)	Thermal conductivity (topsoil)
heat_capacity	$MJ/(m^3 K)$	Heat capacity (topsoil)
thermal_diffusivity	mm^2/s	Thermal diffusivity (topsoil)
thermal_ds_conductivity	W/(m K)	Thermal conductivity-dry soil (topsoil)
heat_ds_capacity	$MJ/(m^3 K)$	Heat capacity-dry soil (topsoil)
thermal_ds_diffusivity	mm^2/s	Thermal diffusivity-dry soil (topsoil)
water_thermal_conductivity	W/(m K)	Water thermal conductivity-saturated soil (topsoil)
water_heat_capacity	$MJ/(m^3 K)$	Water heat capacity-saturated soil (topsoil)
water_thermal_diffusivity	mm^2/s	Water thermal diffusivity-saturated soil (topsoil)
water_content	m^3/m^3	Water content (topsoil)
particle_density	g/cm^3	Particle density
k_avail	mg-K/100g of soil	Available Potassium (topsoil)
mg_avail	mg-Mg/100g of soil	Available Magnesium (topsoil)
cec	cmol/kg	CEC (topsoil)
soc_30_50	%	SOC (30-50 cm)
ph_kcl_30_50	_	pH in KCl (30-50 cm)
ph_h2o_30_50	_	pH in water (30-50 cm)
clay_30_50	%	Clay fraction (30-50 cm)
silt_30_50	%	Silt fraction (30-50 cm)
sand_30_50	%	Sand fraction (30-50 cm)
cec_30_50	cmol/kg	CEC (30-50cm)
thermal_conductivity_40_50	W/(m K)	Thermal conductivity (40-50 cm)
heat_capacity_40_50	$MJ/(m^3 K)$	Heat capacity (40-50 cm)
thermal_diffusivity_40_50	mm^2/s	Thermal diffusivity (40-50 cm)
thermal_conductivity_ds_40_50	W/(m K)	Thermal conductivity-dry soil (40-50 cm)

heat_capacity_ds_40_50	MJ/(m^3 K)	Heat capacity-dry soil (40-50 cm)
thermal_diffusivity_ds_40_50	mm^2/s	Thermal diffusivity-dry soil (40-50 cm)
water_thermal_cond_40_50	W/(m K)	Water thermal conductivity-saturated soil (40-50 cm)
water_heat_capacity_40_50	MJ/(m^3 K)	Water heat capacity-saturated soil (40-50 cm)
water_thermal_diff_40_50	mm^2/s	Water thermal diffusivity-saturated soil (40-50 cm)
water_content_40_50	m^3/m^3	Water content (40-50 cm)
wet_gluten_cont	%	Wet gluten content

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Experiment 1:

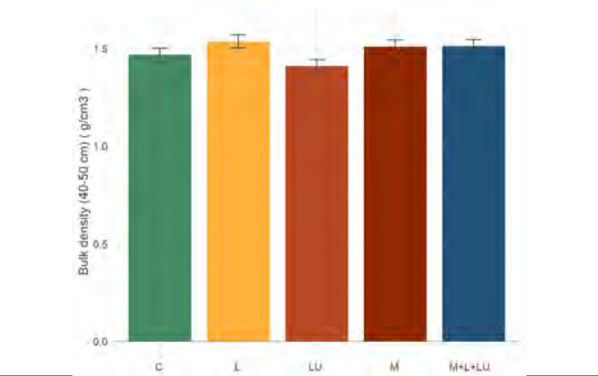

Figure 1: IA_EX1_NR_bd_bot

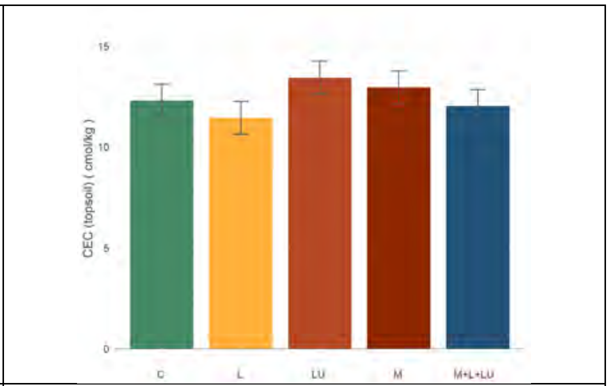

Figure 2: IA_EX1_NR_cec

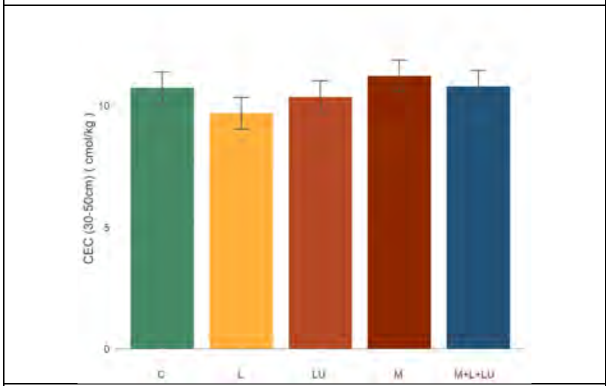

Figure 3: IA_EX1_NR_cec_30_50

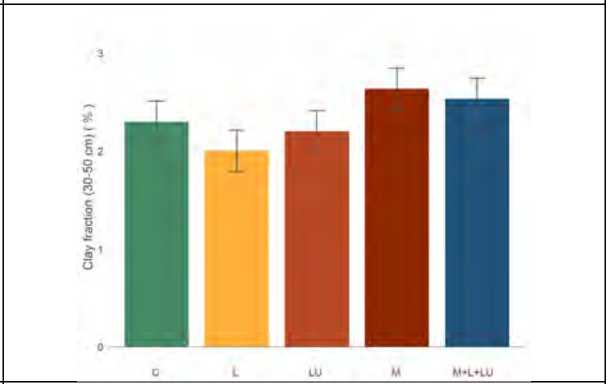

Figure 4: IA_EX1_NR_clay_30_50

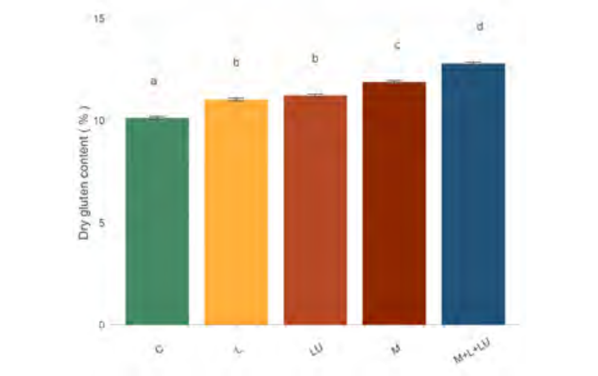

Figure 5: IA_EX1_NR_dry_gluten_cont

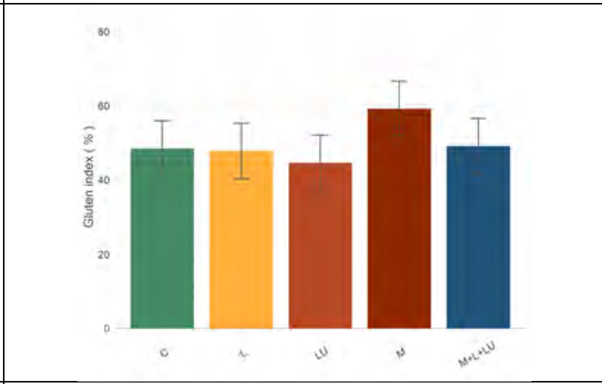

Figure 6: IA_EX1_NR_gluten_inde

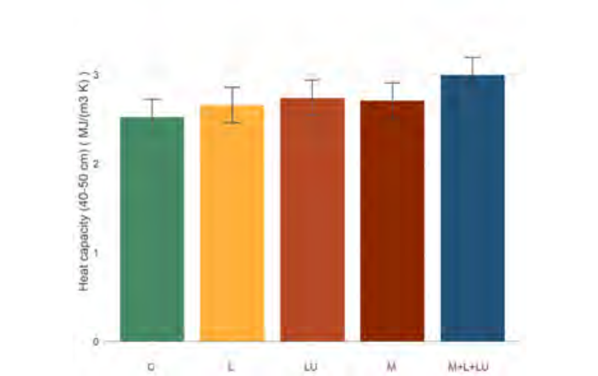

Figure 7: IA_EX1_NR_heat_capacity_40_50

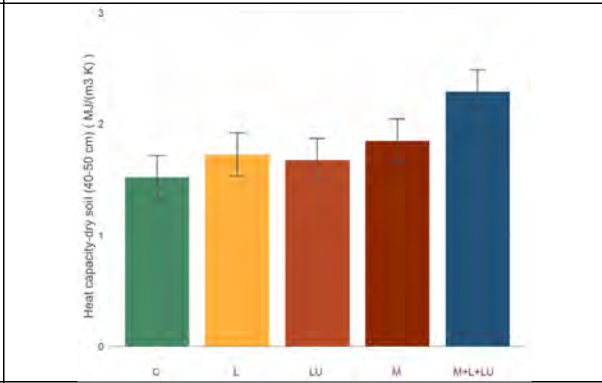

Figure 8: IA_EX1_NR_heat_capacity_ds_40_50

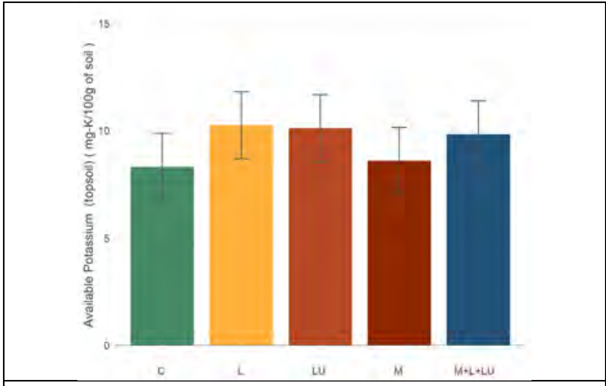

Figure 9: IA_EX1_NR_k_avail

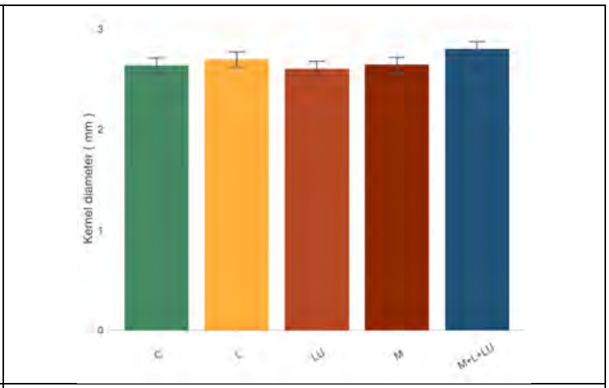

Figure 10: IA_EX1_NR_kernel_diam

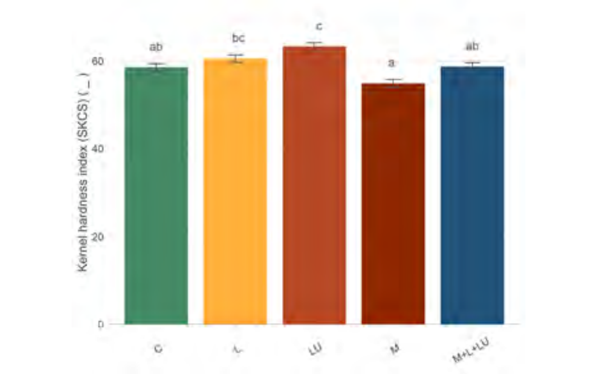

Figure 11: IA_EX1_NR_kernel_hardness_index

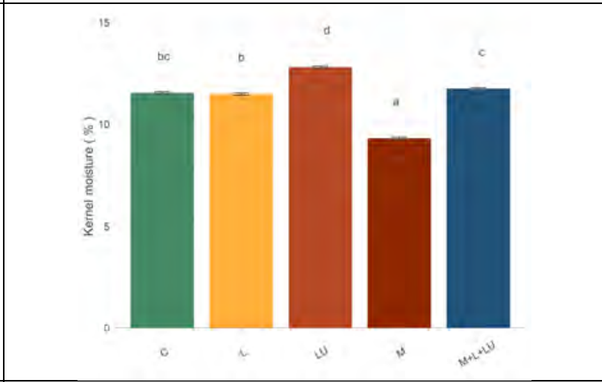

Figure 12: IA_EX1_NR_kernel_mois

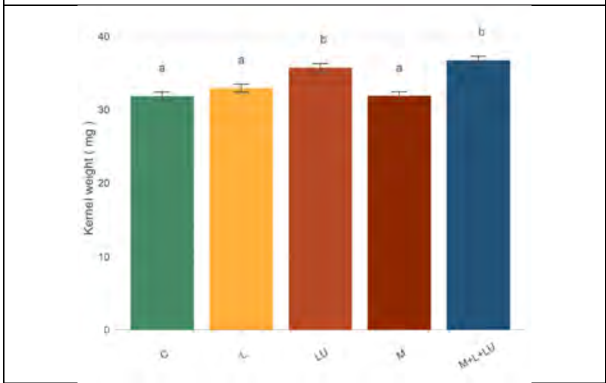

Figure 13: IA_EX1_NR_kernel_weig

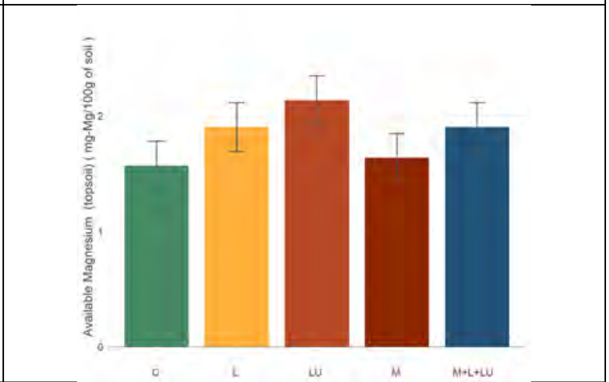

Figure 14: IA_EX1_NR_mg_avail

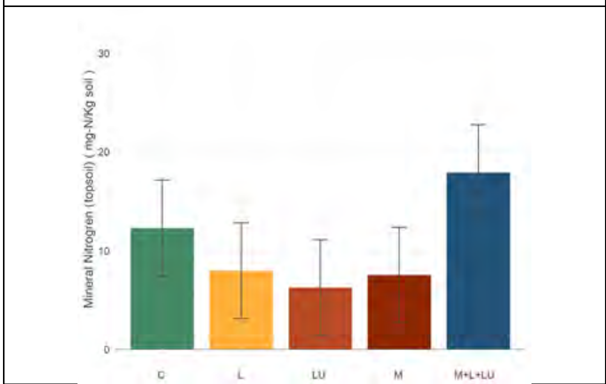

Figure 15: IA_EX1_NR_nmin_top

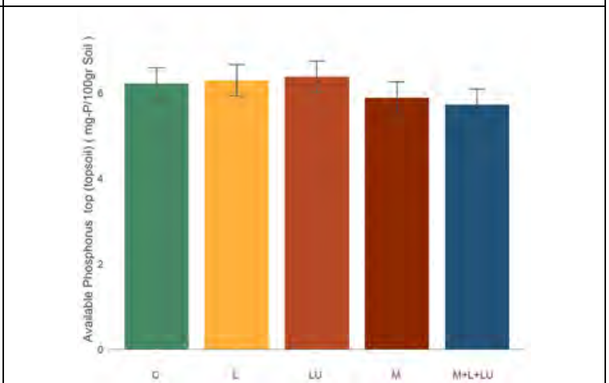

Figure 16: IA_EX1_NR_p_avail

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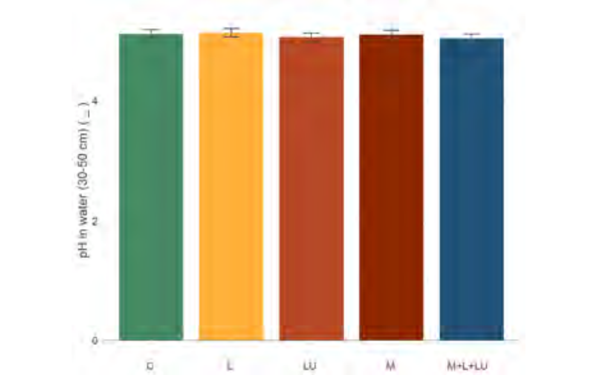


Figure 17: IA_EX1_NR_ph_h2o_30_50

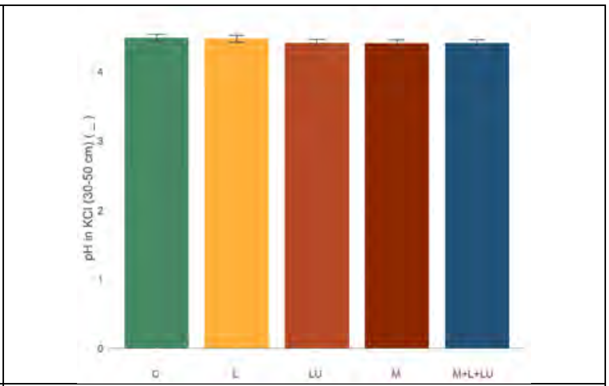


Figure 18: IA_EX1_NR_ph_kcl_30_50

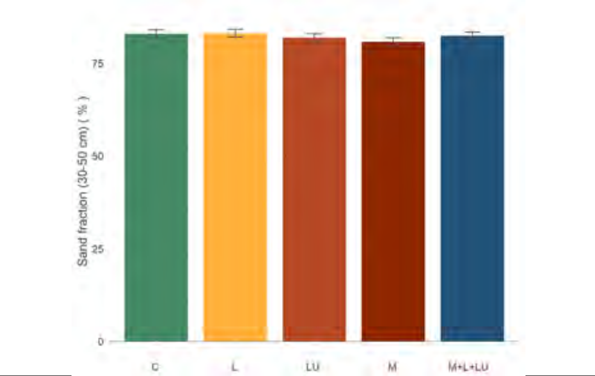


Figure 19: IA_EX1_NR_sand_30_50

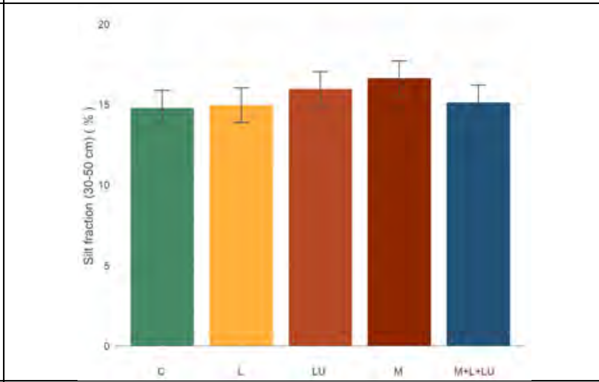


Figure 20: IA_EX1_NR_silt_30_50

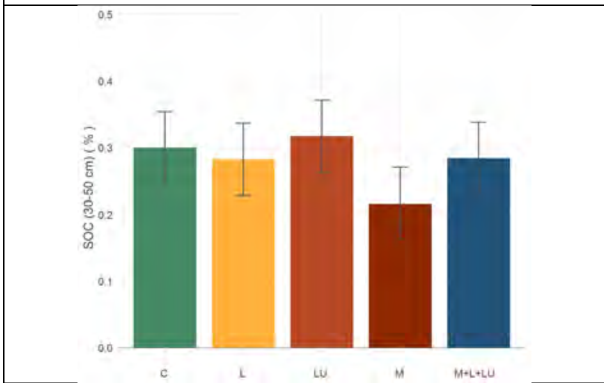


Figure 21: IA_EX1_NR_soc_30_50

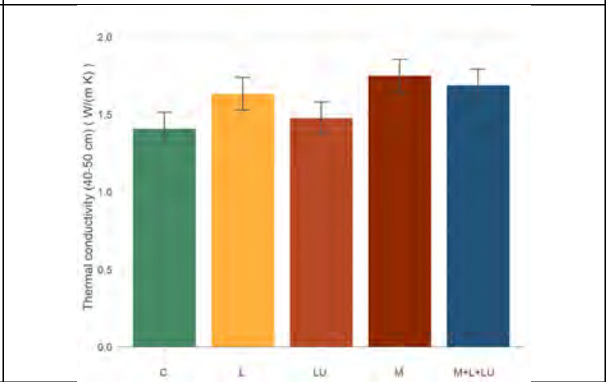


Figure 22: IA_EX1_NR_thermal_conductivity_40_50

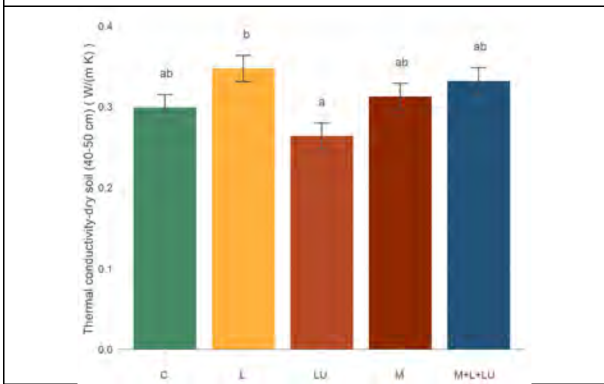
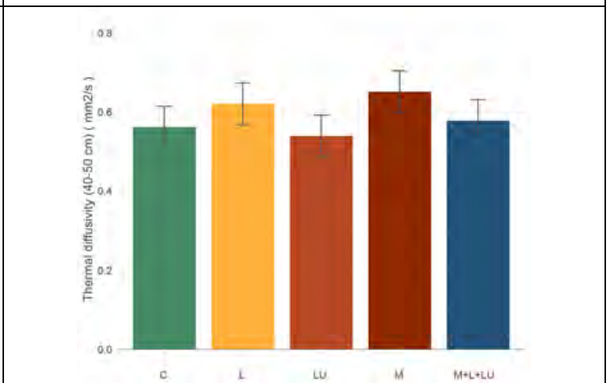


Figure 23: IA_EX1_NR_thermal_conductivity_ds_40_50



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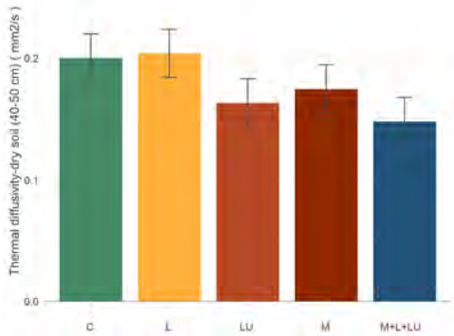

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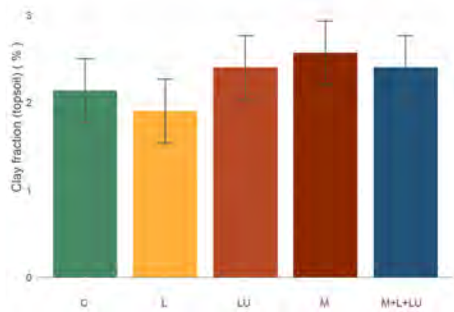


Figure 26: IA_EX1_NR_top_clay

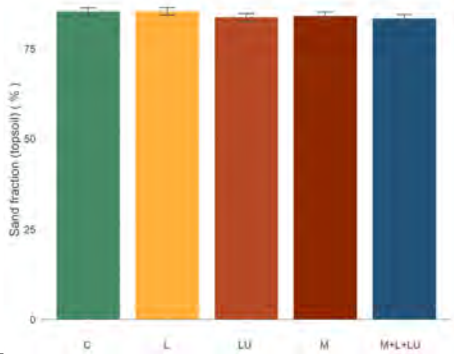


Figure 27: IA_EX1_NR_top_sand

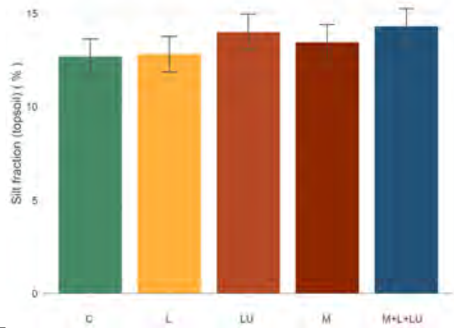
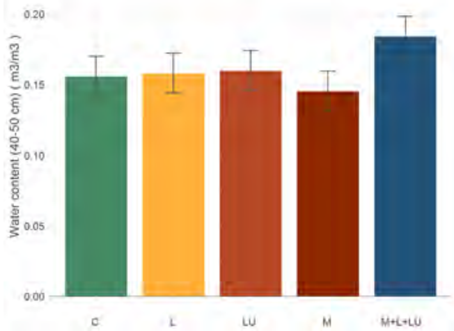


Figure 28: IA_EX1_NR_top_silt



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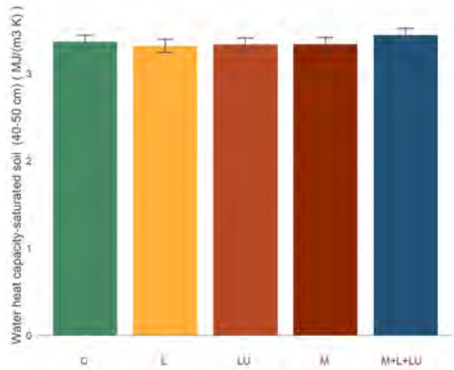


Figure 30: IA_EX1_NR_water_heat_capacity_40_50

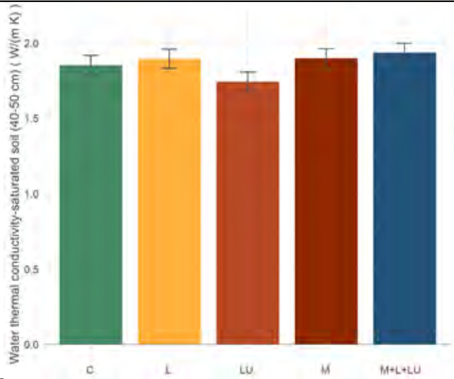


Figure 31: IA_EX1_NR_water_thermal_cond_40_50

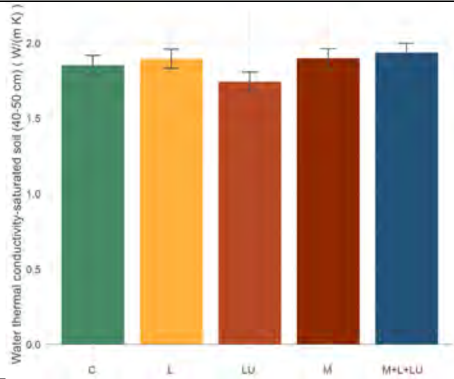
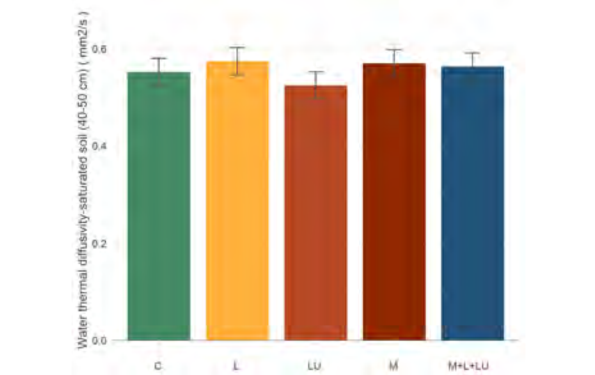


Figure 32: IA_EX1_NR_water_thermal_conductivity_40_50



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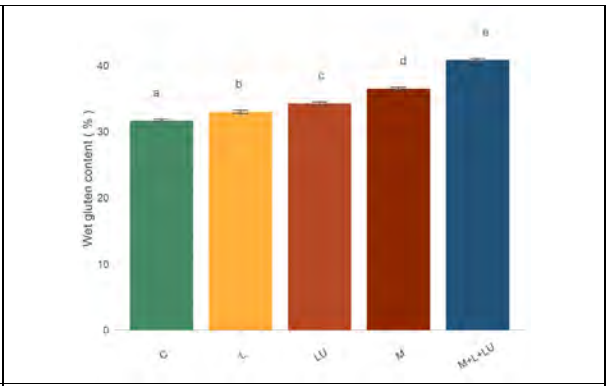


Figure 34: IA_EX1_NR_wet_gluten_cont

Figure 35: IA_EX1_NSI_date_heat_capacity

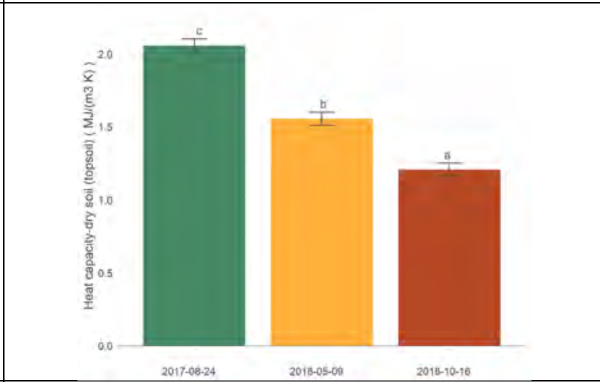


Figure 36: IA_EX1_NSI_date_heat_ds_capacity

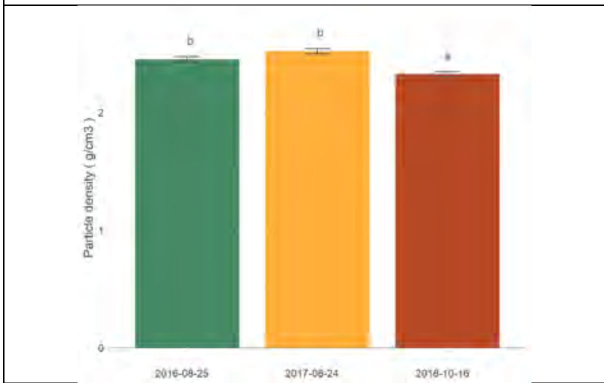
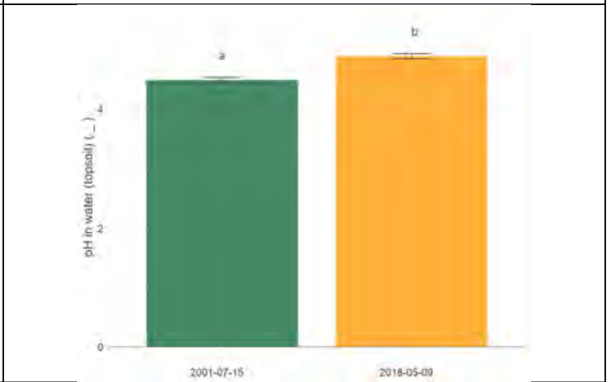


Figure 37: IA_EX1_NSI_date_particle_density



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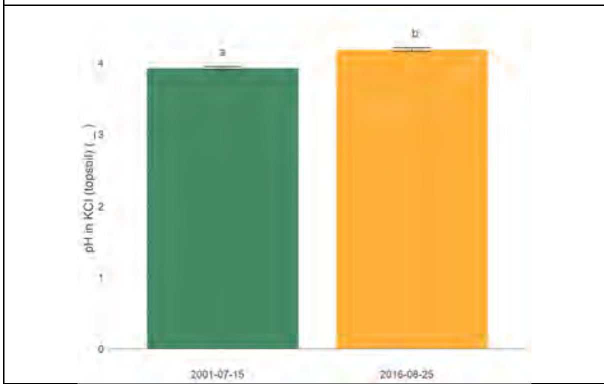

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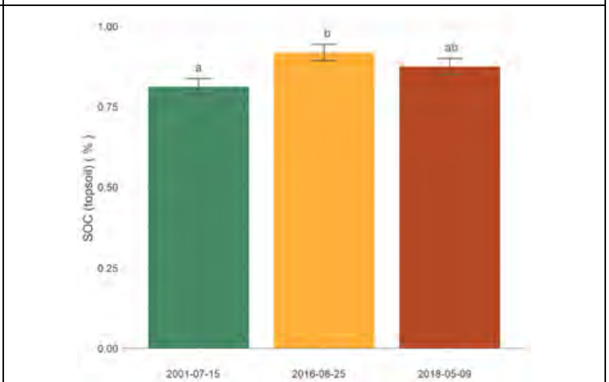

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Figure 41: IA_EX1_NSI_date_thermal_conductivity

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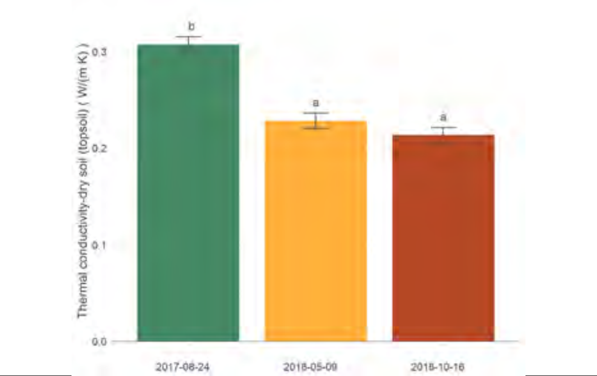

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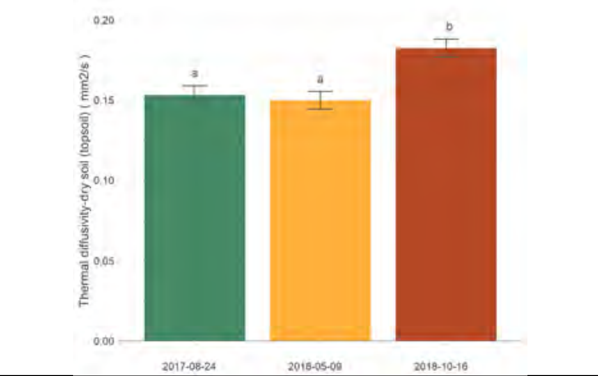

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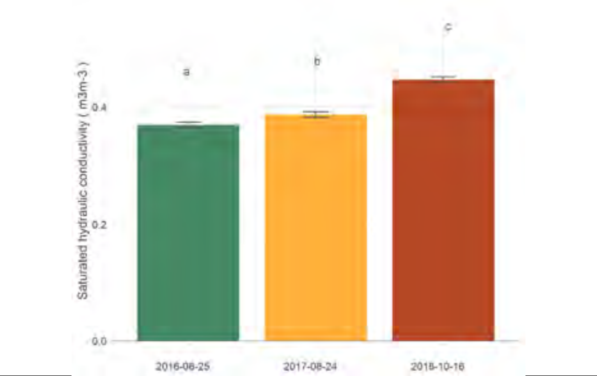

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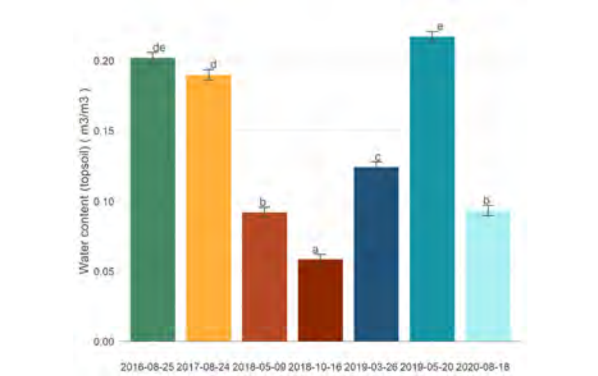

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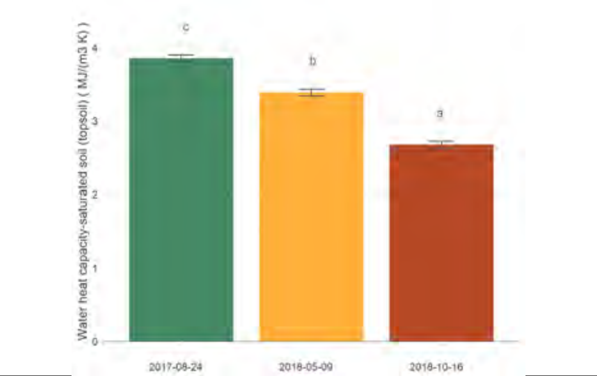


Figure 47: IA_EX1_NSI_date_water_heat_capacity

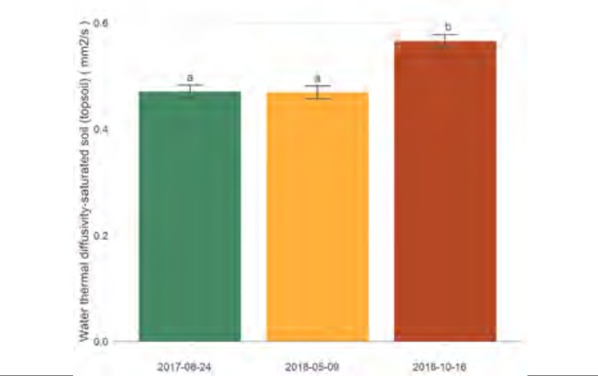


Figure 48: IA_EX1_NSI_date_water_thermal_diffusivity

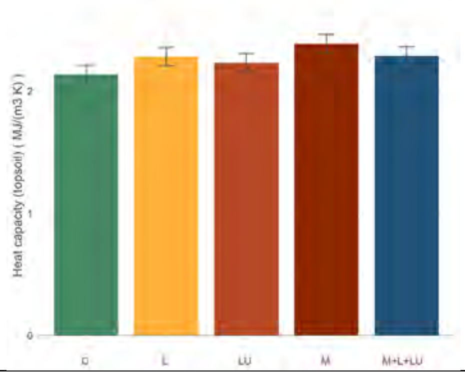


Figure 49: IA_EX1_NSI_treat_heat_capacity

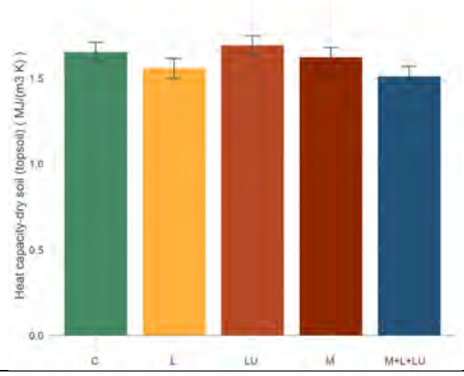


Figure 50: IA_EX1_NSI_treat_heat_ds_capacity

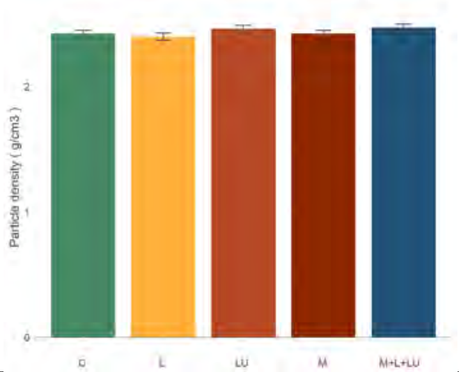


Figure 51: IA_EX1_NSI_treat_particle_density

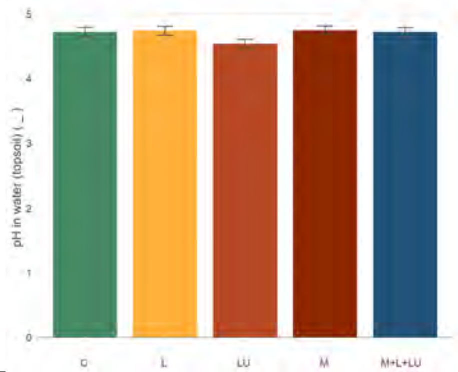


Figure 52: IA_EX1_NSI_treat_ph_h2o

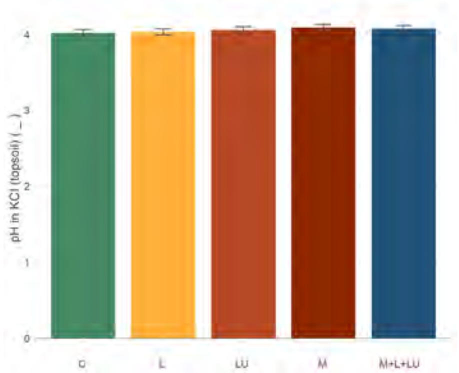


Figure 53: IA_EX1_NSI_treat_ph_kcl

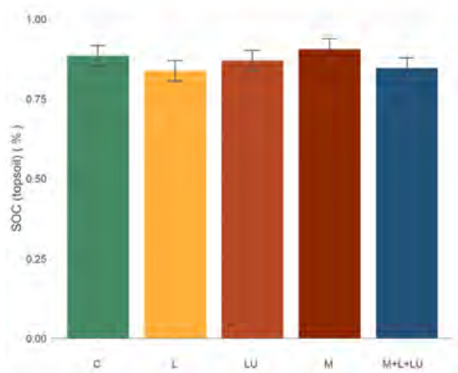


Figure 54: IA_EX1_NSI_treat_soc

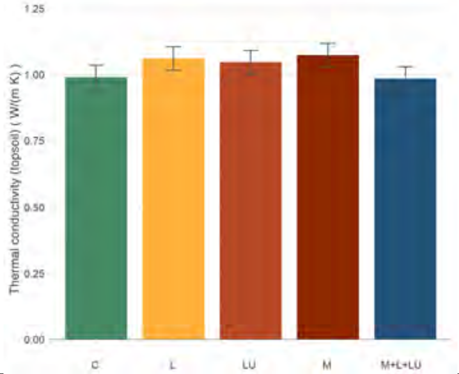


Figure 55: IA_EX1_NSI_treat_thermal_conductivity

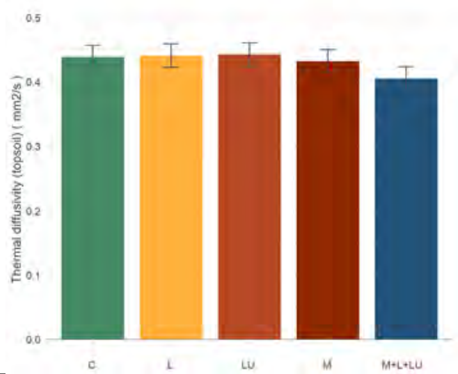


Figure 56: IA_EX1_NSI_treat_thermal_diffusivity

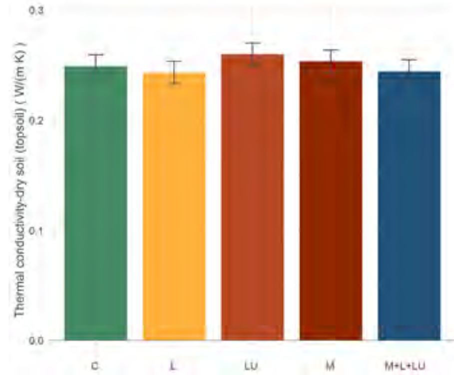


Figure 57: IA_EX1_NSI_treat_thermal_ds_conductivity

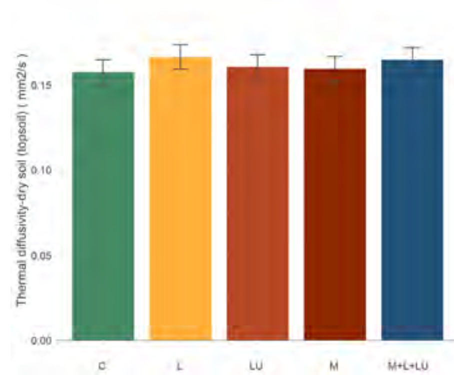
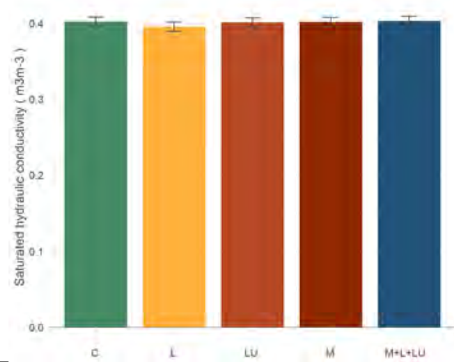


Figure 58: IA_EX1_NSI_treat_thermal_ds_diffusivity



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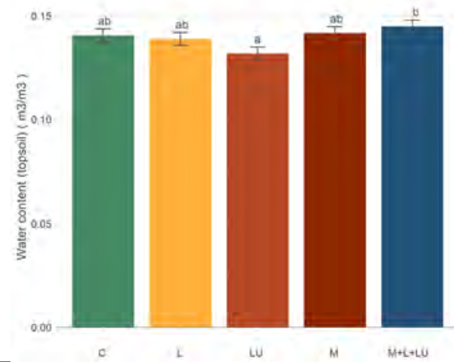


Figure 60: IA_EX1_NSI_treat_water_content

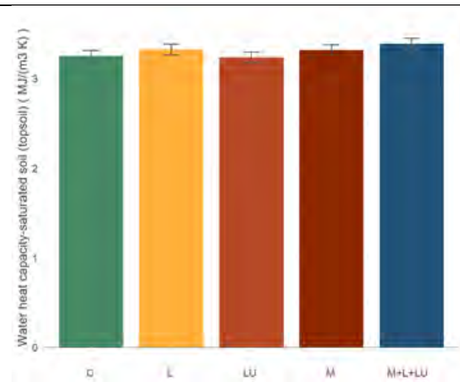


Figure 61: IA_EX1_NSI_treat_water_heat_capacity

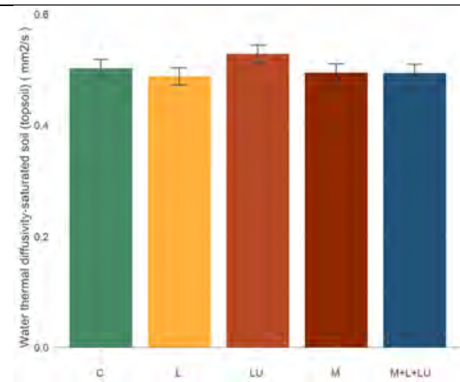


Figure 62: IA_EX1_NSI_treat_water_thermal_diffusivity

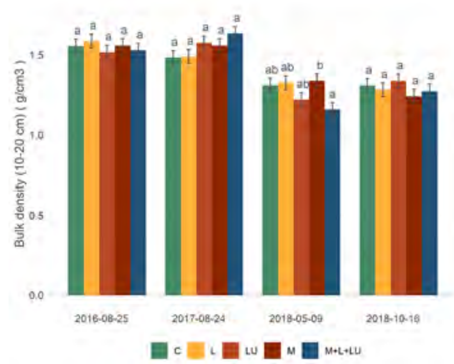


Figure 63: IA_EX1_SI_bd_top

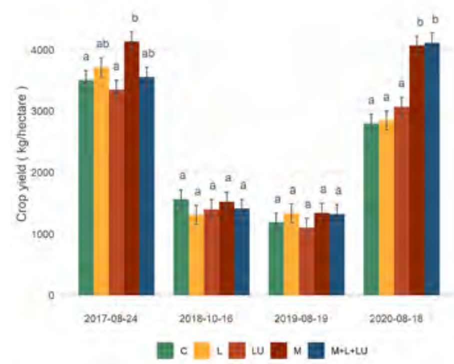


Figure 64: IA_EX1_SI_crop_yield_ha

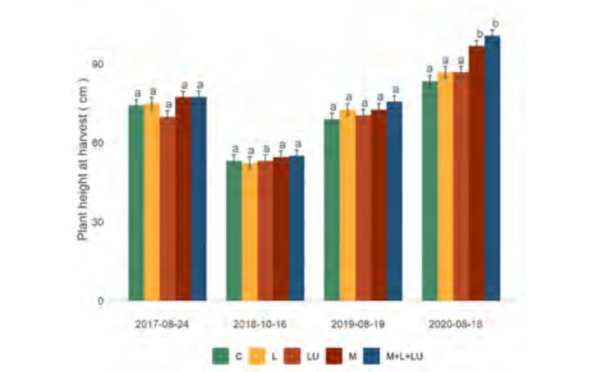
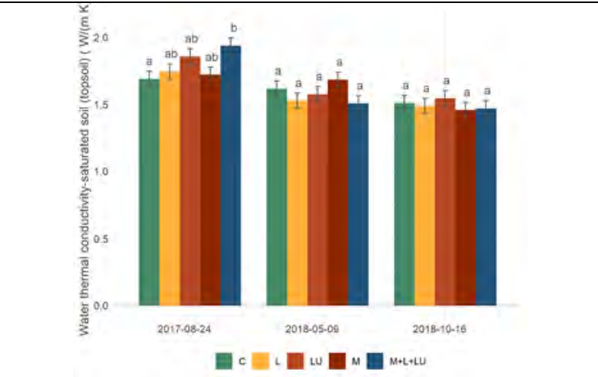


Figure 65: IA_EX1_SI_plant_height



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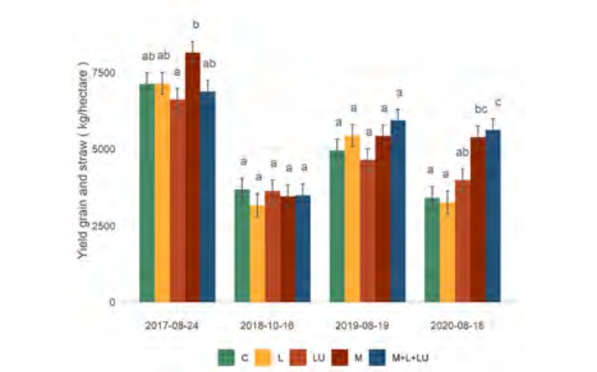


Figure 67: IA_EX1_SI_yield_grain_straw

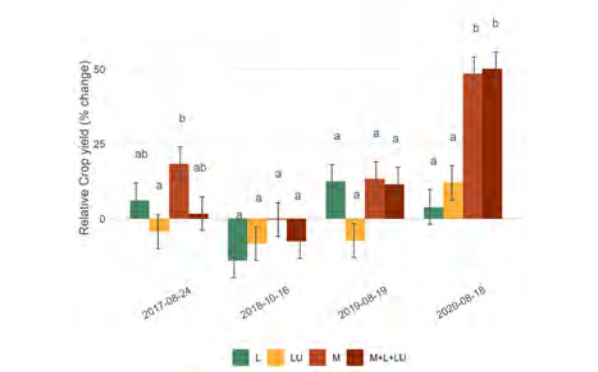


Figure 68: IA_EX1SI_Relat_crop_yield_ha

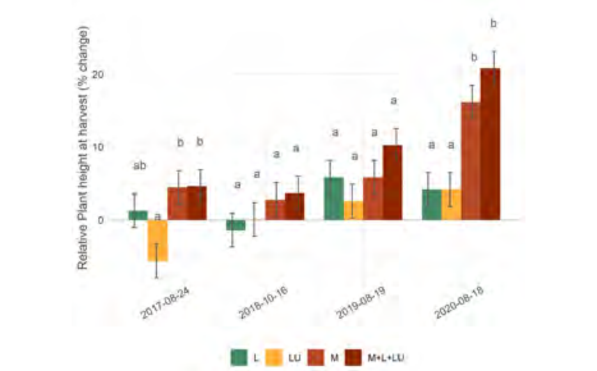
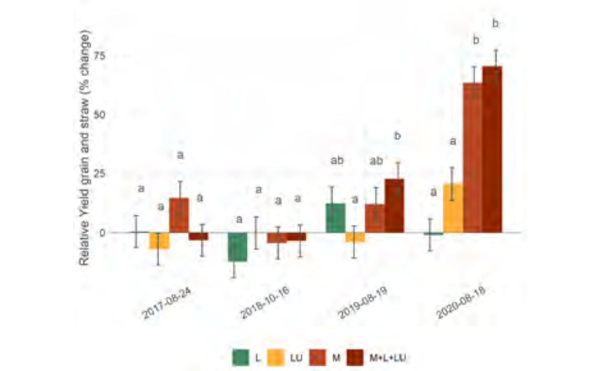


Figure 69: IA_EX1SI_Relat_plant_height



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10. Poland: Figures from the Meteorological analysis

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The meteorological station, Siedlce, for Poland is also available as ECAD station 333. Measurement started 1961 until 2020.

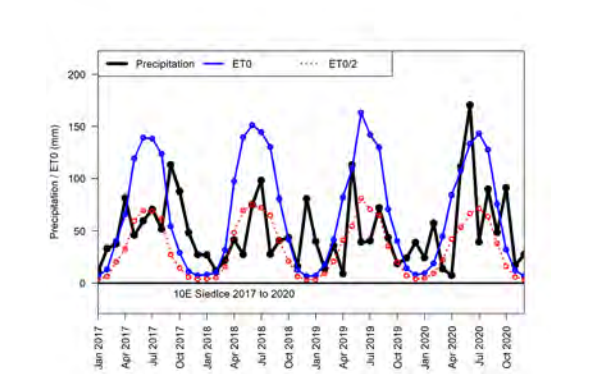

Figure 1: 10E Siedlce 00aFAOgrow

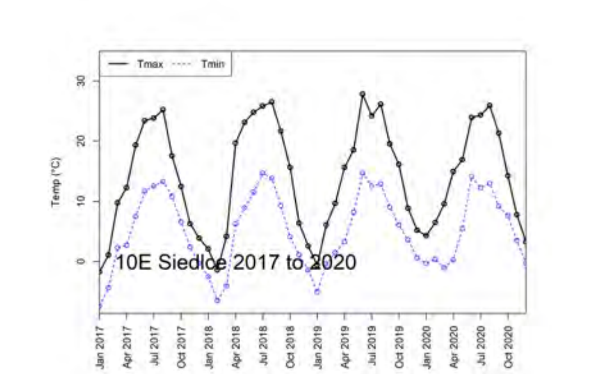

Figure 2: 10E Siedlce 00b TnTx

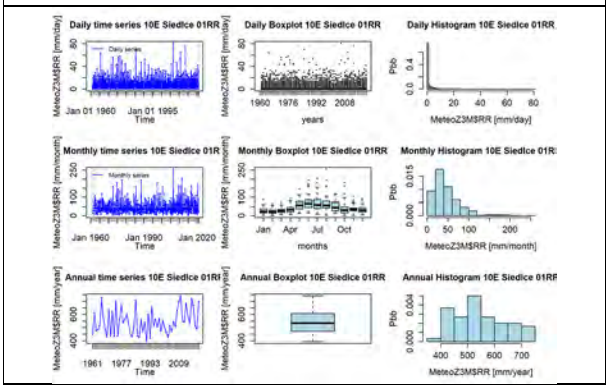
Figure 3: 10E Siedlce 01RRhyplo

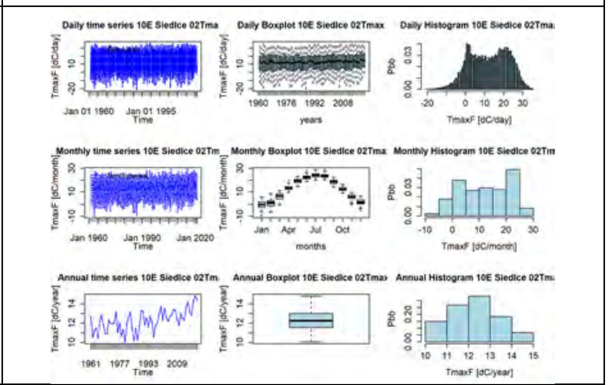
Figure 4: 10E Siedlce 02Tmaxhyplo

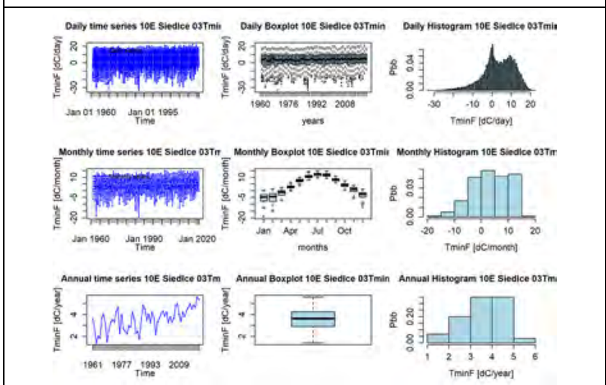
Figure 5: 10E Siedlce 03Tminhyplo

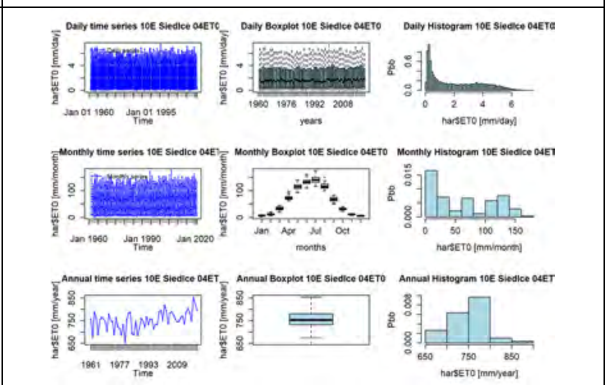
Figure 6: 10E Siedlce 04ET0hyplo

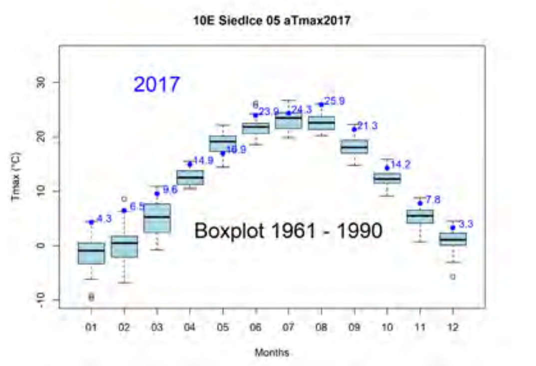

Figure 7: 10E Siedlce 05 aTmax2017box

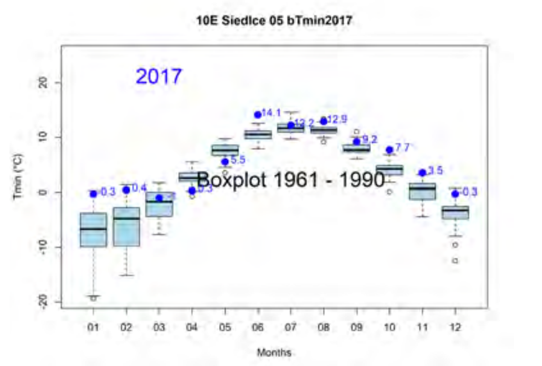

Figure 8: 10E Siedlce 05 bTmin2017box

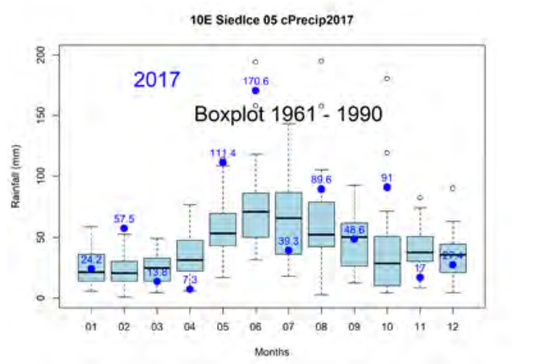

Figure 9: 10E Siedlce 05 cPrecip2017box

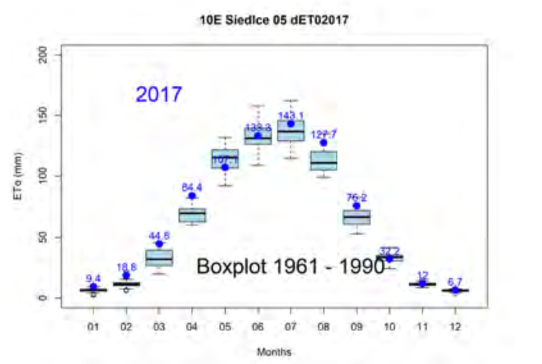

Figure 10: 10E Siedlce 05 dET02017box

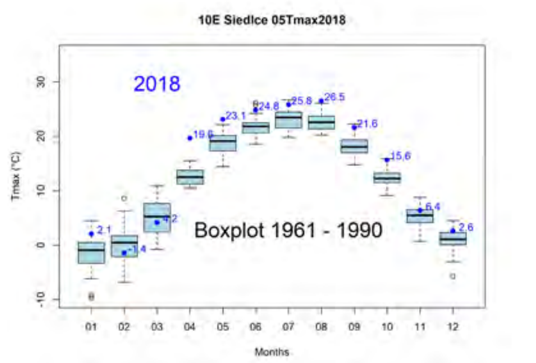

Figure 11: 10E Siedlce 05Tmax2018box

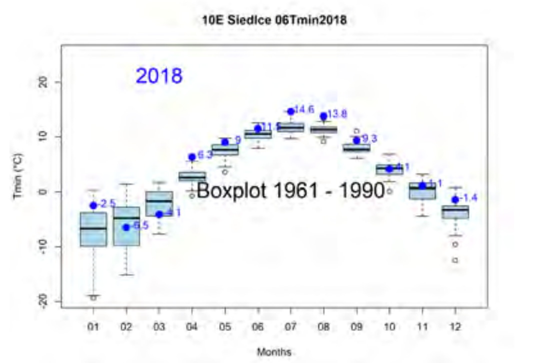

Figure 12: 10E Siedlce 06Tmin2018box

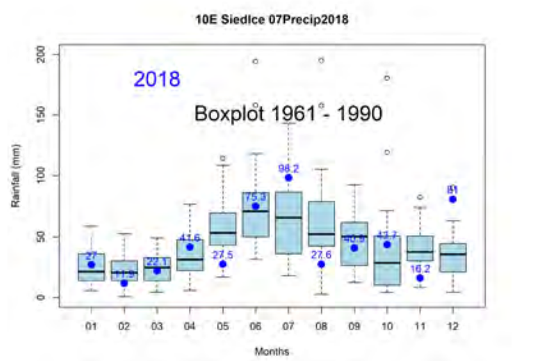

Figure 13: 10E Siedlce 07Precip2018box

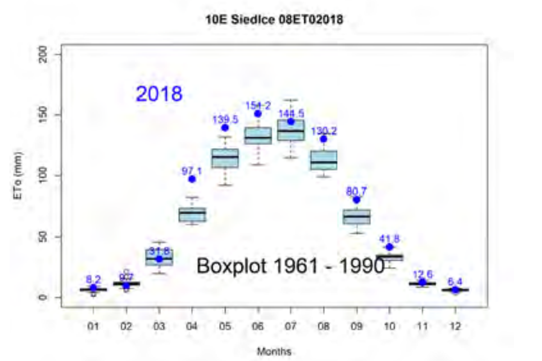

Figure 14: 10E Siedlce 08ET02018box

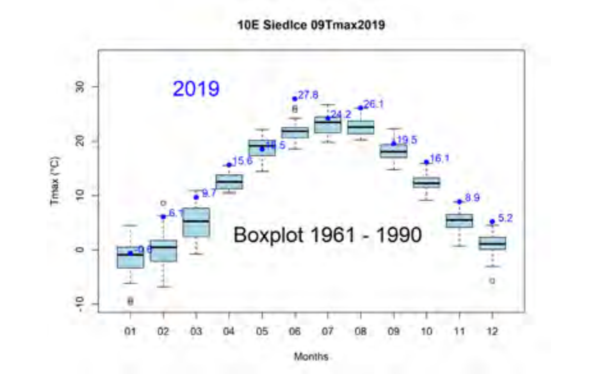

Figure 15: 10E Siedlce 09Tmax2019box

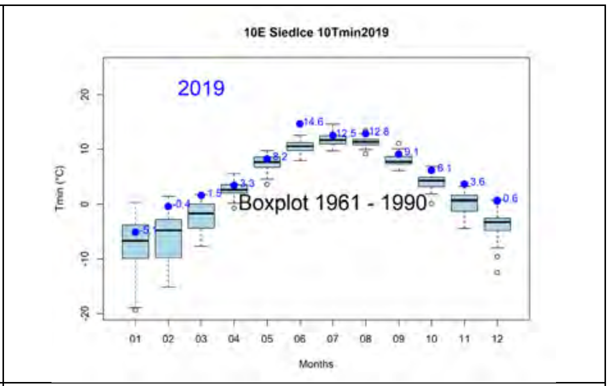

Figure 16: 10E Siedlce 10Tmin2019box

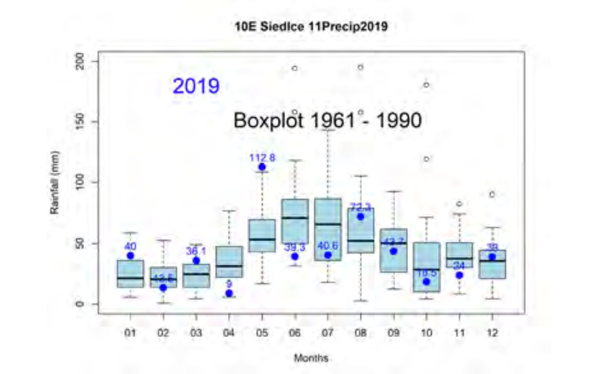

Figure 17: 10E Siedlce 11Precip2019box

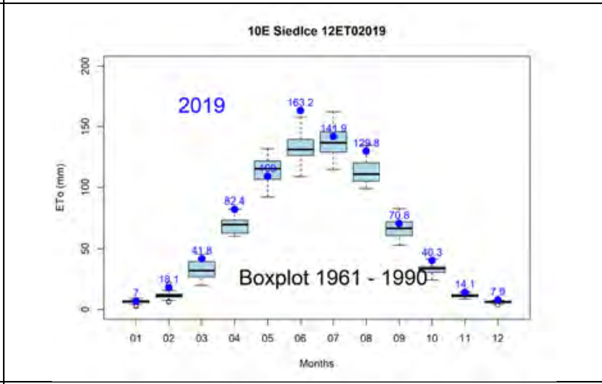

Figure 18: 10E Siedlce 12ET02019box

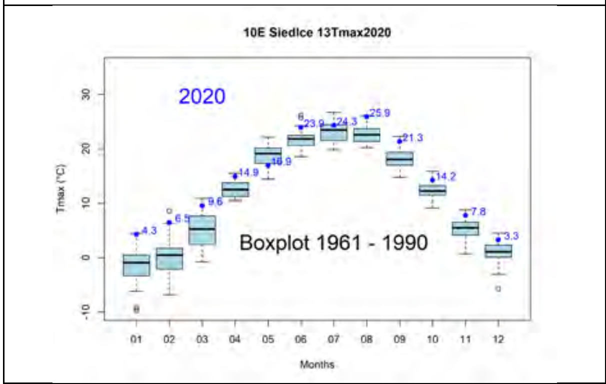

Figure 19: 10E Siedlce 13Tmax2020box

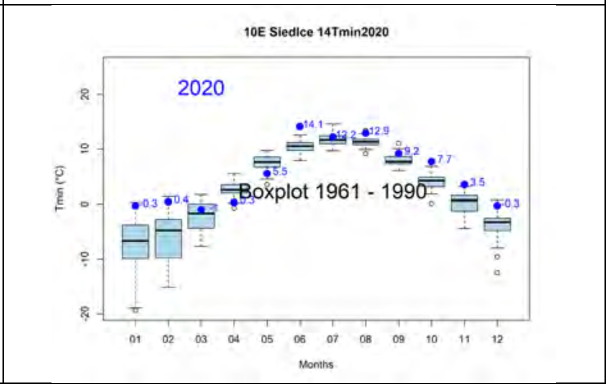

Figure 20: 10E Siedlce 14Tmin2020box

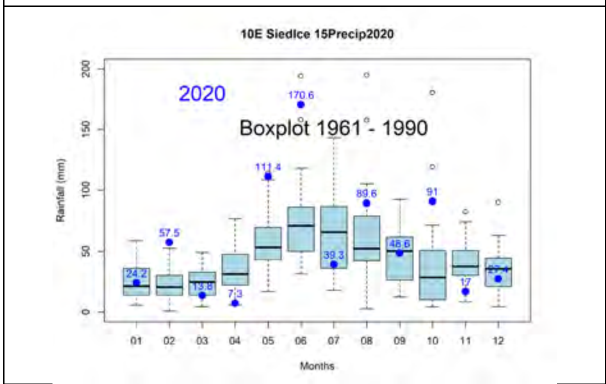

Figure 21: 10E Siedlce 15Precip2020box

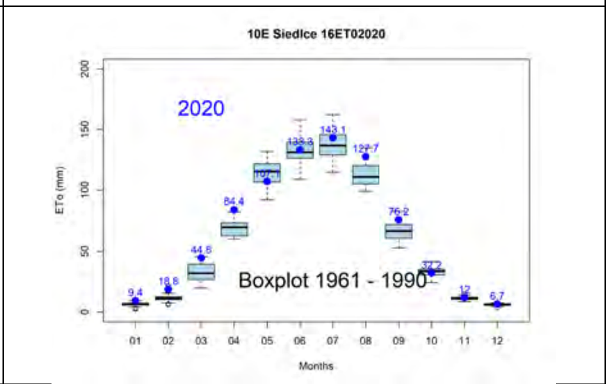

Figure 22: 10E Siedlce 16ET02020box

11. Portugal: Figures from the analysis

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When only one plot with the control was compared with single plots per SICS treatment a Mixed-effect statistical analysis is not possible. The response variable values per treatment are visualized. In some cases, several measurements of the same indicator were made within the same plot. Then the average is shown for that plot and day and visualized as a mean value for each day. The standard deviation of the measurements **within the same plot** is presented with **dashed lines**. However, it is important to stress that they cannot be used for group comparison between the treatments. Measurements within the same plot are spatially repeated measurements and are not independent of each other. The interpretation of the solid lines (between replicated plots) is fundamentally different from the dashed lines.

Table 1: Indicators measured and analyzed

Observation code	Unit	Description
bd_top	%	g/cm3
nmin_top	g/cm3	mg-N/Kg soil
p_avail	g/cm3	mg-P/100gr Soil
k_plus	m/s	cmol+/kg
ca2_plus	mg-N/Kg soil	cmol+/kg
na_plus	mg-P/100gr Soil	cmol+/kg
mg2plus	cmol/kg	cmol+/kg
soc	cmol/kg	%
ph_kcl	cmol/kg	_
ph_h2o	cmol/kg	_
ec1_5	%	dS/m
weed_infestation	_	%
earthworm_no	mg C/kg	no/m2
crop_yield_ha	mg/kg	kg/ha
K_avail	mg/kg	mg-K/100gr Soil
Ksat	mg/kg	mm/h

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SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

Experiment 1:

Per field for experiment 1

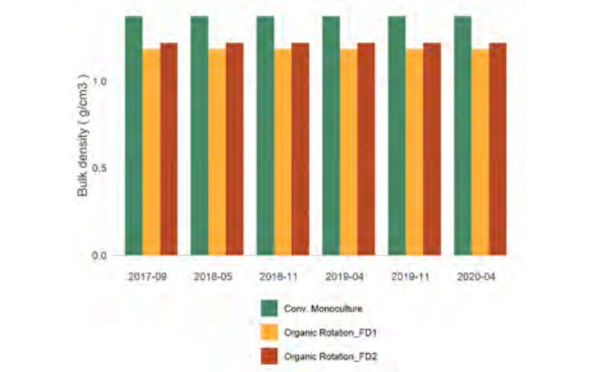

Figure 1: ESAC_EX1a_bd_top

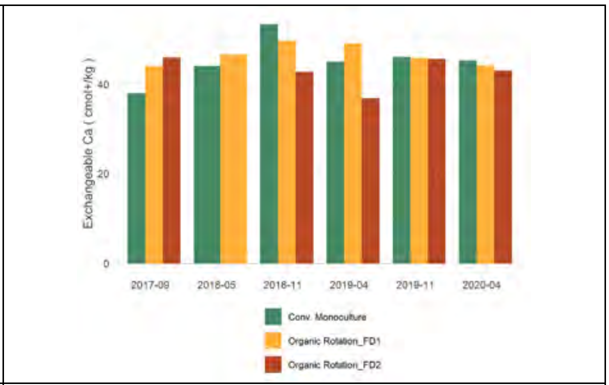

Figure 2: ESAC_EX1a_ca2_plus

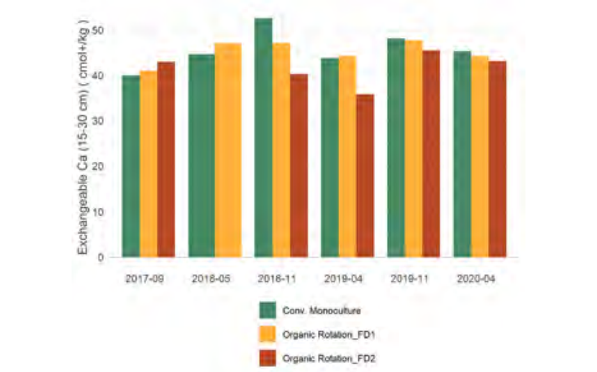

Figure 3: ESAC_EX1a_ca2_plus_15_30

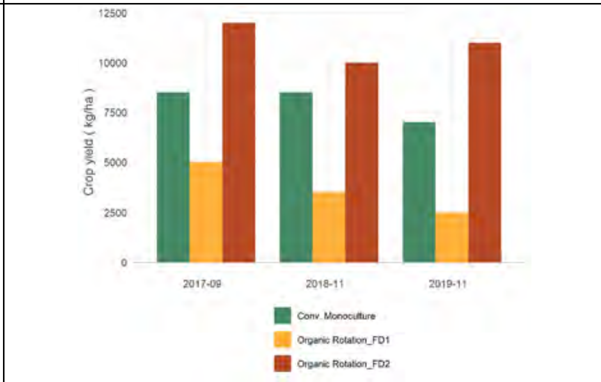

Figure 4: ESAC_EX1a_crop_yield_ha

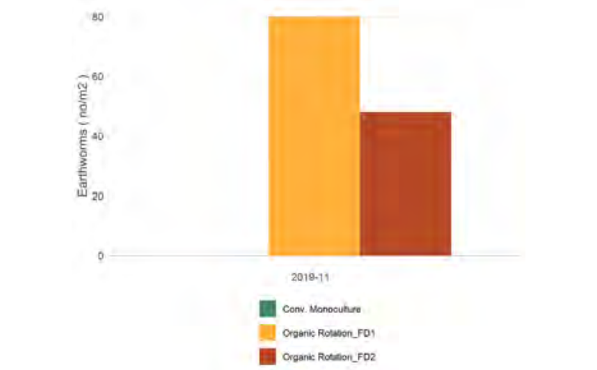

Figure 5: ESAC_EX1a_earthworm_no

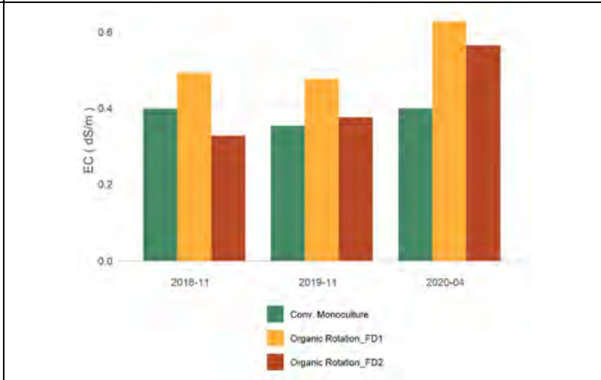

Figure 6: ESAC_EX1a_ec1_5

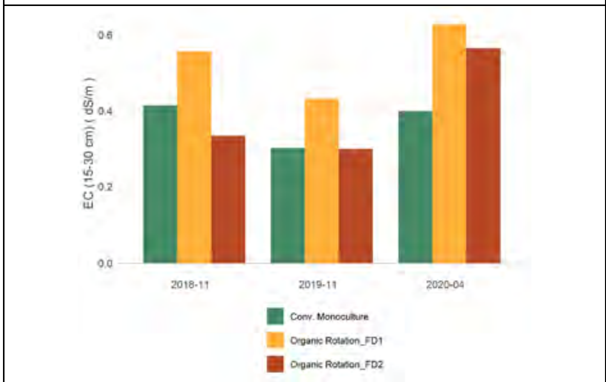

Figure 7: ESAC_EX1a_ec1_5_15_30

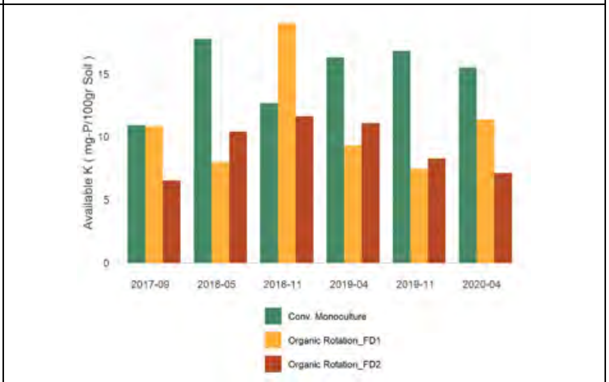

Figure 8: ESAC_EX1a_K_avail

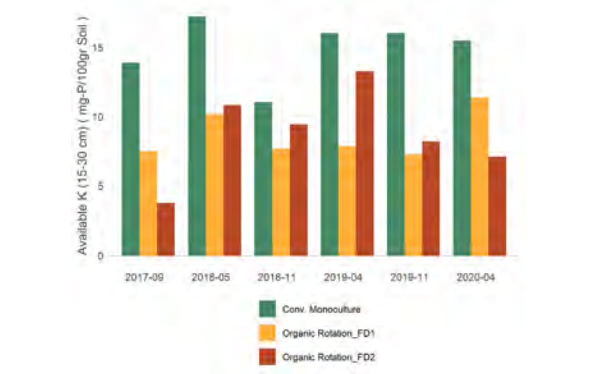

Figure 9: ESAC_EX1a_K_avail_15_30

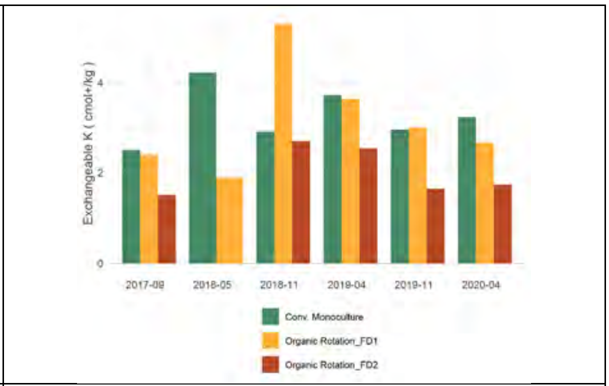

Figure 10: ESAC_EX1a_k_plus

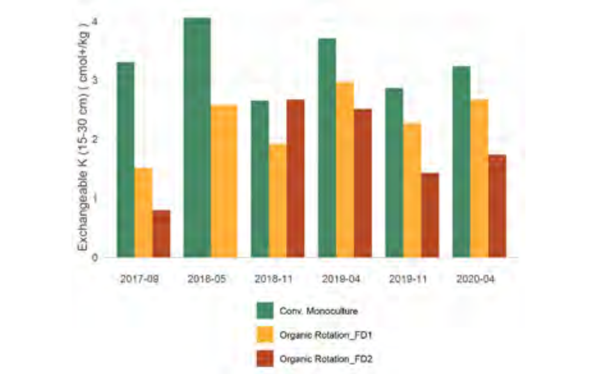

Figure 11: ESAC_EX1a_k_plus_15_30

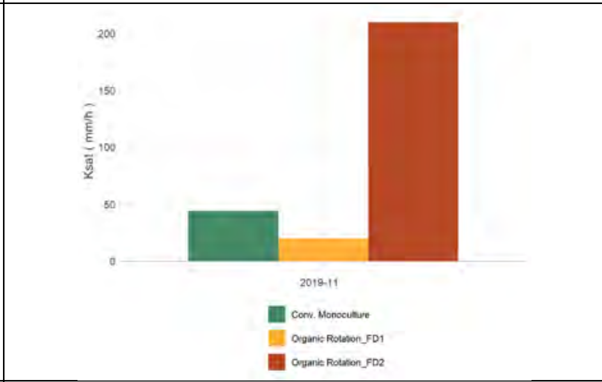

Figure 12: ESAC_EX1a_Ksat

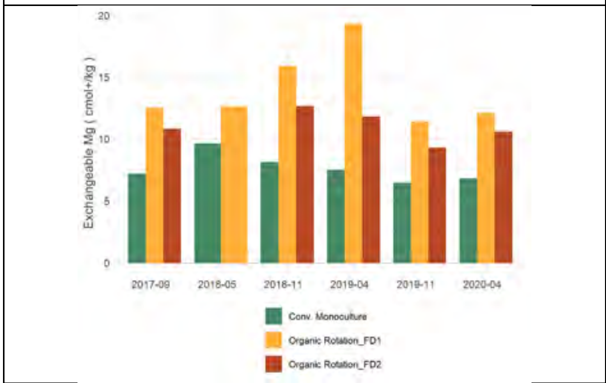

Figure 13: ESAC_EX1a_mg2plus

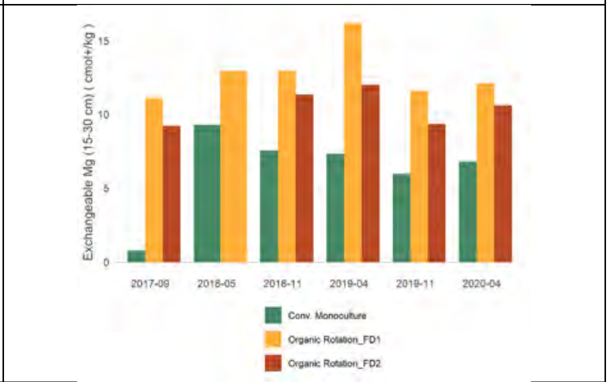

Figure 14: ESAC_EX1a_mg2plus_15_30

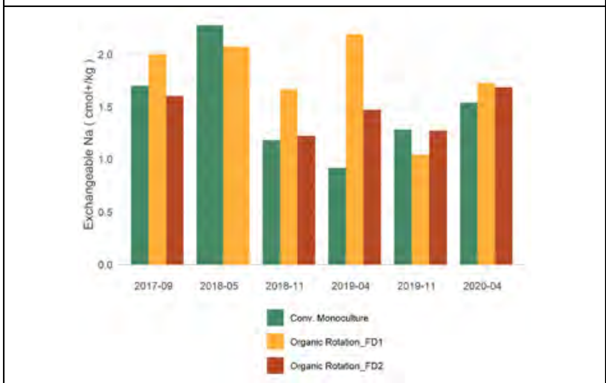

Figure 15: ESAC_EX1a_na_plus

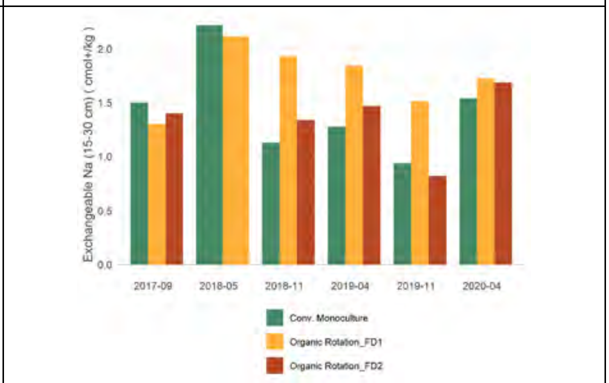

Figure 16: ESAC_EX1a_na_plus_15_30

Figure 17: ESAC_EX1a_nmin_15_30

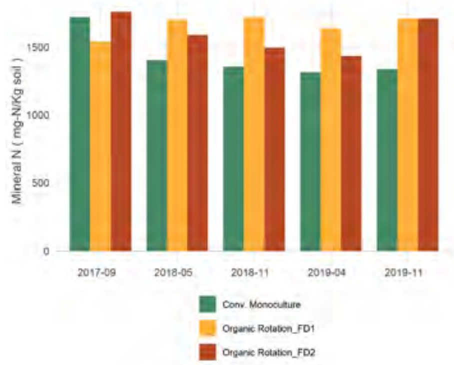

Figure 18: ESAC_EX1a_nmin_top

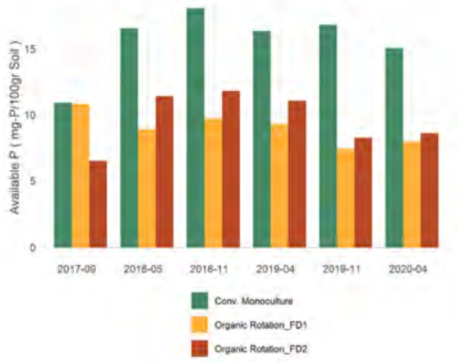

Figure 19: ESAC_EX1a_p_avail

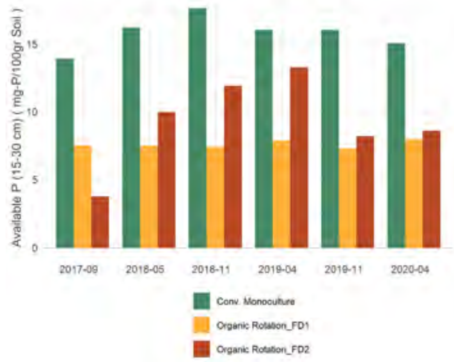

Figure 20: ESAC_EX1a_p_avail_15_30

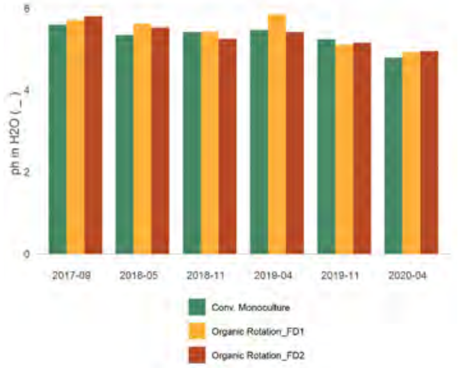

Figure 21: ESAC_EX1a_ph_h2o

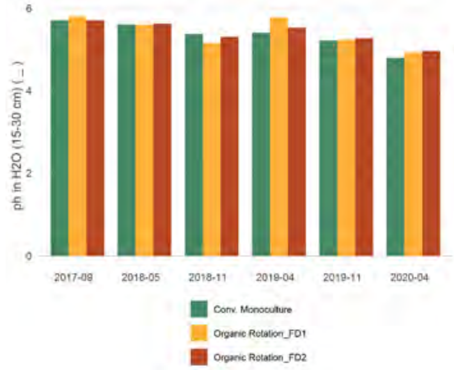

Figure 22: ESAC_EX1a_ph_h2o_15_30

Figure 23: ESAC_EX1a_ph_kcl

Figure 24: ESAC_EX1a_ph_kcl_15_30

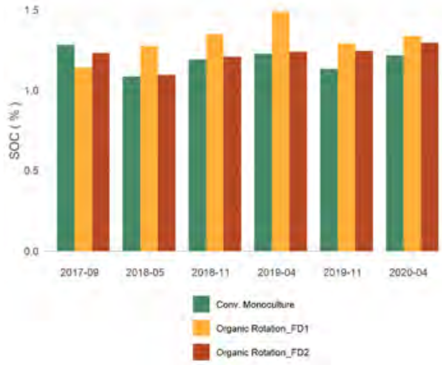

Figure 25: ESAC_EX1a_soc

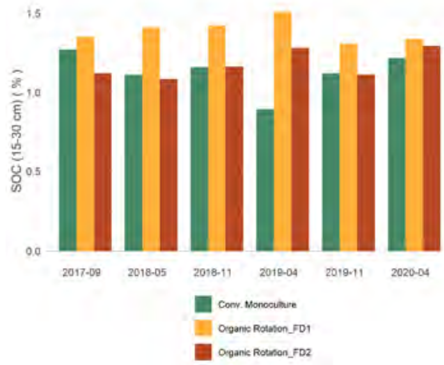

Figure 26: ESAC_EX1a_soc_15_30

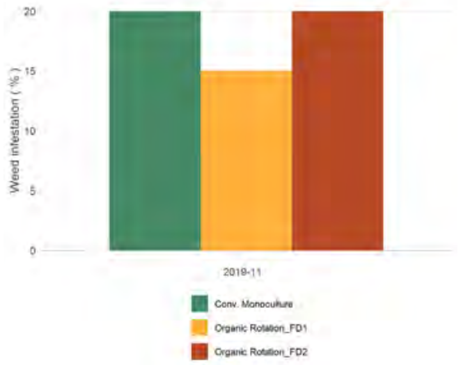

Figure 27: ESAC_EX1a_weed_infestation

Per treatment for experiment 1

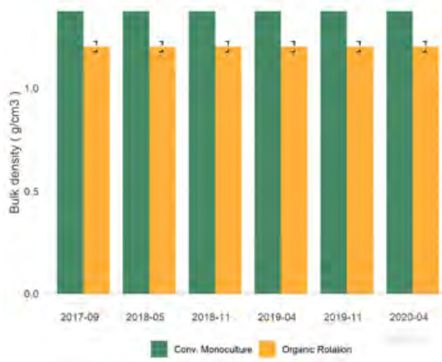

Figure 28: ESAC_EX1_bd_top

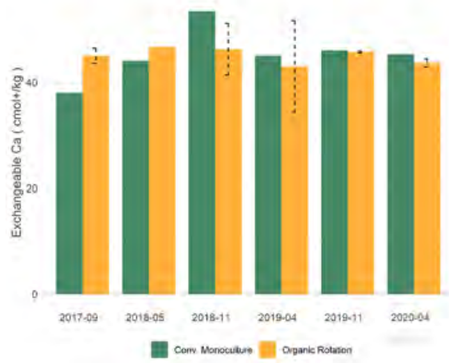

Figure 29: ESAC_EX1_ca2_plus

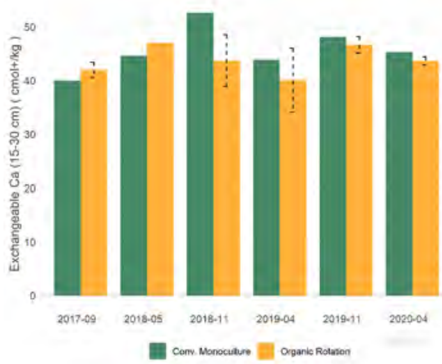

Figure 30: ESAC_EX1_ca2_plus_15_30

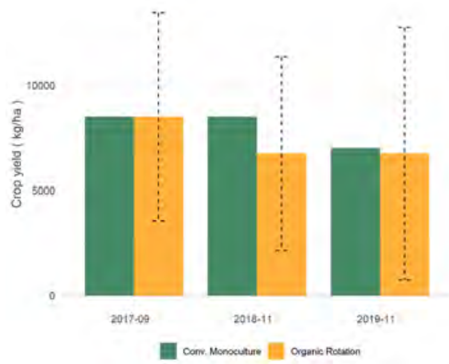

Figure 31: ESAC_EX1_crop_yield_ha

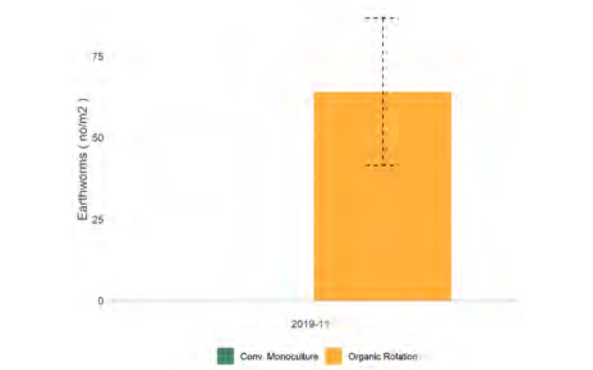

Figure 32: ESAC_EX1_earthworm_no

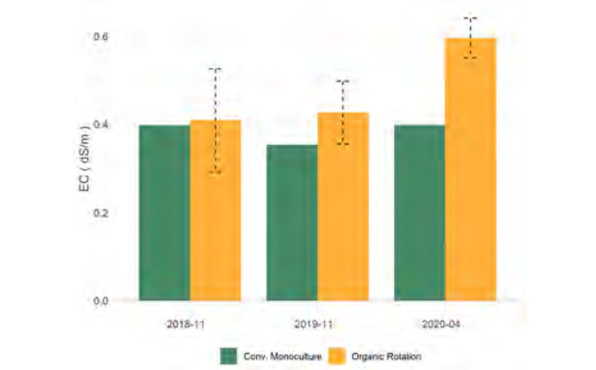

Figure 33: ESAC_EX1_ec1_5

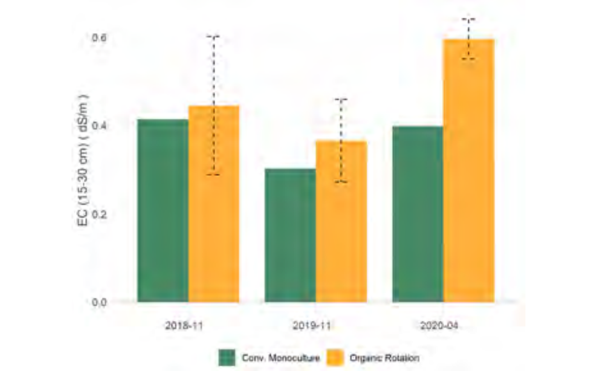

Figure 34: ESAC_EX1_ec1_5_15_30

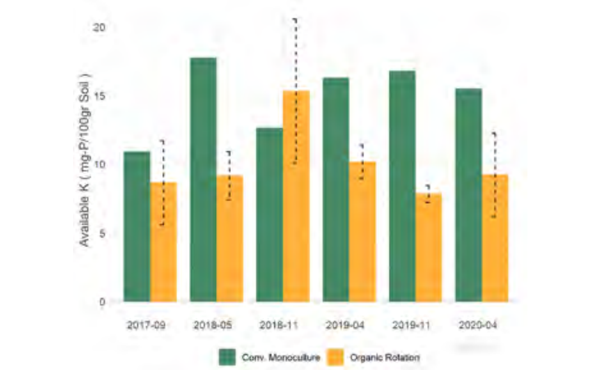

Figure 35: ESAC_EX1_K_avail

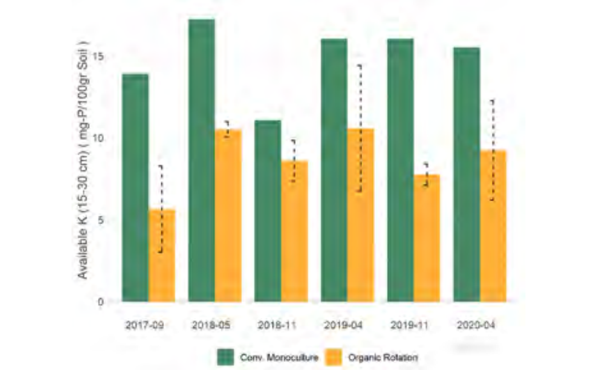

Figure 36: ESAC_EX1_K_avail_15_30

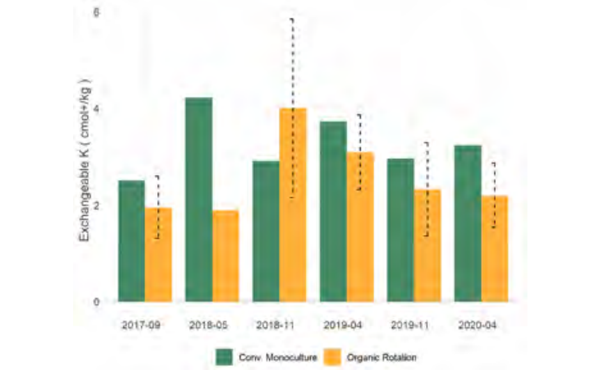

Figure 37: ESAC_EX1_k_plus

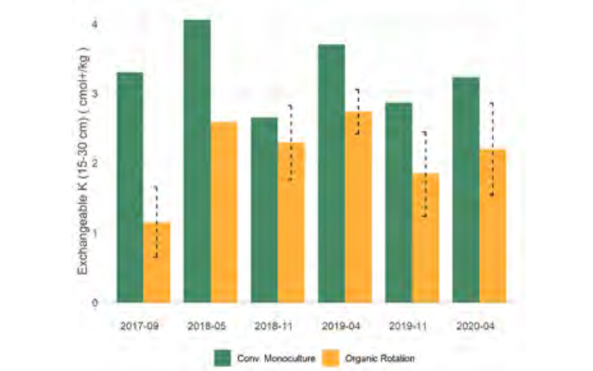

Figure 38: ESAC_EX1_k_plus_15_30

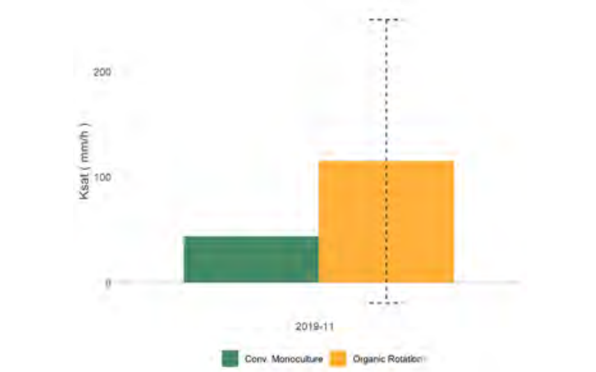

Figure 39: ESAC_EX1_Ksat

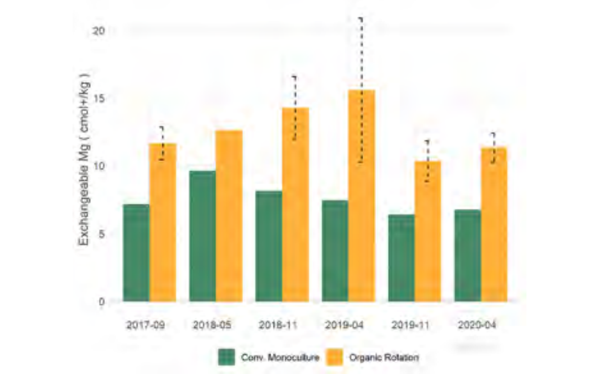

Figure 40: ESAC_EX1_mg2plus

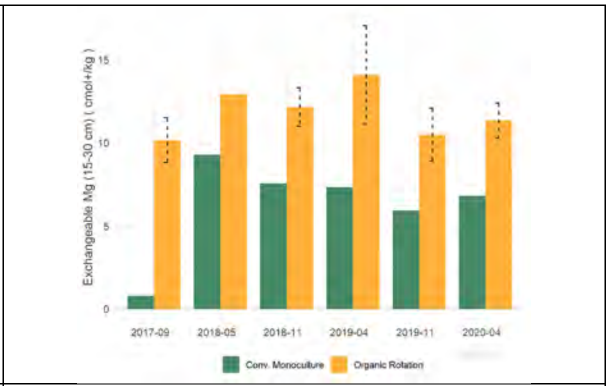

Figure 41: ESAC_EX1_mg2plus_15_30

Figure 42: ESAC_EX1_na_plus

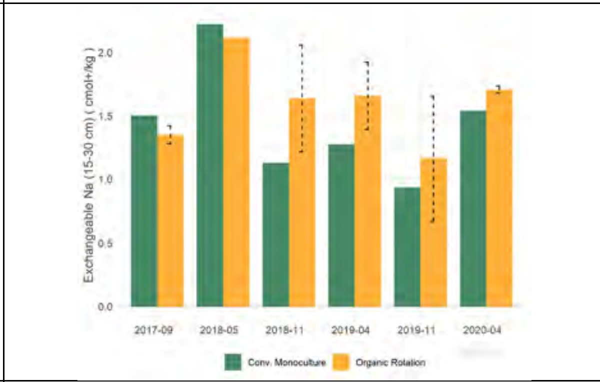

Figure 43: ESAC_EX1_na_plus_15_30

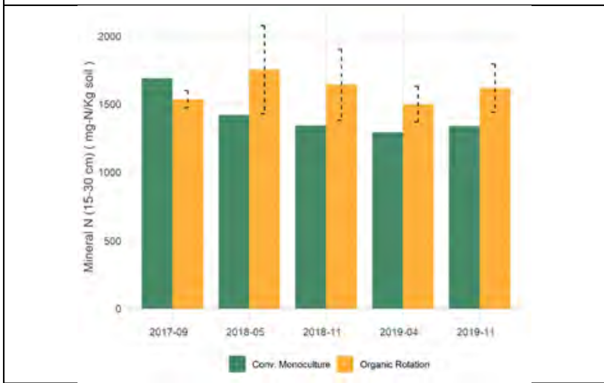

Figure 44: ESAC_EX1_nmin_15_30

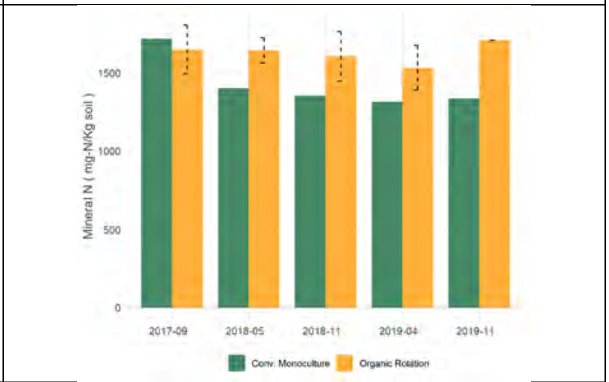

Figure 45: ESAC_EX1_nmin_top

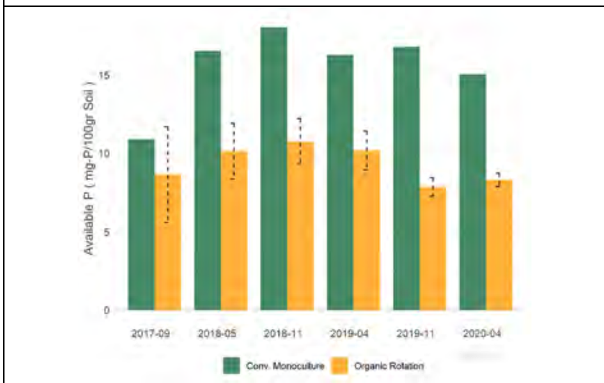

Figure 46: ESAC_EX1_p_avail

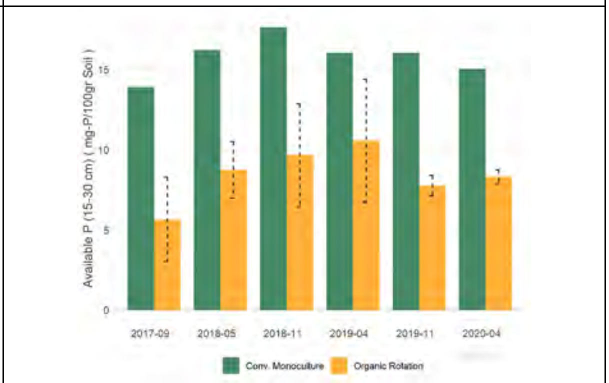

Figure 47: ESAC_EX1_p_avail_15_30

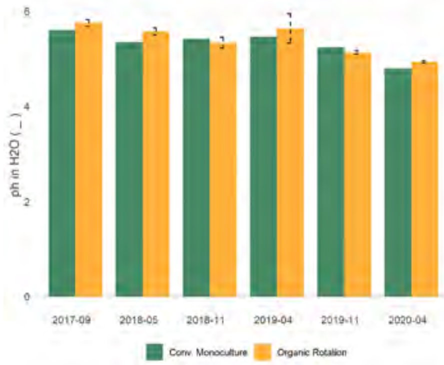

Figure 48: ESAC_EX1_ph_h2o

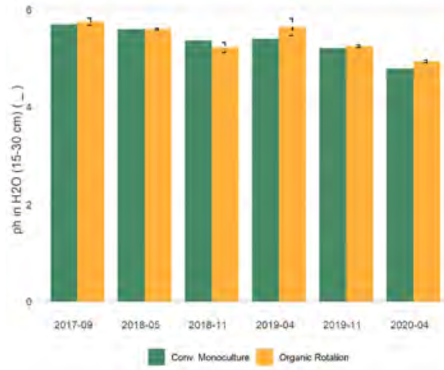

Figure 49: ESAC_EX1_ph_h2o_15_30

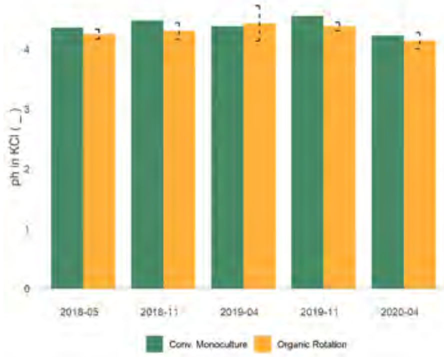

Figure 50: ESAC_EX1_ph_kcl

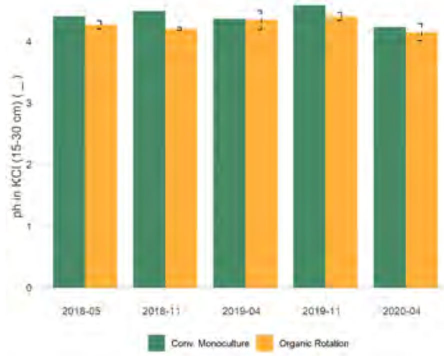

Figure 51: ESAC_EX1_ph_kcl_15_30

Figure 52: ESAC_EX1_soc

Figure 53: ESAC_EX1_soc_15_30

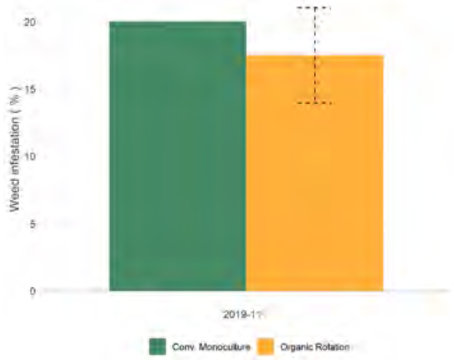

Figure 54: ESAC_EX1_weed_infestation

Experiment 2:

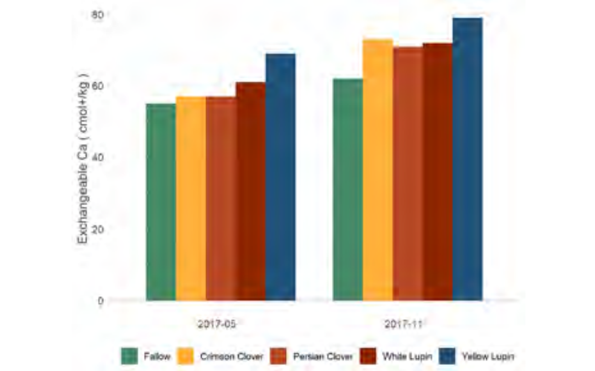

Figure 55: ESAC_EX2_ca2_plus

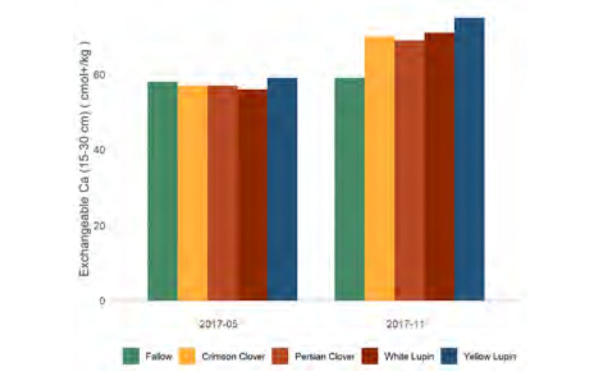

Figure 56: ESAC_EX2_ca2_plus_15_30

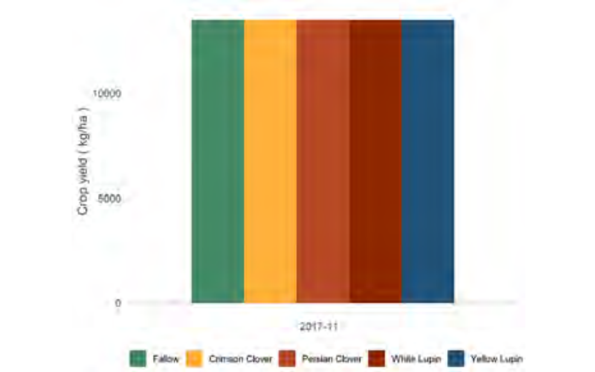

Figure 57: ESAC_EX2_crop_yield_ha

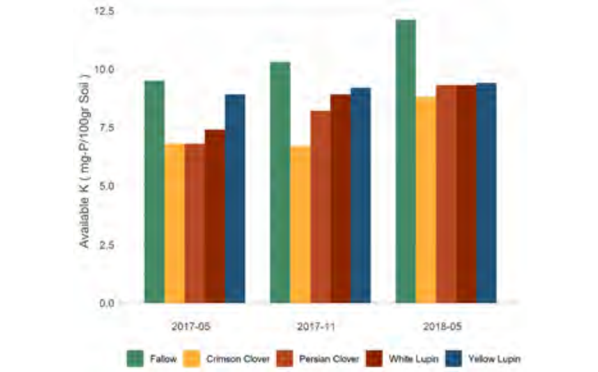

Figure 58: ESAC_EX2_K_avail

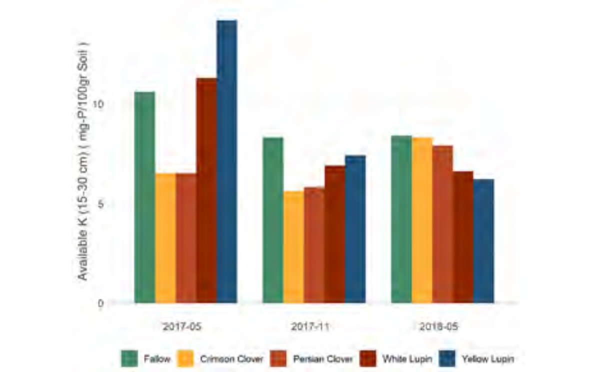

Figure 59: ESAC_EX2_K_avail_15_30

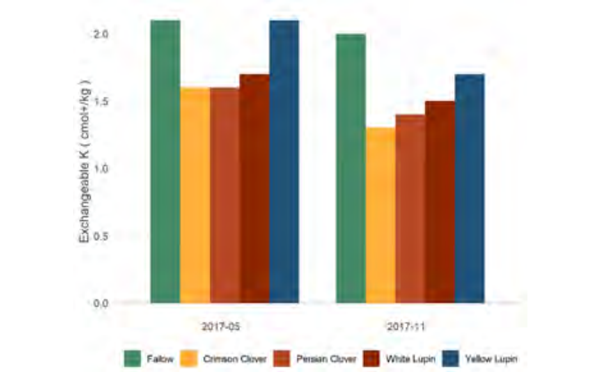

Figure 60: ESAC_EX2_k_plus

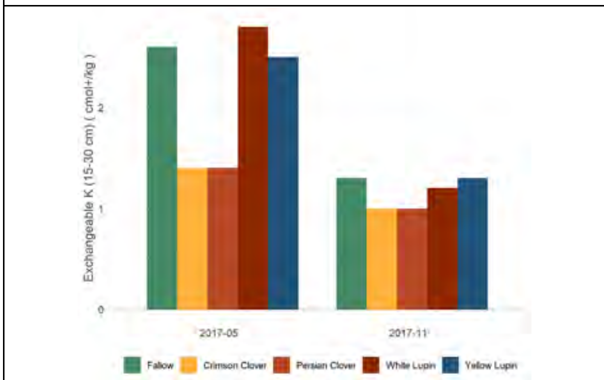

Figure 61: ESAC_EX2_k_plus_15_30

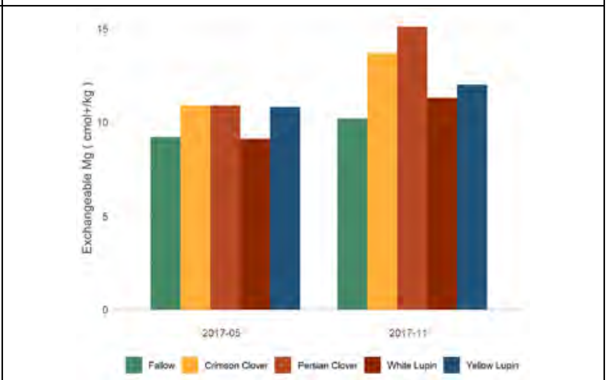

Figure 62: ESAC_EX2_mg2plus

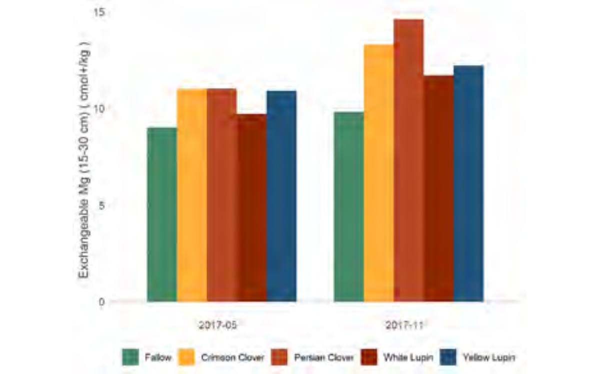

Figure 63: ESAC_EX2_mg2plus_15_30

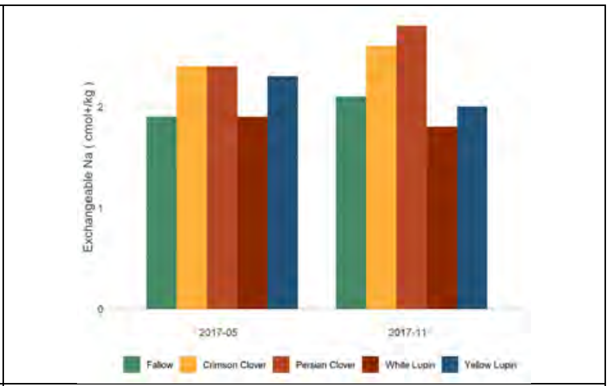

Figure 64: ESAC_EX2_na_plus

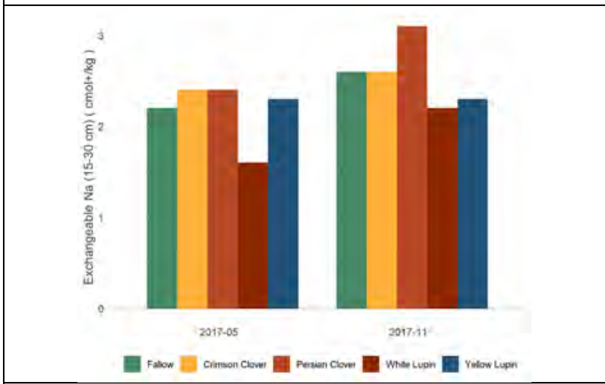

Figure 65: ESAC_EX2_na_plus_15_30

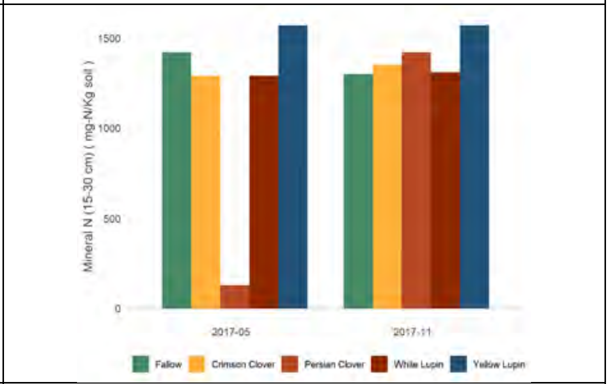

Figure 66: ESAC_EX2_nmin_15_30

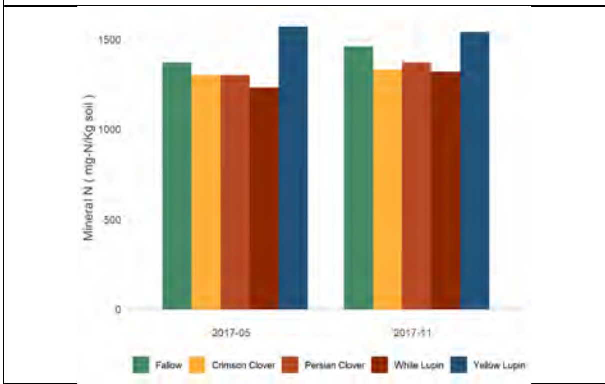

Figure 67: ESAC_EX2_nmin_top

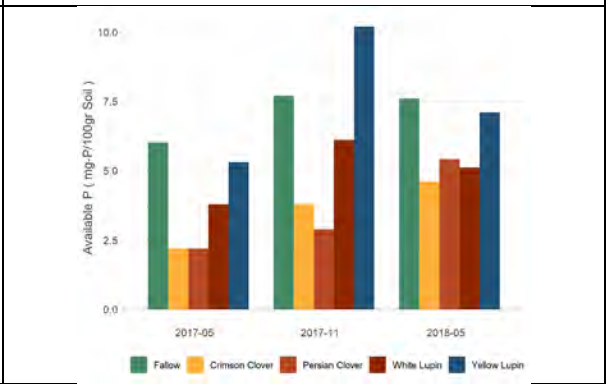

Figure 68: ESAC_EX2_p_avail

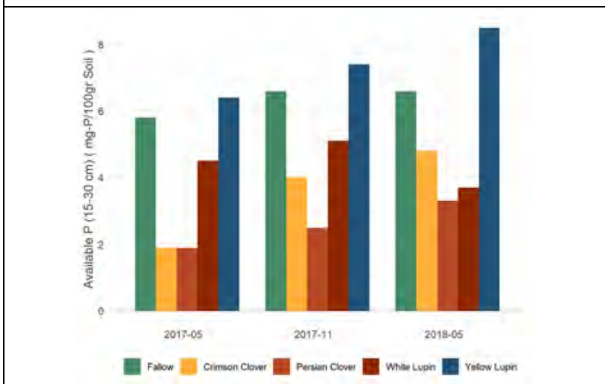

Figure 69: ESAC_EX2_p_avail_15_30

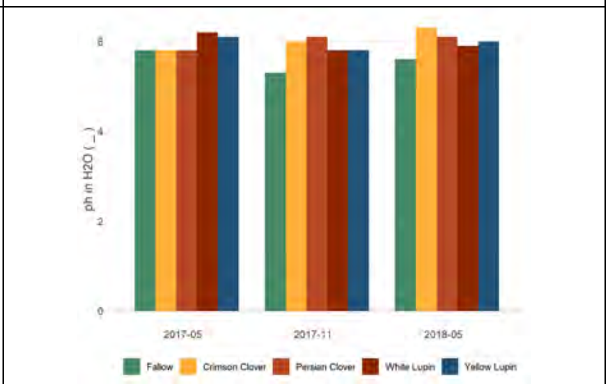

Figure 70: ESAC_EX2_ph_h2o

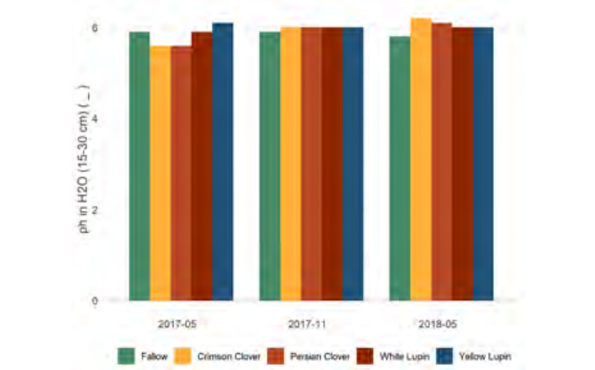

Figure 71: ESAC_EX2_ph_h2o_15_30

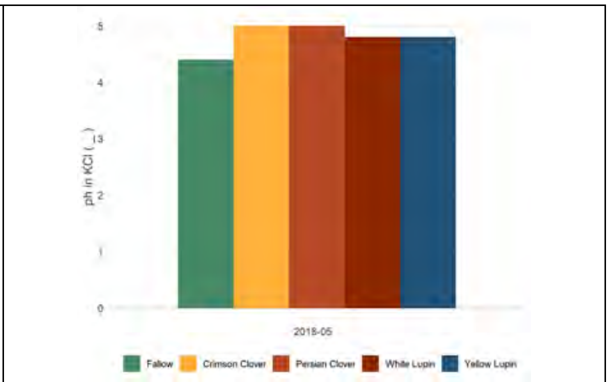

Figure 72: ESAC_EX2_ph_kcl

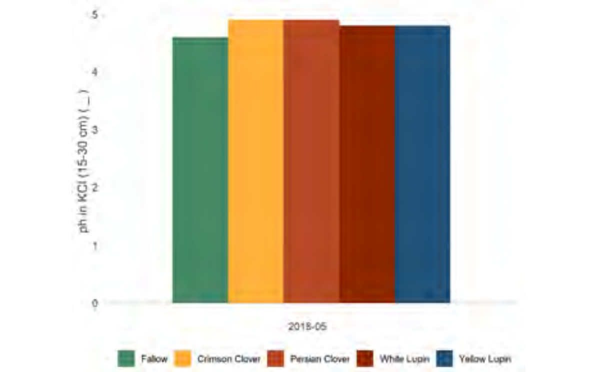

Figure 73: ESAC_EX2_ph_kcl_15_30

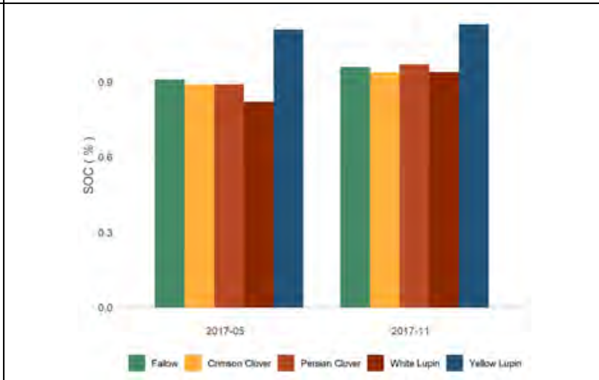

Figure 74: ESAC_EX2_soc

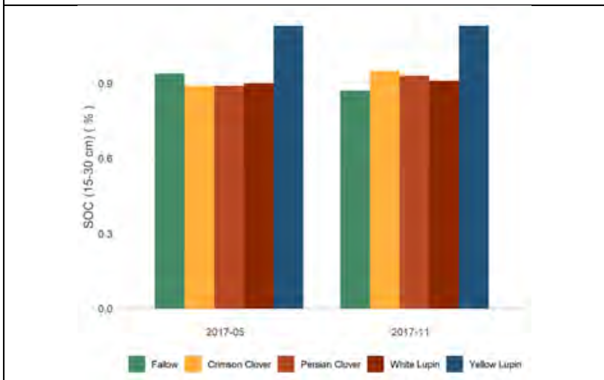

Figure 75: ESAC_EX2_soc_15_30

Experiment 3:

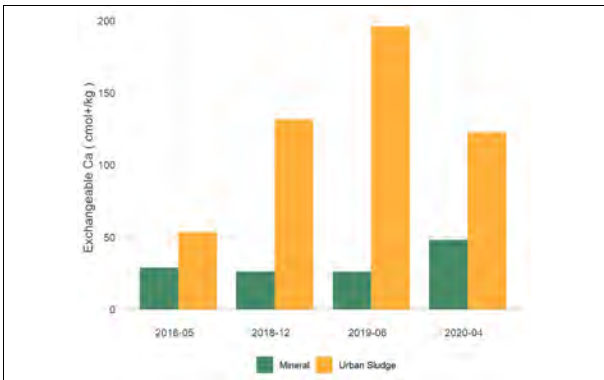

Figure 76: ESAC_EX3_ca2_plus

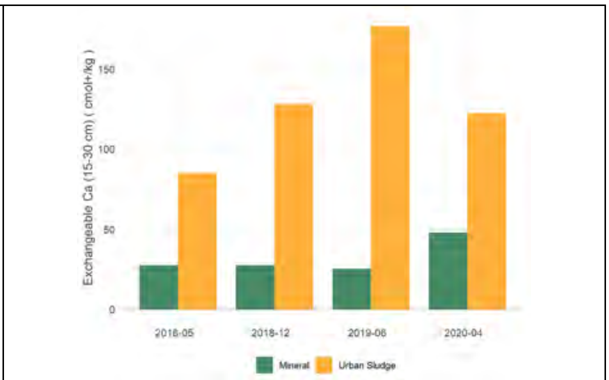

Figure 77: ESAC_EX3_ca2_plus_15_30

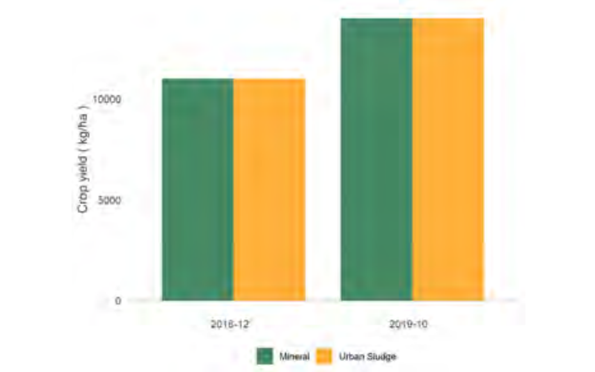

Figure 78: ESAC_EX3_crop_yield_ha

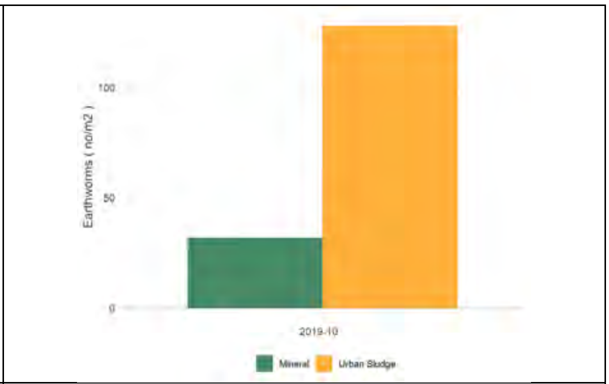

Figure 79: ESAC_EX3_earthworm_no

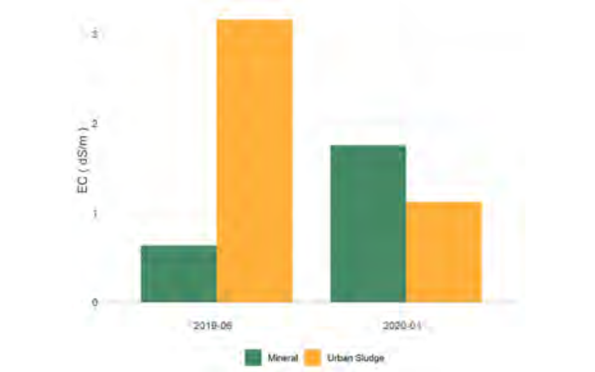

Figure 80: ESAC_EX3_ec1_5

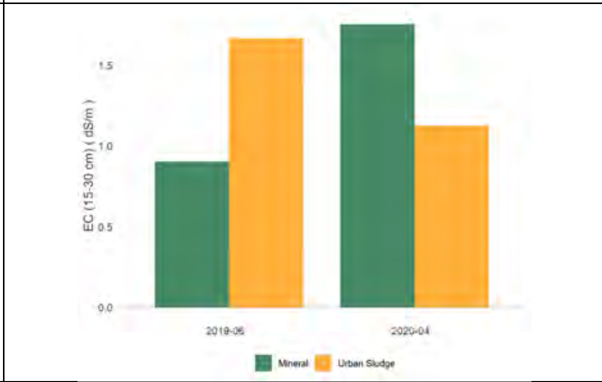

Figure 81: ESAC_EX3_ec1_5_15_30

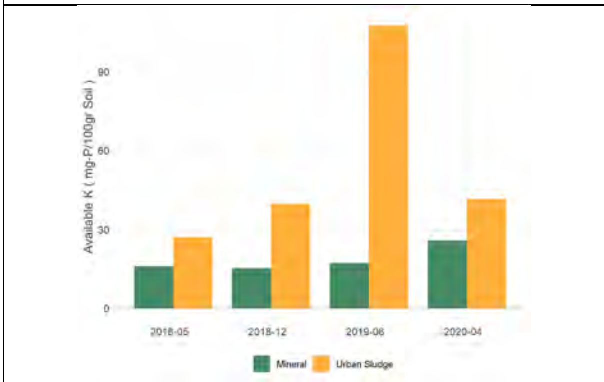

Figure 82: ESAC_EX3_K_avail

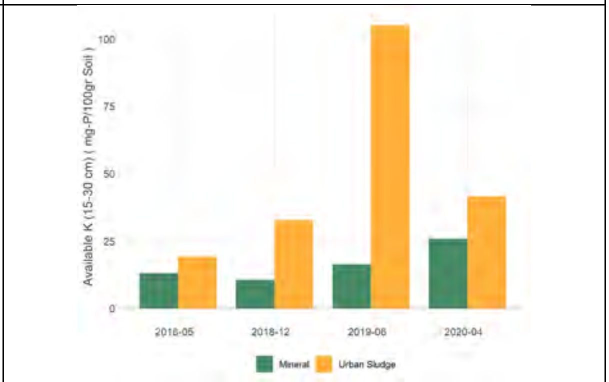

Figure 83: ESAC_EX3_K_avail_15_30

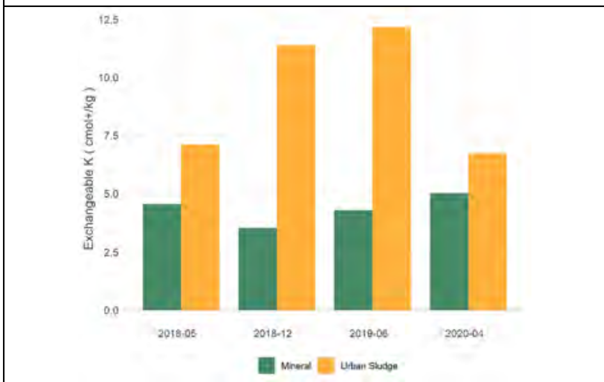

Figure 84: ESAC_EX3_k_plus

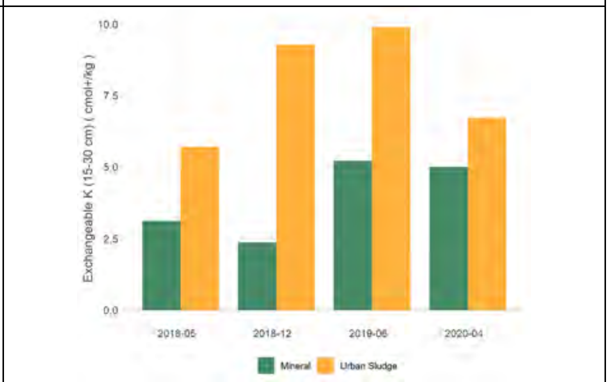

Figure 85: ESAC_EX3_k_plus_15_30

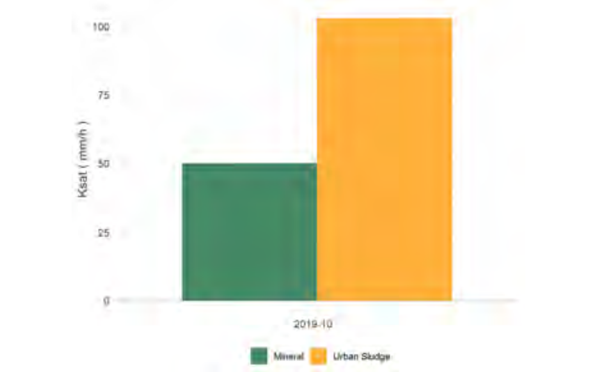

Figure 86: ESAC_EX3_Ksat

Figure 87: ESAC_EX3_mg2plus

Figure 88: ESAC_EX3_mg2plus_15_30

Figure 89: ESAC_EX3_na_plus

Figure 90: ESAC_EX3_na_plus_15_30

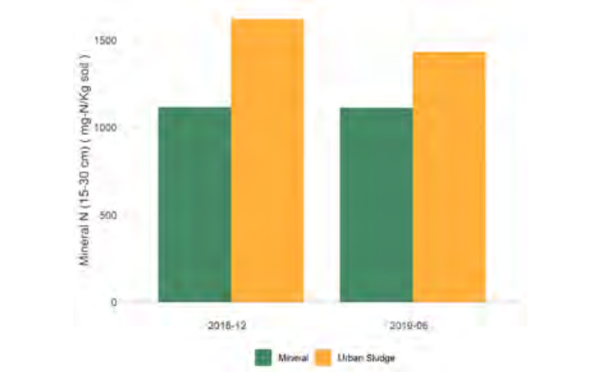

Figure 91: ESAC_EX3_nmin_15_30

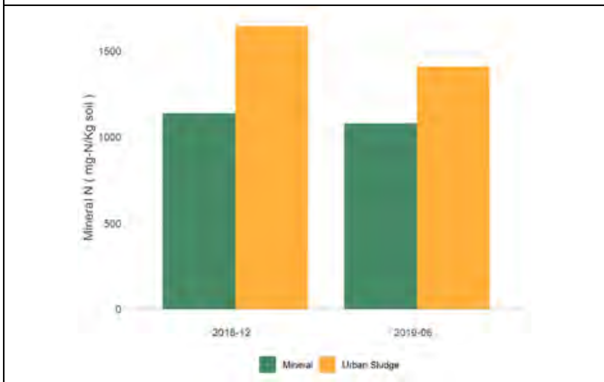

Figure 92: ESAC_EX3_nmin_top

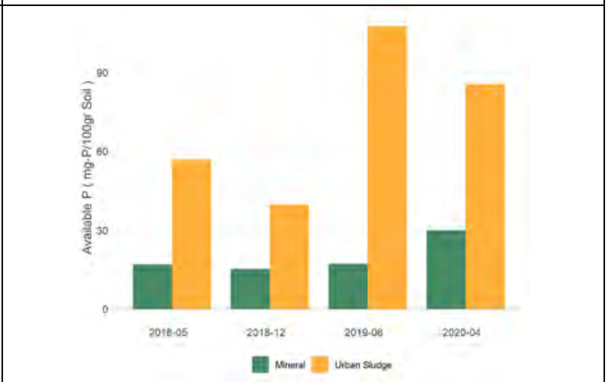

Figure 93: ESAC_EX3_p_avail

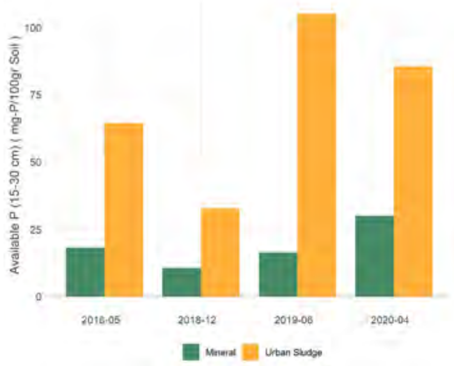

Figure 94: ESAC_EX3_p_avail_15_30

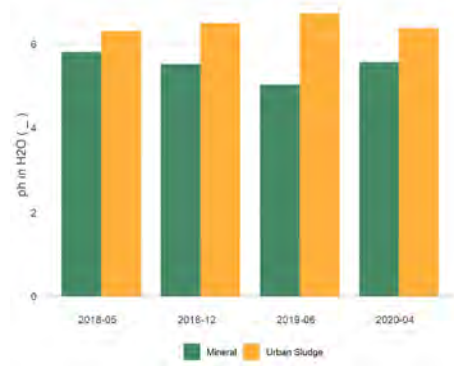

Figure 95: ESAC_EX3_ph_h2o

Figure 96: ESAC_EX3_ph_h2o_15_30

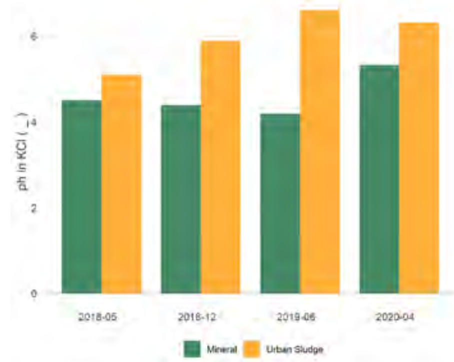

Figure 97: ESAC_EX3_ph_kcl

Figure 98: ESAC_EX3_ph_kcl_15_30

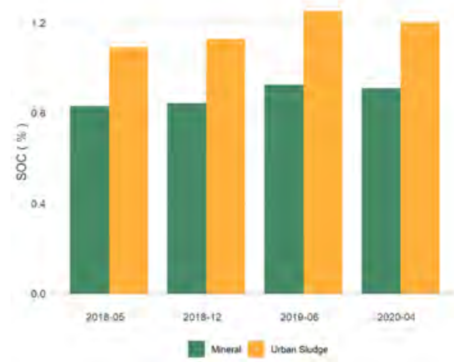

Figure 99: ESAC_EX3_soc

Figure 100: ESAC_EX3_soc_15_30

Experiment 4:

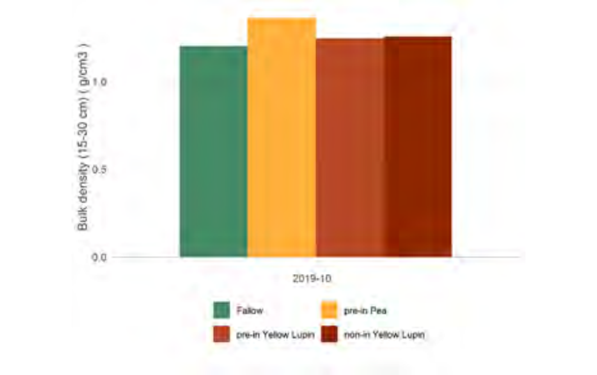

Figure 101: ESAC_EX4_bd_15_30

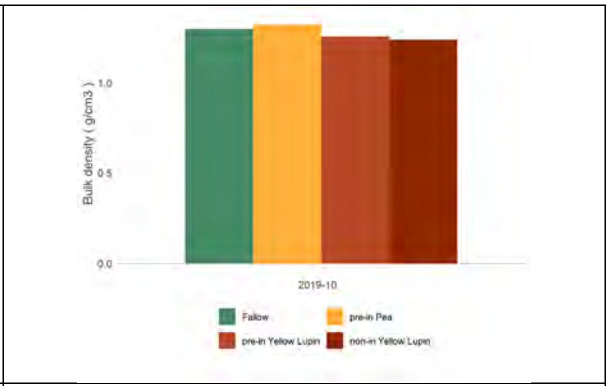

Figure 102: ESAC_EX4_bd_top

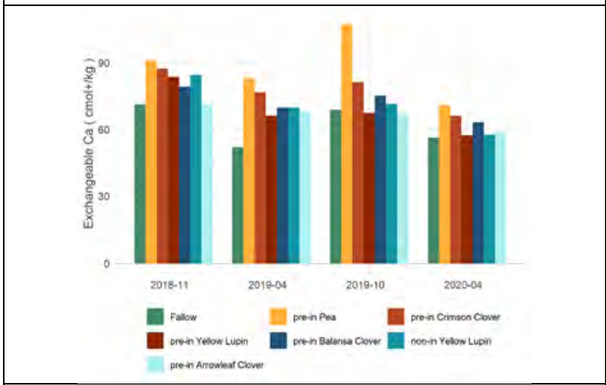

Figure 103: ESAC_EX4_ca2_plus

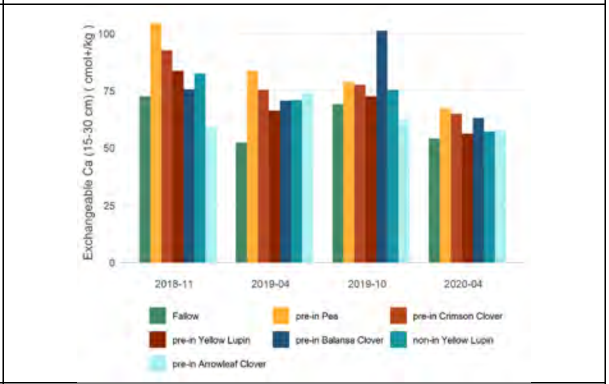

Figure 104: ESAC_EX4_ca2_plus_15_30

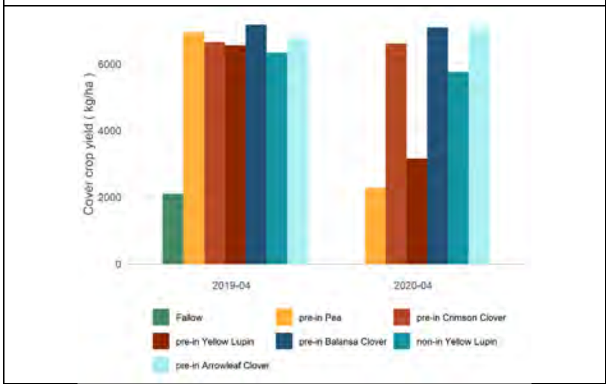

Figure 105: ESAC_EX4_cover_crop_yield

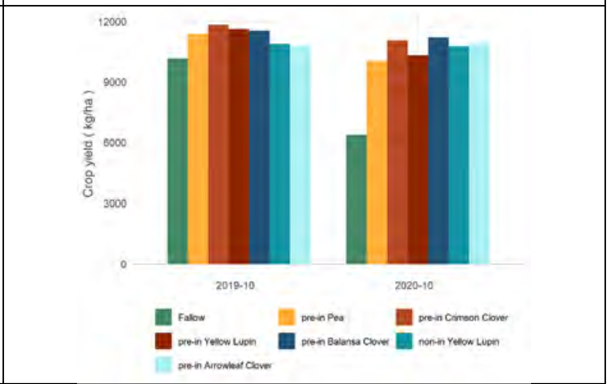

Figure 106: ESAC_EX4_crop_yield_ha

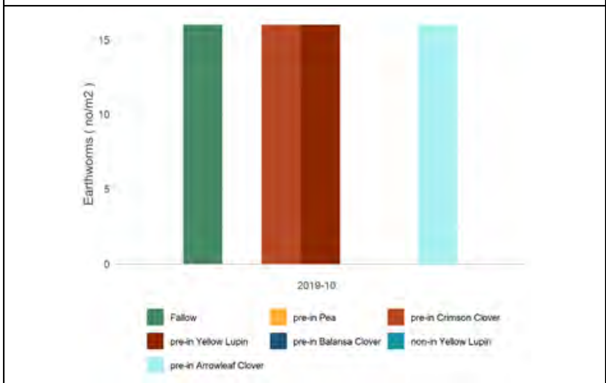

Figure 107: ESAC_EX4_earthworm_no

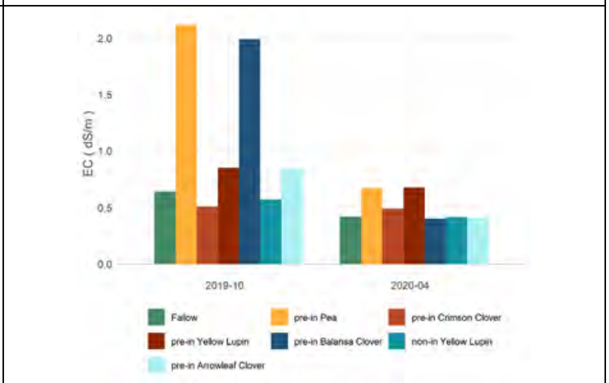

Figure 108: ESAC_EX4_ec1_5

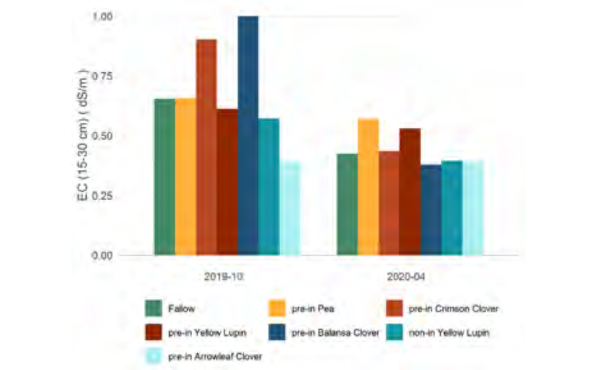

Figure 109: ESAC_EX4_ec1_5_15_30

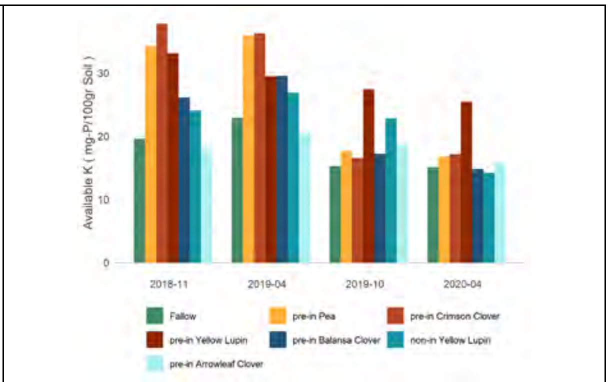

Figure 110: ESAC_EX4_K_avail

Figure 111: ESAC_EX4_K_avail_15_30

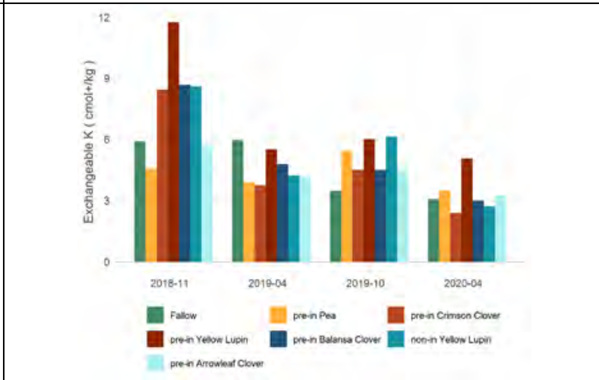

Figure 112: ESAC_EX4_k_plus

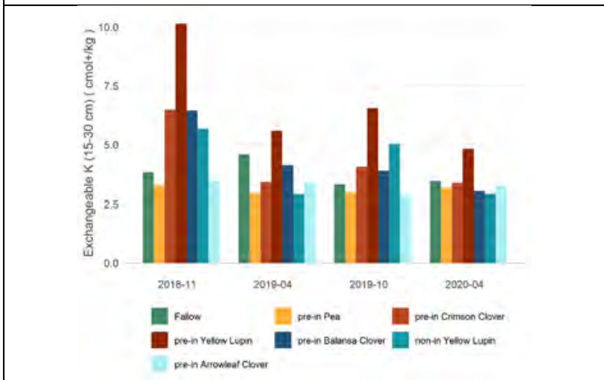

Figure 113: ESAC_EX4_k_plus_15_30

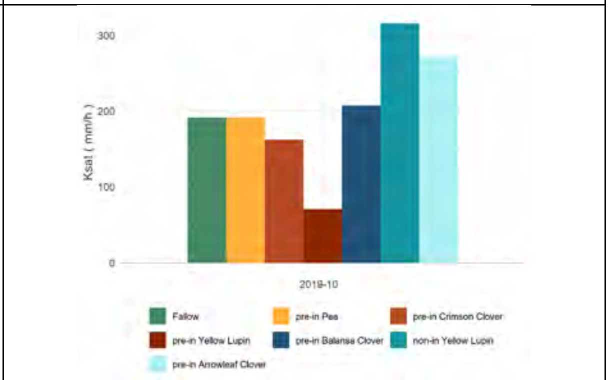

Figure 114: ESAC_EX4_Ksat

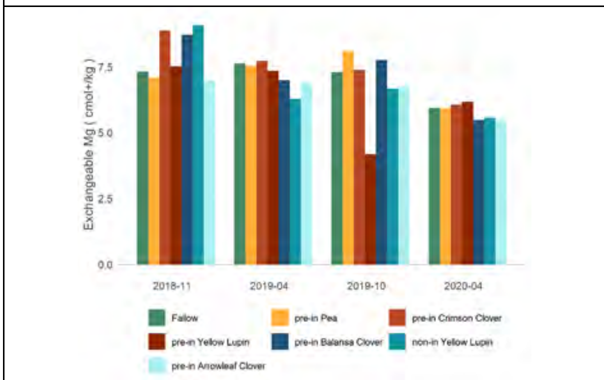

Figure 115: ESAC_EX4_mg2plus

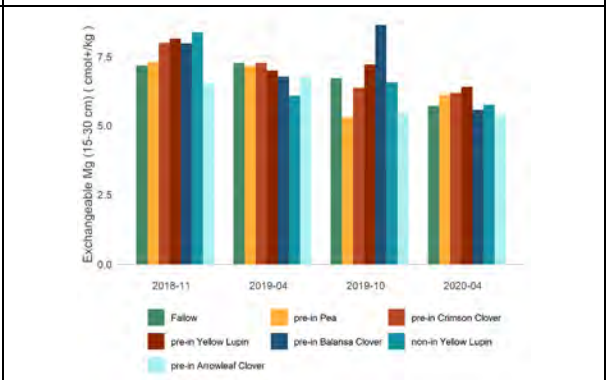

Figure 116: ESAC_EX4_mg2plus_15_30

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Figure 117: ESAC_EX4_na_plus

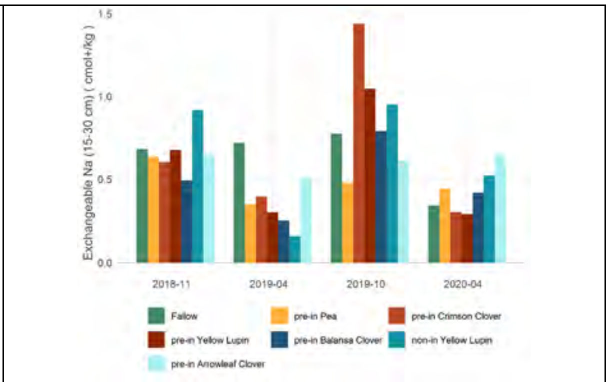

Figure 118: ESAC_EX4_na_plus_15_30

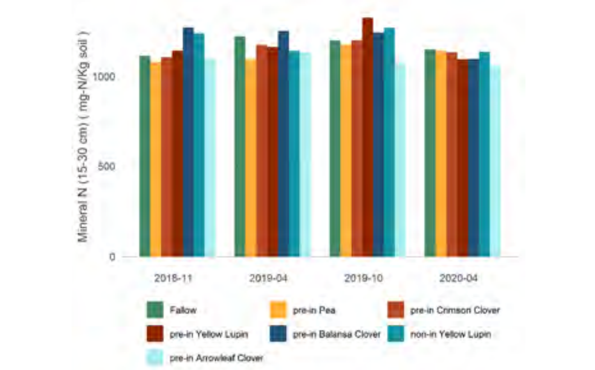

Figure 119: ESAC_EX4_nmin_15_30

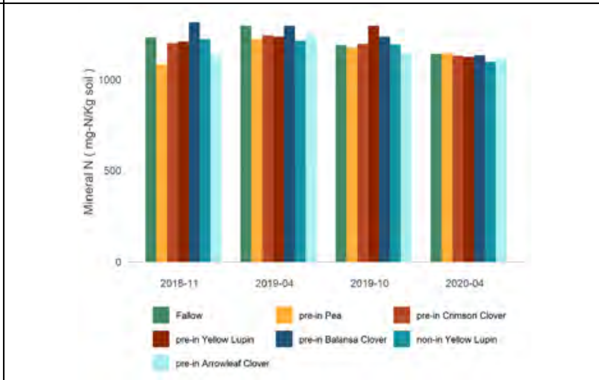

Figure 120: ESAC_EX4_nmin_top

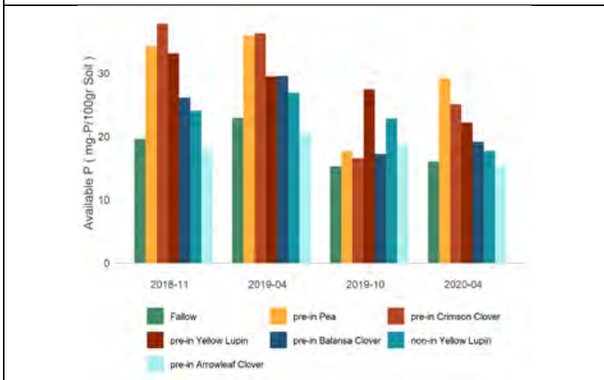

Figure 121: ESAC_EX4_p_avail

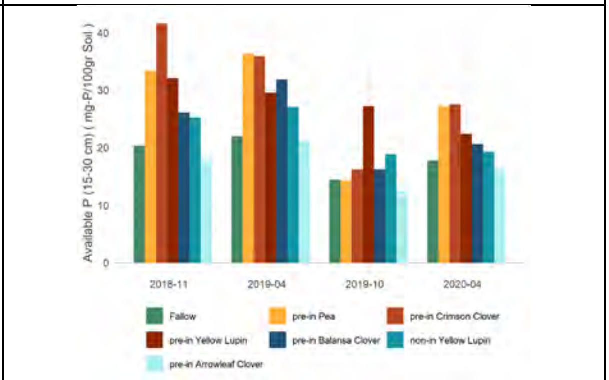

Figure 122: ESAC_EX4_p_avail_15_30

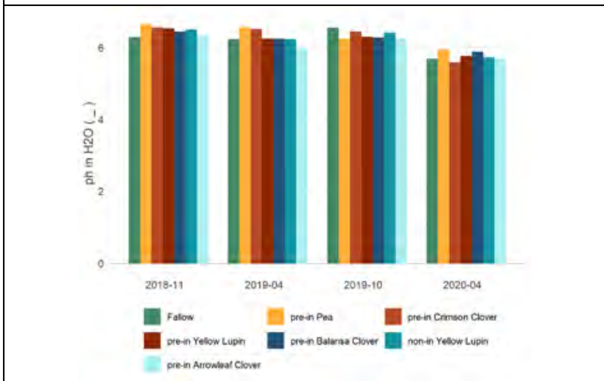

Figure 123: ESAC_EX4_ph_h2o

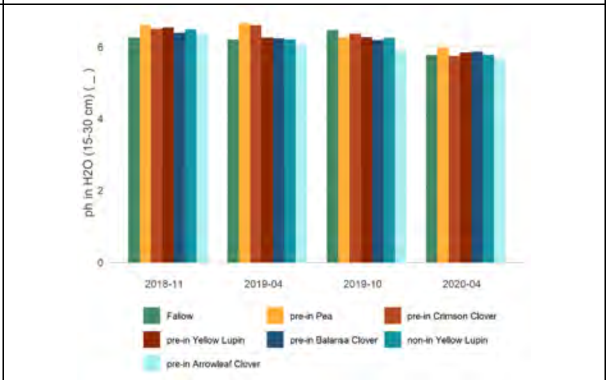

Figure 124: ESAC_EX4_ph_h2o_15_30

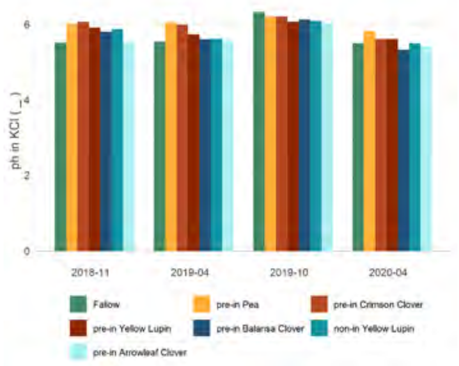

Figure 125: ESAC_EX4_ph_kcl

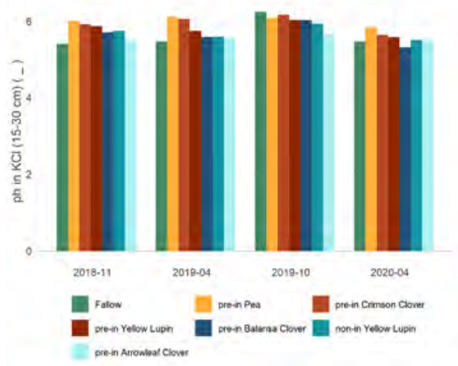

Figure 126: ESAC_EX4_ph_kcl_15_30

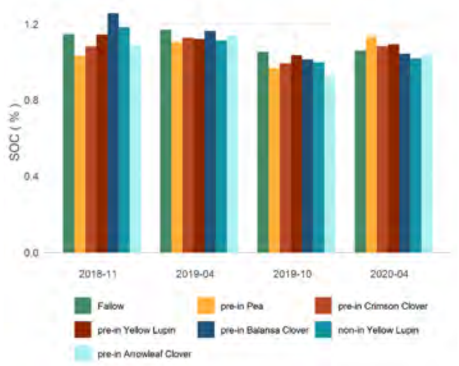

Figure 127: ESAC_EX4_soc

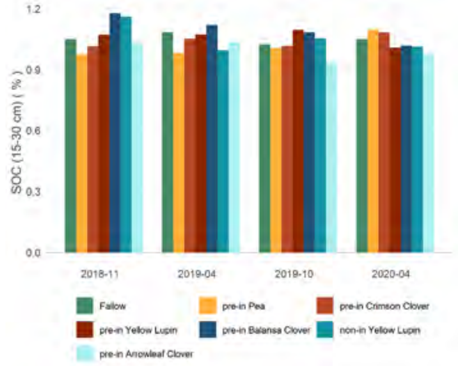

Figure 128: ESAC_EX4_soc_15_30

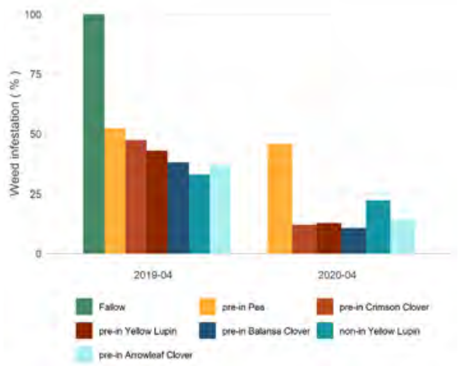

Figure 129: ESAC_EX4_weed_infestation

11. Portugal: Figures from the exploratory meteorological analysis

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The figures of the meteorological analysis are explained in the general introduction to D5.3

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11E Coimbra (ECAD213)

Long standing station of Coimbra Measurement started in 1864 but on ECAD only available from 1900 till 1996. So, the period of the experiments is not covered. The research station ESAC is shown below and the normal 1961-90 for Coimbra 5 (as in ECAD213) is compared with the ESAC data for 2018 to 2020.

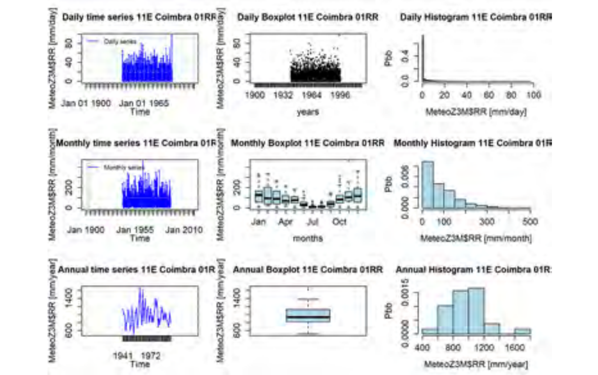

Figure 1: 11E COIMBRA 01RRhyplo

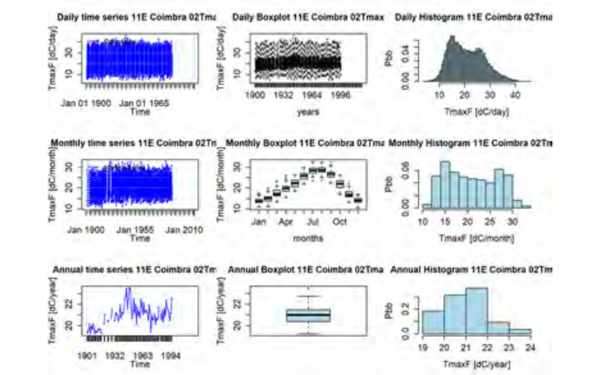

Figure 2: 11E COIMBRA 02Tmaxhyplo

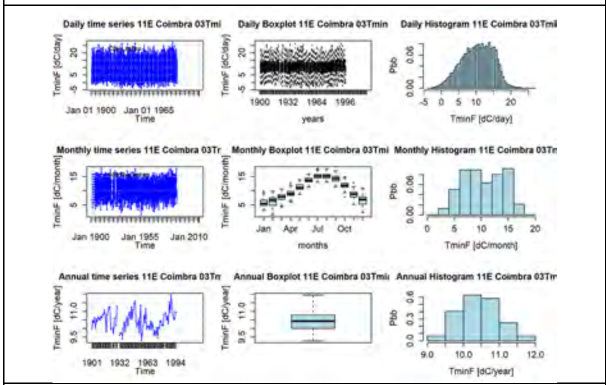

Figure 3: 11E COIMBRA 03Tminhyplo

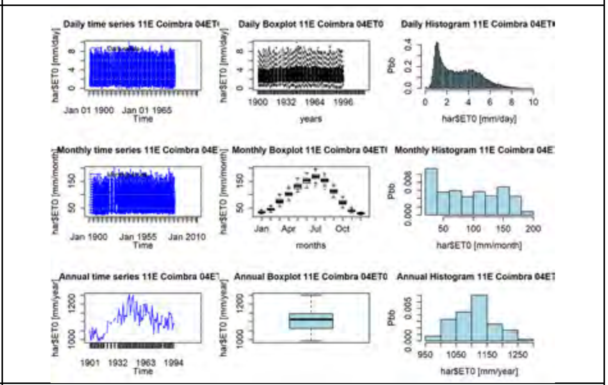

Figure 4: 11E COIMBRA 04ET0hyplo

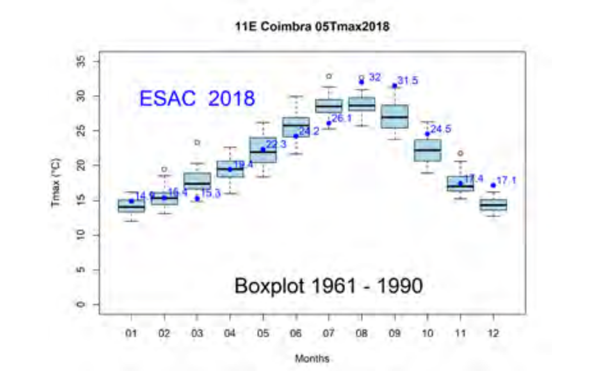

Figure 5: 11E COIMBRA 05Tmax2018box

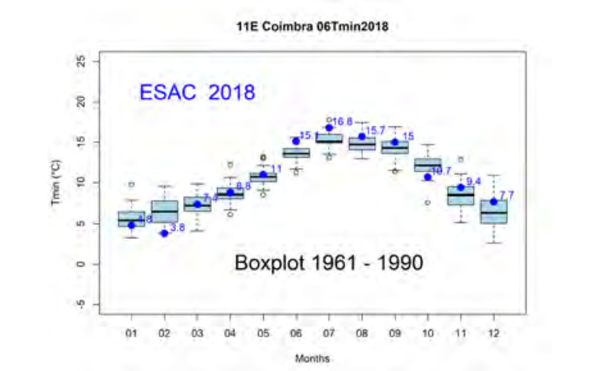

Figure 6: 11E COIMBRA 06Tmin2018box

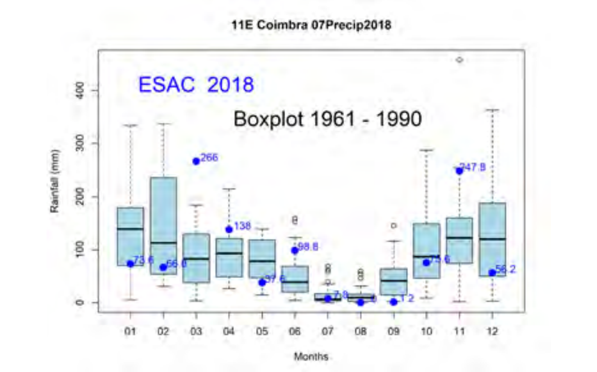

Figure 7: 11E COIMBRA 07Precip2018box

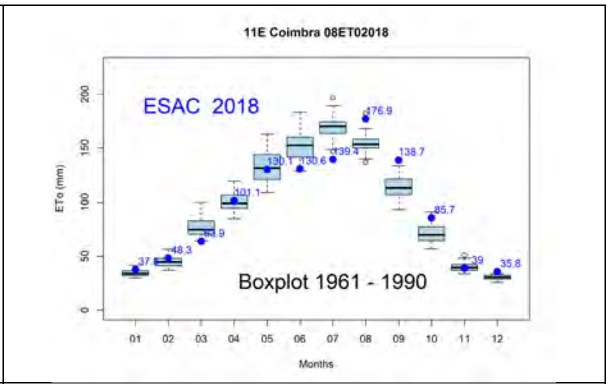

Figure 8: 11E COIMBRA 08ETO2018box

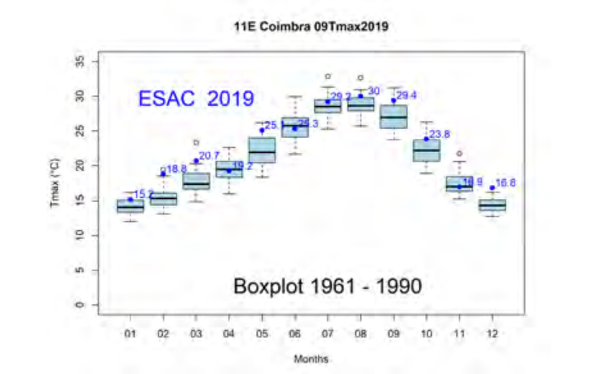

Figure 9: 11E COIMBRA 09Tmax2019box

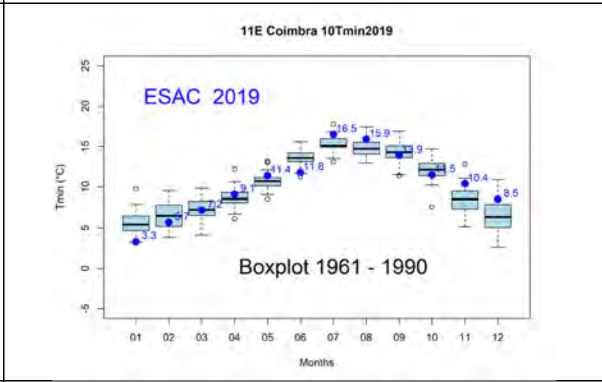

Figure 10: 11E COIMBRA 10Tmin2019box

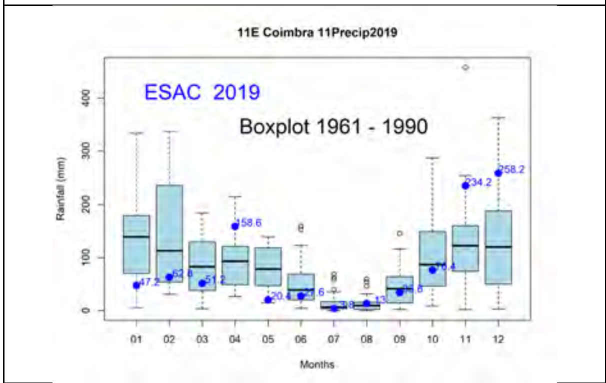

Figure 11: 11E COIMBRA 11Precip2019box

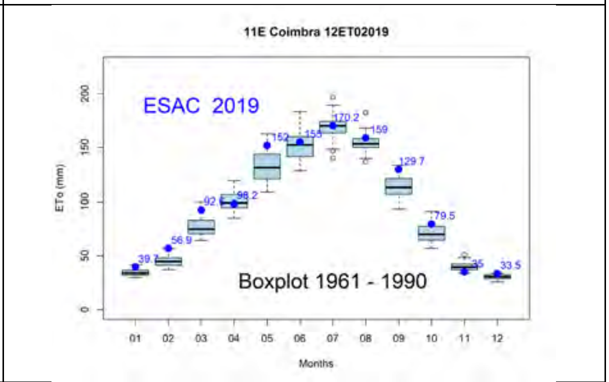

Figure 12: 11E COIMBRA 12ETO2019box

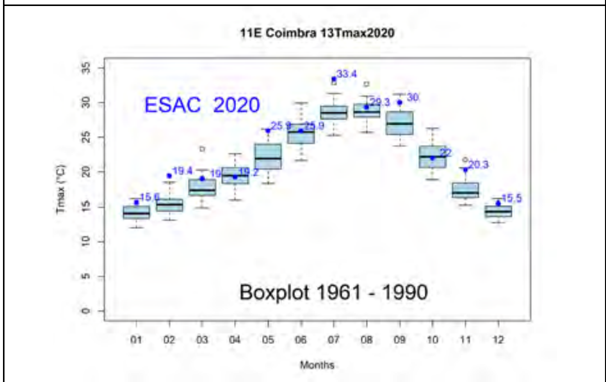

Figure 13: 11E COIMBRA 13Tmax2020box

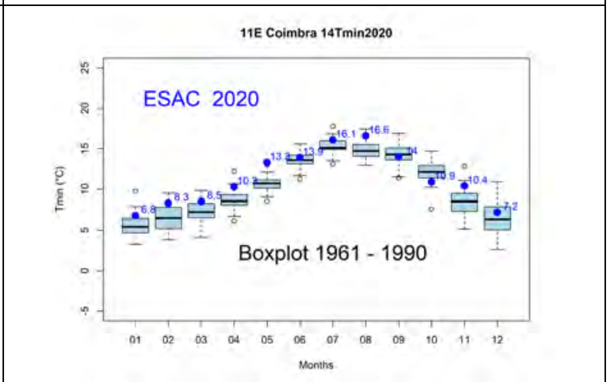

Figure 14: 11E COIMBRA 14Tmin2020box

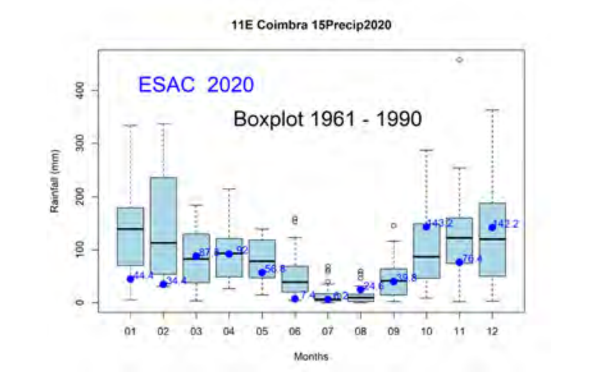

Figure 15: 11E COIMBRA 15Precip2020box

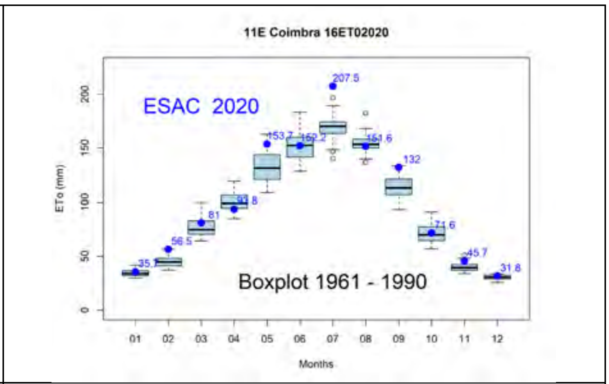

Figure 16: 11E COIMBRA 16ET02020box

11a ESAC-Coimbra (research station)

Research station ESAC covers the period of the STE.

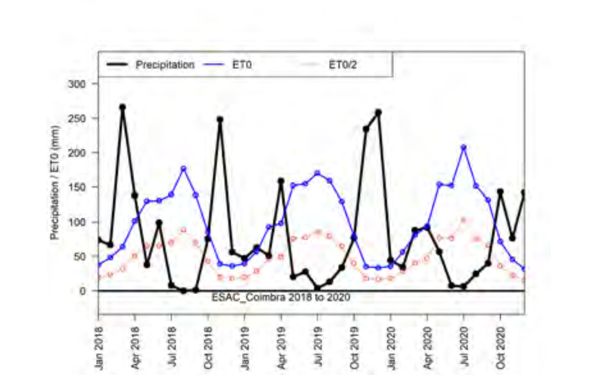

Figure 17: 11aESAC_Coimbra 00aFAOgrow

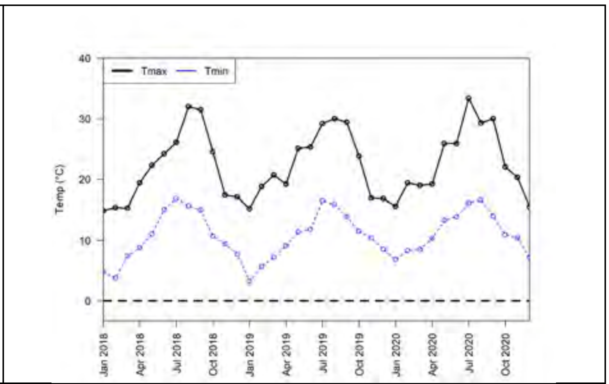

Figure 18: 11aESAC_Coimbra 00bTnTx

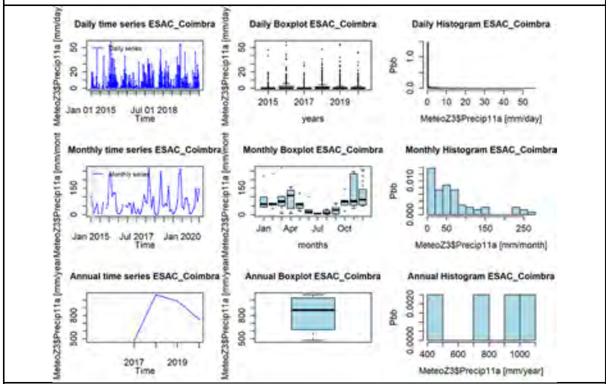

Figure 19: 11aESAC_Coimbra 01PrecHyplo

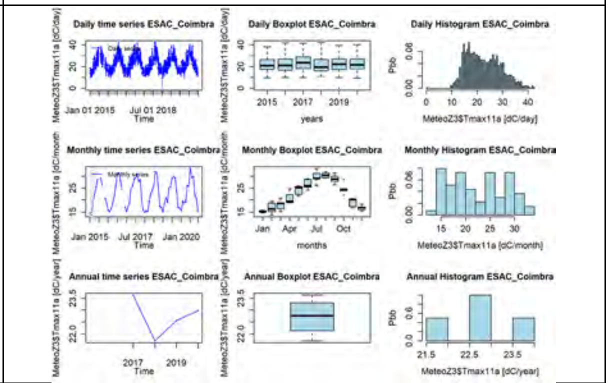

Figure 20: 11aESAC_Coimbra 02TmaxHyplo

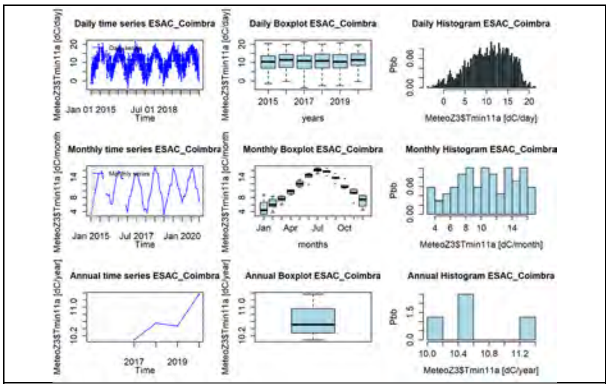

Figure 21: 11aESAC_Coimbra 03TminHyplo

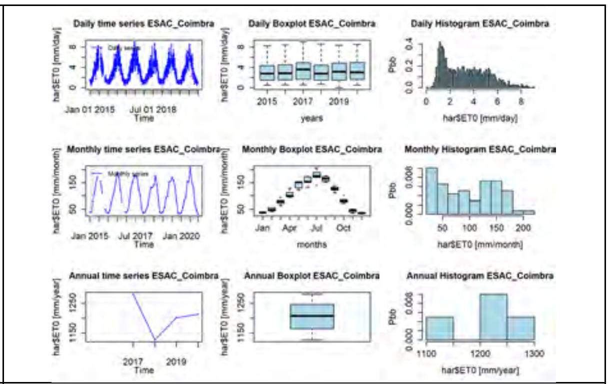

Figure 22: 11aESAC_Coimbra 04ET0Hyplo

13. Greece: Figures from the analysis

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Table 1: Variables measured and analysed in both tested treatments (Control and SICS) for the three farm fields

Observation code	Unit	Description
ksat	cm s^{-1}	Saturated hydraulic conductivity
wsa	-	Water stable aggregates score
bd_top	g/cm^3	Bulk density of topsoil (10-20 cm)
bd_bot	g/cm^3	Bulk density of bottom soil (40-50 cm)
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available Phosphorous (P)
k_plus	cmol+/kg	Exchangeable Potassium (K^+)
na_plus	cmol+/kg	Exchangeable Sodium (Na^+)
mg2plus	cmol+/kg	Exchangeable Magnesium (Mg^{2+})
soc	%	Soil organic carbon (SOC)
ph_h2o	_	pH in water
ec1_5	dS/m	Electrical Conductivity (1:5 soil:water)
weed_infestation	%	Percentage of Weed infestation
earthworm_no	no/m^2	Earthworm number per m^2
crop_yield_ha	kg/ha	Crop yield
soil_erosion_ha	tn/ha	Soil erosion

Dourakis (EX1_a)

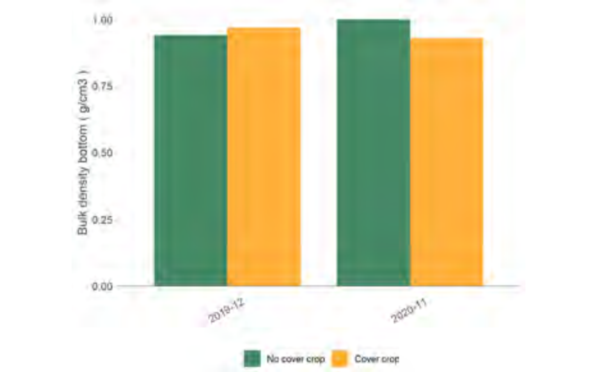

Figure 1: TUC_EX1_a_bd_bot

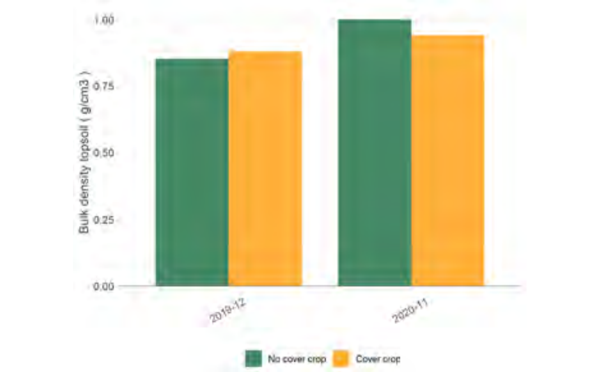

Figure 2: TUC_EX1_a_bd_top

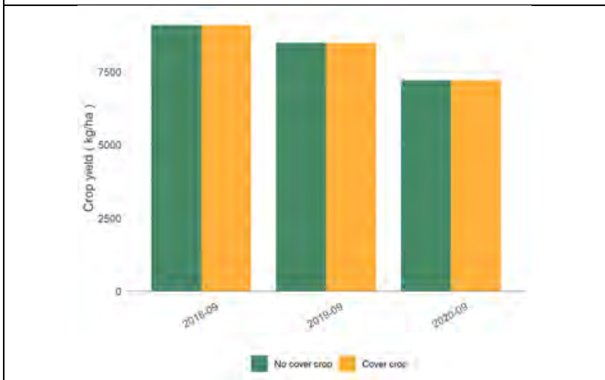

Figure 3: TUC_EX1_a_crop_yield_ha

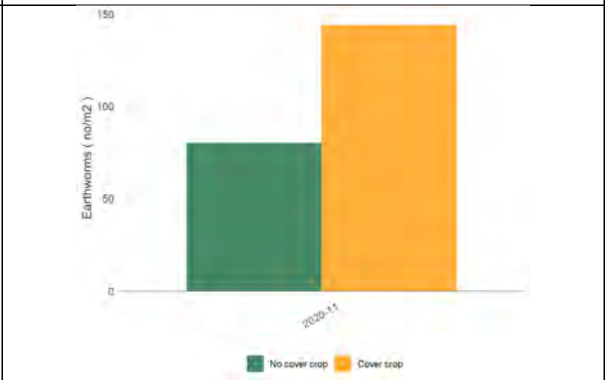

Figure 4: TUC_EX1_a_earthworm_no

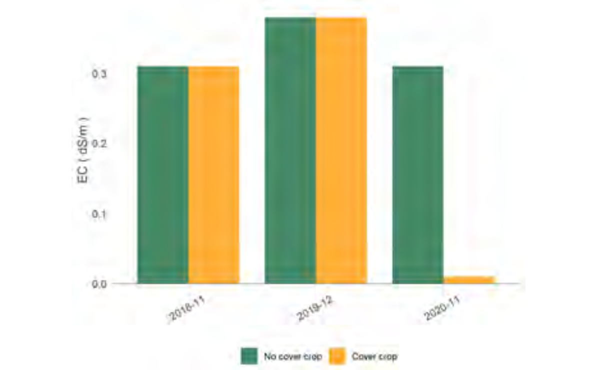

Figure 5: TUC_EX1_a_ec1_5

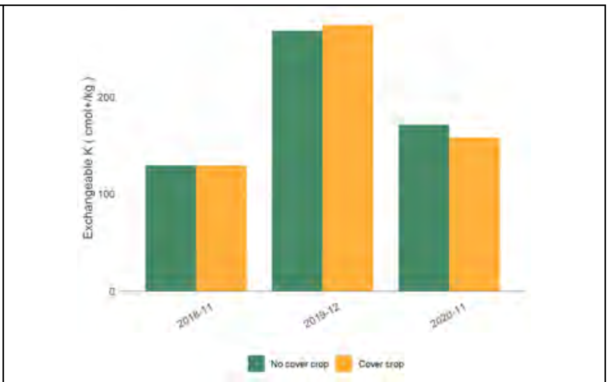

Figure 6: TUC_EX1_a_k_plus

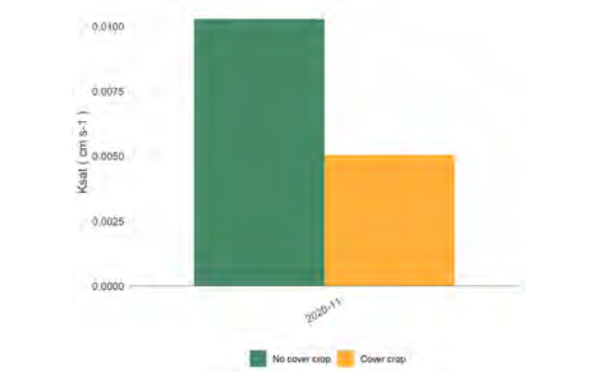

Figure 7: TUC_EX1_a_ksat

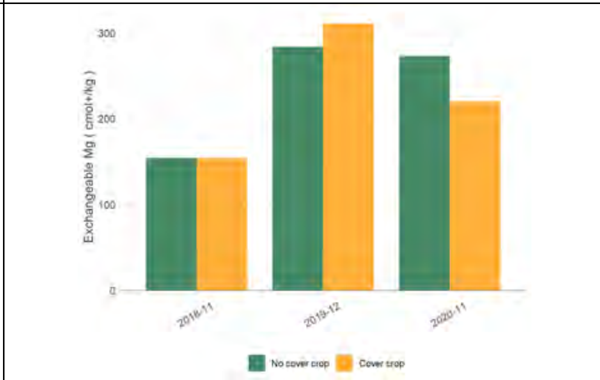

Figure 8: TUC_EX1_a_mg2plus

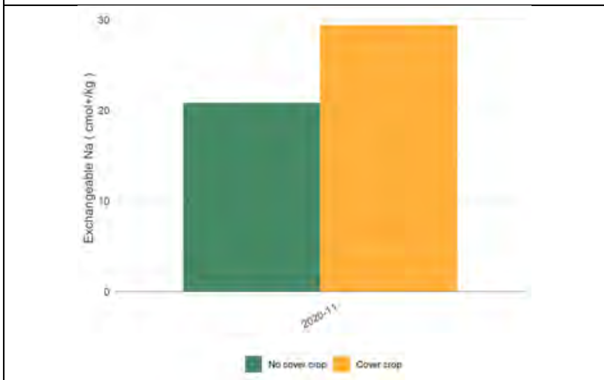

Figure 9: TUC_EX1_a_na_plus

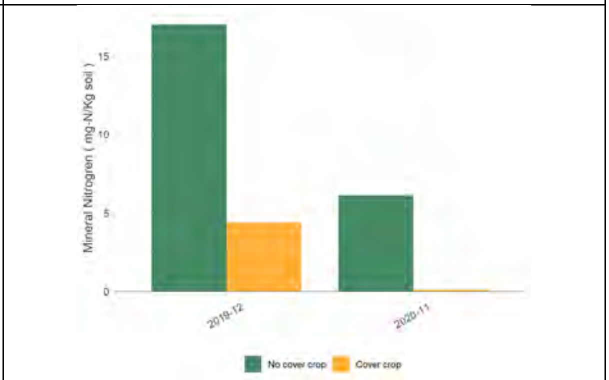

Figure 10: TUC_EX1_a_nmin_top

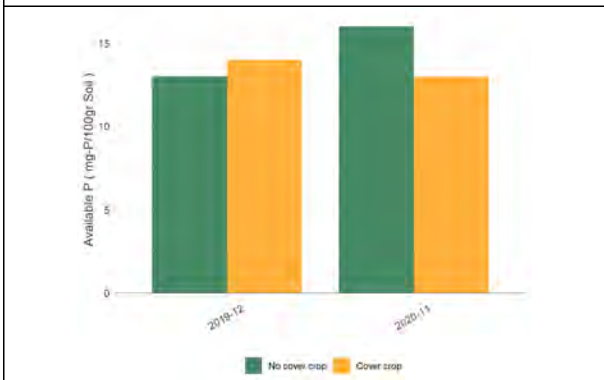

Figure 11: TUC_EX1_a_p_avail

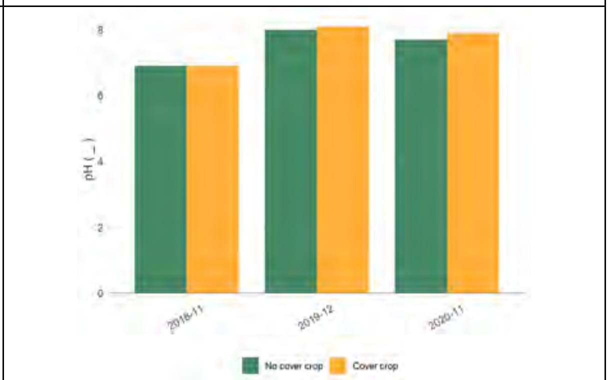

Figure 12: TUC_EX1_a_ph_h2o

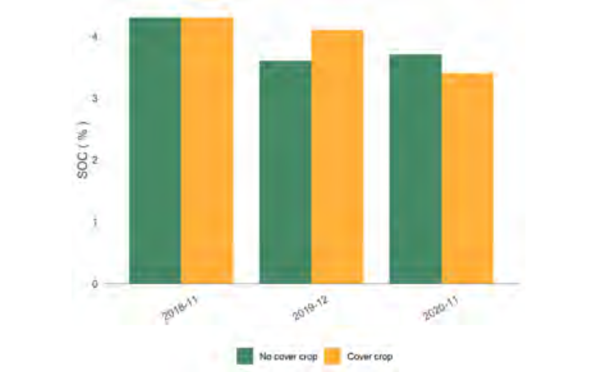	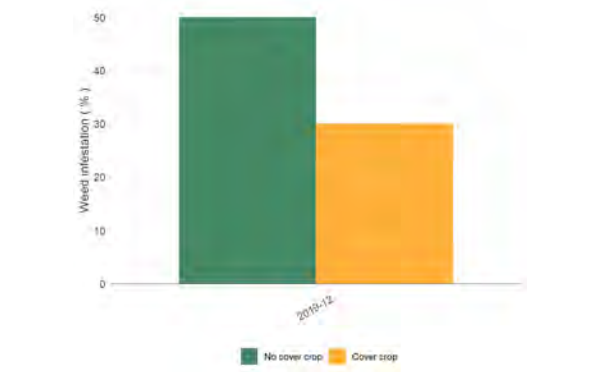
Figure 13: TUC_EX1_a_soc	*Figure 14: TUC_EX1_a_weed_infestation*

Koufos (EX1_b)

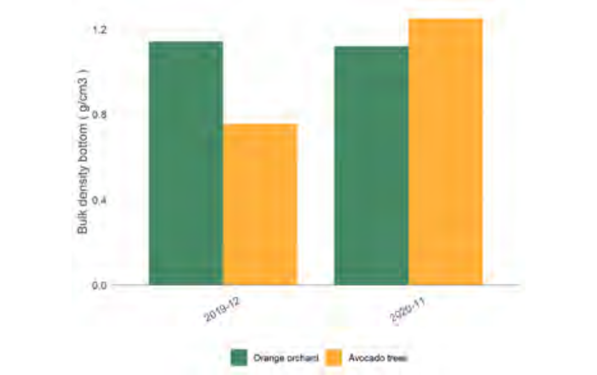

Figure 15: TUC_EX1_b_bd_bot

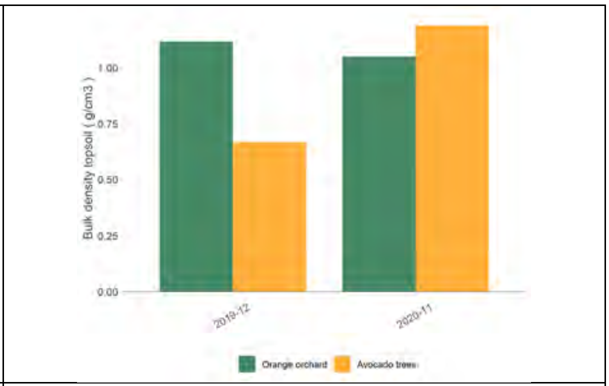

Figure 16: TUC_EX1_b_bd_top

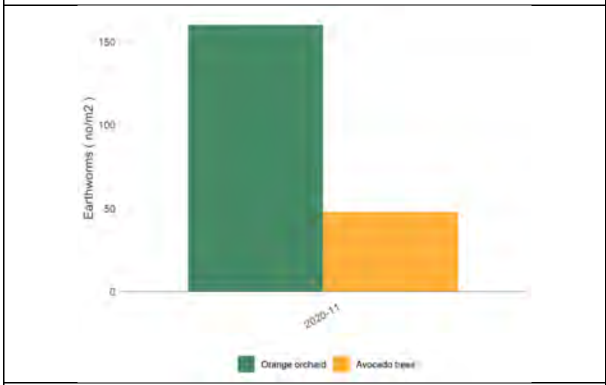

Figure 17: TUC_EX1_b_earthworm_no

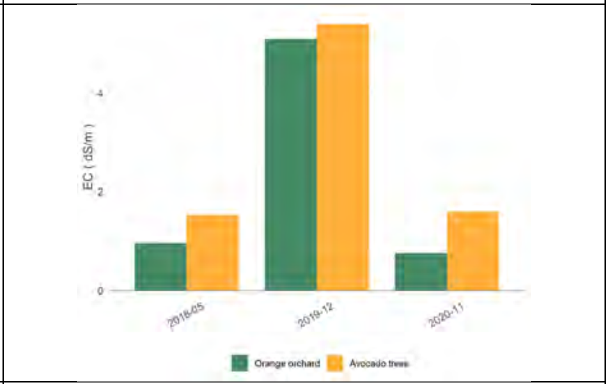

Figure 18: TUC_EX1_b_ec1_5

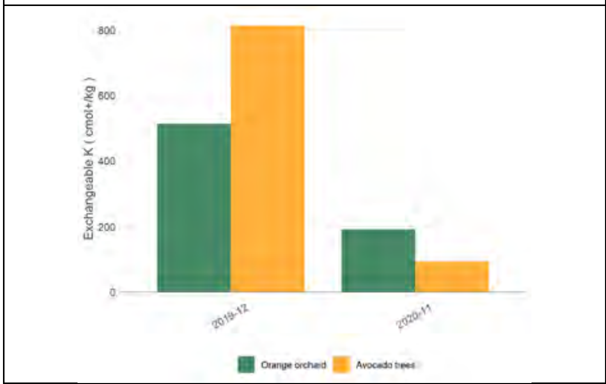

Figure 19: TUC_EX1_b_k_plus

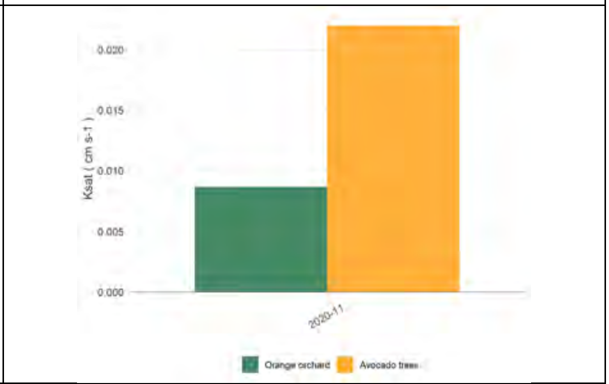

Figure 20: TUC_EX1_b_ksat

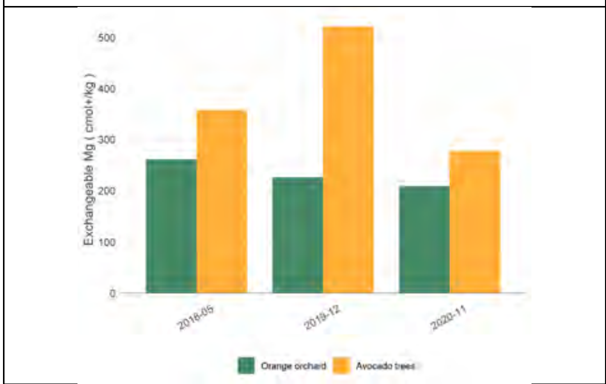

Figure 21: TUC_EX1_b_mg2plus

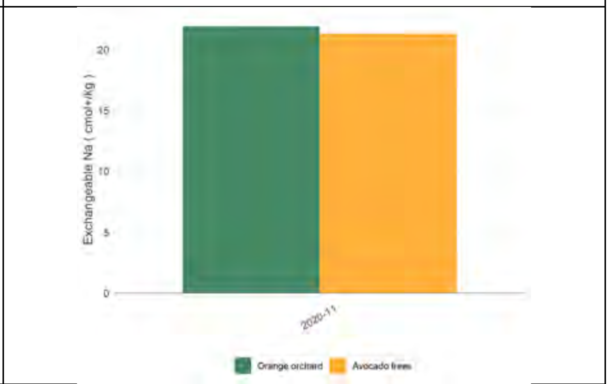

Figure 22: TUC_EX1_b_na_plus

SoilCare
SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

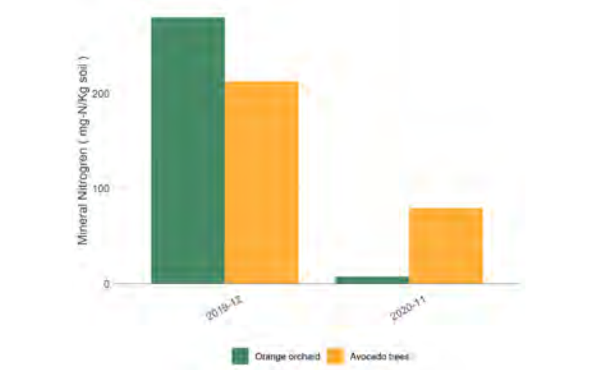

Figure 23: TUC_EX1_b_nmin_top

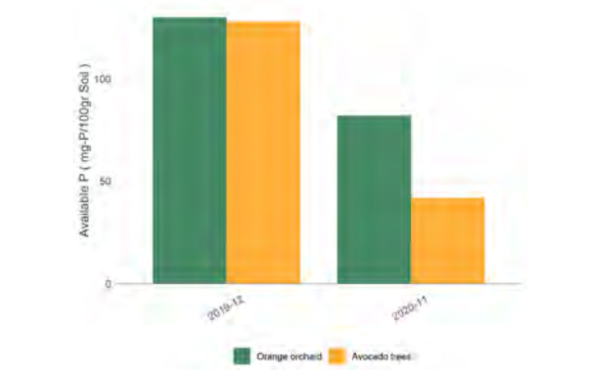

Figure 24: TUC_EX1_b_p_avail

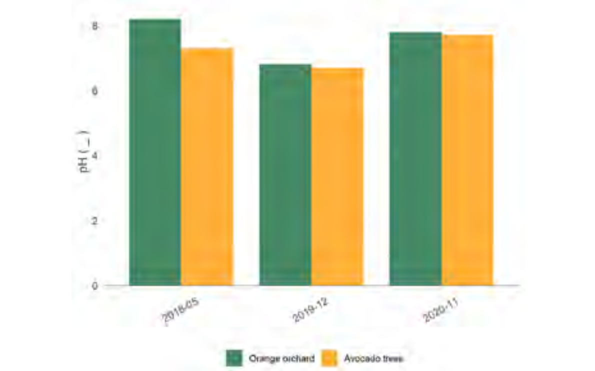

Figure 25: TUC_EX1_b_ph_h2o

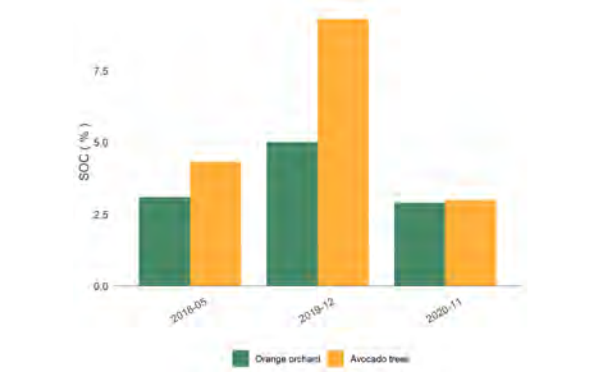

Figure 26: TUC_EX1_b_soc

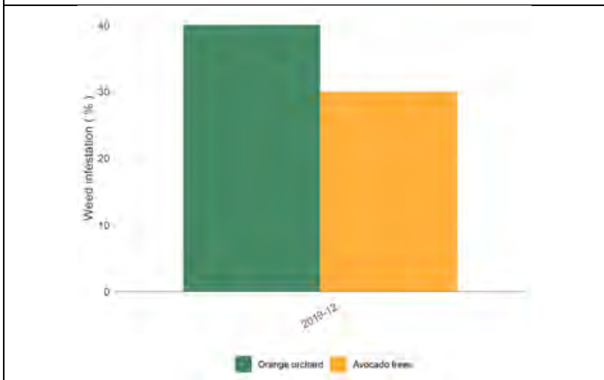

Figure 27: TUC_EX1_b_weed_infestation

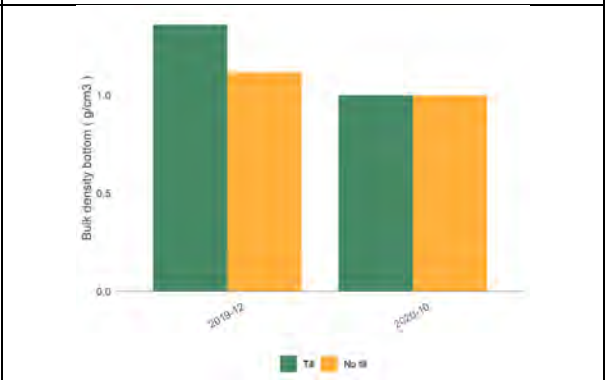

Figure 28: TUC_EX1_c_bd_bot

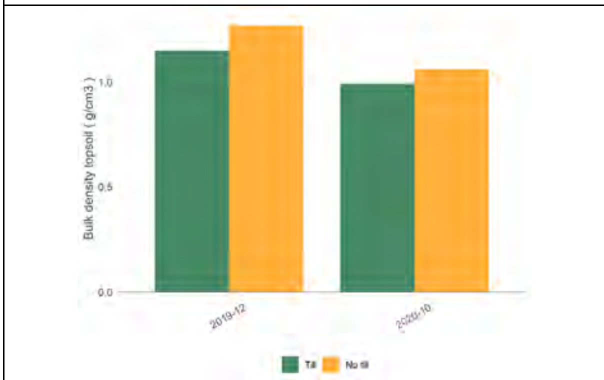

Figure 29: TUC_EX1_c_bd_top

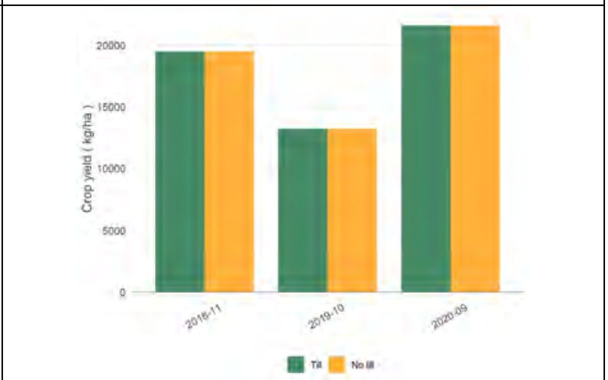

Figure 30: TUC_EX1_c_crop_yield_ha

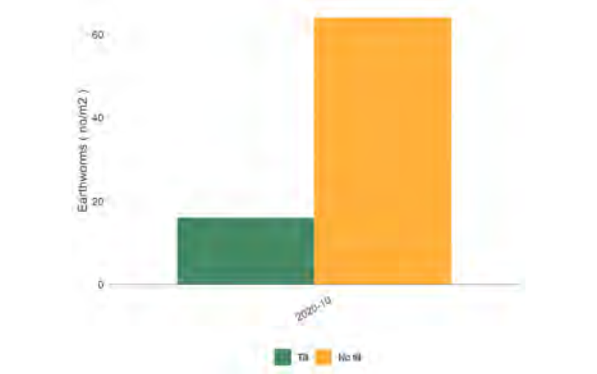

Figure 31: TUC_EX1_c_earthworm_no

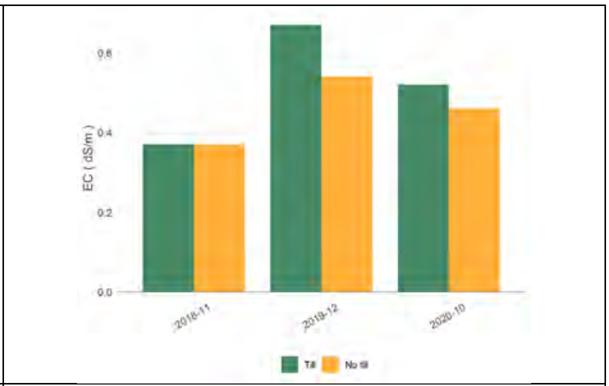

Figure 32: TUC_EX1_c_ec1_5

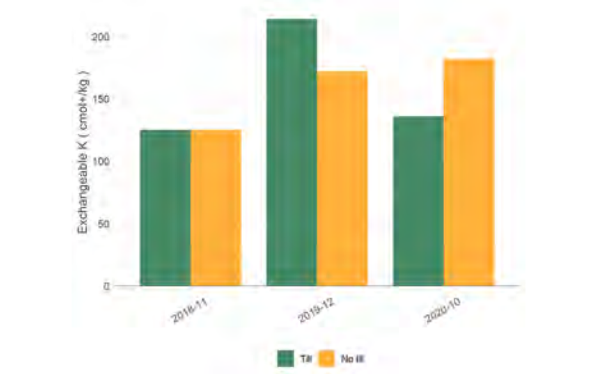

Figure 33: TUC_EX1_c_k_plus

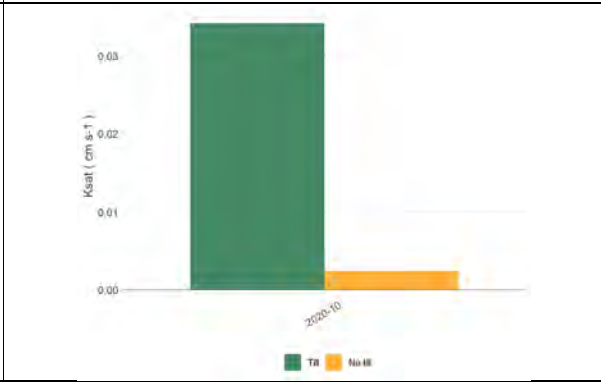

Figure 34: TUC_EX1_c_ksat

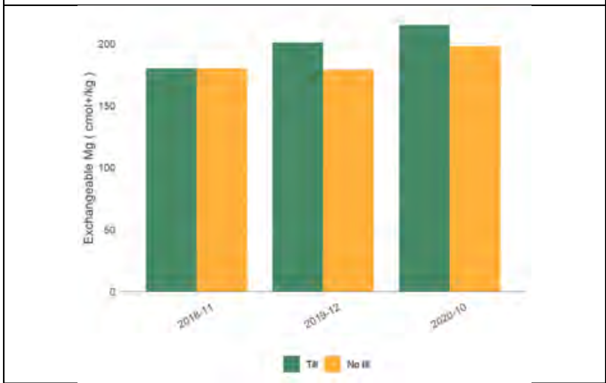

Figure 35: TUC_EX1_c_mg2plus

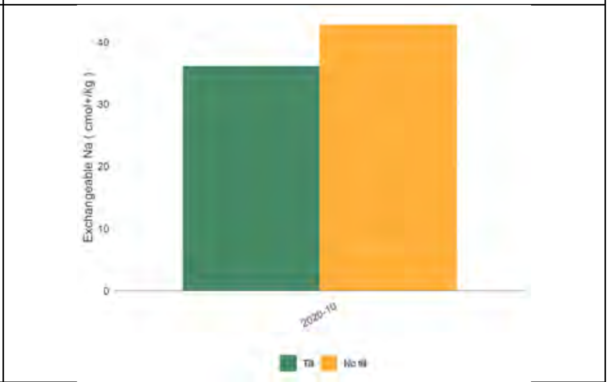

Figure 36: TUC_EX1_c_na_plus

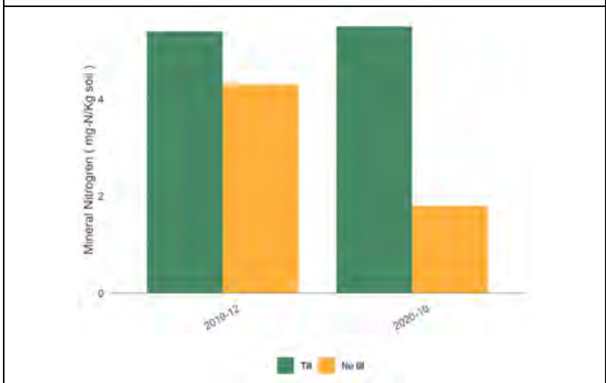

Figure 37: TUC_EX1_c_nmin_top

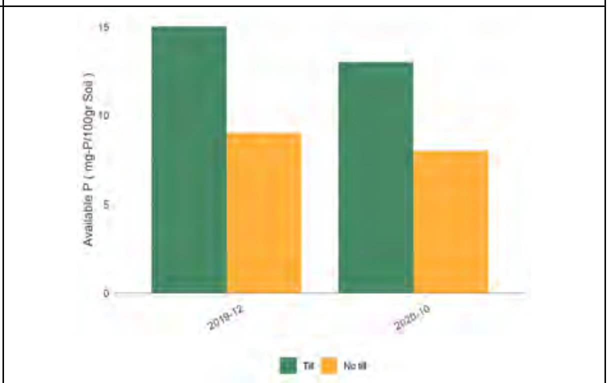

Figure 38: TUC_EX1_c_p_avail

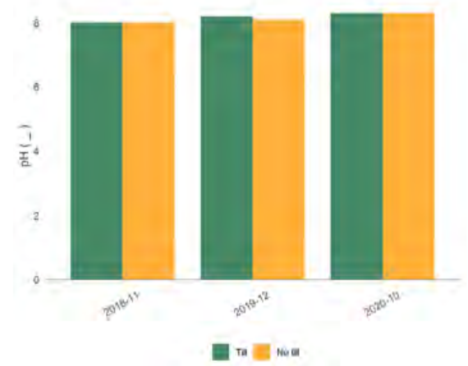

Figure 39: TUC_EX1_c_ph_h2o

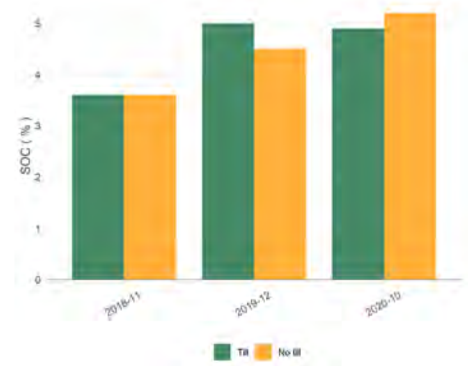

Figure 40: TUC_EX1_c_soc

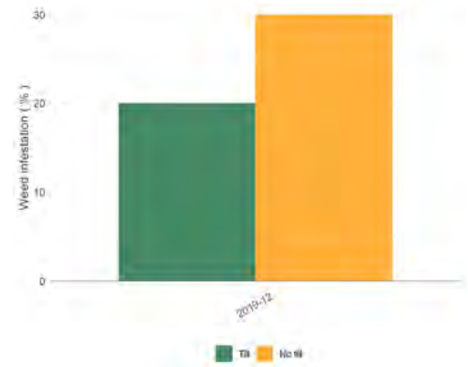

Figure 41: TUC_EX1_c_weed_infestation

Astrikas (EX1_c)

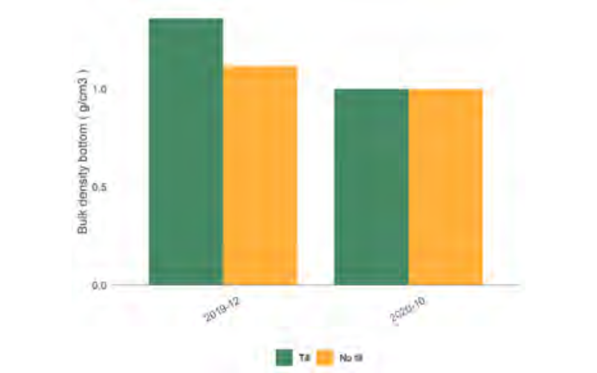

Figure 42: TUC_EX1_c_bd_bot

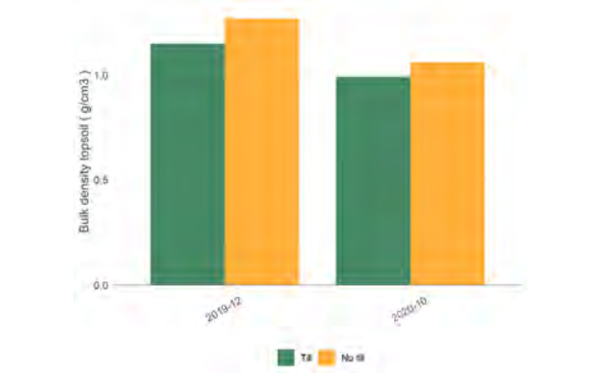

Figure 43: TUC_EX1_c_bd_top

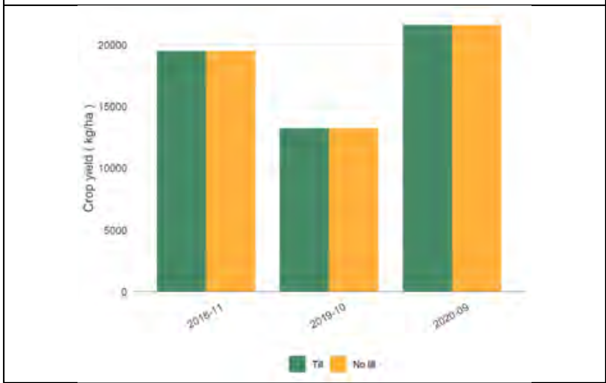

Figure 44: TUC_EX1_c_crop_yield_ha

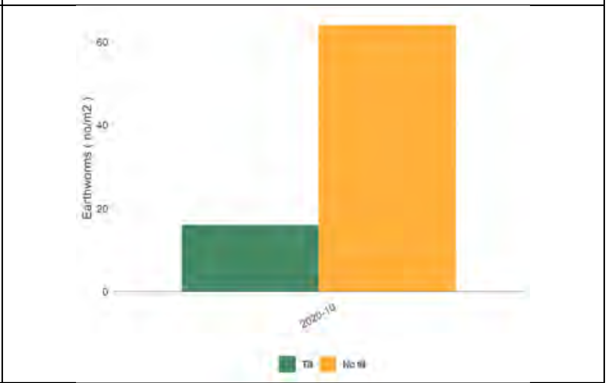

Figure 45: TUC_EX1_c_earthworm_no

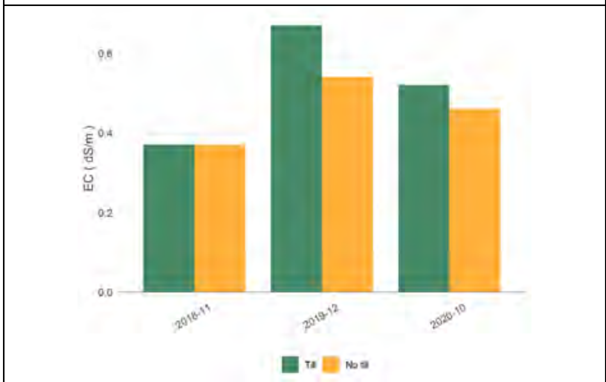

Figure 46: TUC_EX1_c_ec1_5

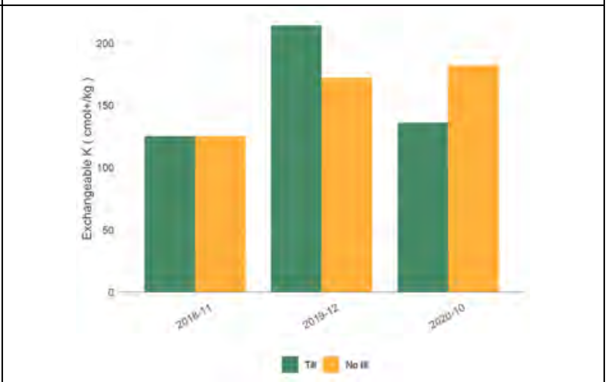

Figure 47: TUC_EX1_c_k_plus

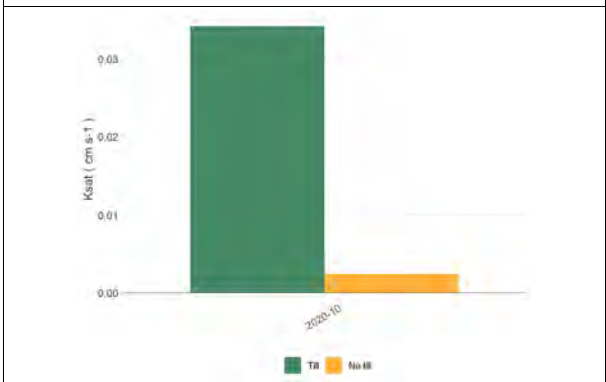

Figure 48: TUC_EX1_c_ksat

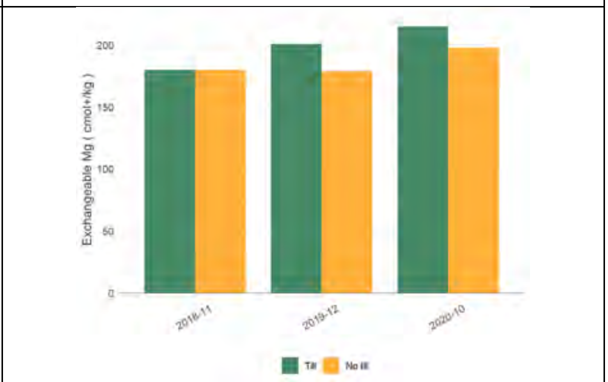

Figure 49: TUC_EX1_c_mg2plus

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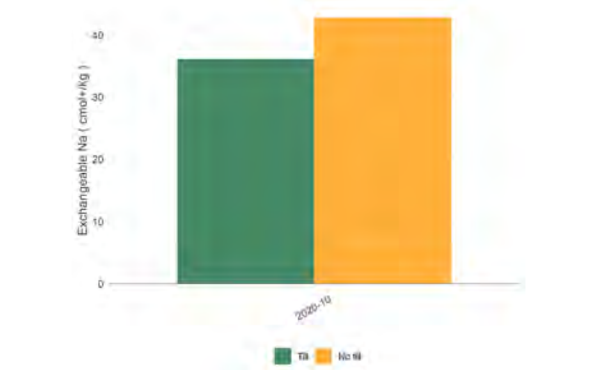

Figure 50: TUC_EX1_c_na_plus

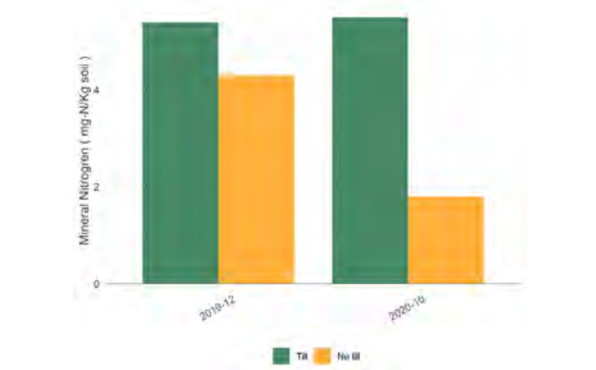

Figure 51: TUC_EX1_c_nmin_top

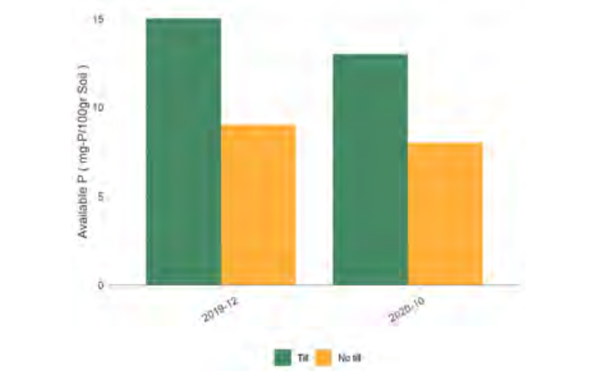

Figure 52: TUC_EX1_c_p_avail

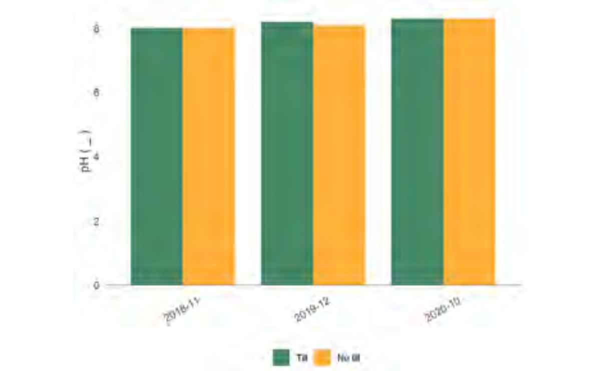

Figure 53: TUC_EX1_c_ph_h2o

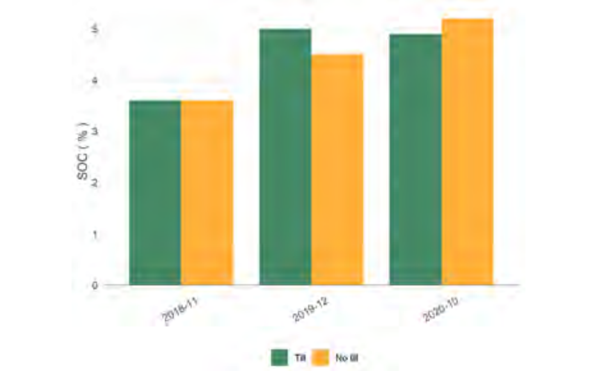

Figure 54: TUC_EX1_c_soc

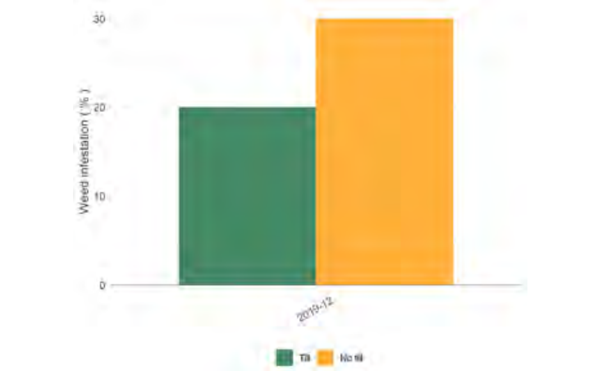

Figure 55: TUC_EX1_c_weed_infestation

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12. Greece: Figures Meteorological data

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See the general introduction to D5.3 for explanation of meteorological analysis as represented in the figures.

List of figures

12E Chania- Souda Airport. (ECAD 327).

This station, listed in ECAD 327, covers 1958 until 2005. This station is located at different distances from the experiments. Unfortunately recent measurements are not provided to ECAD.

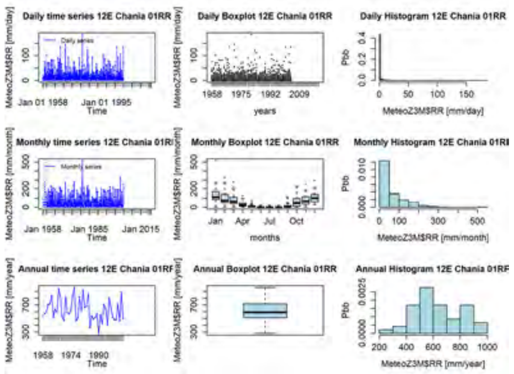

Figure 1: 12E Chania 01RRhyplo

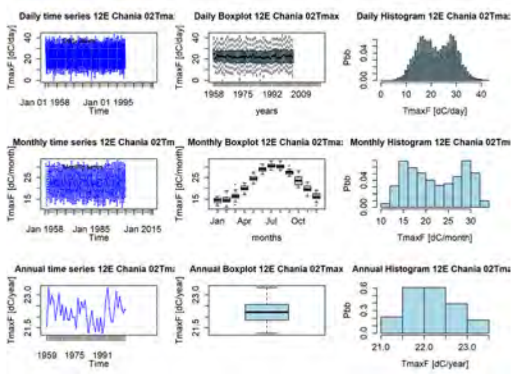

Figure 2: 12E Chania 02Tmaxhyplo

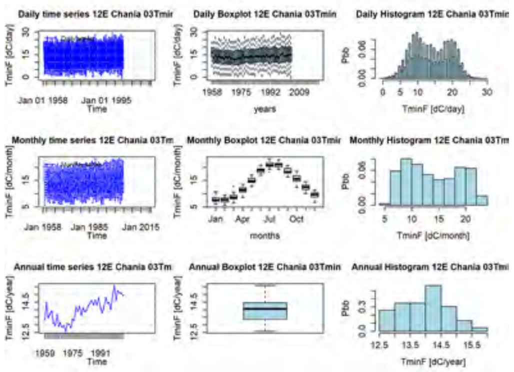

Figure 3: 12E Chania 03Tminhyplo

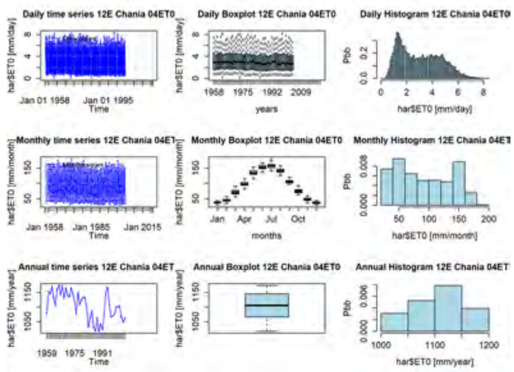

Figure 4: 12E Chania 04ET0hyplo

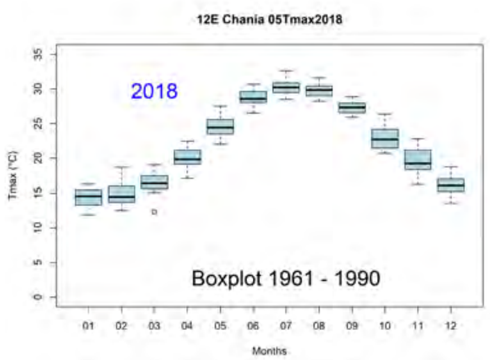

Figure 5: 12E Chania 05Tmaxbox

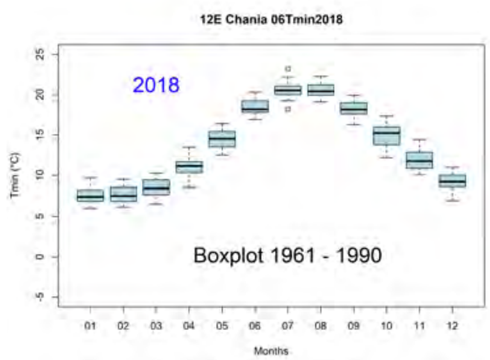

Figure 6: 12E Chania 06Tminbox

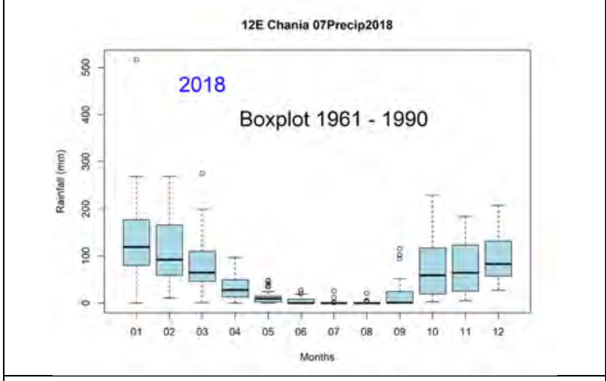

Figure 7: 12E Chania 07Precipbox

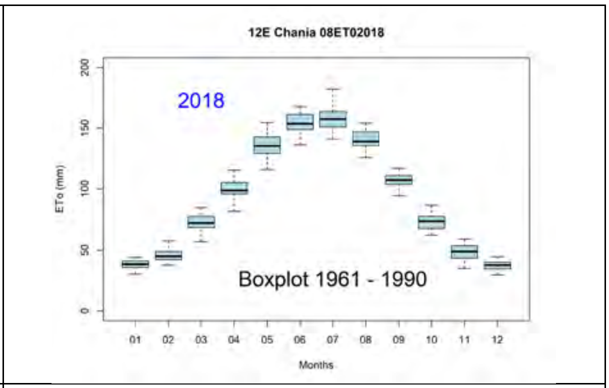

Figure 8: 12E Chania 08ET0box

12a Kolumpari

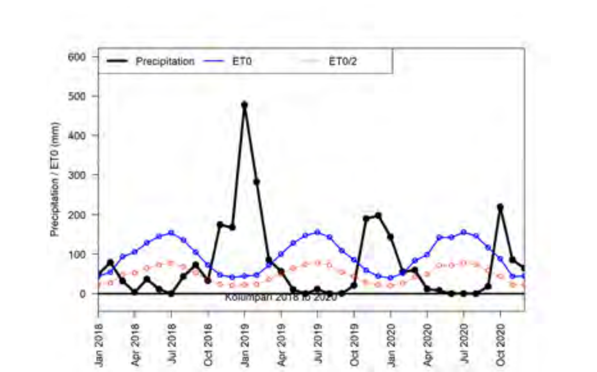

Figure 9: 12aKolumpari 00aFAOgrow

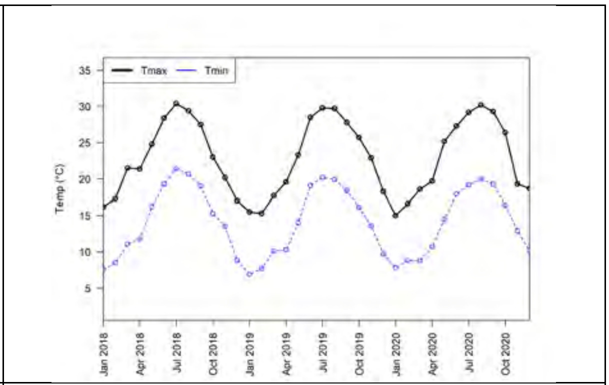

Figure 10: 12aKolumpari 00bTnTx

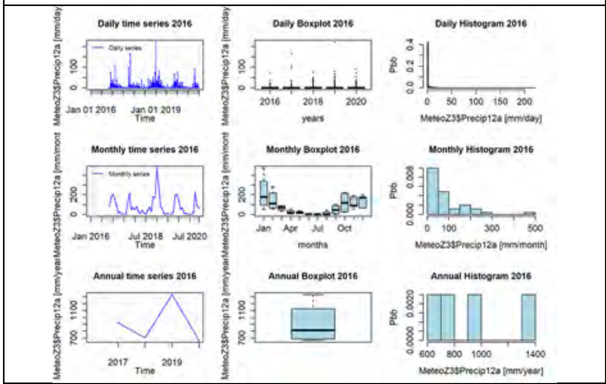

Figure 11: 12aKolumpari 01PrecHyplo

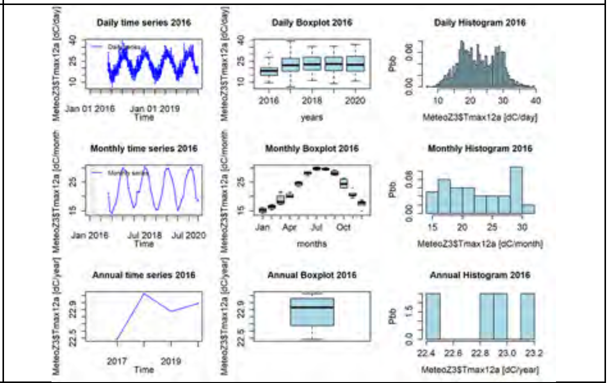

Figure 12: 12aKolumpari 02TmaxHyplo

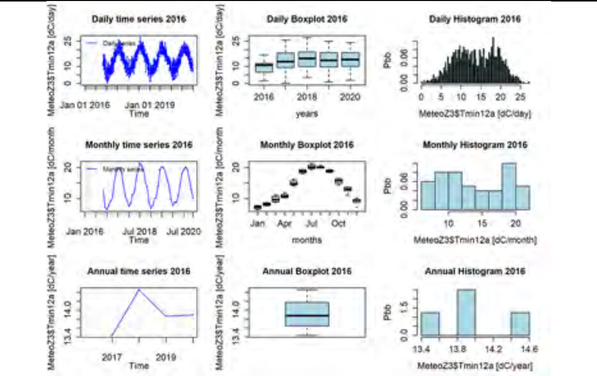

Figure 13: 12aKolumpari 03TminHyplo

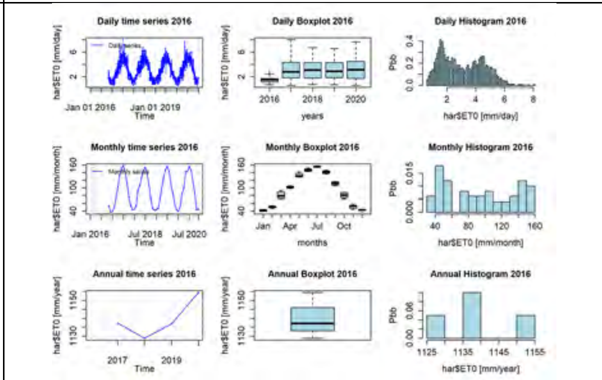

Figure 14: 12aKolumpari 04ET0Hyplo

12b Alikianos

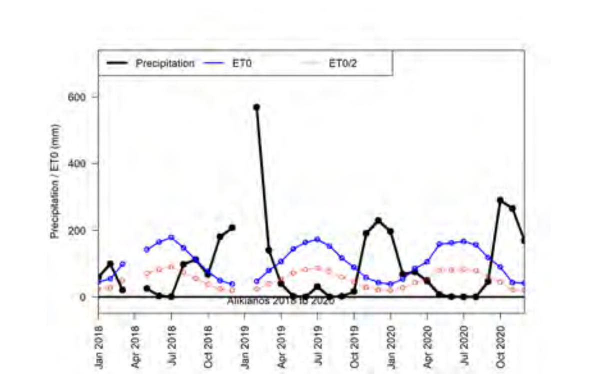

Figure 15: 12bAlikianos 00aFAOgrow

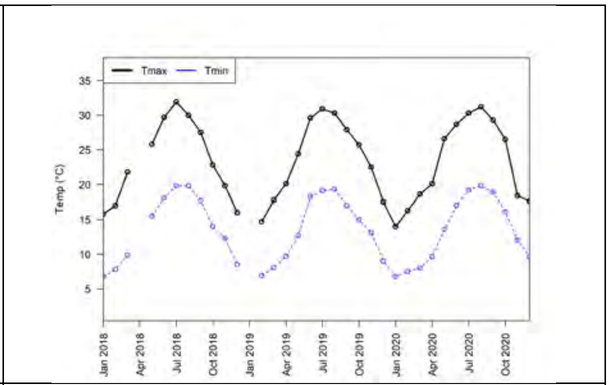

Figure 16: 12bAlikianos 00bTnTx

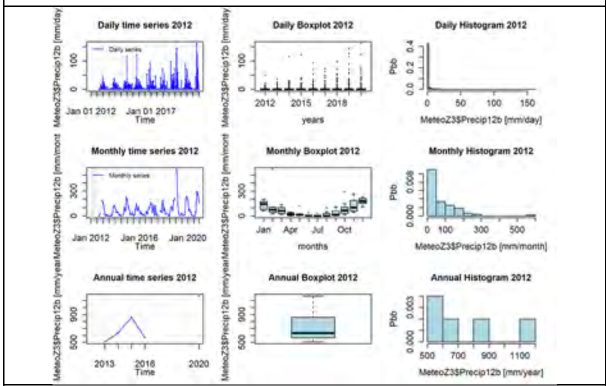

Figure 17: 12bAlikianos 01PrecHyplo

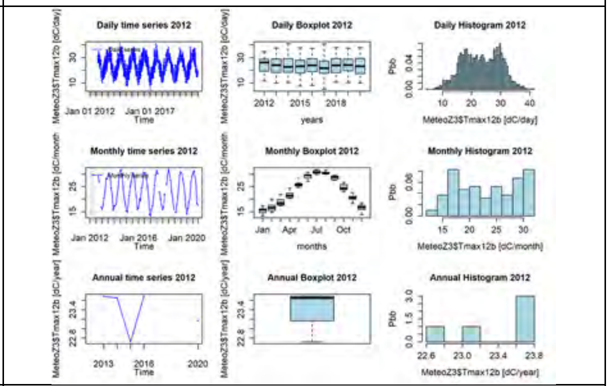

Figure 18: 12bAlikianos 02TmaxHyplo

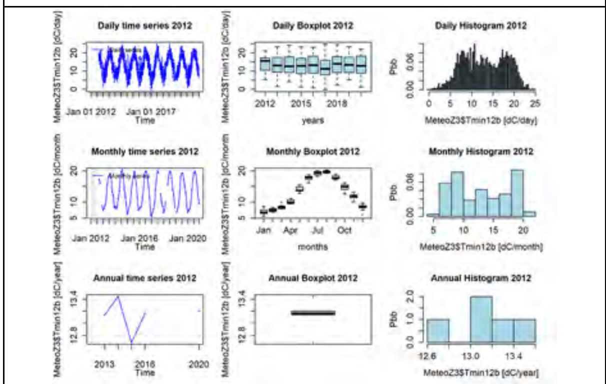

Figure 19: 12bAlikianos 03TminHyplo

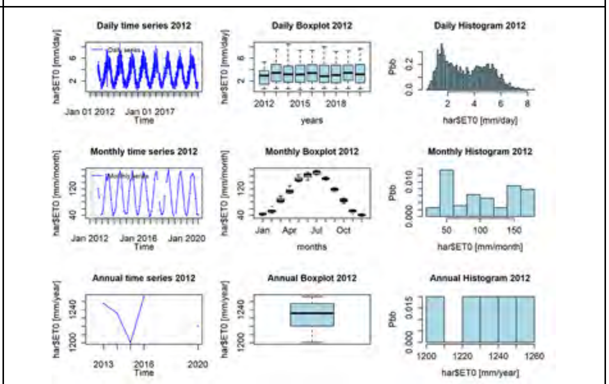

Figure 20: 12bAlikianos 04ET0Hyplo

12c Vrysses

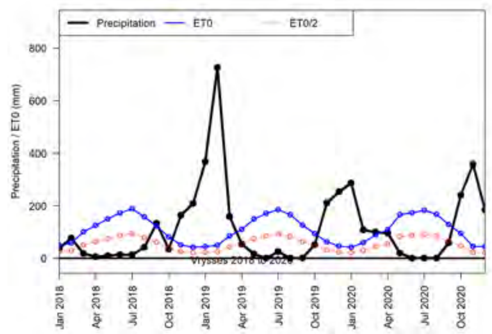

Figure 21: 12cVrysses 00aFAOgrow

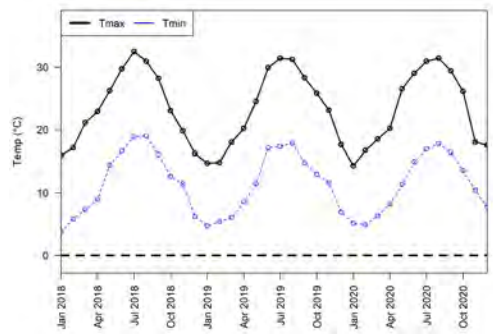

Figure 22: 12cVrysses 00bTnTx

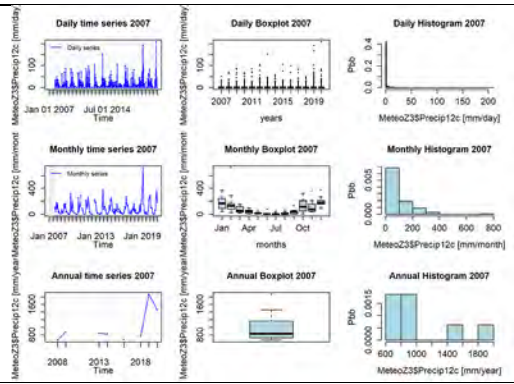

Figure 23: 12cVrysses 01PrecHyplo

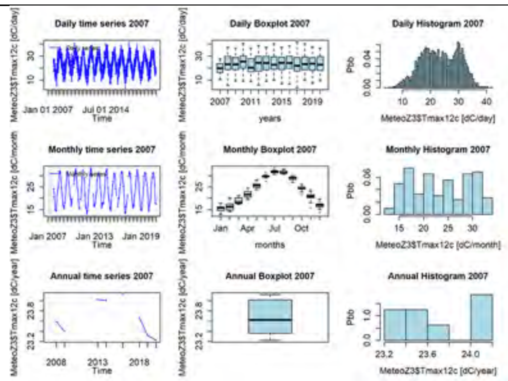

Figure 24: 12cVrysses 02TmaxHyplo

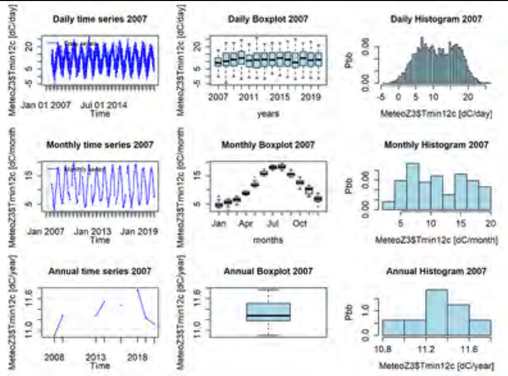

Figure 25: 12cVrysses 03TminHyplo

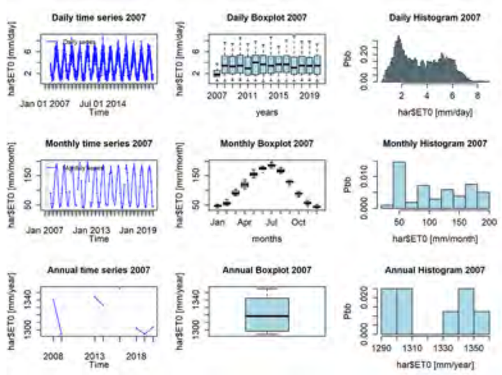

Figure 26: 12cVrysses 04ET0Hyplo

13. Sweden: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement "Treatment*Date", and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Observation code	**Unit**	**Description in the Y-axis**
crop_yield_ha	m3m-3	Crop yield
bd_top	m3m-3	Bulk density (10-15 cm)
bd_bot	m3m-3	Bulk density (28-33 cm)
top_gravel_fraction	%	Percentage of gravels fraction >2 mm

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Experiment 1:

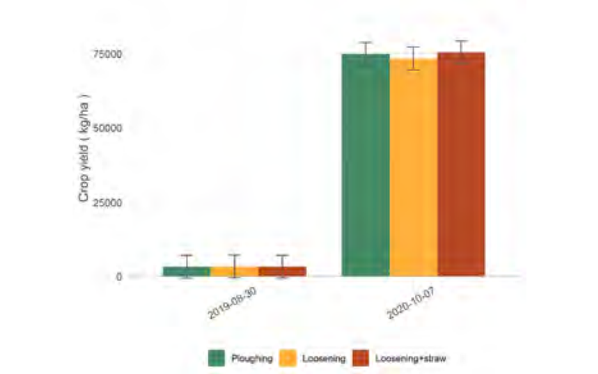

Figure 1: SLU_EX1_crop_yield_ha

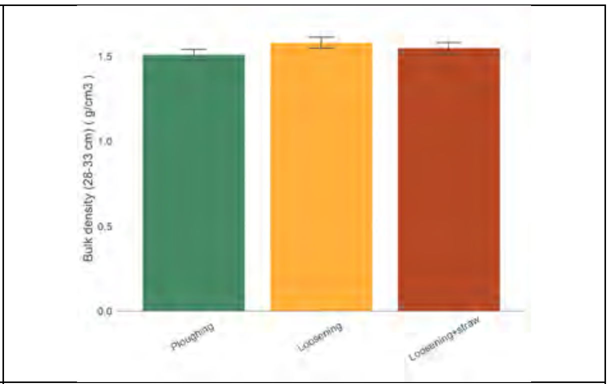

Figure 2: SLU_EX1_NR_bd_bot

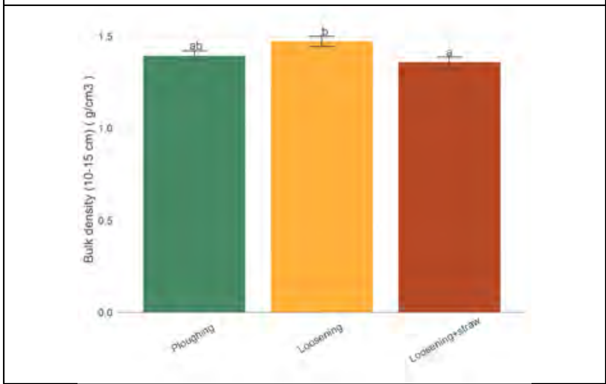

Figure 3: SLU_EX1_NR_bd_top

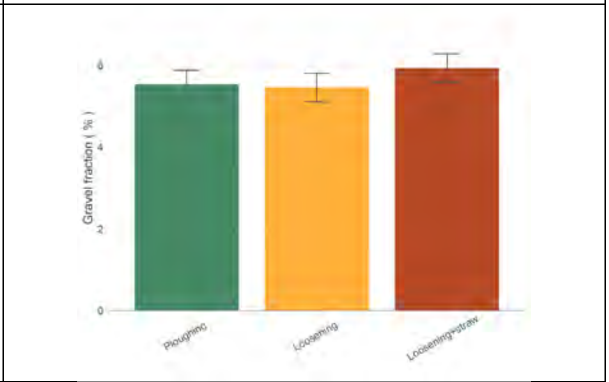

Figure 4: SLU_EX1_NR_top_gravel_fraction

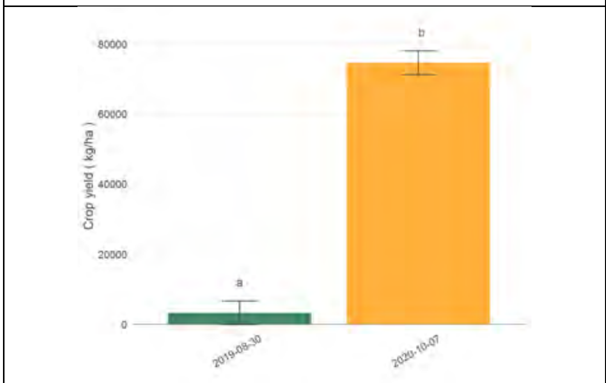

Figure 5: SLU_EX1_NSI_date_crop_yield_ha

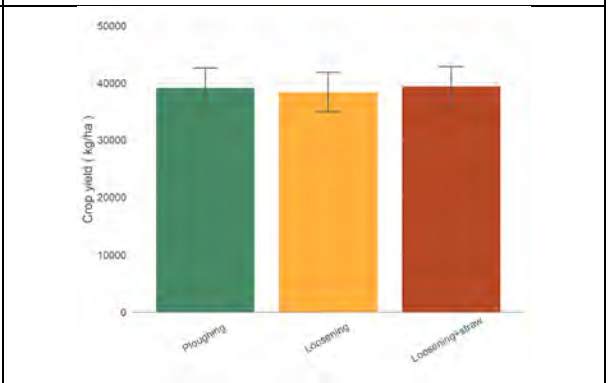

Figure 6: SLU_EX1_NSI_treat_crop_yield_ha

13. Sweden: Figures from the analysis

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13E Lund (ECAD463)

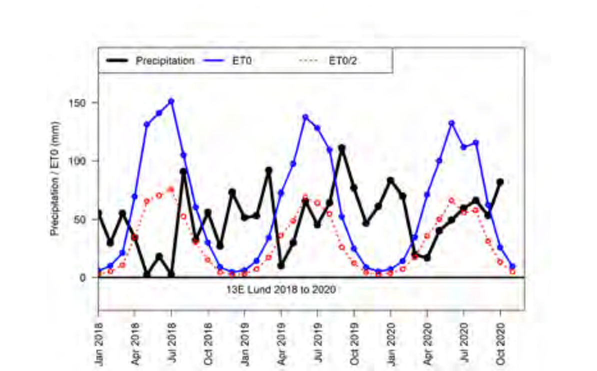


Figure 1: 13E Lund 00aFAOgrow

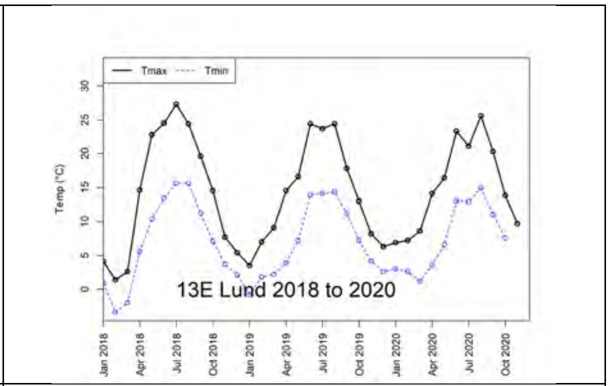


Figure 2: 13E Lund 00b TnTx

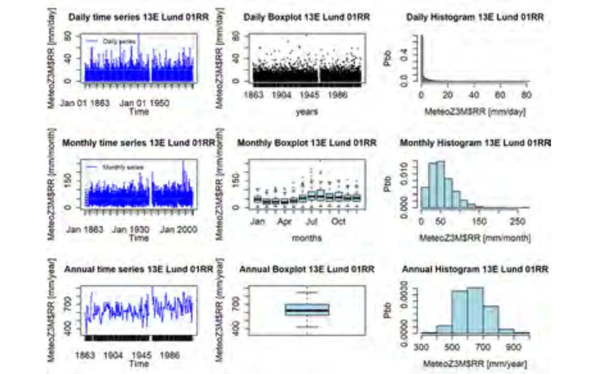


Figure 3: 13E Lund 01RRhyplo

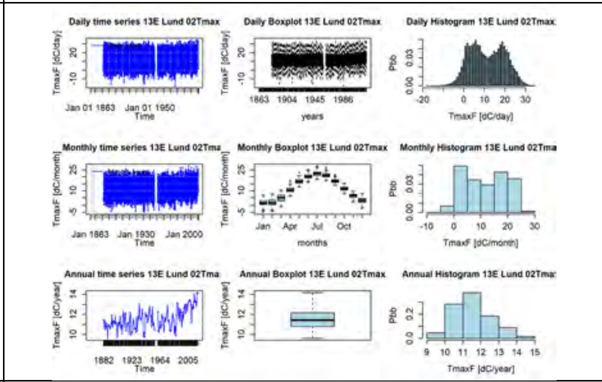


Figure 4: 13E Lund 02Tmaxhyplo

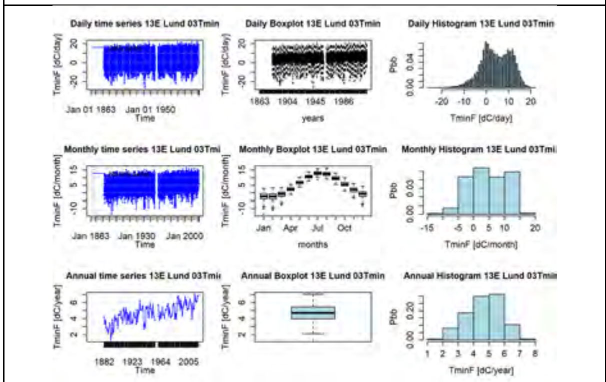


Figure 5: 13E Lund 03Tminhyplo

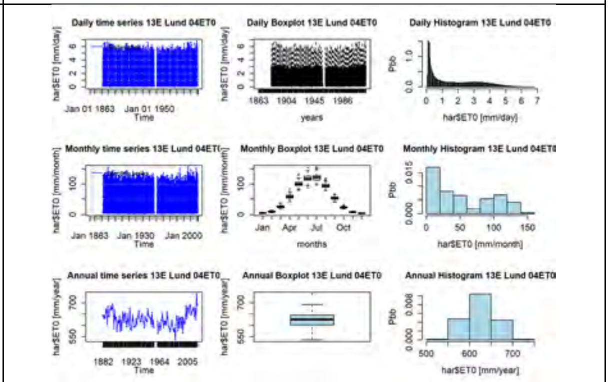


Figure 6: 13E Lund 04ET0hyplo

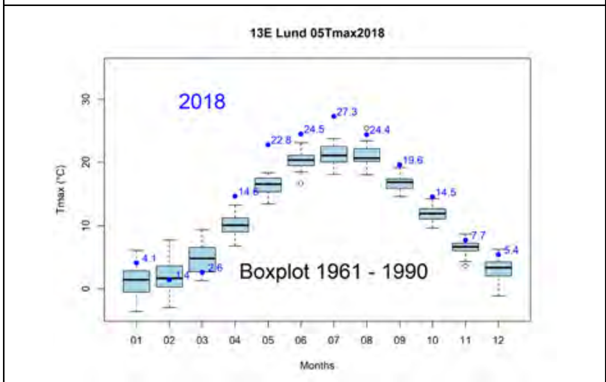


Figure 7: 13E Lund 05Tmax2018box

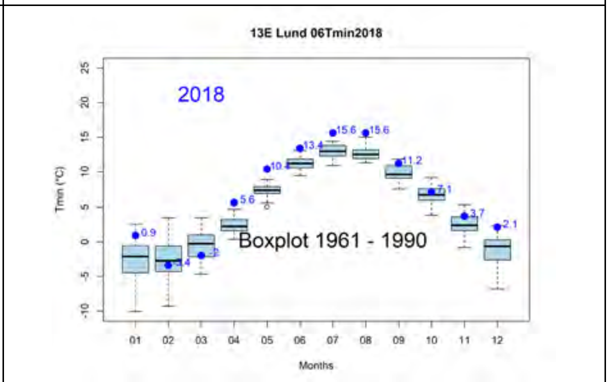


Figure 8: 13E Lund 06Tmin2018box

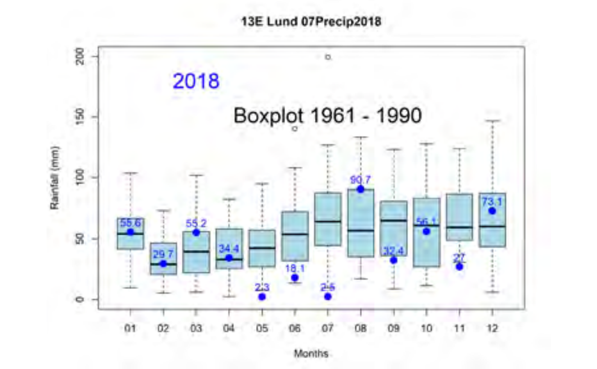


Figure 9: 13E Lund 07Precip2018box

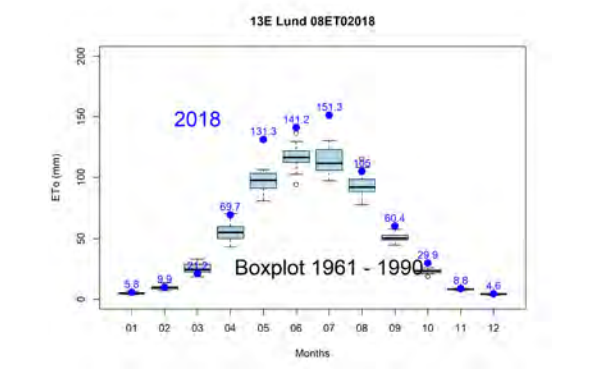


Figure 10: 13E Lund 08ETO2018box

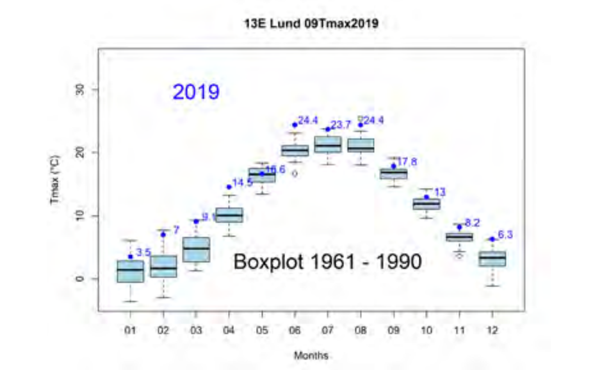
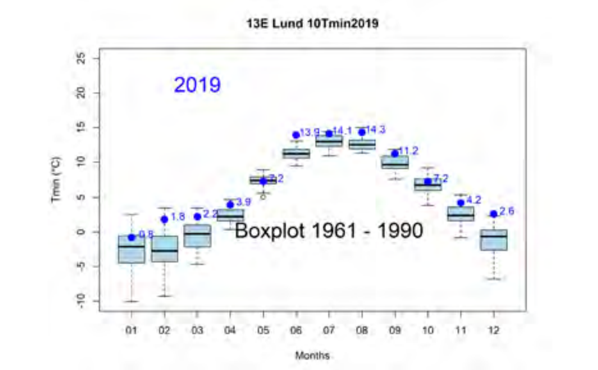


Figure 11: 13E Lund 09Tmax2019box



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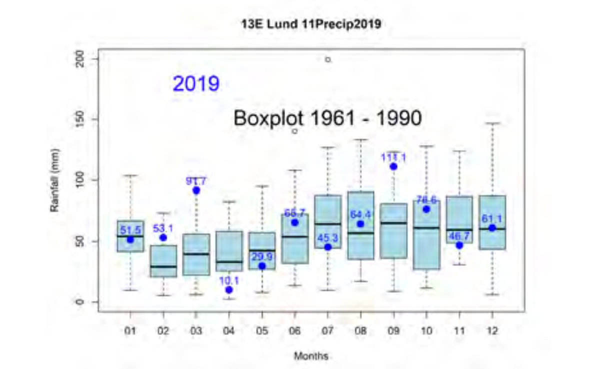
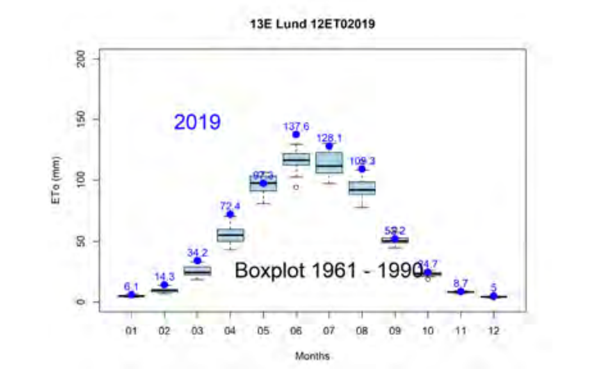


Figure 13: 13E Lund 11Precip2019box



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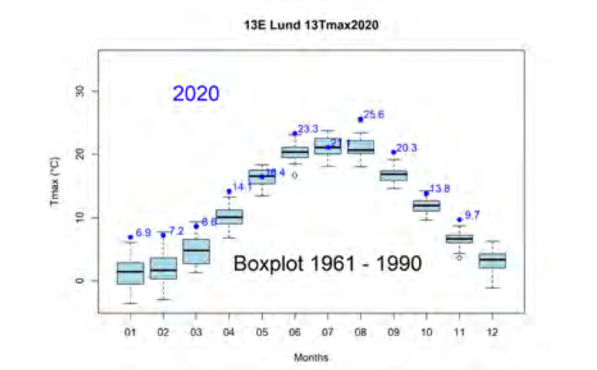

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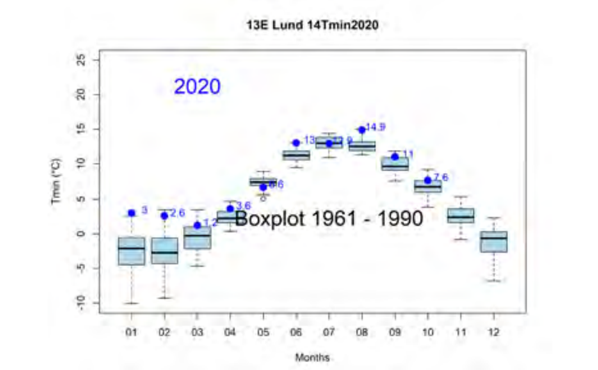

Figure 16: 13E Lund 14Tmin2020box

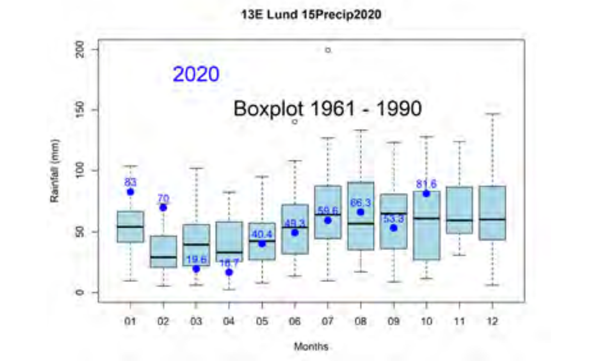	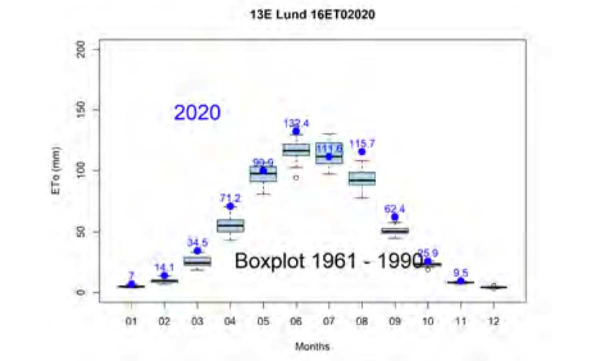
Figure 17: 13E Lund 15Precip2020box	*Figure 18: 13E Lund 16ET02020box*

13a Horby_A

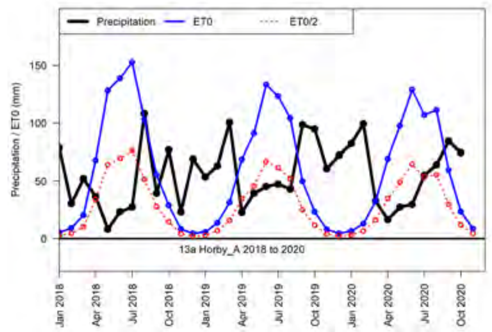

Figure 19: 13a Horby_A 00aFAOgrow

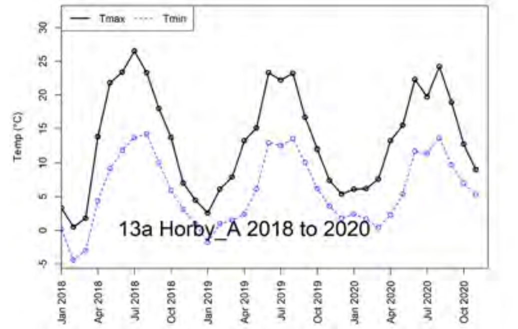

Figure 20: 13a Horby_A 00b TnTx

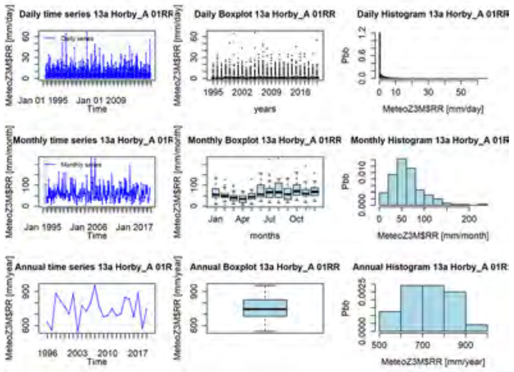

Figure 21: 13a Horby_A 01RRhyplo

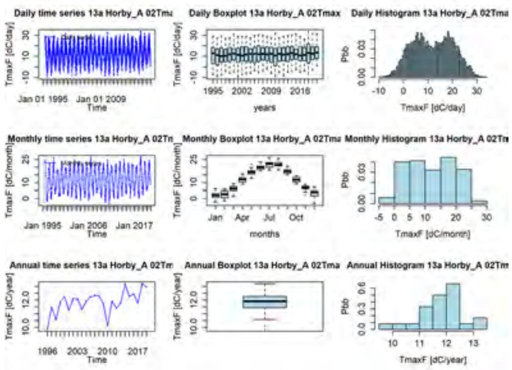

Figure 22: 13a Horby_A 02Tmaxhyplo

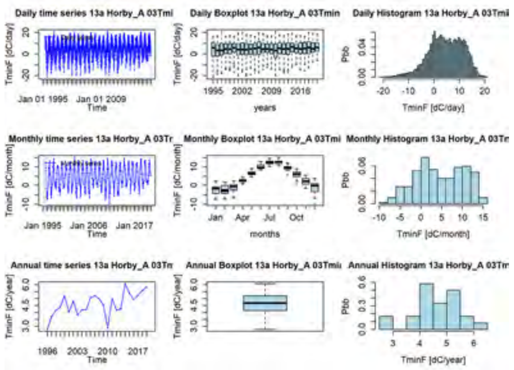

Figure 23: 13a Horby_A 03Tminhyplo

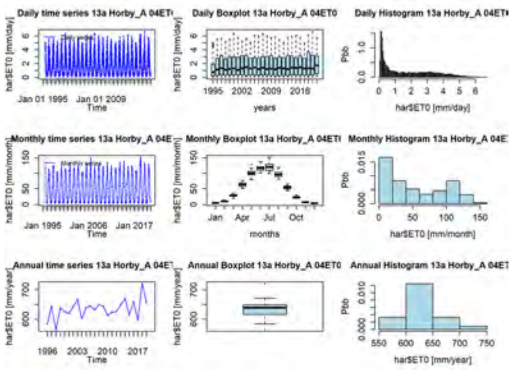

Figure 24: 13a Horby_A 04ET0hyplo

14. CZECH Republic: Figures from the analysis

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Table 1: Indicators measured and analysed

Observation code	Unit	Description
bd_top	g/cm3	Bulk density topsoil
bd_bot	g/cm3	Bulk density bottom
top_clay	%	Clay
top_silt	%	Silt
top_sand	%	Sand
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in H2O
earthworm_no	no/m2	Earthworms
crop_yield_ha	kg/ha	Crop yield
gluten_index	_	Gluten index
crop_n_cont	% of dry mass	Nitrogen content

Table 2:Indicators measured only for the three tillage treatments where CAN is applied

Observation code	Unit	Description
top_wc_pf2_0	m3m-3	Water content at FC
top_wc_pf4_2	m3m-3	Water content at PWP
top_wc_pf2_7	m3m-3	Water content at stress point
top_wc_pf_1_8	m3m-3	Water content pF1.08
top_satur_wc	m3m-3	Water content Saturation
wsa	%	WSA
bd_top	g/cm3	Bulk density topsoil
soc	%	SOC

The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement “Treatment*Date”, and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table of Figures

Experiment:

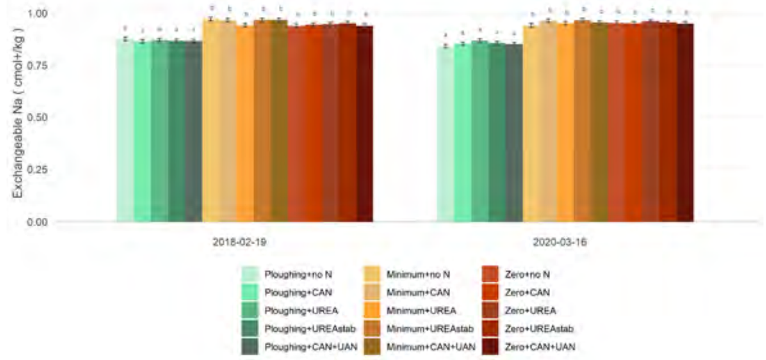


Figure 1: VURV_EX1_SI_na_plus

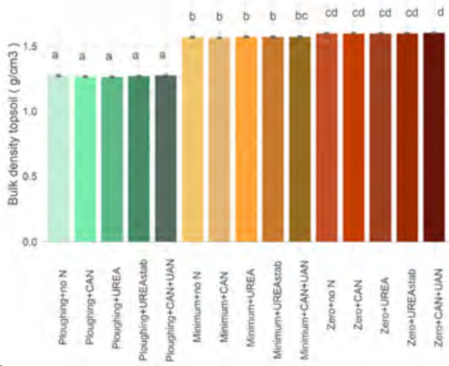


Figure 2: VURV_EX1_NSI_treat_bd_top

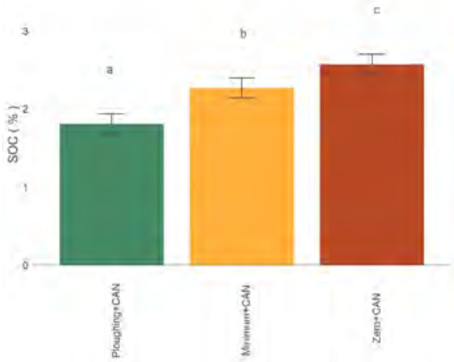


Figure 3: VURV_EX1_NR_soc

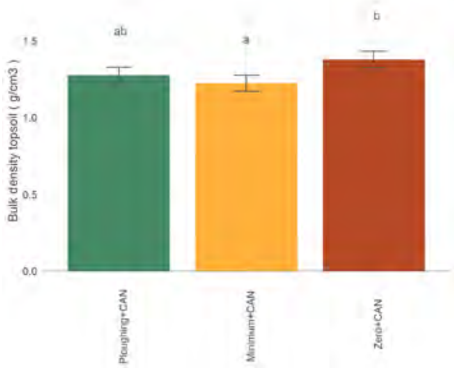


Figure 4: VURV_EX1_NR_bd_top

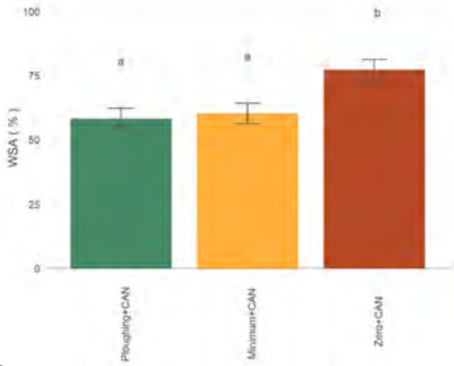


Figure 5: VURV_EX1_NR_wsa

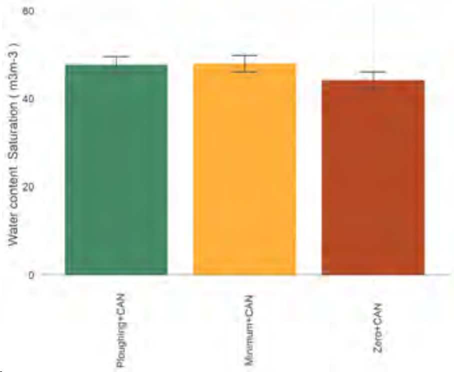


Figure 6: VURV_EX1_NR_top_satur_wc

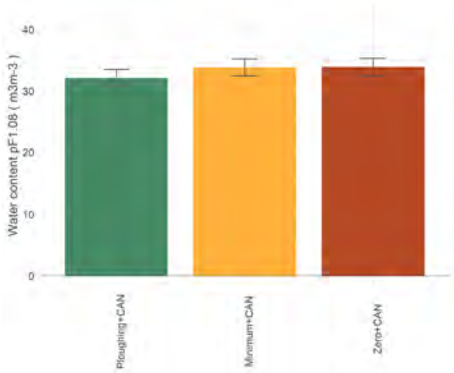


Figure 7: VURV_EX1_NR_top_wc_pf_1_8

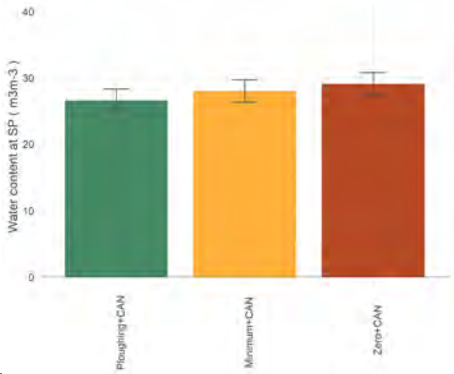


Figure 8: VURV_EX1_NR_top_wc_pf2_7

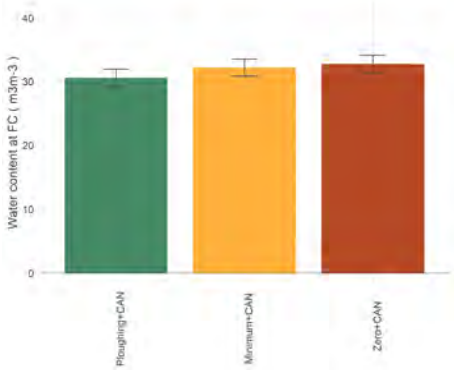


Figure 9: VURV_EX1_NR_top_wc_pf2_0

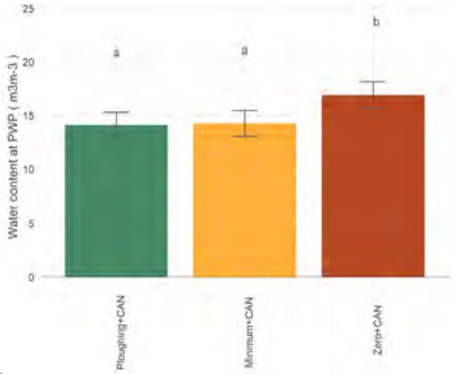


Figure 10: VURV_EX1_NR_top_wc_pf4_2

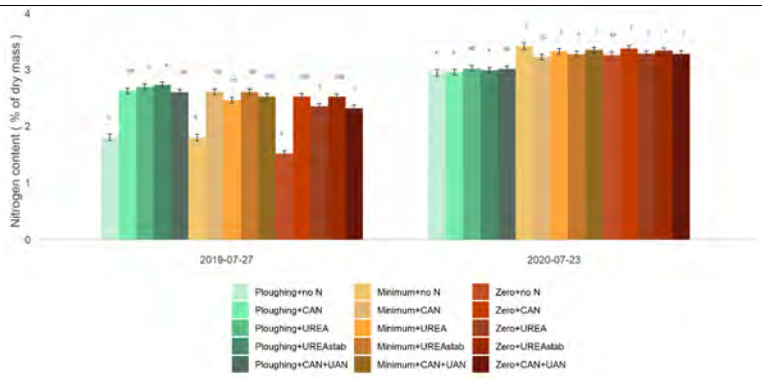


Figure 11: VURV_EX1_SI_crop_n_cont

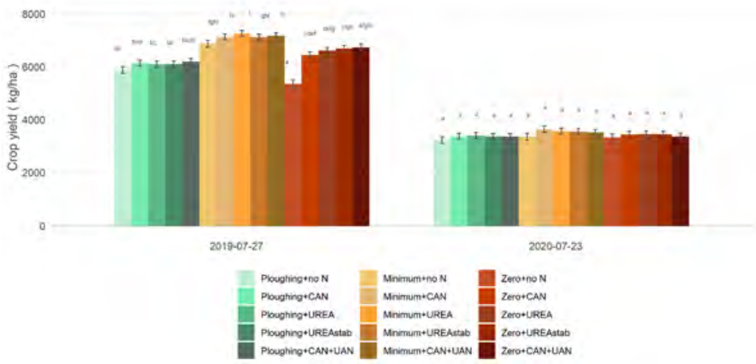


Figure 12: VURV_EX1_SI_crop_yield_ha

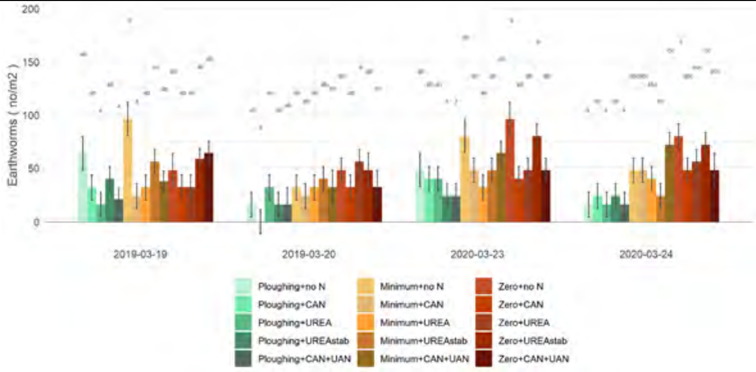


Figure 13: VURV_EX1_SI_earthworm_no

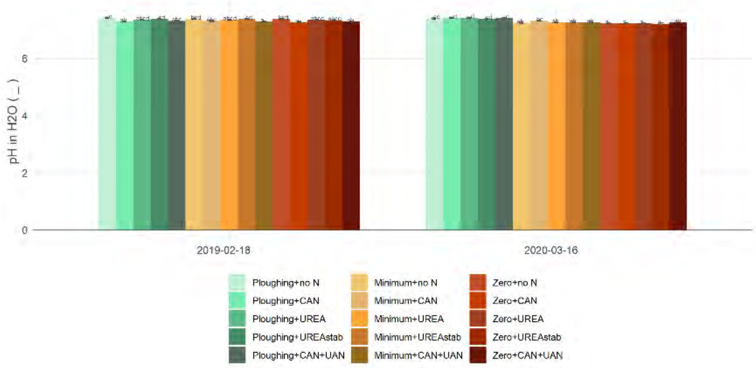


Figure 14: VURV_EX1_SI_ph_h2o

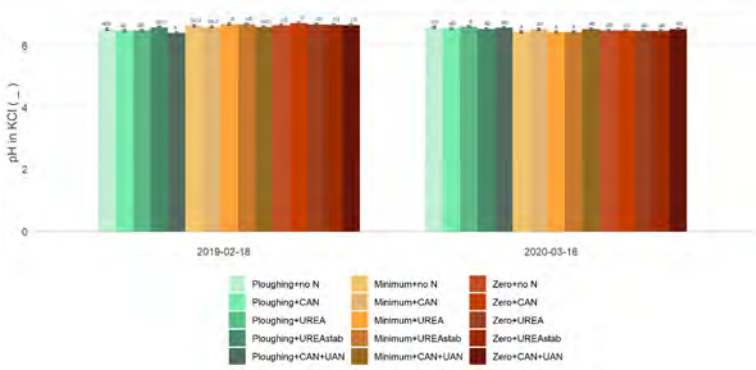


Figure 15: VURV_EX1_SI_ph_kcl

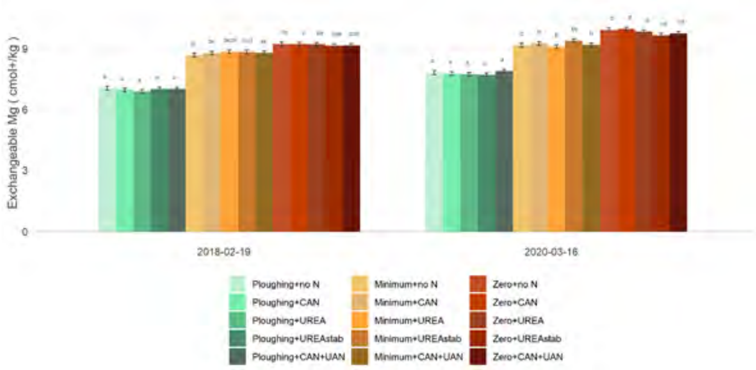


Figure 16: VURV_EX1_SI_mg2plus

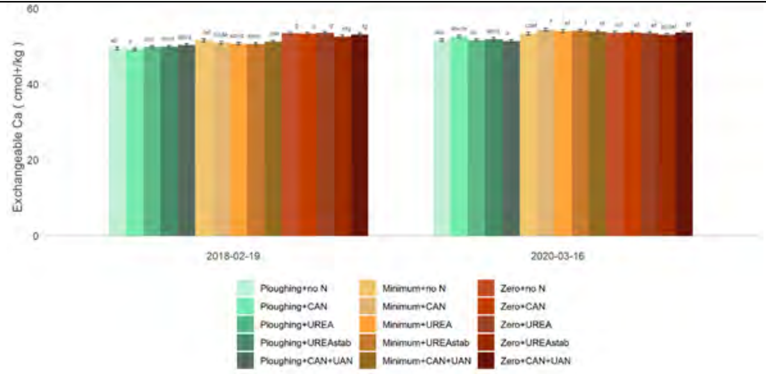


Figure 17: VURV_EX1_SI_ca2_plus

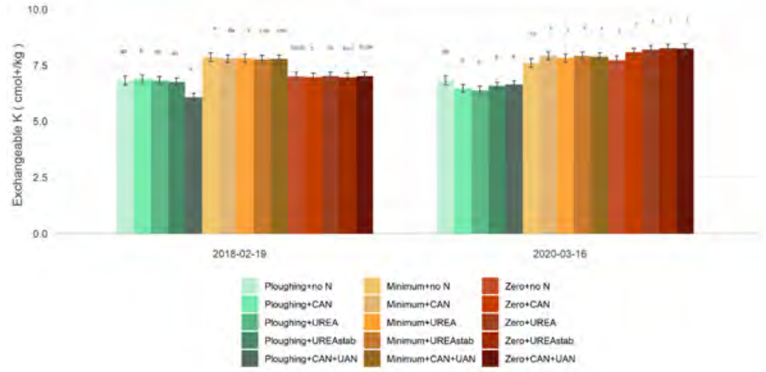


Figure 18: VURV_EX1_SI_k_plus

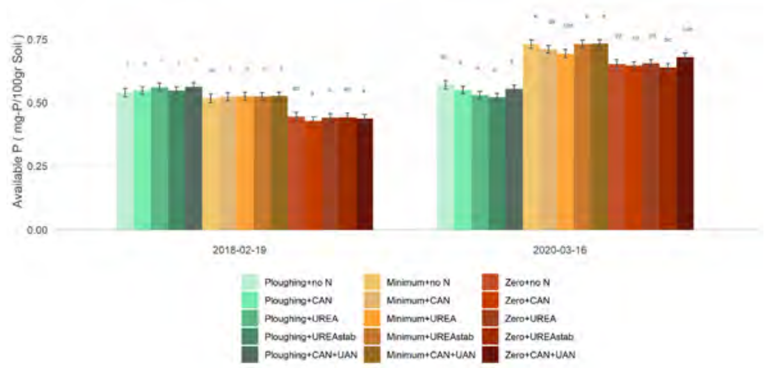


Figure 19: VURV_EX1_SI_p_avail

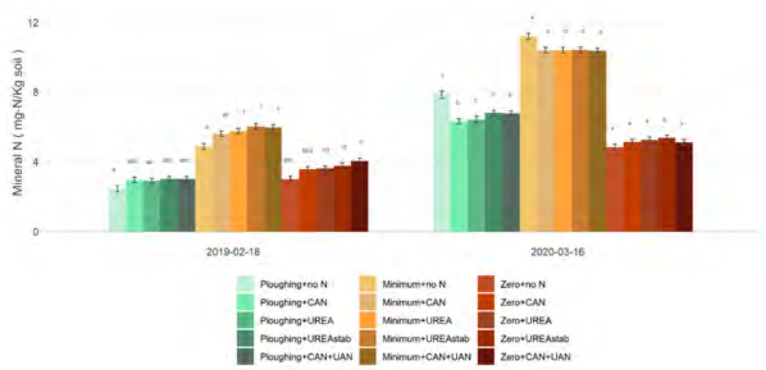


Figure 20: VURV_EX1_SI_nmin_top

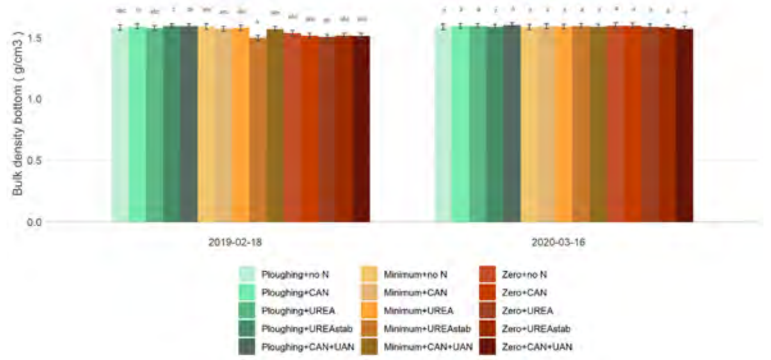


Figure 21: VURV_EX1_SI_bd_bot

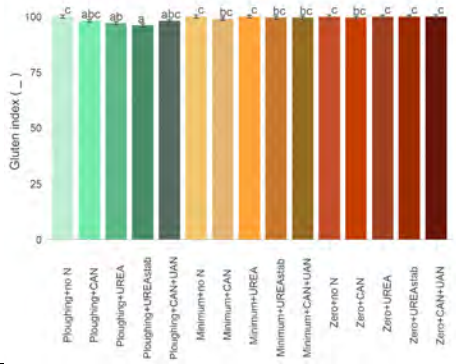


Figure 22: VURV_EX1_NR_gluten_index

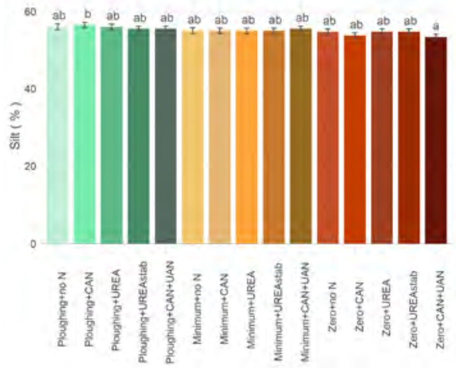
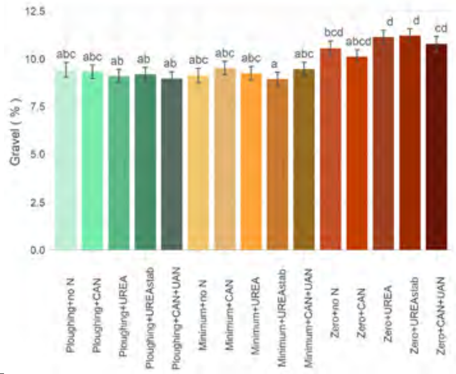


Figure 23: VURV_EX1_NR_top_silt



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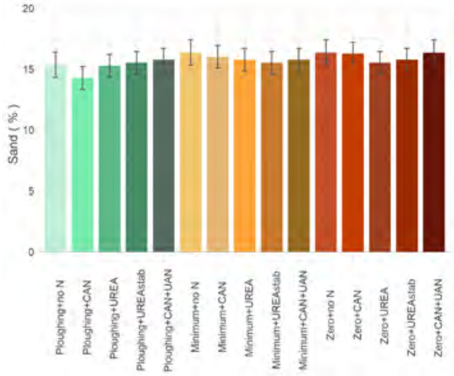

Figure 25: VURV_EX1_NR_top_sand

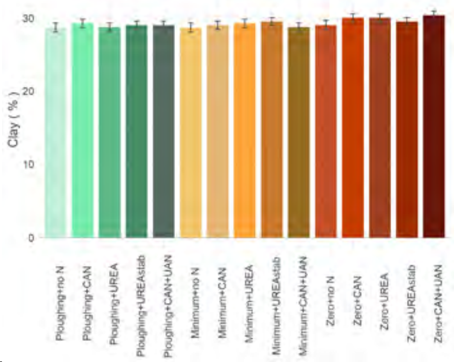

Figure 26: VURV_EX1_NR_top_clay

14 Czech: Figures from the meteorological analysis

At the time of producing this report the year 2020 was not yet available. The website for Vurz was hacked and the meteorological service had not yet released the 2020 data for Praha Klementinum.

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For explanation of the meteorological figures consult the introduction to D5.3.

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14E Praha Klementinum (ECAD 27)

Praha Klem(entinum) is the first and most long standing Czech meteorological station. Measurements of temperature started in 1775 making it the oldest on in the world. Data are available up to December 2019. Available from:

http://portal.chmi.cz/historicka-data/pocasi/praha-klementinum?l=en#

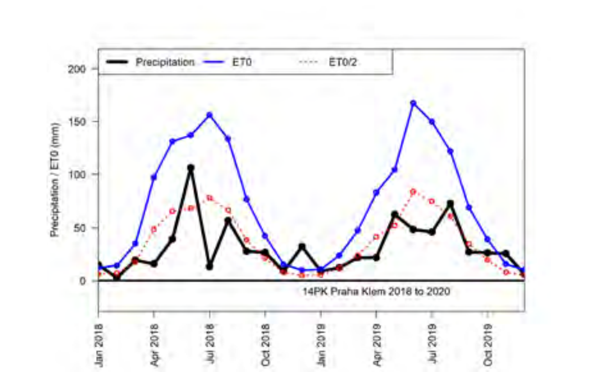

Figure 1: 14PK Praha Klem 00aFAOgrow

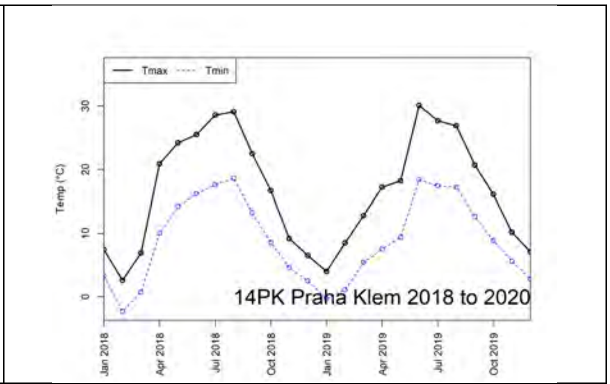

Figure 2: 14PK Praha Klem 00b TnTx

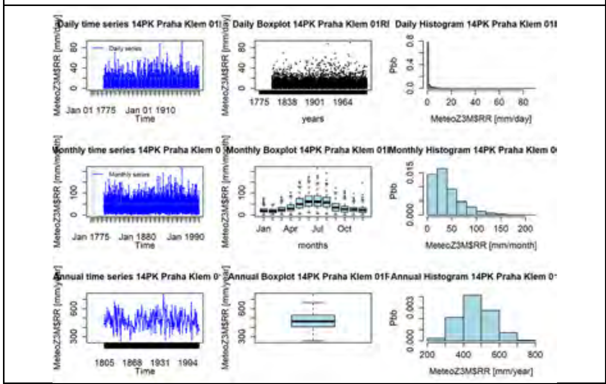

Figure 3: 14PK Praha Klem 01RRhyplo

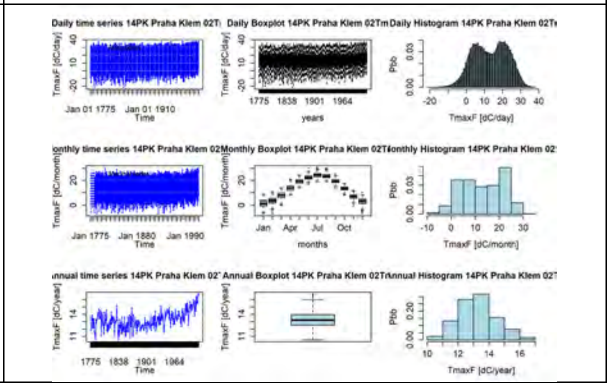

Figure 4: 14PK Praha Klem 02Tmaxhyplo

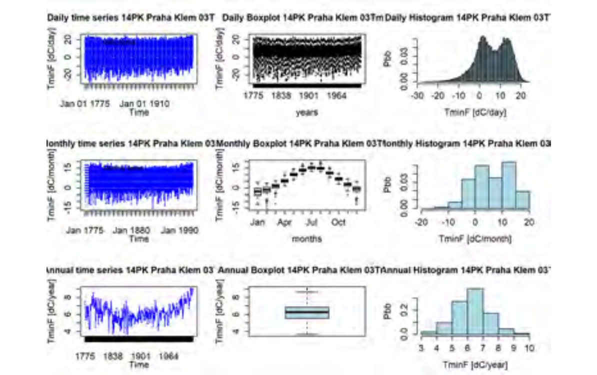

Figure 5: 14PK Praha Klem 03Tminhyplo

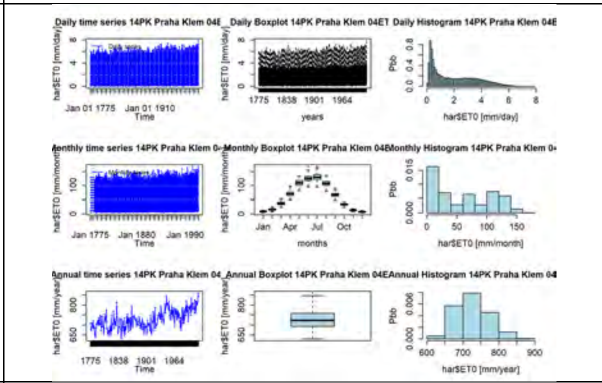

Figure 6: 14PK Praha Klem 04ET0hyplo

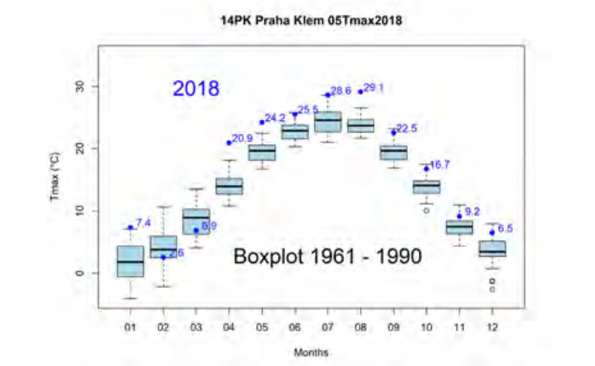

Figure 7: 14PK Praha Klem 05Tmax2018box

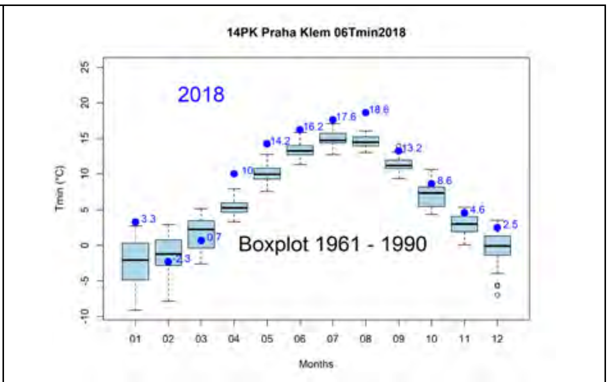

Figure 8: 14PK Praha Klem 06Tmin2018box

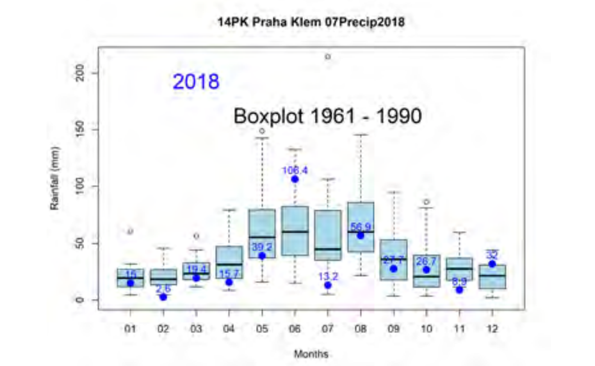

Figure 9: 14PK Praha Klem 07Precip2018box

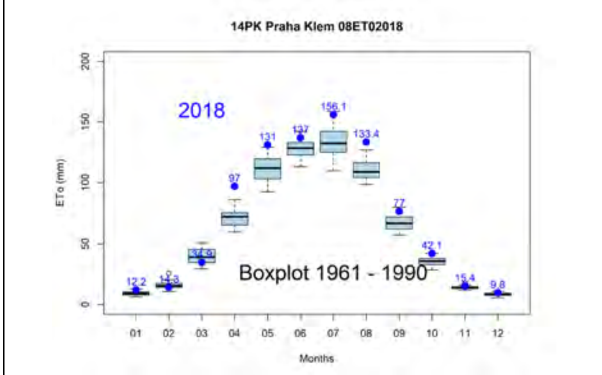

Figure 10: 14PK Praha Klem 08ETO2018box

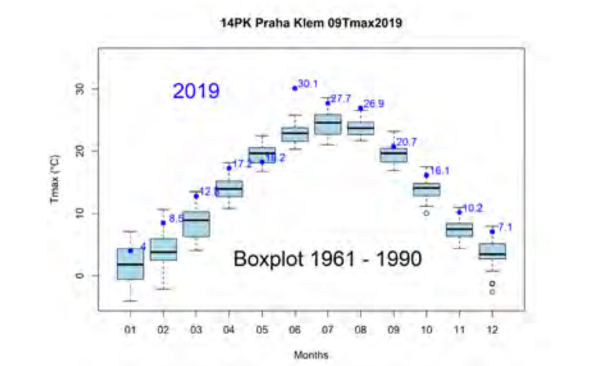

Figure 11: 14PK Praha Klem 09Tmax2019box

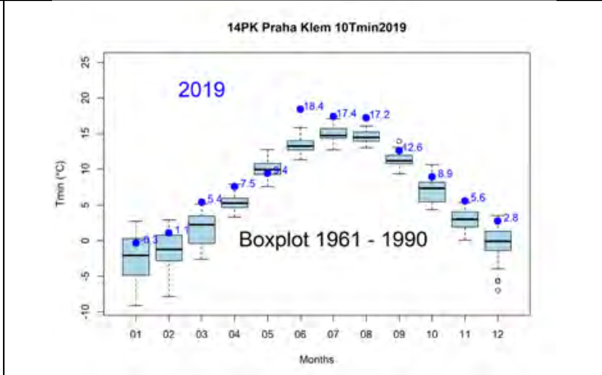

Figure 12: 14PK Praha Klem 10Tmin2019box

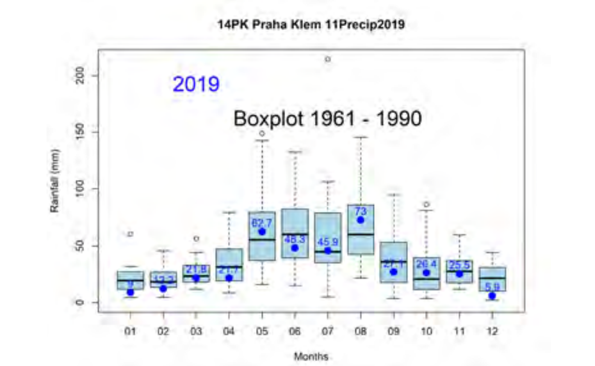

Figure 13: 14PK Praha Klem 11Precip2019box

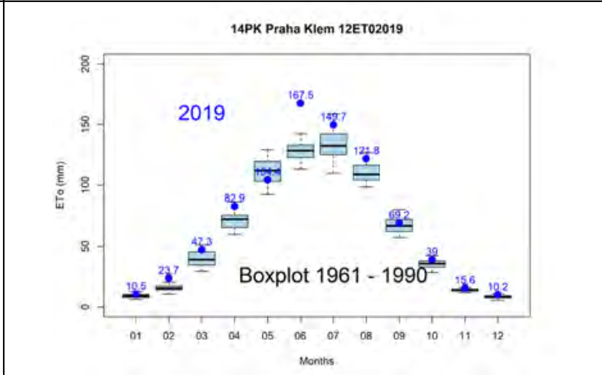

Figure 14: 14PK Praha Klem 12ETO2019box

14a VURZ_CZ_st1

This is the station belonging to the Crop Research Institute and is next to the experimental fields.

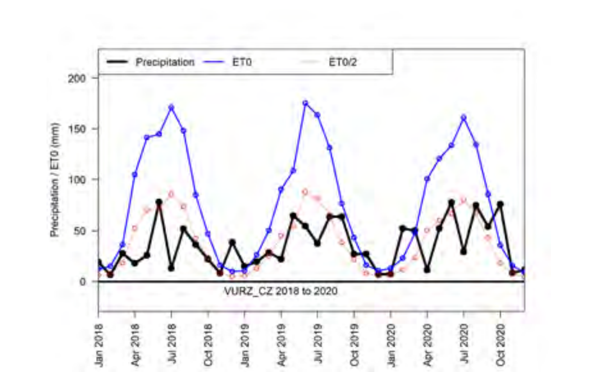

Figure 15: 14aVURZ_CZ 00aFAOgrow

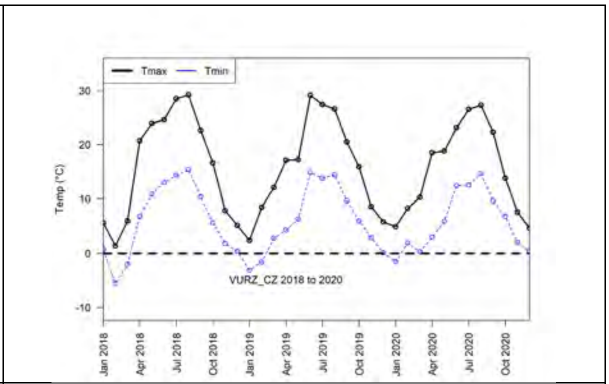

Figure 16: 14aVURZ_CZ 00bTnTx

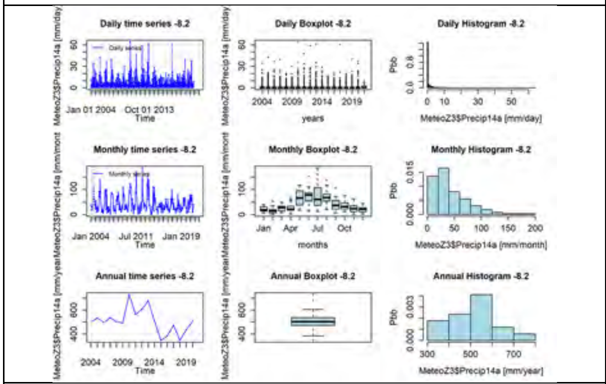

Figure 17: 14aVURZ_CZ 01PrecHyplo

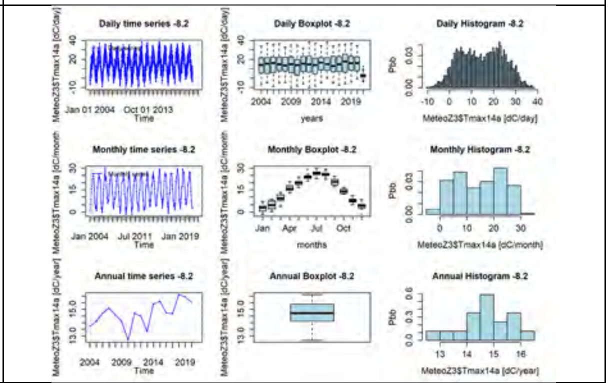

Figure 18: 14aVURZ_CZ 02TmaxHyplo

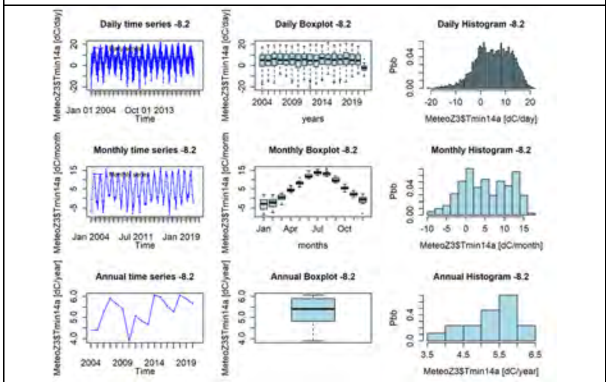

Figure 19: 14aVURZ_CZ 03TminHyplo

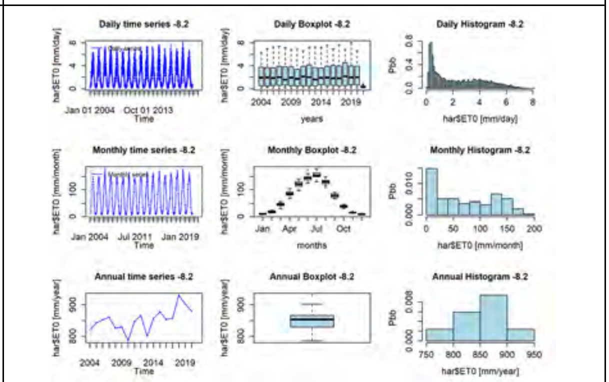

Figure 20: 14aVURZ_CZ 04ET0Hyplo

15. Spain: Figures from the analysis

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The general explanation of the filenames for the figures

A general and more extensive explanation will be provided in the first part of D5.3.

The figures label includes the abbreviation of the institute (e.g. UH), the experiment number (e.g. EX1), the category of analysis (NR, SI, NSI_treat, NSI_date) and the response indicator (e.g. SOC)

Differences between treatments or dates were analysed with a Mixed-Effects Model using the full factorial statement “Treatment*Date”, and for the variables measured only once the Treatment factor used. Significant grouping is based on Tukey and indicated by letters.

This is reflected in the figures below in the following ways:

1) NR: When one indicator measured only once during a growing season the label includes the NR (Not repeated).

Then we get the information if the different treatments affect the response variable. (Treatments with different letters on top cause statistically significant different effects on the response variable)

2) Repeated during the growing season: In the case of **repeated measurements** we have two different possible results from the models:

2a) **SI:** when the interaction between the treatment and date of measurement is significant then we represent the impact of the treatment on all different dates

Then we get the information on when and which treatment causes statistically significant effects to the response variable.

(Treatments with different letters on top of each different date cause statistically significant effects on the response variable)

2b) NSI: when the interaction of the treatment effect and the date effect is not significant, we check separately the effect of treatment and the effect of date.

Then we get the following information

2b1) NSI_date: the date of sampling/measurement gives a significant effect. In this case, the model groups the results of all treatments together each separate date. The period of sampling plays an important role in the response variable.

(Dates with different letters on top cause statistically significant different effects on the response variable)

2b2) NSI_treat: the treatment effect is significant. In this case, the model groups the results of each date for each separate treatment. The treatment affects the response variable in all the different periods measured.

(Treatments with different letters on top cause statistically significant effects on the response variable independently the timing of sampling)

Table 1: Indicators measured and analysed

Observation code	**Unit**	**Description**
top_wc_pf2_0	m3m-3	Water content FC
top_wc_pf4_2	m3m-3	Water content PWP
top_wc_pf2_7	m3m-3	Water content pF2.7
top_wc_pf_1_8	m3m-3	Water content pF1.8
top_satur_wc	m3m-3	Water content Saturation
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density
top_clay	%	Clay
top_silt	%	Silt
top_sand	%	Sand
top_gravel_fraction	%	Gravel
nmin_top	mg-N/Kg soil	Mineral N
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol+/kg	Exchangeable K
ca2_plus	cmol+/kg	Exchangeable Ca
na_plus	cmol+/kg	Exchangeable Na
mg2plus	cmol+/kg	Exchangeable Mg
soc	%	SOC
ph_kcl	_	pH in KCl
ph_h2o	_	pH in H2O
ec1_5	dS/m	EC
crop_yield_ha	kg/ha	Crop yield
labileC	mg/kg	Labile C
Cr	% (w/w)	Cr
Mn	% (w/w)	Mn
Fe	% (w/w)	Fe
Ni	% (w/w)	Ni
Cu	% (w/w)	Cu
Zn	% (w/w)	Zn
As	% (w/w)	As
Pb	% (w/w)	Pb

Table of Figures

SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

Experiment 1:

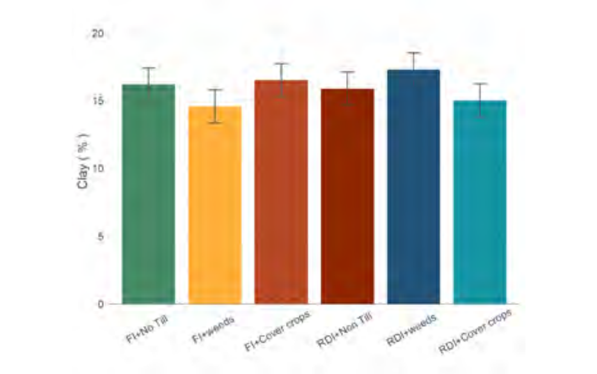

Figure 1: UAL_EX1_NR_top_clay

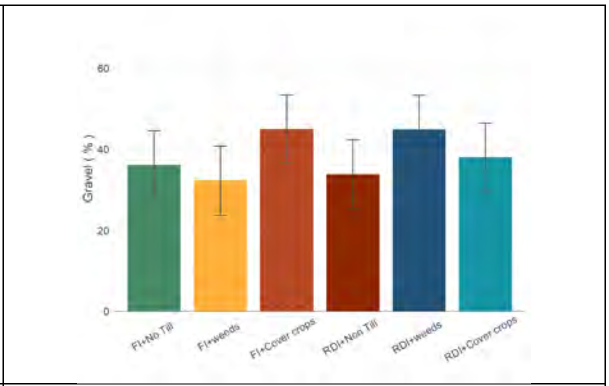

Figure 2: UAL_EX1_NR_top_gravel_fraction

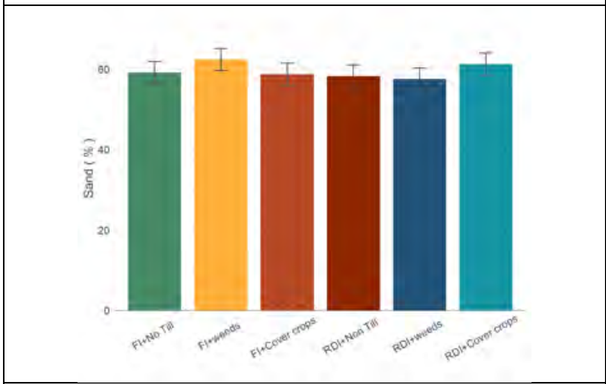

Figure 3: UAL_EX1_NR_top_sand

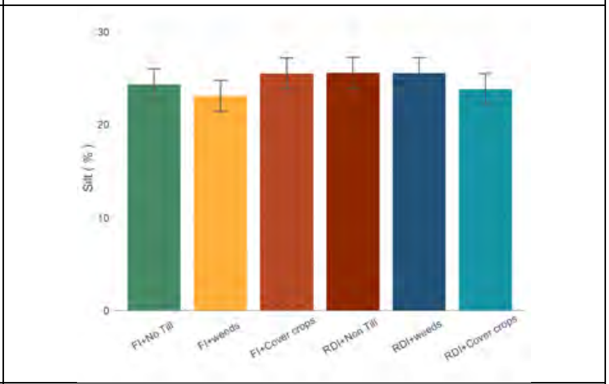

Figure 4: UAL_EX1_NR_top_silt

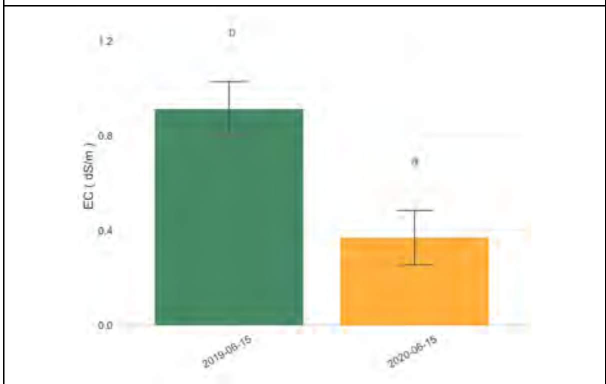

Figure 5: UAL_EX1_NSI_date_ec1_5

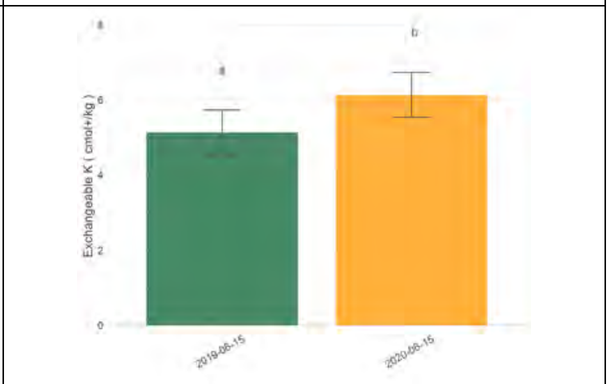

Figure 6: UAL_EX1_NSI_date_k_plus

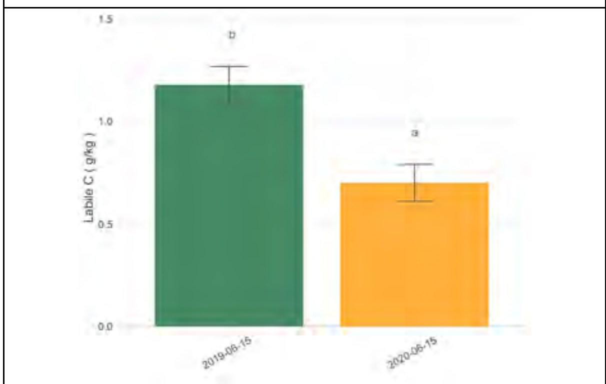

Figure 7: UAL_EX1_NSI_date_labileC

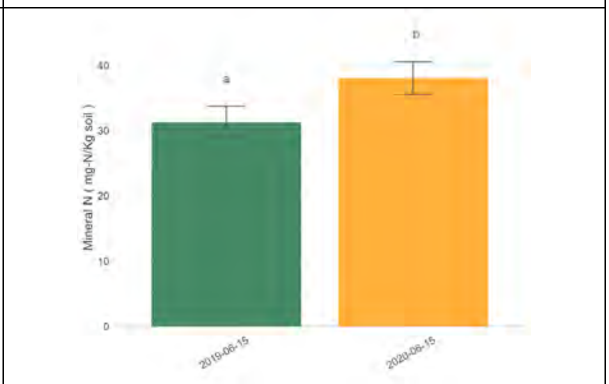

Figure 8: UAL_EX1_NSI_date_nmin_top

Figure 9: UAL_EX1_NSI_date_ph_kcl

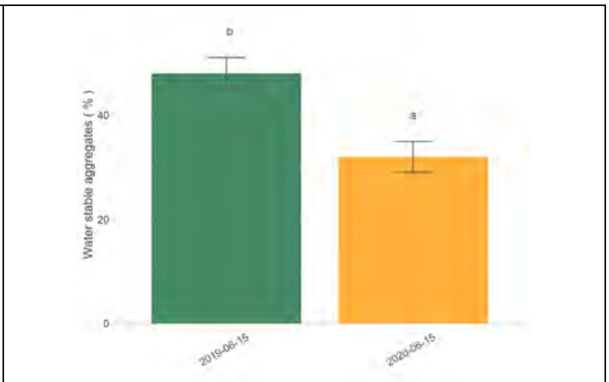

Figure 10: UAL_EX1_NSI_date_wsa

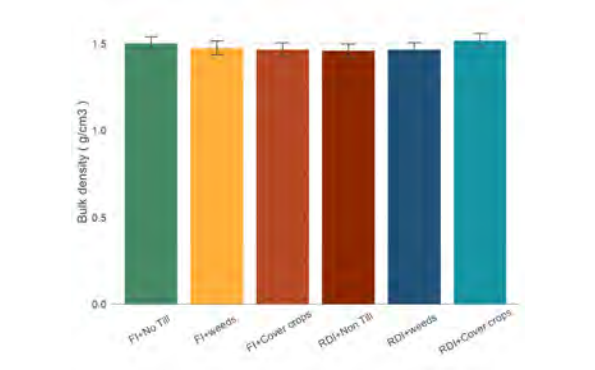

Figure 11: UAL_EX1_NSI_treat_bd_top

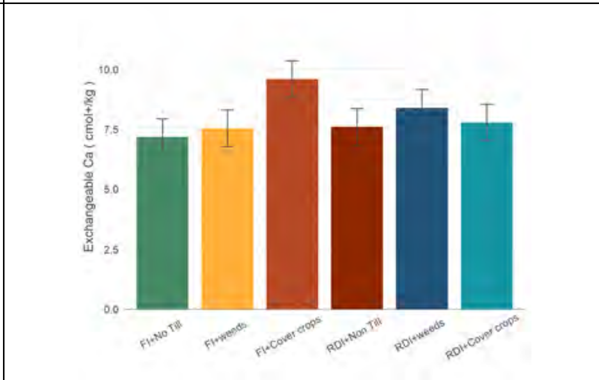

Figure 12: UAL_EX1_NSI_treat_ca2_plus

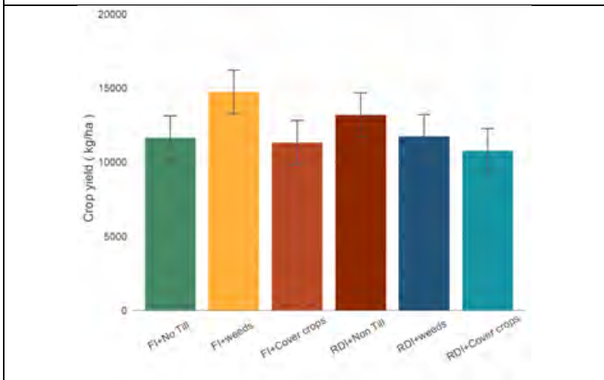

Figure 13: UAL_EX1_NSI_treat_crop_yield_ha

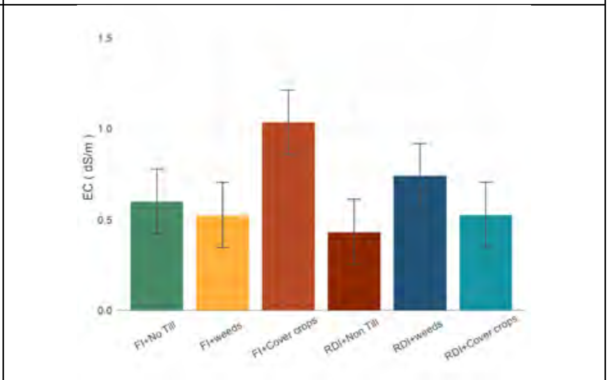

Figure 14: UAL_EX1_NSI_treat_ec1_5

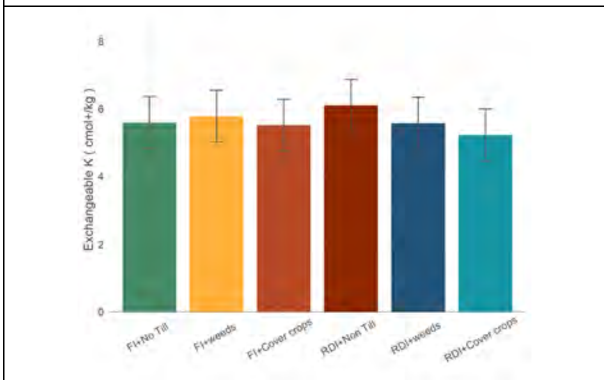

Figure 15: UAL_EX1_NSI_treat_k_plus

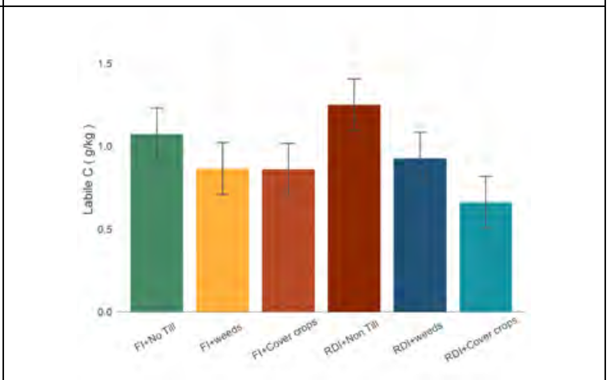

Figure 16: UAL_EX1_NSI_treat_labileC

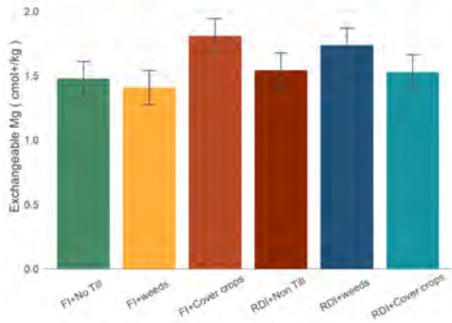

Figure 17: UAL_EX1_NSI_treat_mg2plus

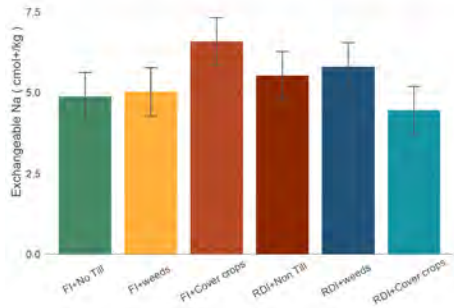

Figure 18: UAL_EX1_NSI_treat_na_plus

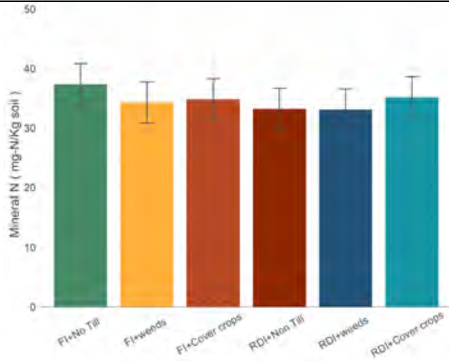

Figure 19: UAL_EX1_NSI_treat_nmin_top

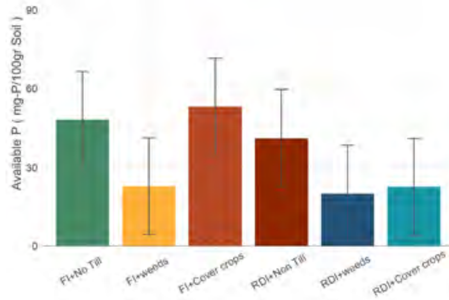

Figure 20: UAL_EX1_NSI_treat_p_avail

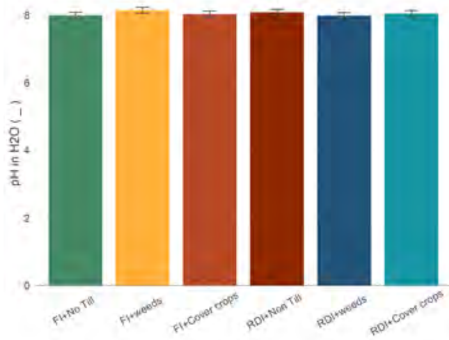

Figure 21: UAL_EX1_NSI_treat_ph_h2o

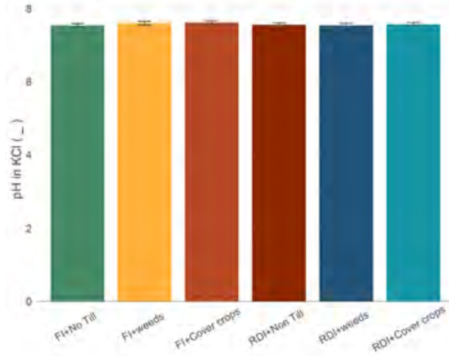

Figure 22: UAL_EX1_NSI_treat_ph_kcl

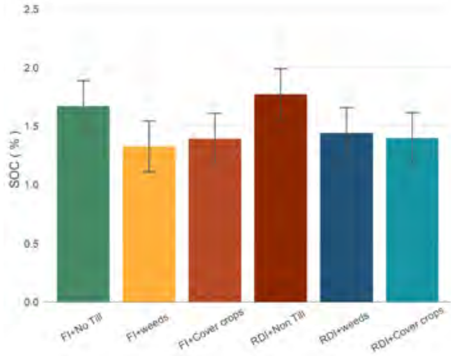

Figure 23: UAL_EX1_NSI_treat_soc

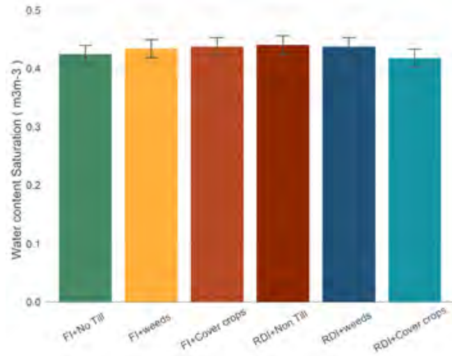

Figure 24: UAL_EX1_NSI_treat_top_satur_wc

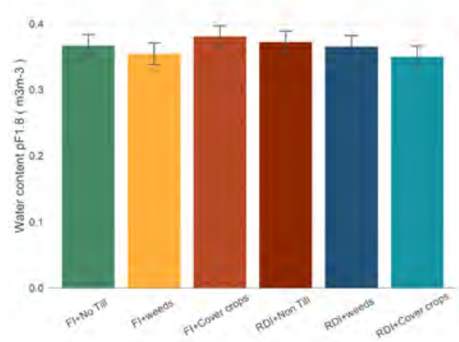

Figure 25: UAL_EX1_NSI_treat_top_wc_pf_1_8

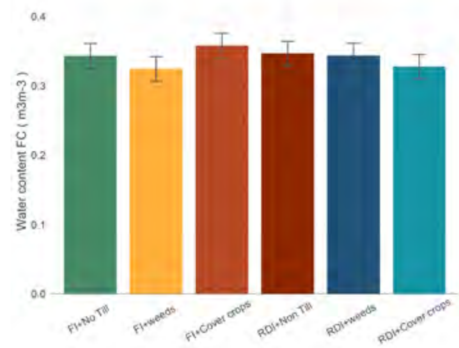

Figure 26: UAL_EX1_NSI_treat_top_wc_pf2_0

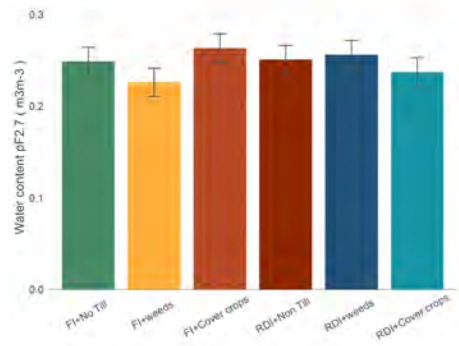

Figure 27: UAL_EX1_NSI_treat_top_wc_pf2_7

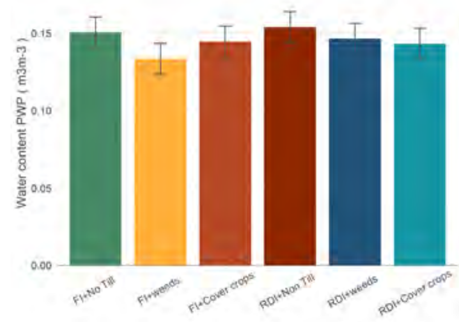

Figure 28: UAL_EX1_NSI_treat_top_wc_pf4_2

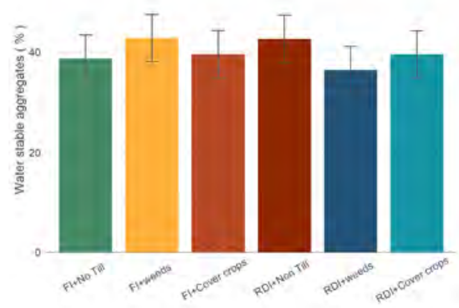

Figure 29: UAL_EX1_NSI_treat_wsa

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Experiment 2

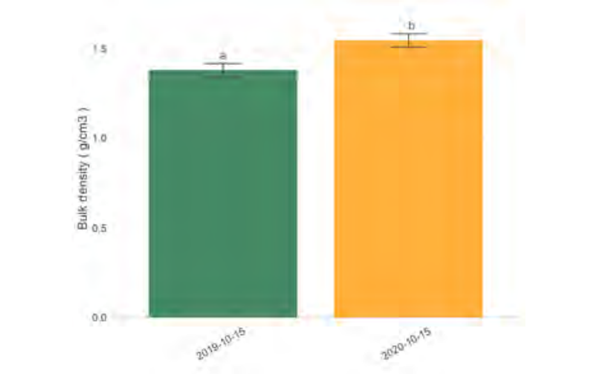


Figure 30: UAL_EX2_NSI_date_bd_top

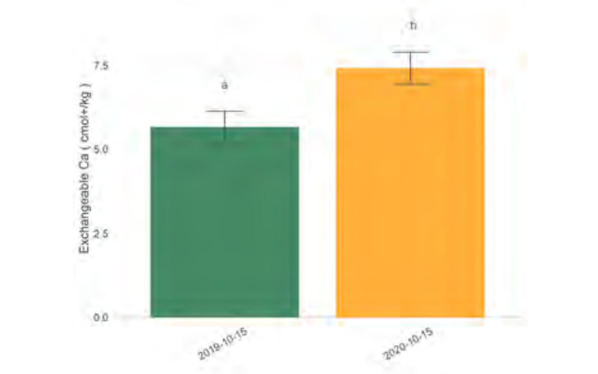


Figure 31: UAL_EX2_NSI_date_ca2_plus

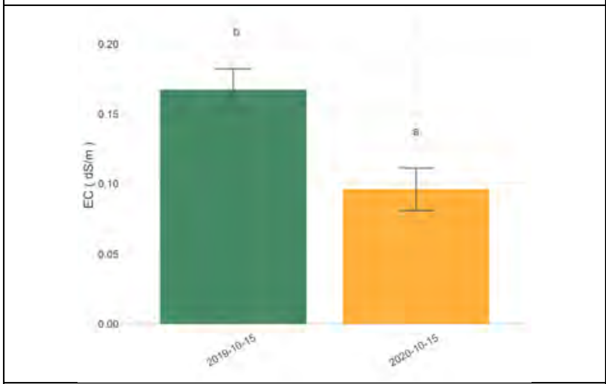


Figure 32: UAL_EX2_NSI_date_ec1_5

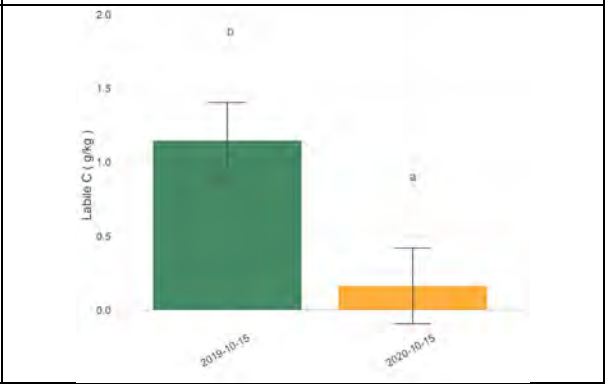


Figure 33: UAL_EX2_NSI_date_labileC

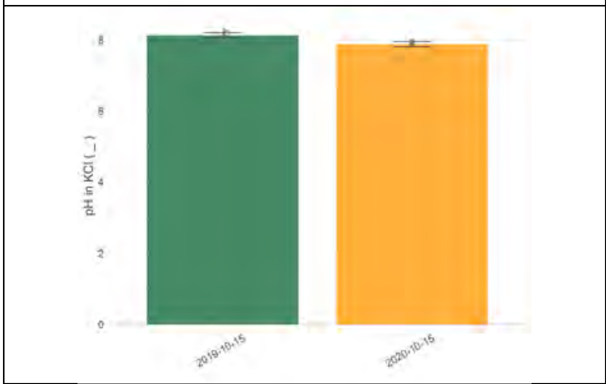


Figure 34: UAL_EX2_NSI_date_ph_kcl

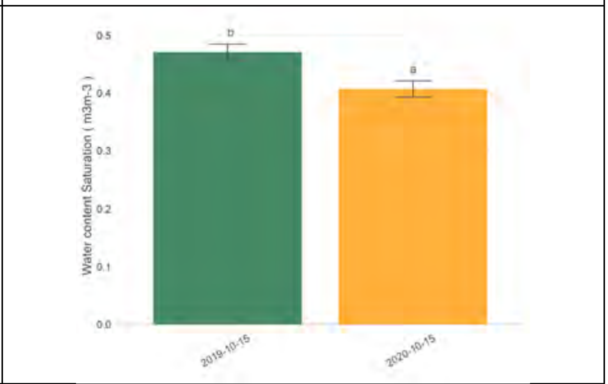


Figure 35: UAL_EX2_NSI_date_top_satur_wc

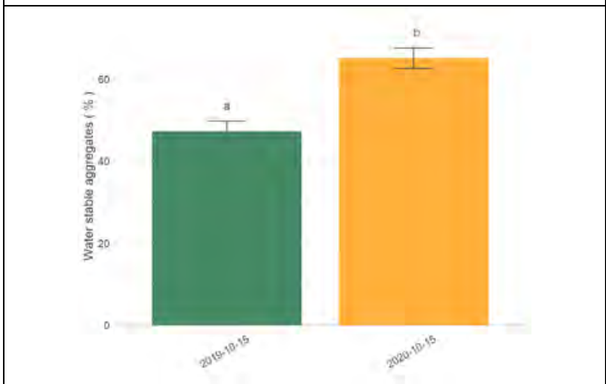


Figure 36: UAL_EX2_NSI_date_wsa

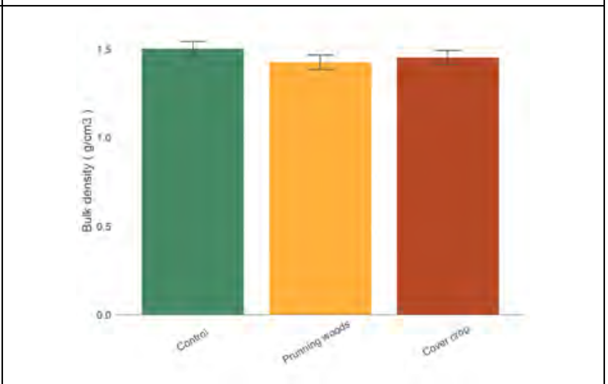


Figure 37: UAL_EX2_NSI_treat_bd_top

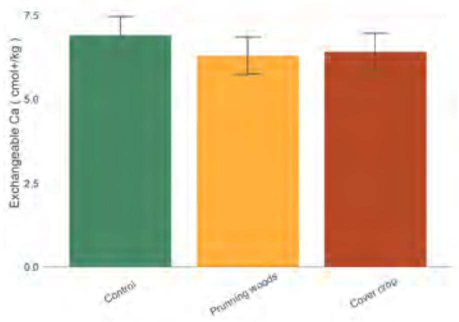
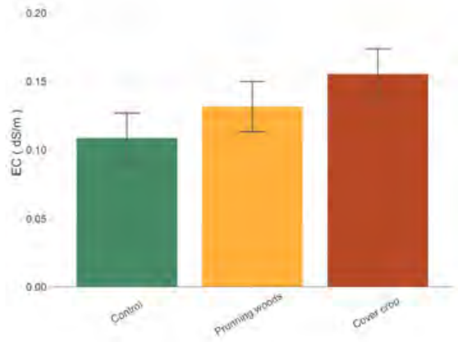
	

Figure 38: UAL_EX2_NSI_treat_ca2_plus	*Figure 39: UAL_EX2_NSI_treat_ec1_5*

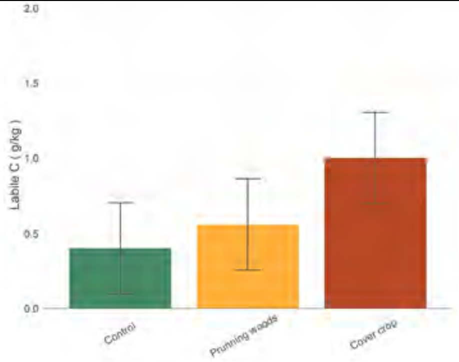
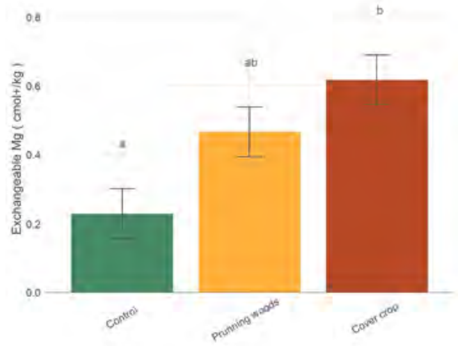

	

Figure 40: UAL_EX2_NSI_treat_labileC	*Figure 41: UAL_EX2_NSI_treat_mg2plus*

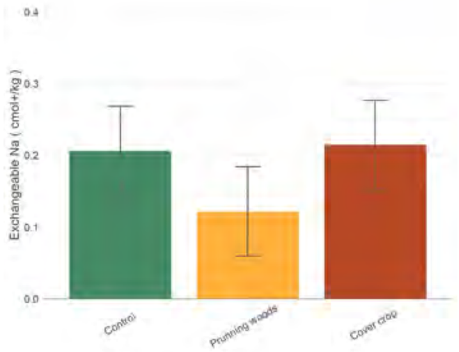
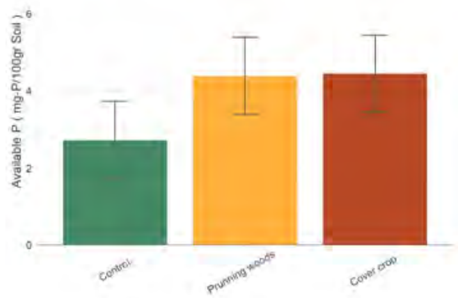

	

Figure 42: UAL_EX2_NSI_treat_na_plus	*Figure 43: UAL_EX2_NSI_treat_p_avail*

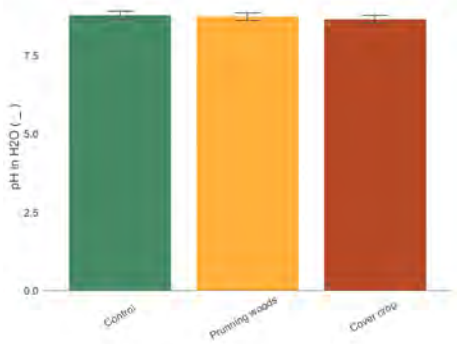
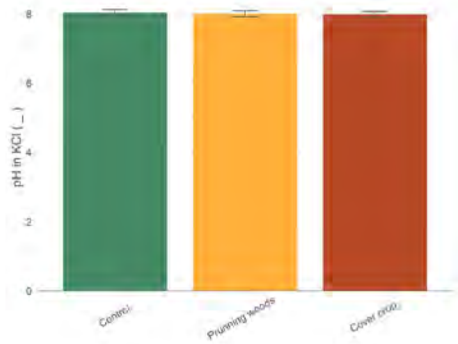

	

Figure 44: UAL_EX2_NSI_treat_ph_h2o	*Figure 45: UAL_EX2_NSI_treat_ph_kcl*

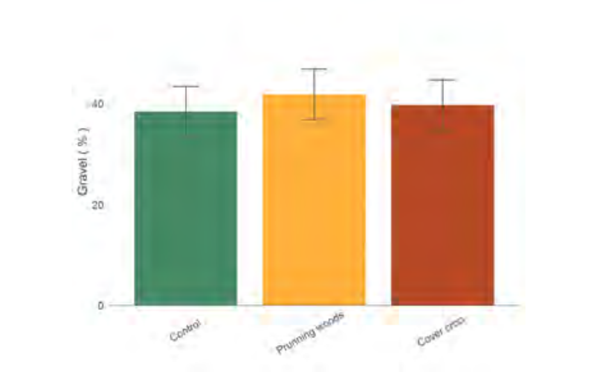


Figure 46: UAL_EX2_NSI_treat_top_gravel_fraction

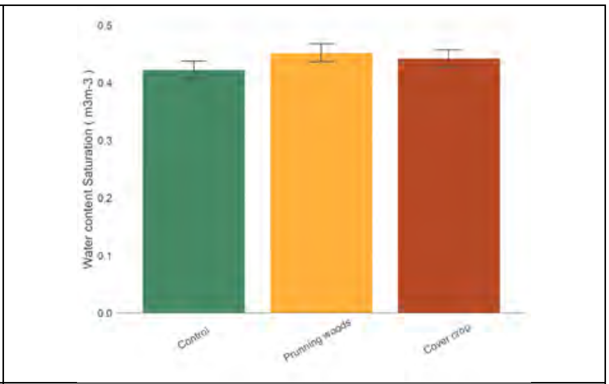


Figure 47: UAL_EX2_NSI_treat_top_satur_wc

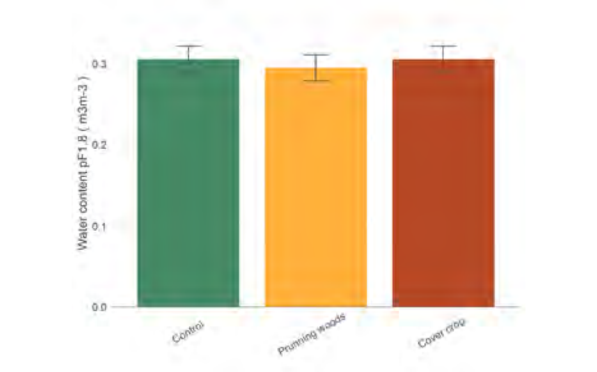


Figure 48: UAL_EX2_NSI_treat_top_wc_pf_1_8

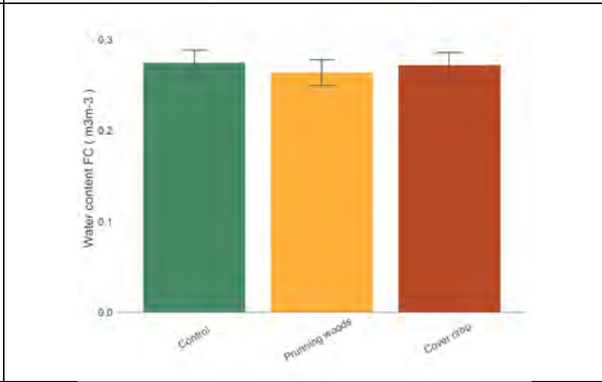


Figure 49: UAL_EX2_NSI_treat_top_wc_pf2_0

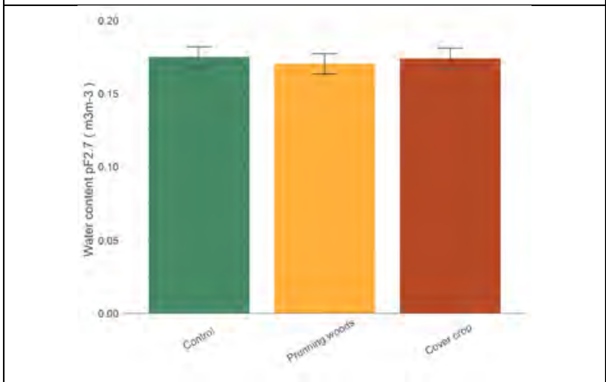


Figure 50: UAL_EX2_NSI_treat_top_wc_pf2_7

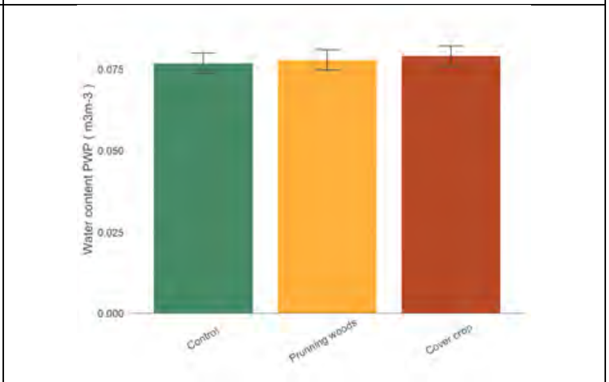


Figure 51: UAL_EX2_NSI_treat_top_wc_pf4_2

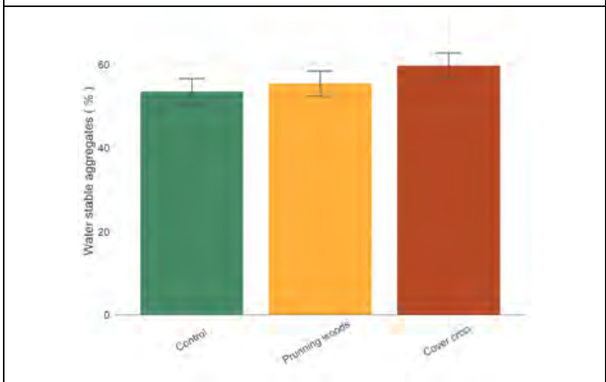


Figure 52: UAL_EX2_NSI_treat_wsa

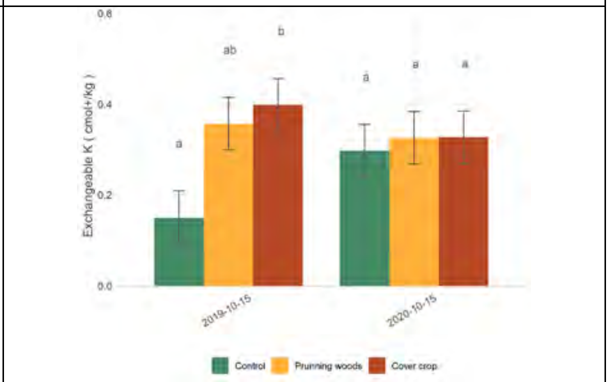


Figure 53: UAL_EX2_SI_k_plus

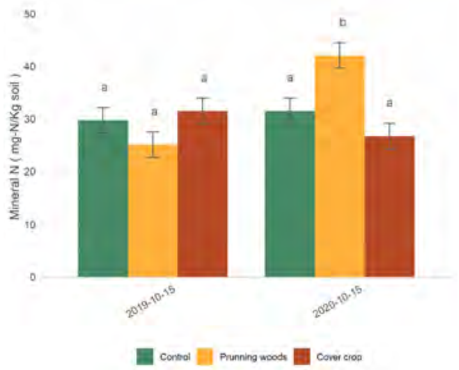


Figure 54: UAL_EX2_SI_nmin_top

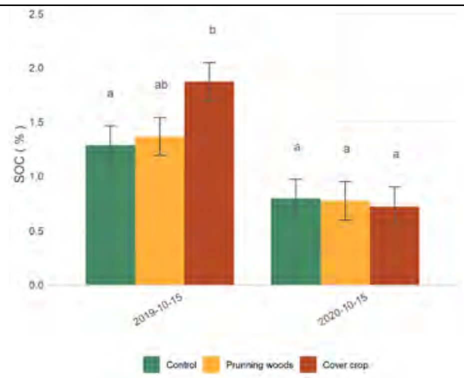


Figure 55: UAL_EX2_SI_soc

Experiment 3

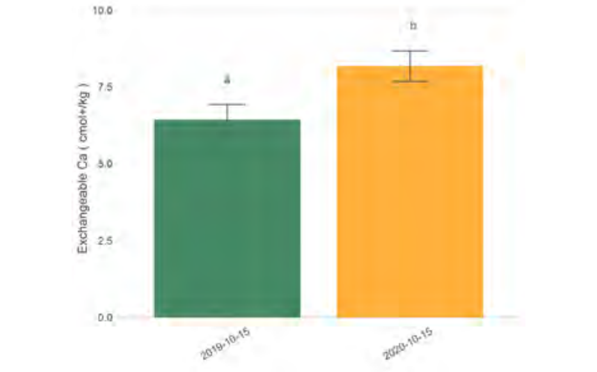


Figure 56: UAL_EX3_NSI_date_ca2_plus

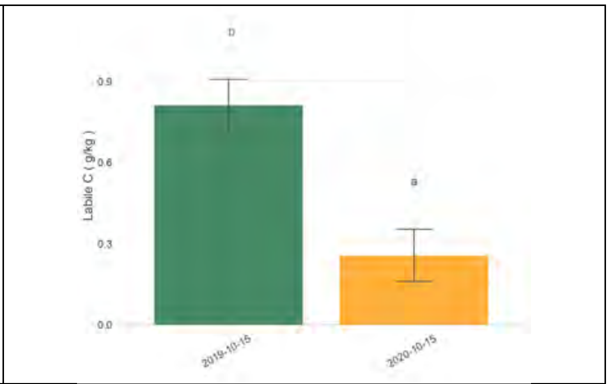


Figure 57: UAL_EX3_NSI_date_labileC

Figure 58: UAL_EX3_NSI_date_ph_h2o

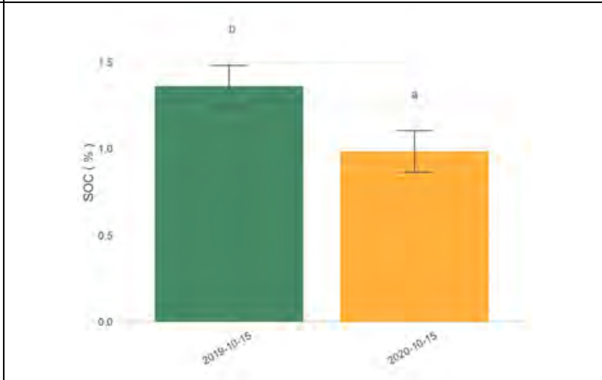


Figure 59: UAL_EX3_NSI_date_soc

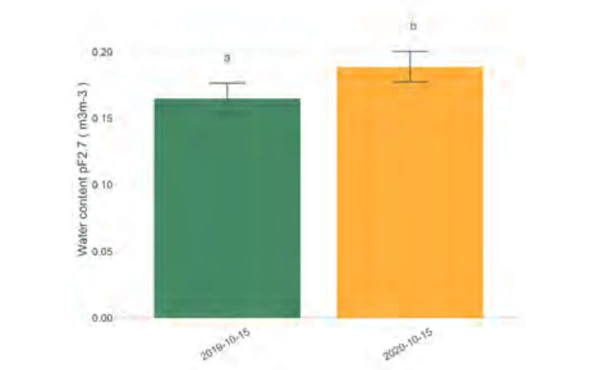


Figure 60: UAL_EX3_NSI_date_top_wc_pf2_7

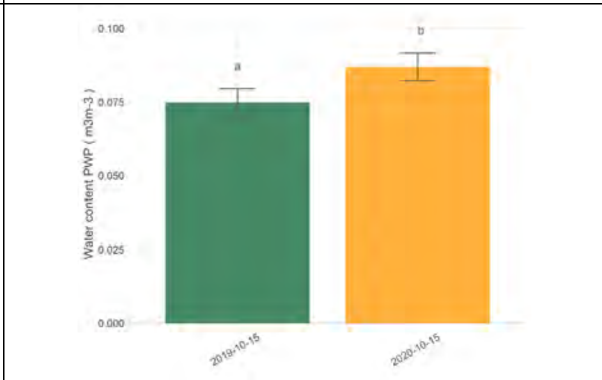


Figure 61: UAL_EX3_NSI_date_top_wc_pf4_2

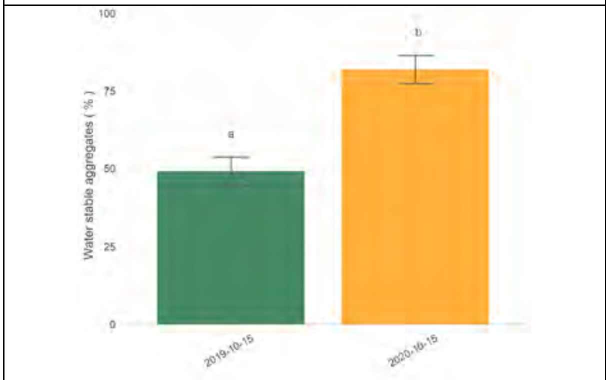


Figure 62: UAL_EX3_NSI_date_wsa

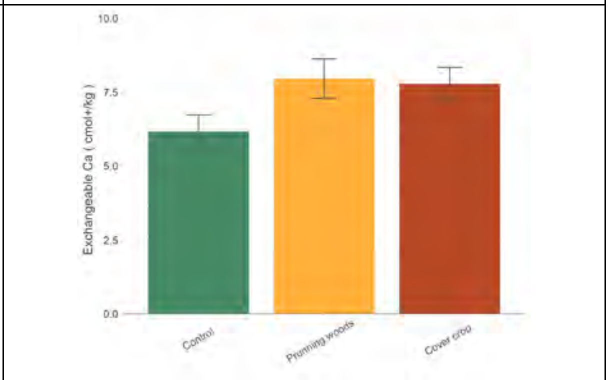
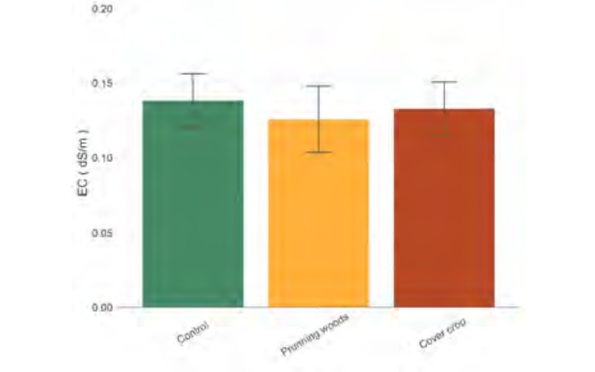


Figure 63: UAL_EX3_NSI_treat_ca2_plus



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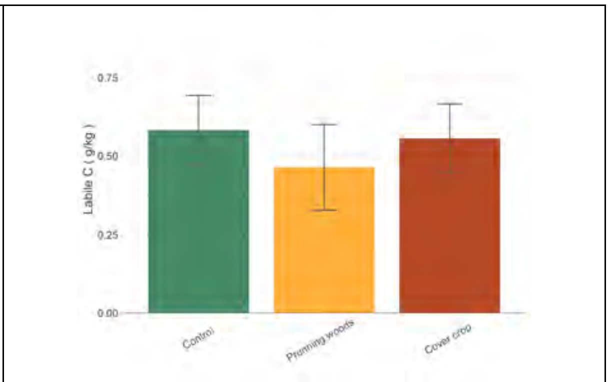

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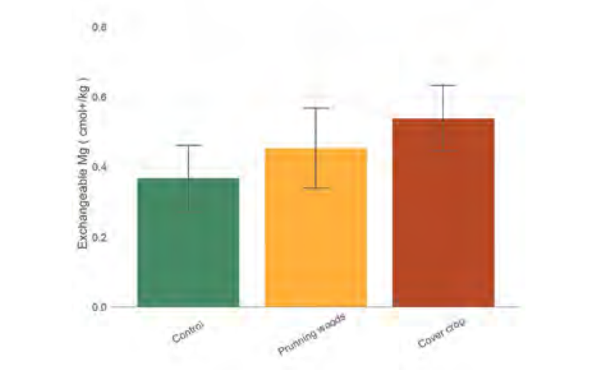

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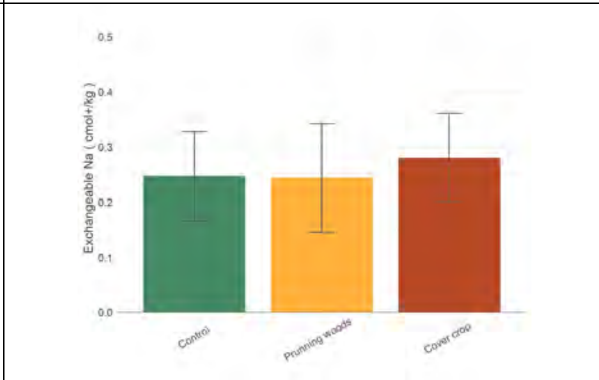
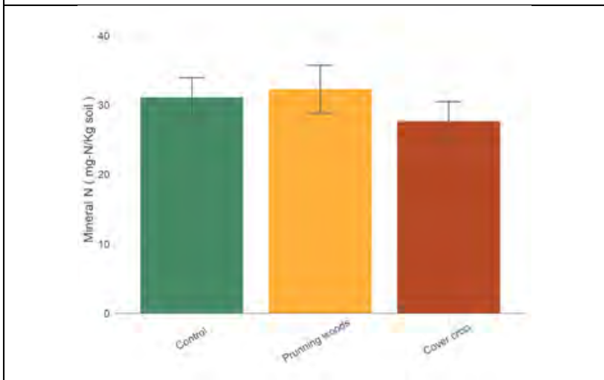


Figure 67: UAL_EX3_NSI_treat_na_plus



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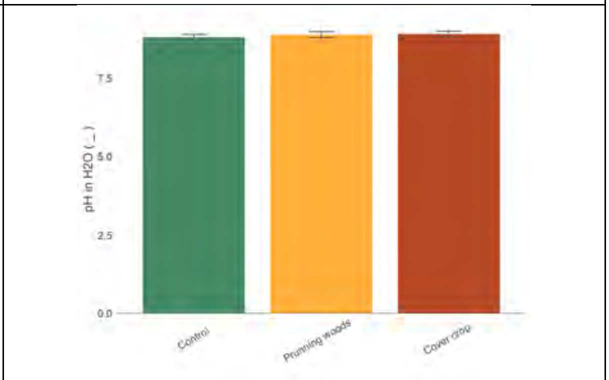
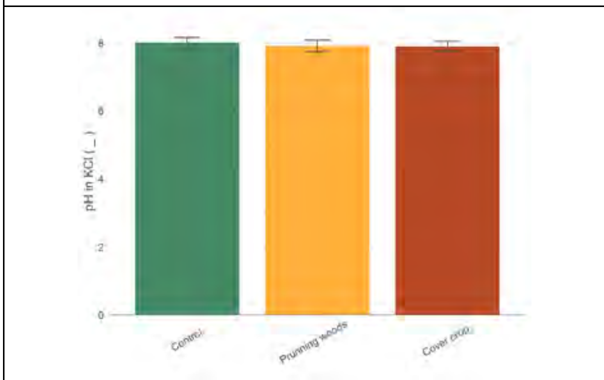


Figure 69: UAL_EX3_NSI_treat_ph_h2o



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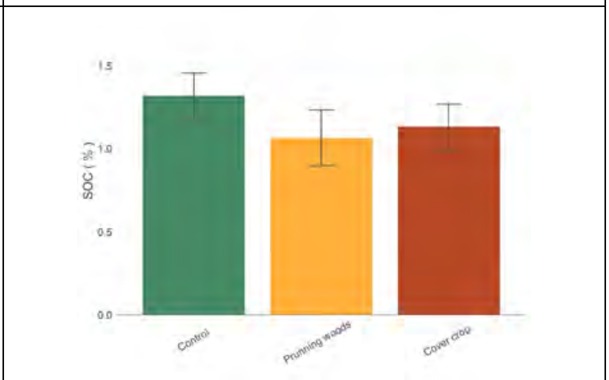

Figure 71: UAL_EX3_NSI_treat_soc

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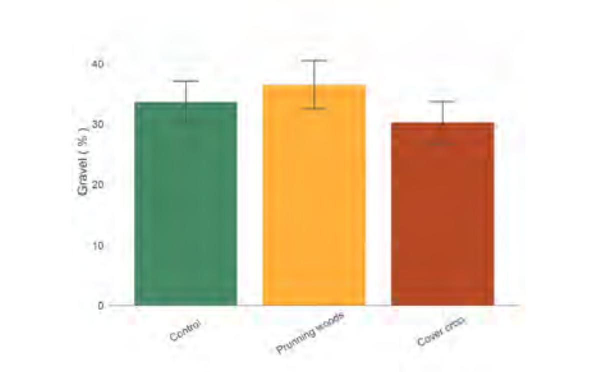

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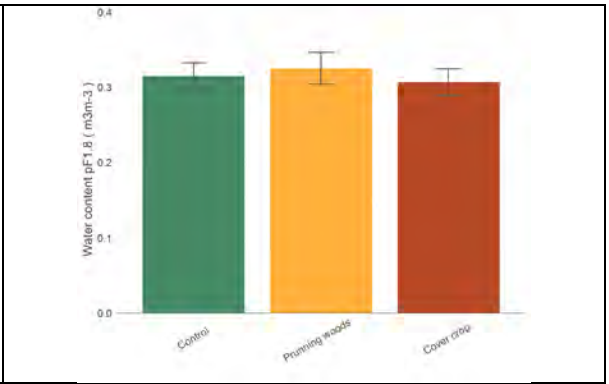

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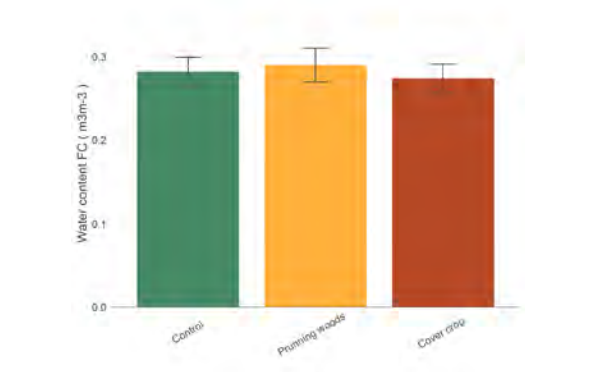


Figure 74: UAL_EX3_NSI_treat_top_wc_pf2_0

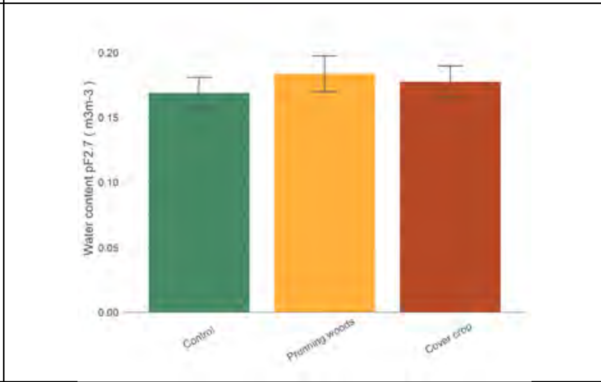
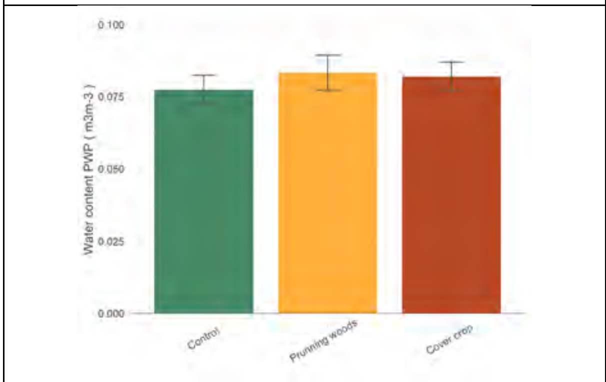


Figure 75: UAL_EX3_NSI_treat_top_wc_pf2_7



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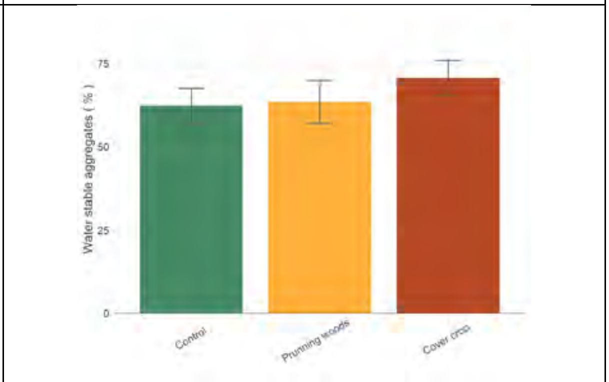

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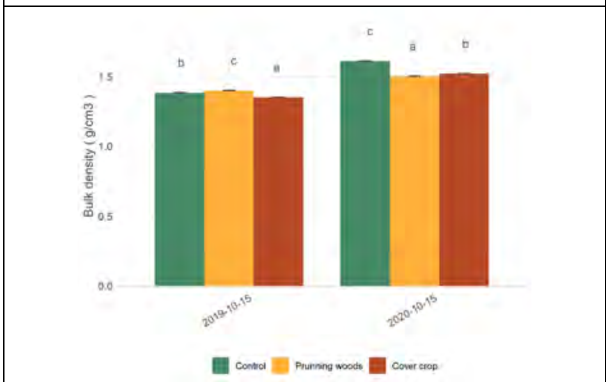
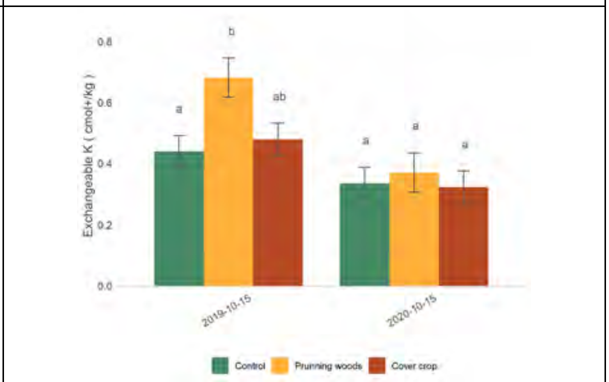


Figure 78: UAL_EX3_SI_bd_top



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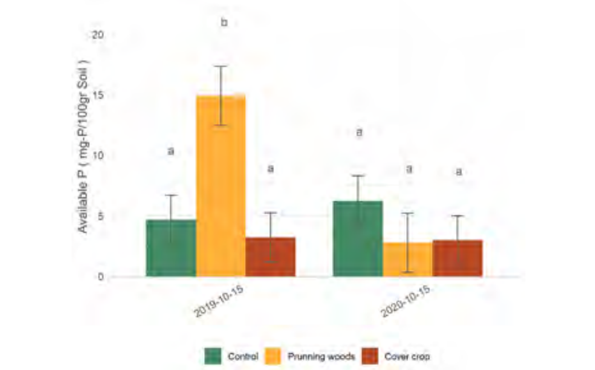	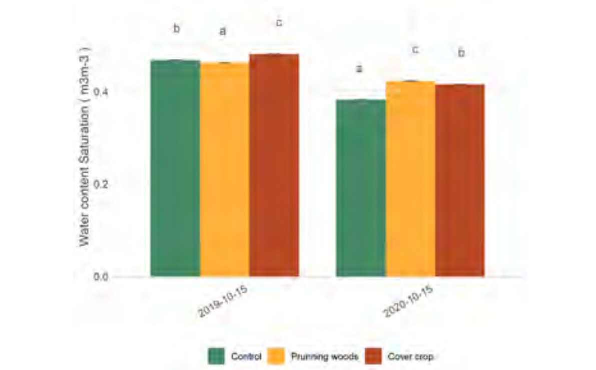
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15. Spain: Meteo Figures

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Almeria has a blended meteorological station with number 3907 in ECAD. Measurement started 1961 till Oct 2020.

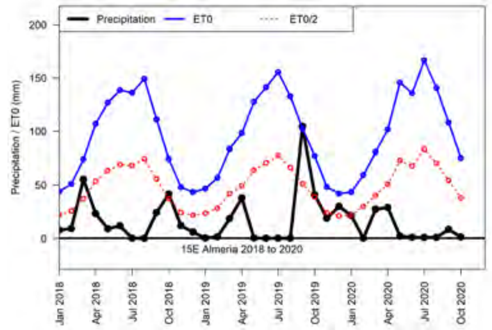


Figure 1: 15E Almeria 00aFAOgrow

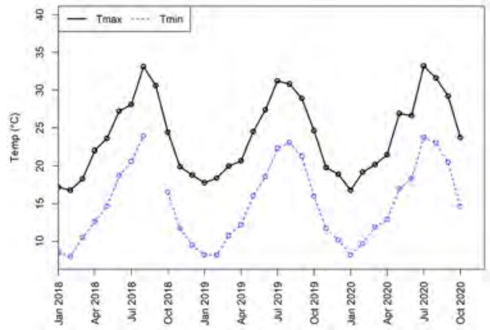


Figure 2: 15E Almeria 00b TnTx

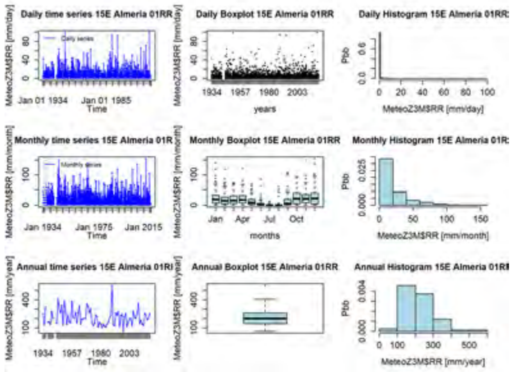


Figure 3: 15E Almeria 01RRhyplo

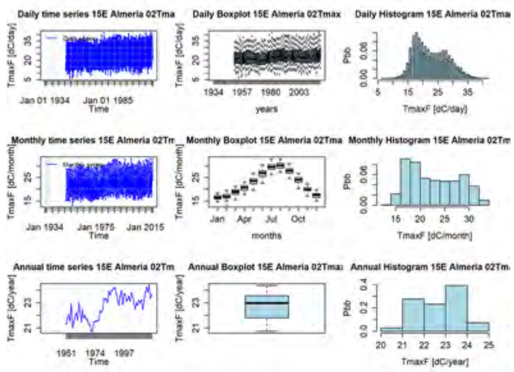


Figure 4: 15E Almeria 02Tmaxhyplo

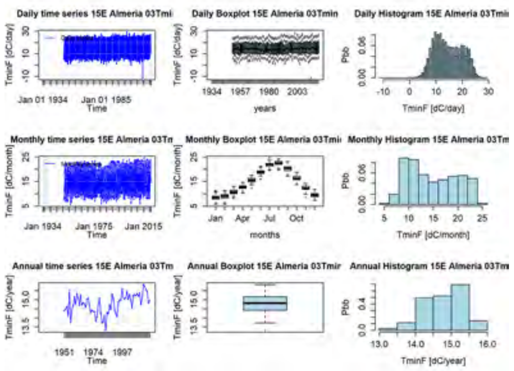


Figure 5: 15E Almeria 03Tminhyplo

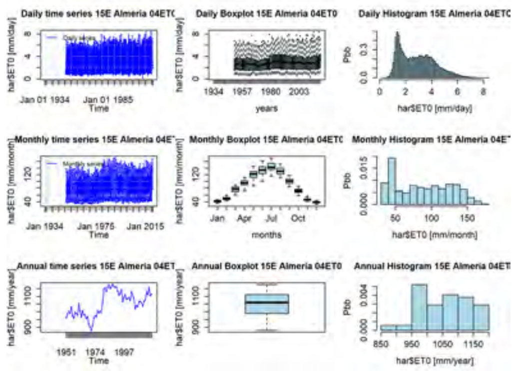


Figure 6: 15E Almeria 04ET0hyplo

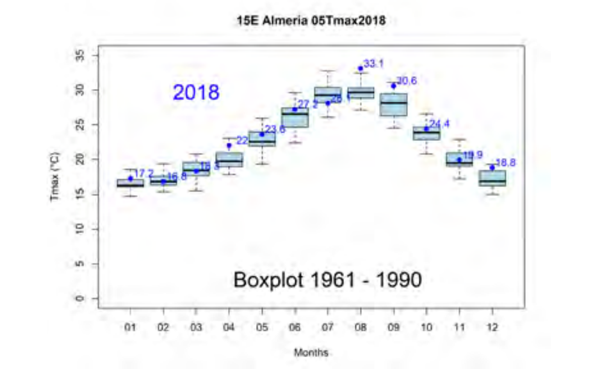


Figure 7: 15E Almeria 05Tmax2018box

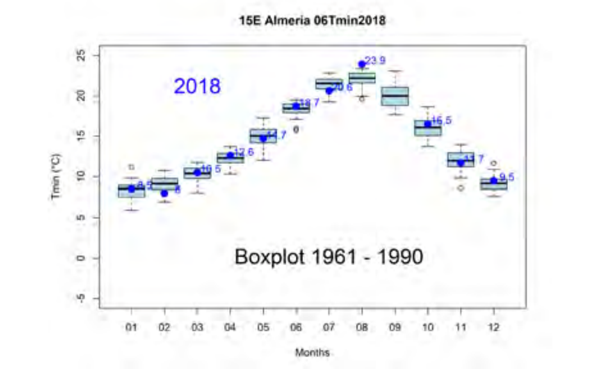


Figure 8: 15E Almeria 06Tmin2018box

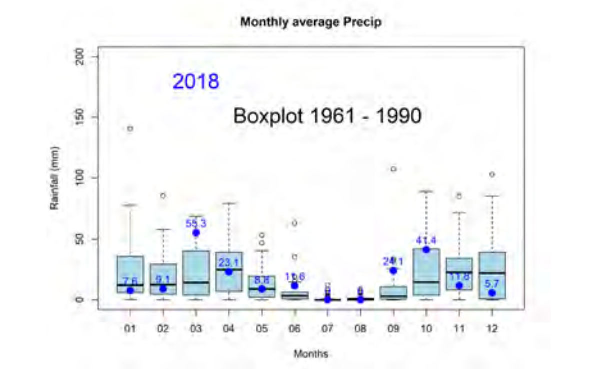
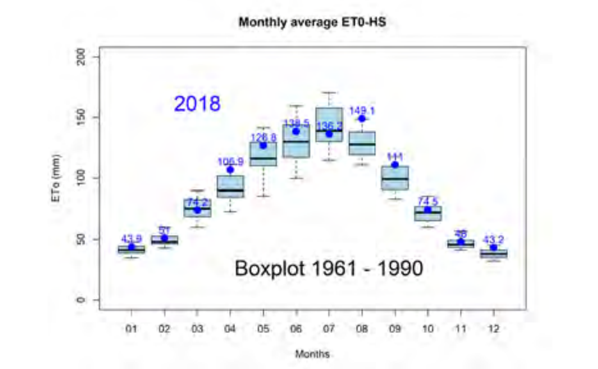


Figure 9: 15E Almeria 07Precip2018box



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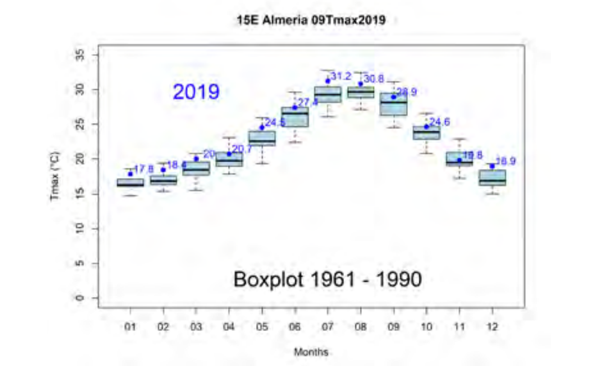

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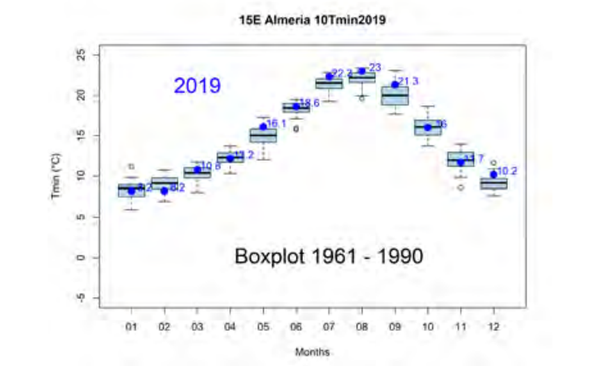

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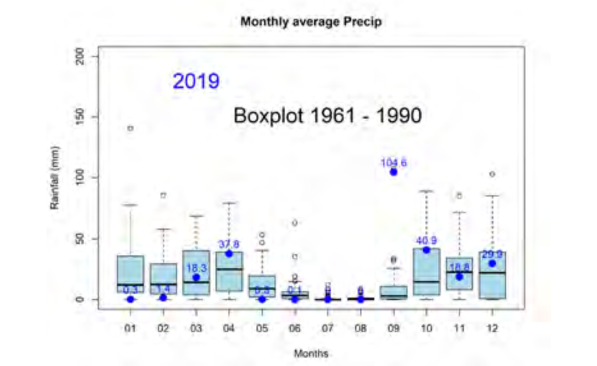
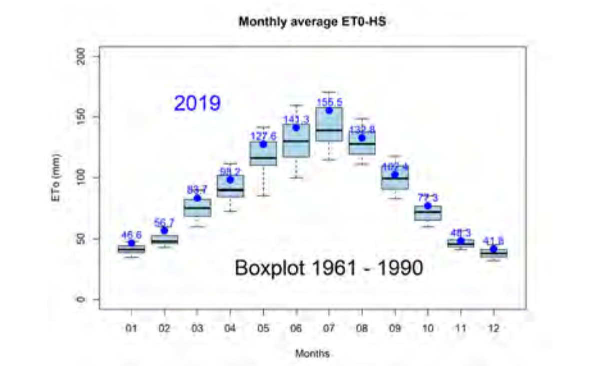


Figure 13: 15E Almeria 11Precip2019box



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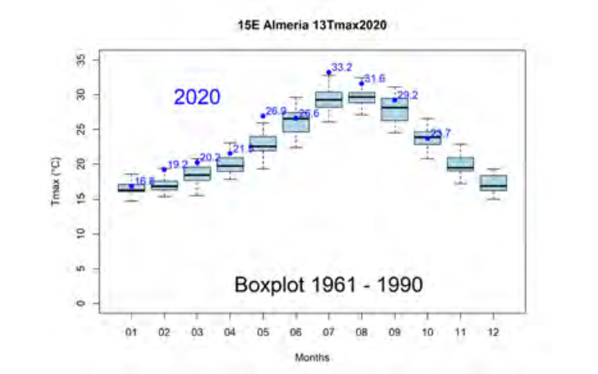

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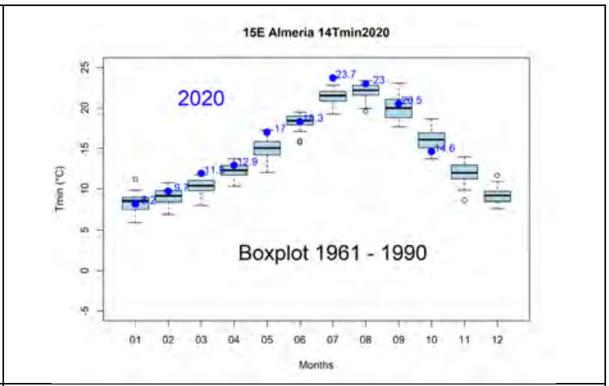

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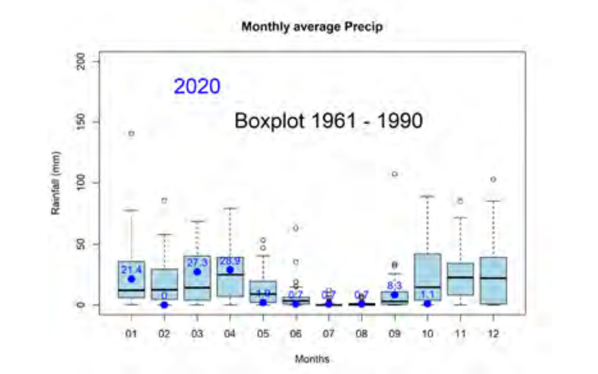


Figure 17: 15E Almeria 15Precip2020box

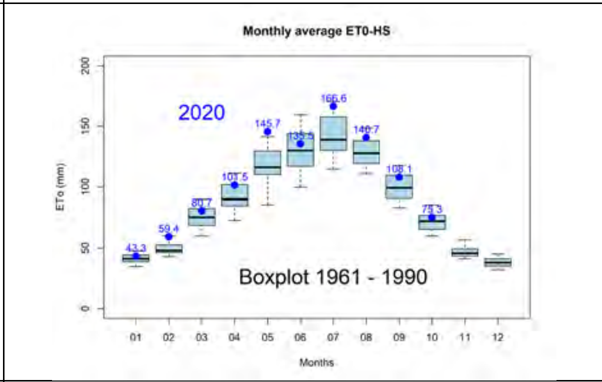
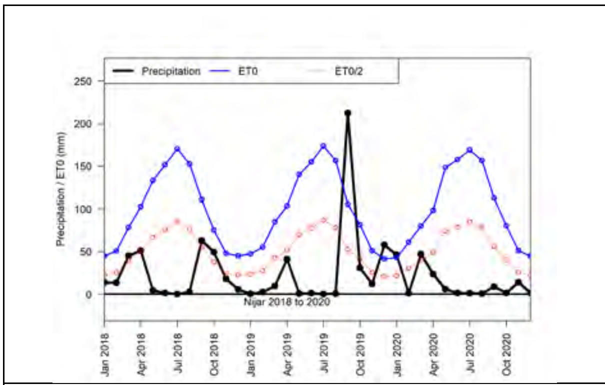


Figure 18: 15E Almeria 16ET02020box

15a Nijar

This meteo station is the closest one to the Agua Amarga experiment. Data provided by the Junta de Andalucia and can be downloaded from a website:

https://www.juntadeandalucia.es/agriculturaypesca/ifapa/riaweb/web/estaciones



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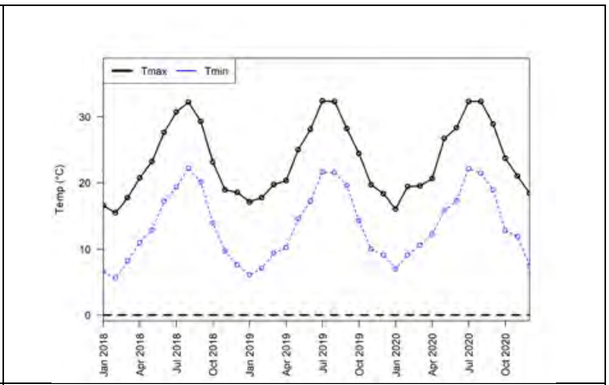

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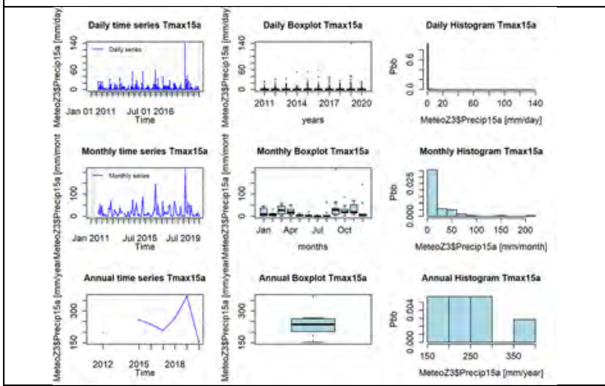

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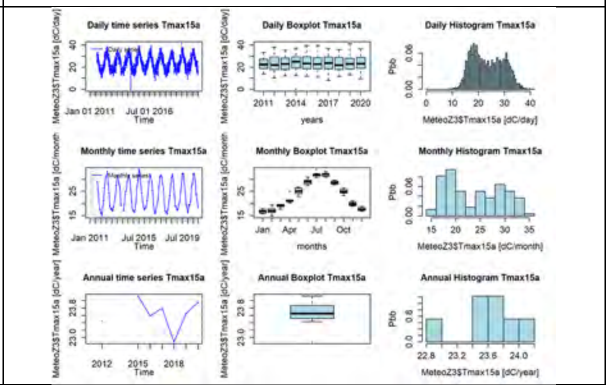

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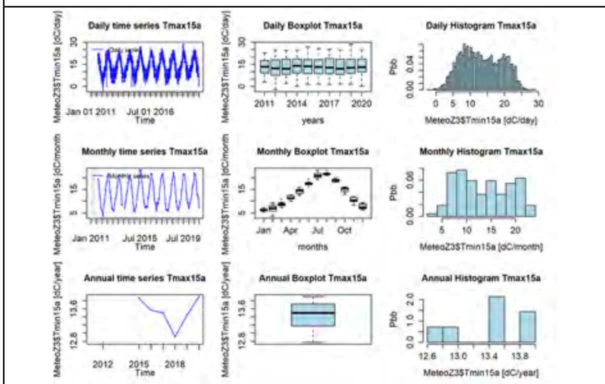

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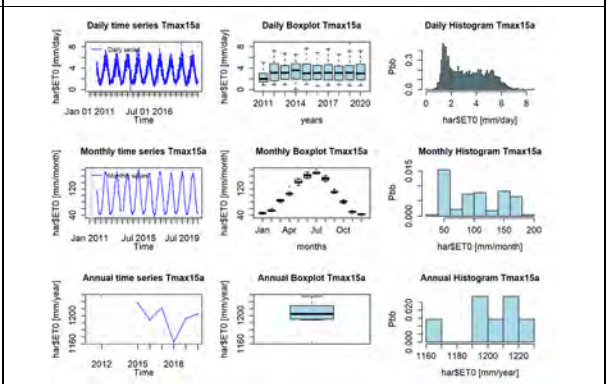


Figure 24: 15aNijar 04ET0Hyplo

15b Tabernas

This meteo station is close to the Tabernas experiment. The data provided by the Junta de Andalucia and can be downloaded from a website:

https://www.juntadeandalucia.es/agriculturaypesca/ifapa/riaweb/web/estaciones

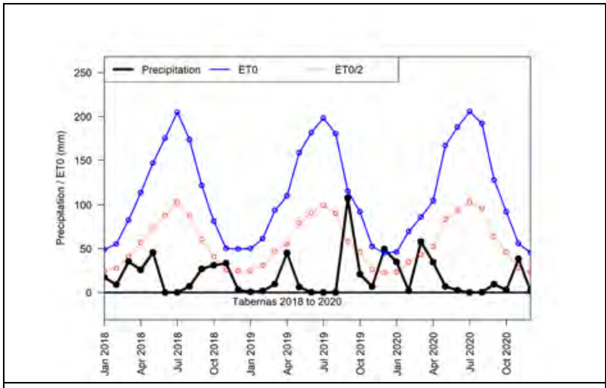
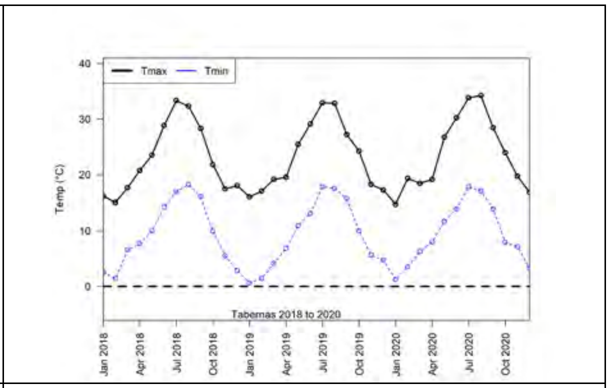


Figure 25: 15bTabernas 00aFAOgrow



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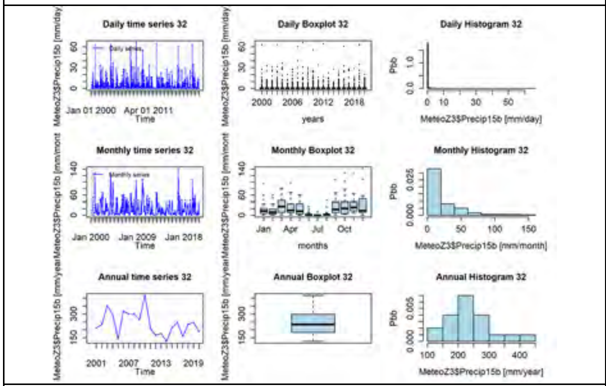


Figure 27: 15bTabernas 01PrecHyplo

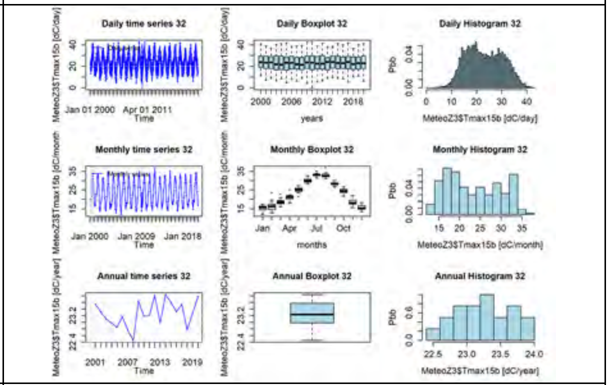


Figure 28: 15bTabernas 02TmaxHyplo

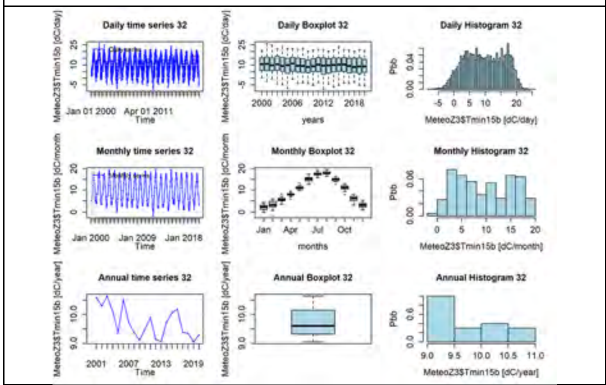
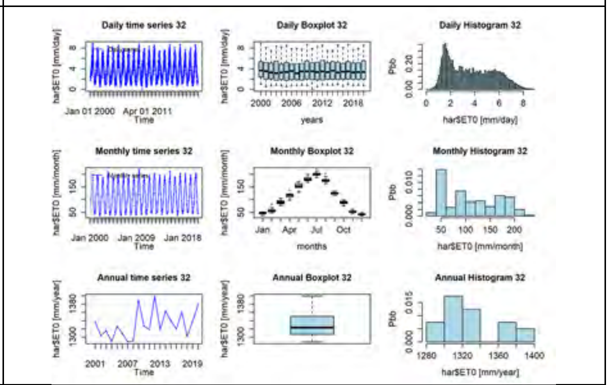


Figure 29: 15bTabernas 03TminHyplo



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16. France: Figures from the analysis

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Experiment 1:

Table 1: Indicators measures and analysed

Observation code	Unit	Description
	Mixed model	
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
kunsat	m/s	Ksat
	Simple analysis	
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol/kg	Exchangeable K
ca2_plus	cmol/kg	Exchangeable Ca
na_plus	cmol/kg	Exchangeable Na
mg2plus	cmol/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
microb_biom_c	mg C/kg	Microbial biomass C
cu	mg/kg	Cu mg/kg EDTA
mn	mg/kg	Mn mg/kg EDTA
zn	mg/kg	Zn mg/kg EDTA
fe	mg/kg	Fe mg/kg EDTA
cec	méq/kg	CEC Metson
N_NO3_0_30_cm	kg/ha	N-NO3 (0-30 cm)
N_NO3_30_60_cm	kg/ha	N-NO3 (30-60 cm)
N_NH4_0_30_cm	kg/ha	N-NH4 (0-30 cm)
N_NH4_30_60_cm	kg/ha	N-NH4 kg/ha (30-60 cm)

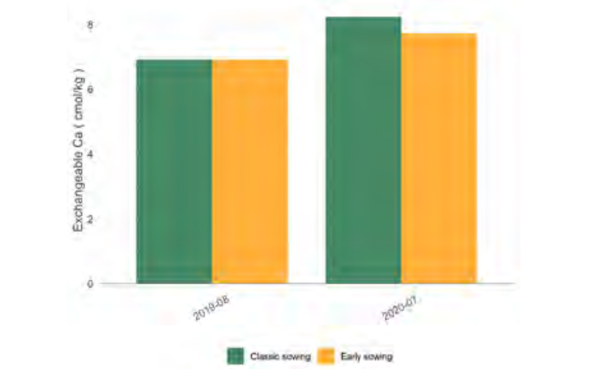

Figure 1: FRAB_EX1__ca2_plus

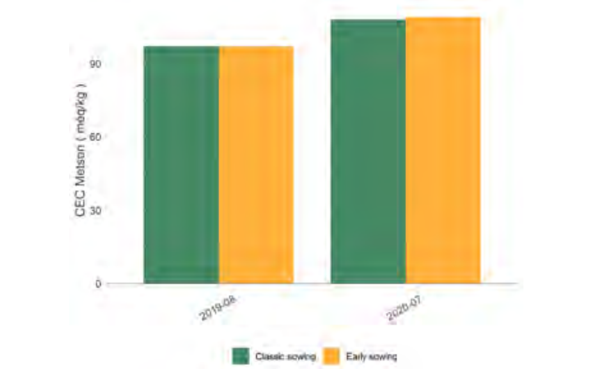

Figure 2: FRAB_EX1__cec

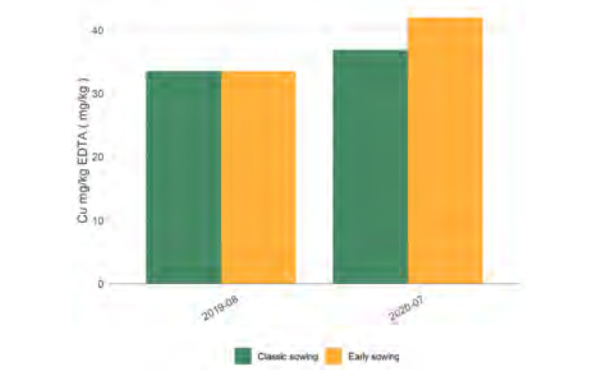

Figure 3: FRAB_EX1__cu

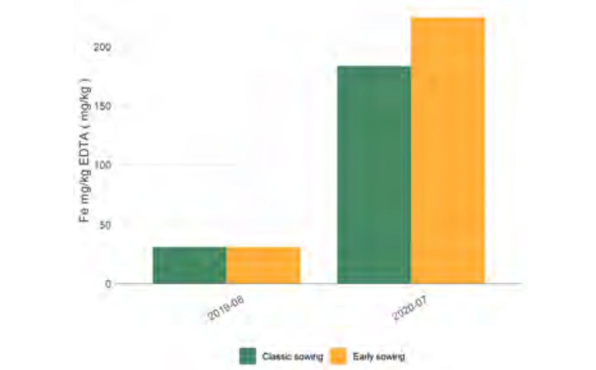

Figure 4: FRAB_EX1__fe

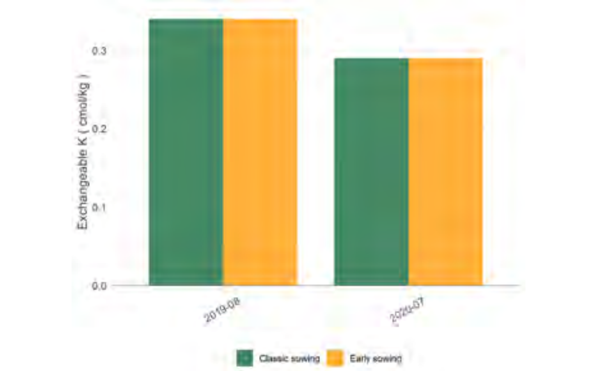

Figure 5: FRAB_EX1__k_plus

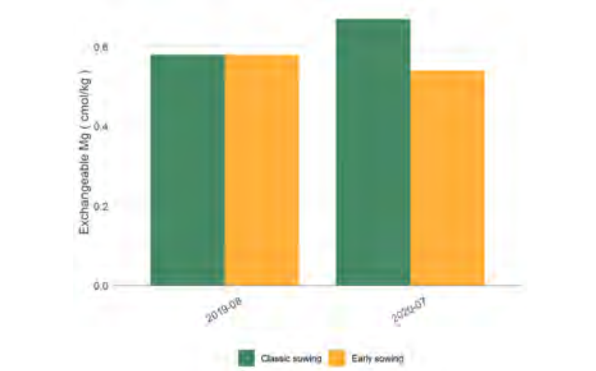

Figure 6: FRAB_EX1__mg2plus

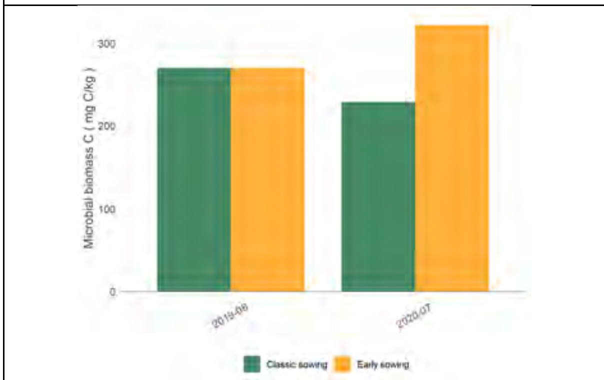

Figure 7: FRAB_EX1__microb_biom_c

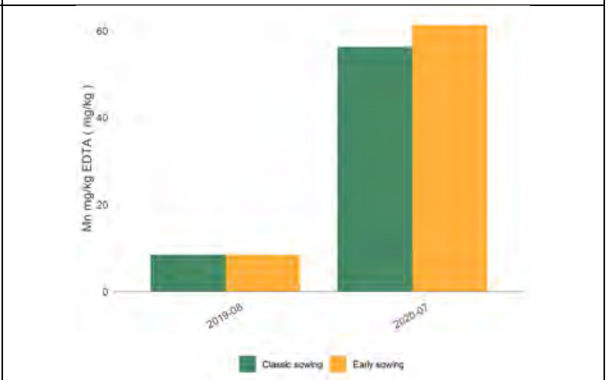

Figure 8: FRAB_EX1__mn

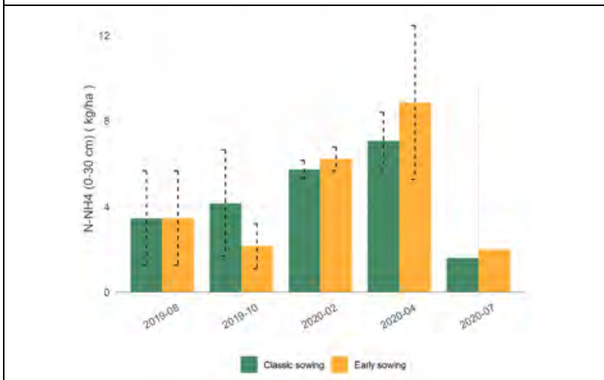

Figure 9: FRAB_EX1__N_NH4_0_30_cm

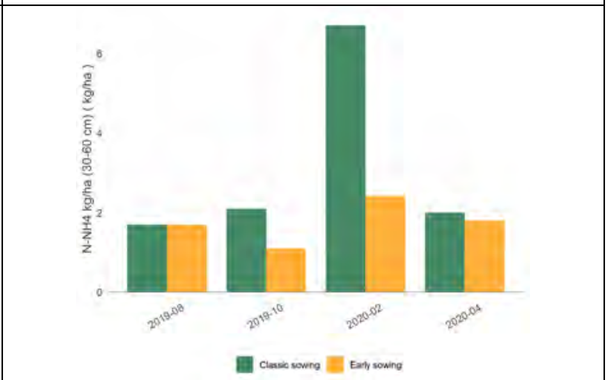

Figure 10: FRAB_EX1__N_NH4_30_60_cm

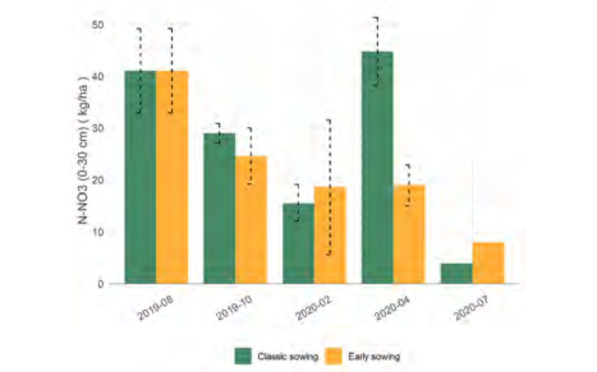

Figure 11: FRAB_EX1__N_NO3_0_30_cm

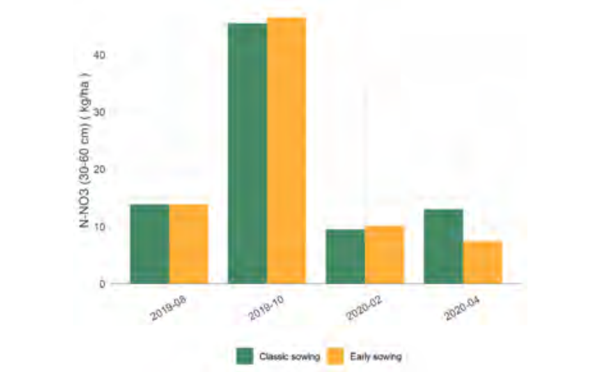

Figure 12: FRAB_EX1__N_NO3_30_60_cm

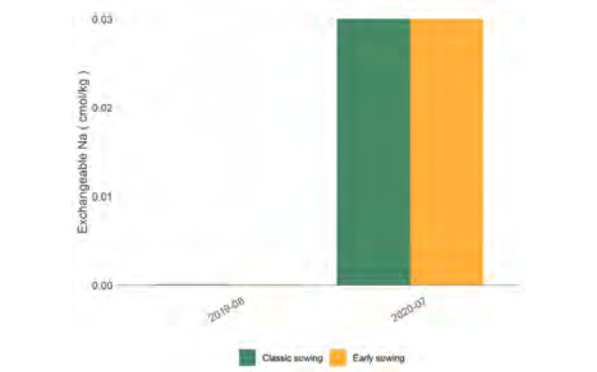

Figure 13: FRAB_EX1__na_plus

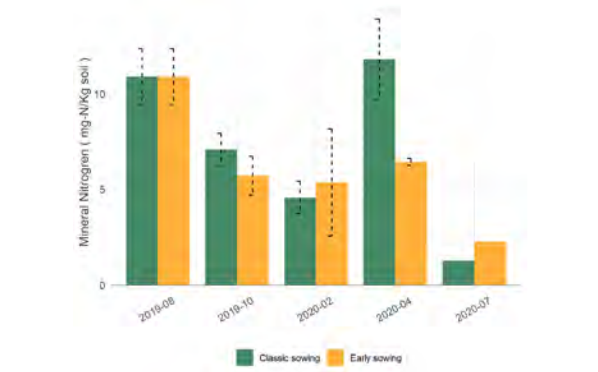

Figure 14: FRAB_EX1__nmin_top

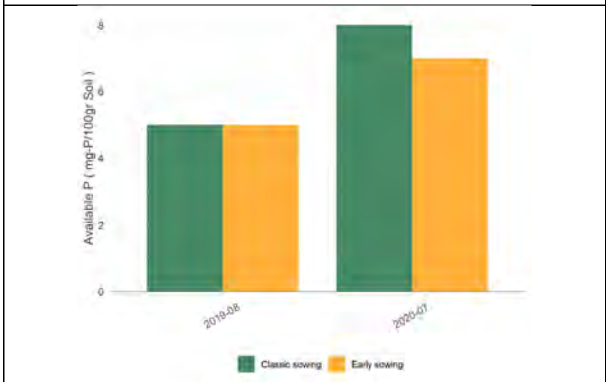

Figure 15: FRAB_EX1__p_avail

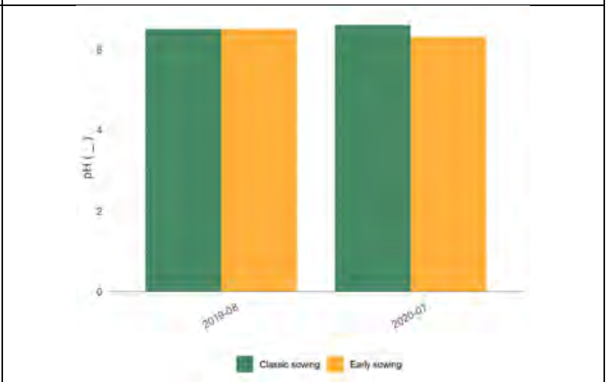

Figure 16: FRAB_EX1__ph_h2o

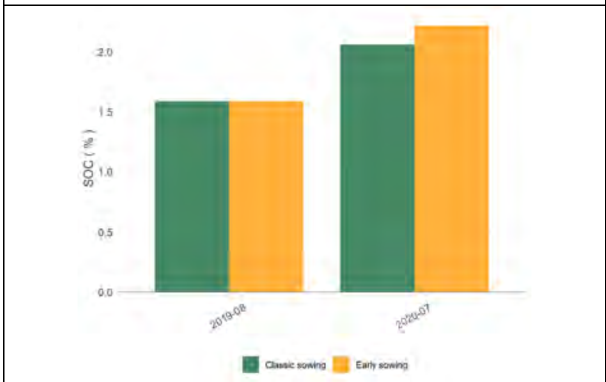

Figure 17: FRAB_EX1__soc

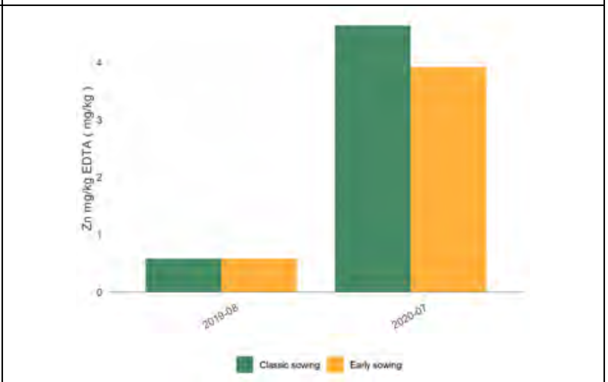

Figure 18: FRAB_EX1__zn

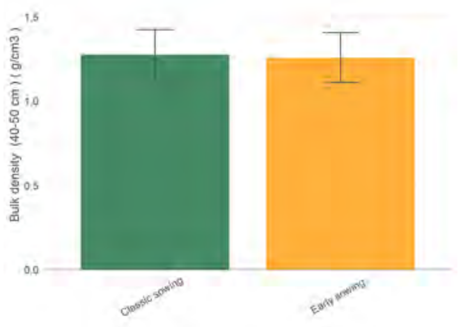	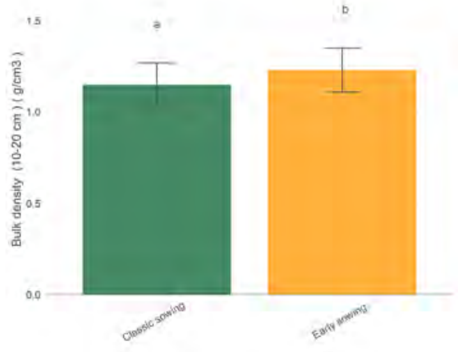
Figure 19: FRAB_EX1_NSI_treat_bd_bot	*Figure 20: FRAB_EX1_NSI_treat_bd_top*
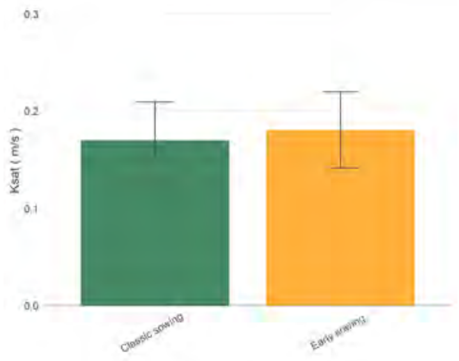	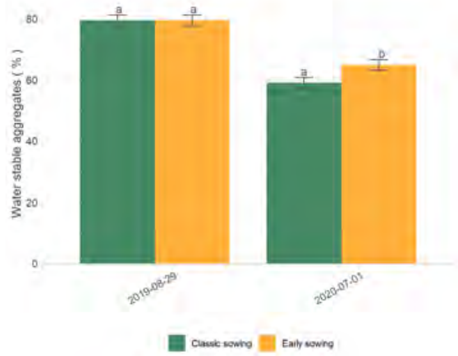
Figure 21: FRAB_EX1_NSI_treat_kunsat	*Figure 22: FRAB_EX1_SI_wsa*

Experiment 2:

Table 2: Indicators measured and analysed

Observation code	Unit	Description
Mixed model		
wsa	%	Water stable aggregates
bd_top	g/cm3	Bulk density (10-20 cm)
bd_bot	g/cm3	Bulk density (40-50 cm)
crop_yield_ha	ton DM/ha	Crop yield
kunsat	m/s	Ksat
Simple analysis		
nmin_top	mg-N/Kg soil	Mineral Nitrogen
p_avail	mg-P/100gr Soil	Available P
k_plus	cmol/kg	Exchangeable K
ca2_plus	cmol/kg	Exchangeable Ca
na_plus	cmol/kg	Exchangeable Na
mg2plus	cmol/kg	Exchangeable Mg
soc	%	SOC
ph_h2o	_	pH
microb_biom_c	mg C/kg	Microbial biomass C
cu	mg/kg	Cu mg/kg EDTA
mn	mg/kg	Mn mg/kg EDTA
zn	mg/kg	Zn mg/kg EDTA
fe	mg/kg	Fe mg/kg EDTA
cec	méq/kg	CEC Metson
N_NO3_0_30_cm	kg/ha	N-NO3 (0-30 cm)
N_NO3_30_60_cm	kg/ha	N-NO3 (30-60 cm)
N_NH4_0_30_cm	kg/ha	N-NH4 (0-30 cm)
N_NH4_30_60_cm	kg/ha	N-NH4 kg/ha (30-60 cm)

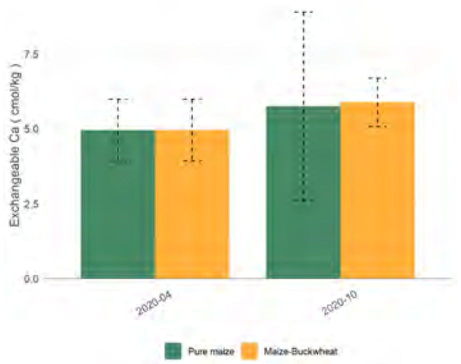

Figure 23: FRAB_EX2_ca2_plus

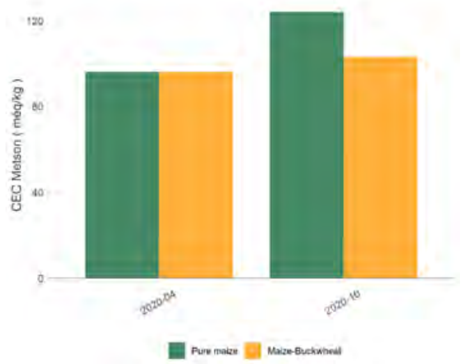

Figure 24: FRAB_EX2_cec

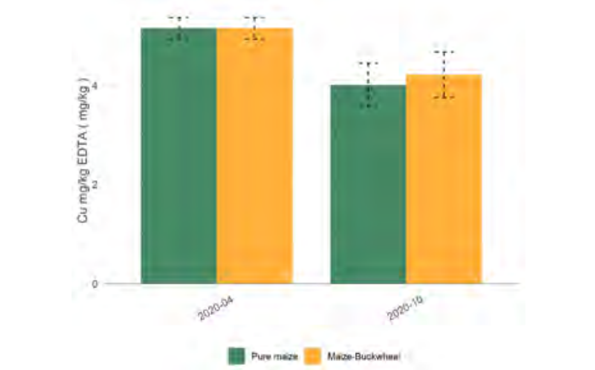

Figure 25: FRAB_EX2_cu

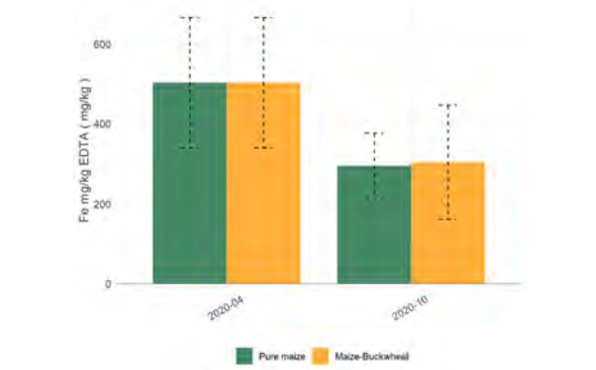

Figure 26: FRAB_EX2_fe

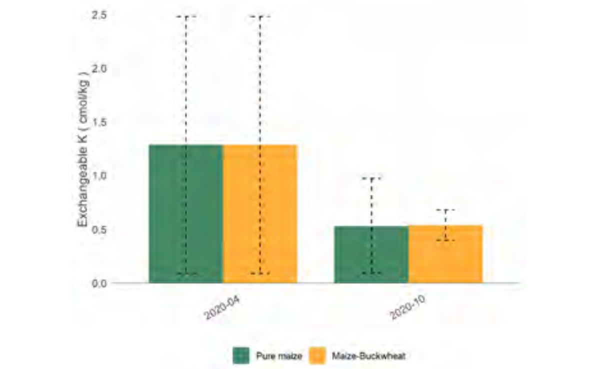

Figure 27: FRAB_EX2_k_plus

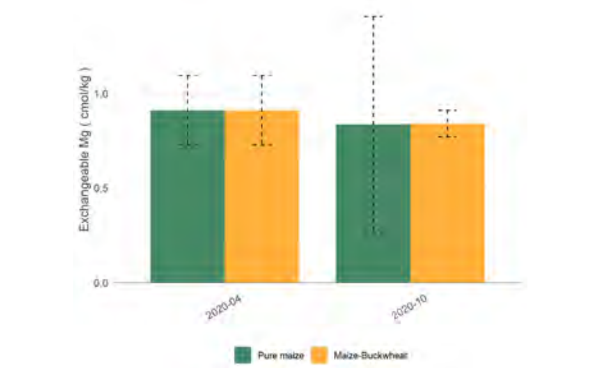

Figure 28: FRAB_EX2_mg2plus

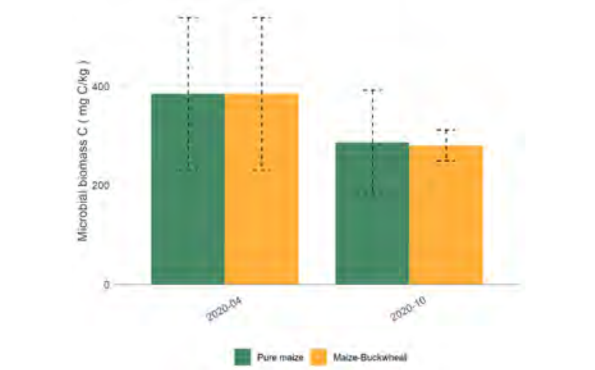

Figure 29: FRAB_EX2_microb_biom_c

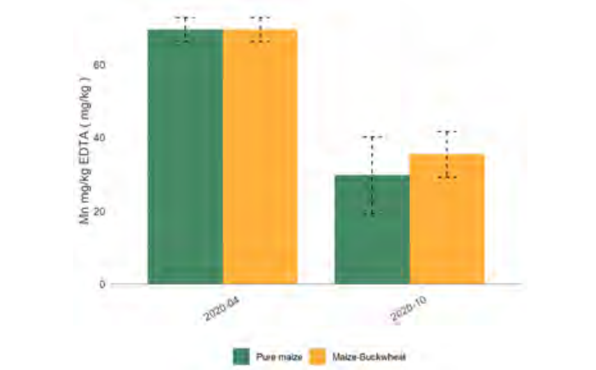

Figure 30: FRAB_EX2_mn

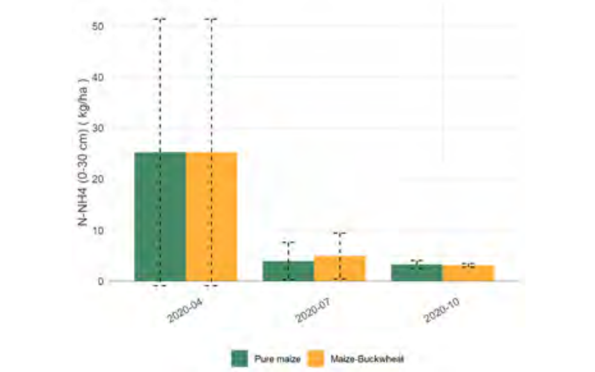

Figure 31: FRAB_EX2_N_NH4_0_30_cm

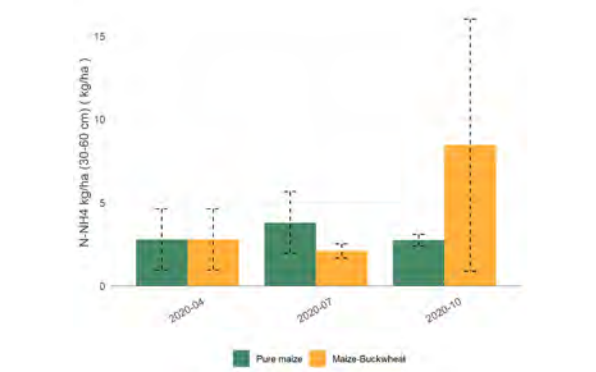

Figure 32: FRAB_EX2_N_NH4_30_60_cm

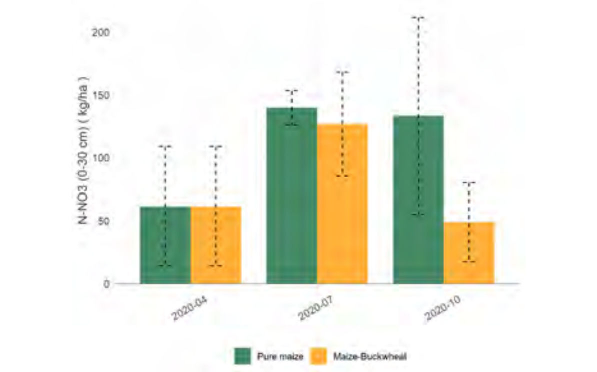

Figure 33: FRAB_EX2_N_NO3_0_30_cm

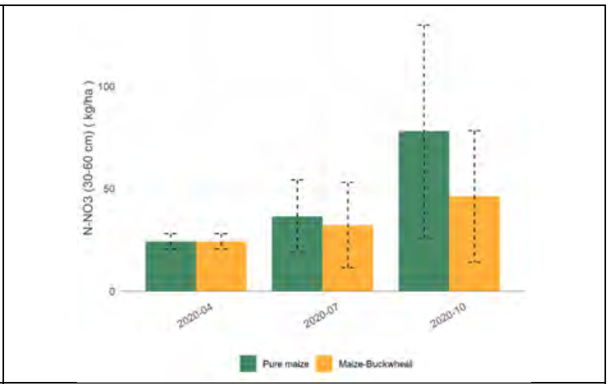

Figure 34: FRAB_EX2_N_NO3_30_60_cm

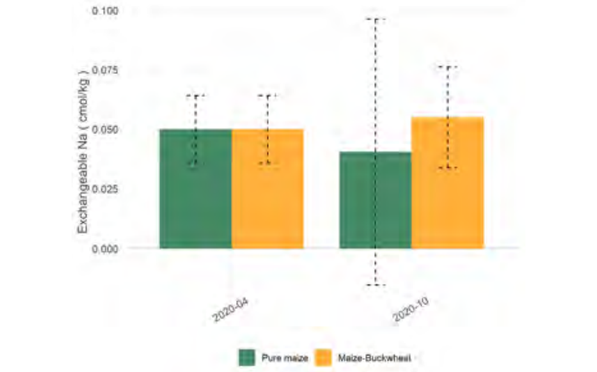

Figure 35: FRAB_EX2_na_plus

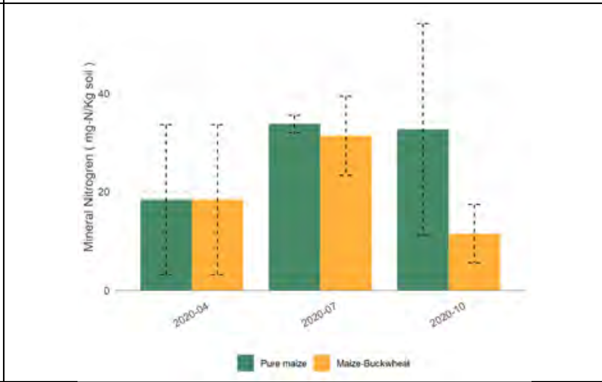

Figure 36: FRAB_EX2_nmin_top

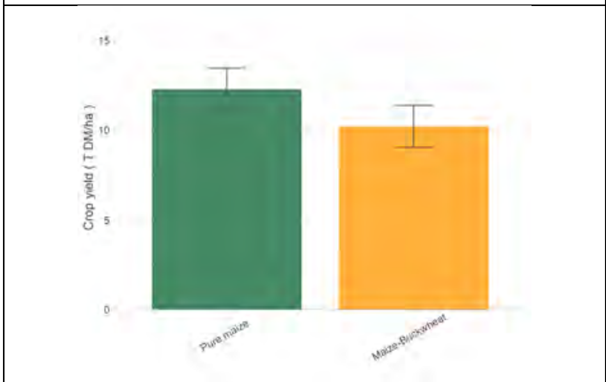

Figure 37: FRAB_EX2_NR_crop_yield_ha

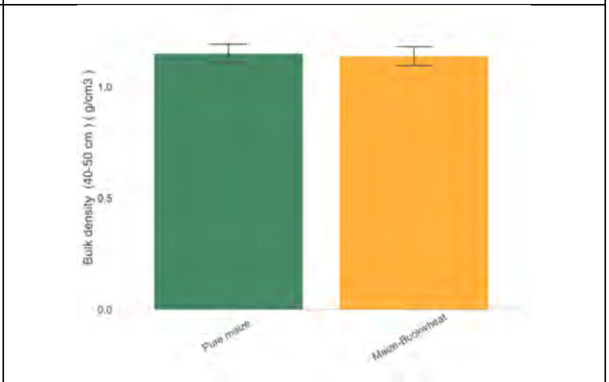

Figure 38: FRAB_EX2_NSI_treat_bd_bot

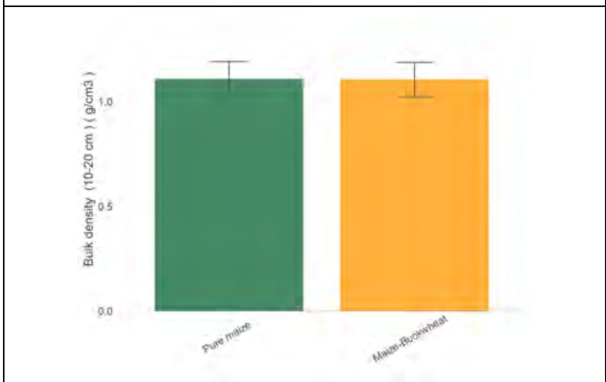

Figure 39: FRAB_EX2_NSI_treat_bd_top

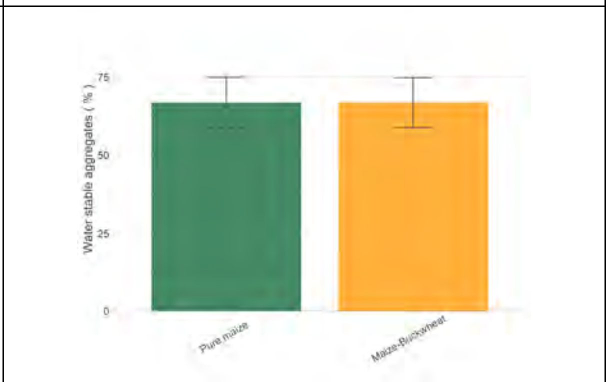

Figure 40: FRAB_EX2_NSI_treat_wsa

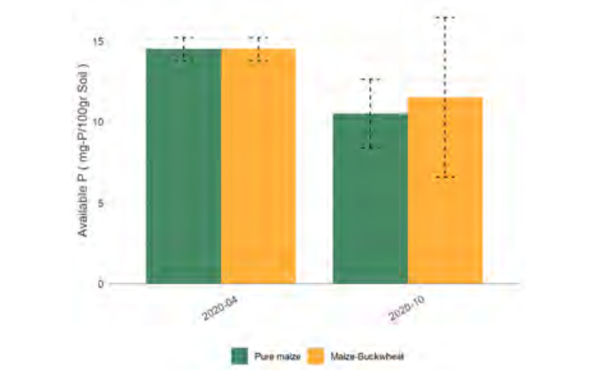

Figure 41: FRAB_EX2_p_avail

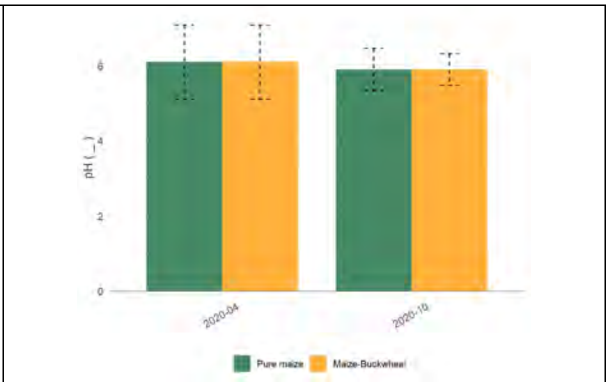

Figure 42: FRAB_EX2_ph_h2o

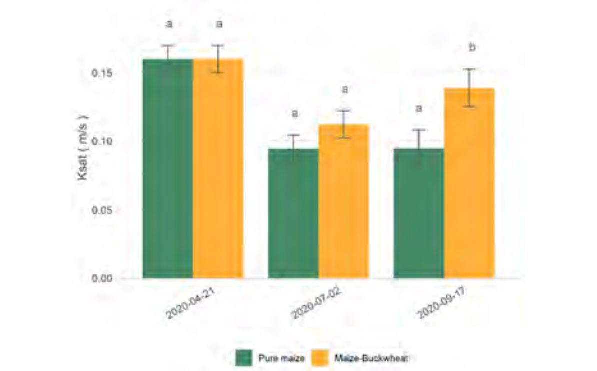

Figure 43: FRAB_EX2_SI_kunsat

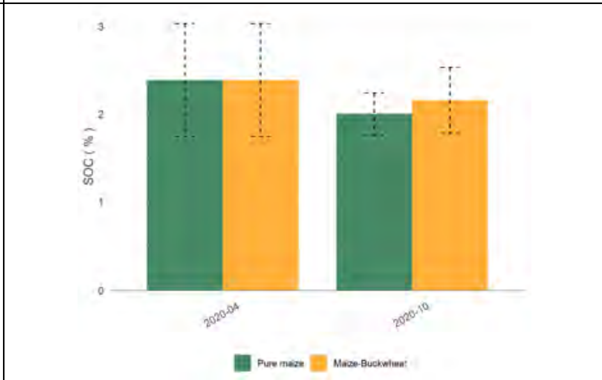

Figure 44: FRAB_EX2_soc

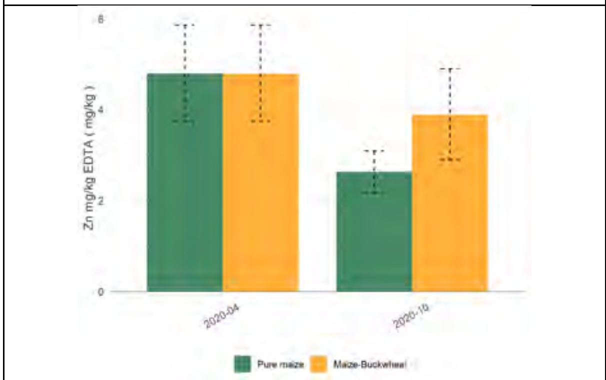

Figure 45: FRAB_EX2_zn

16. France: Figures Meteorological data

Please read the introductory part to D5.3 to understand the figures of the meteorological analysis.

List of figures

E) Rennes Saint Jacques . (ECAD 322).

This station, listed in ECAD, covers 01 November 1944 until November 2020 and the station is located at 19 km from the experiments.

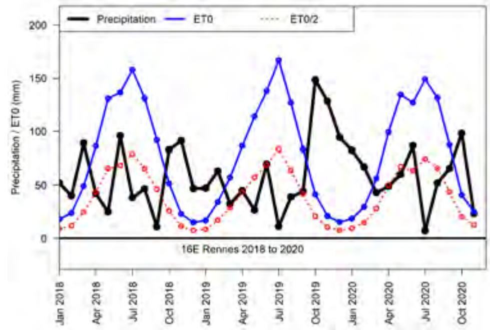

Figure 1: 16E Rennes 00aFAOgrow

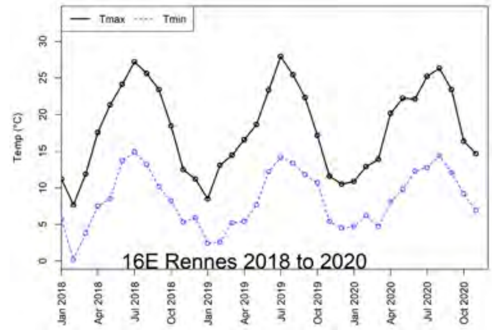

Figure 2: 16E Rennes 00b TnTx

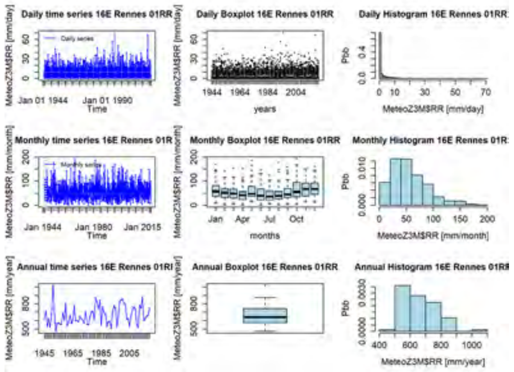

Figure 3: 16E Rennes 01RRhyplo

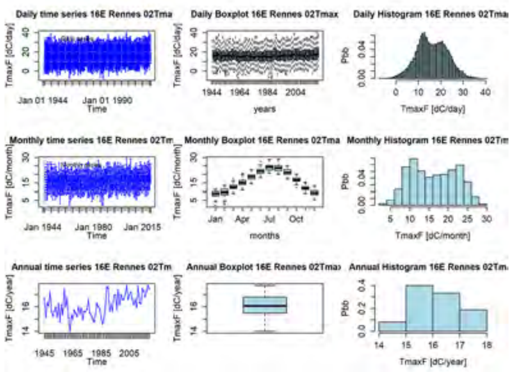

Figure 4: 16E Rennes 02Tmaxhyplo

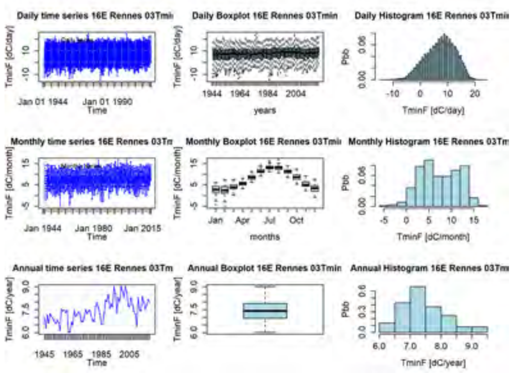

Figure 5: 16E Rennes 03Tminhyplo

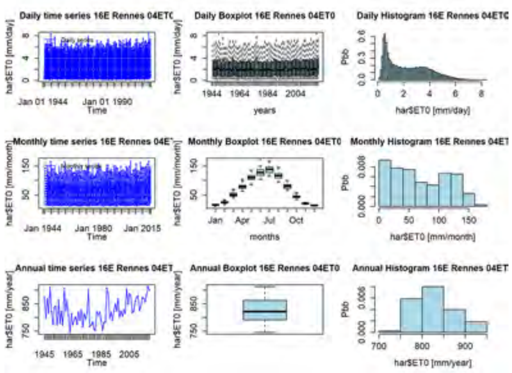

Figure 6: 16E Rennes 04ET0hyplo

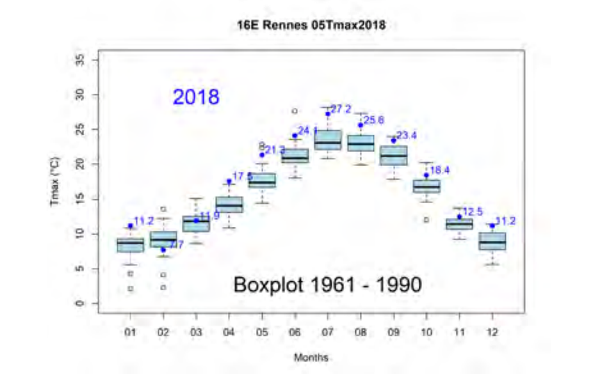

Figure 7: 16E Rennes 05Tmax2018box

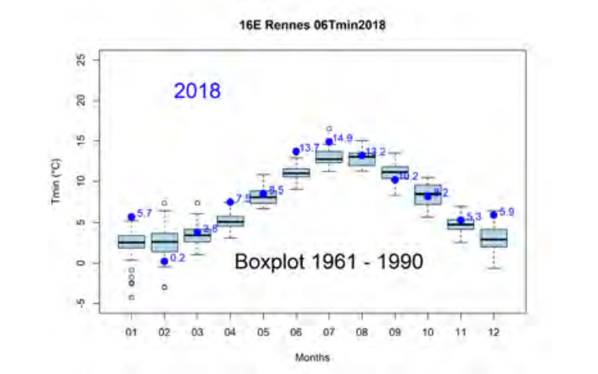

Figure 8: 16E Rennes 06Tmin2018box

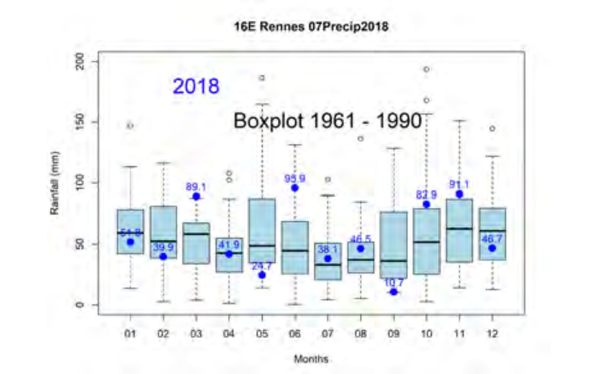

Figure 9: 16E Rennes 07Precip2018box

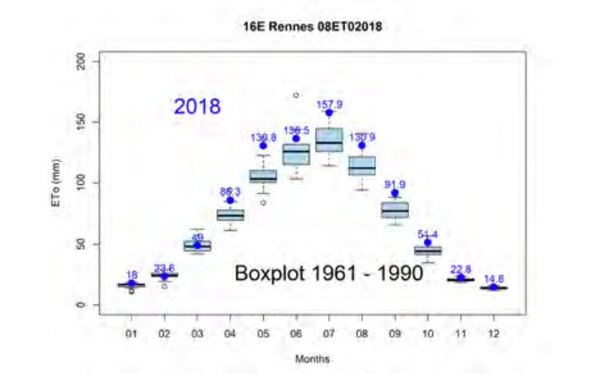

Figure 10: 16E Rennes 08ETO2018box

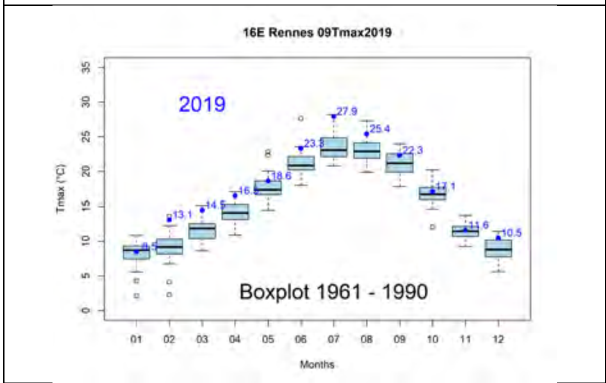

Figure 11: 16E Rennes 09Tmax2019box

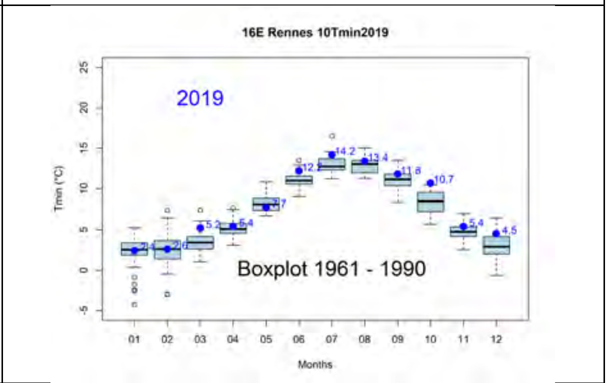

Figure 12: 16E Rennes 10Tmin2019box

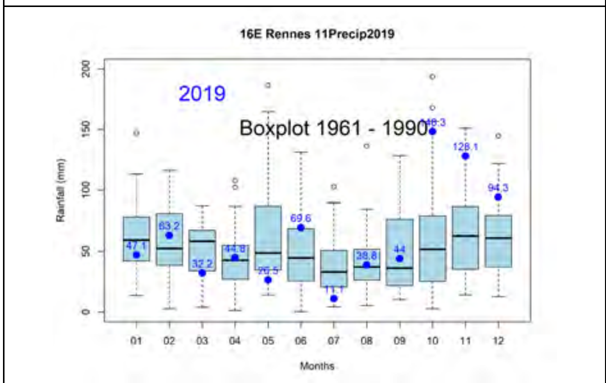

Figure 13: 16E Rennes 11Precip2019box

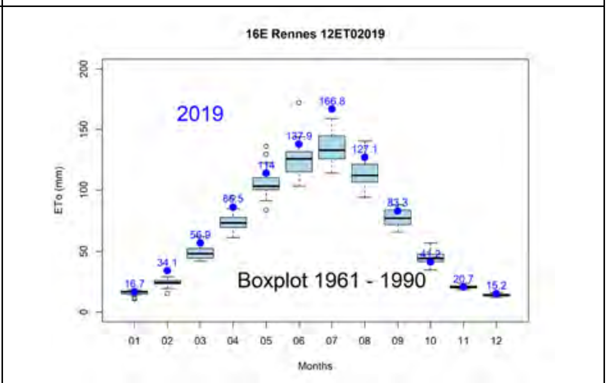

Figure 14: 16E Rennes 12ETO2019box

SOILCARE FOR PROFITABLE AND SUSTAINABLE CROP PRODUCTION IN EUROPE

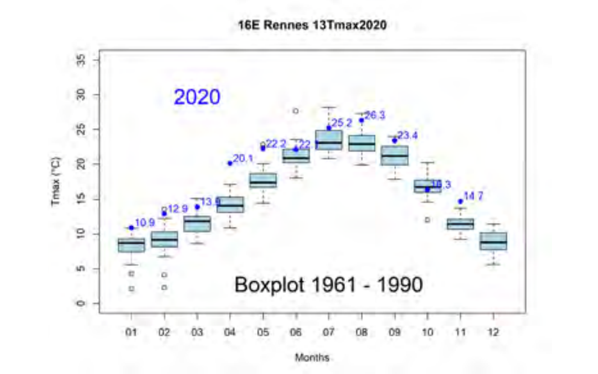

Figure 15: 16E Rennes 13Tmax2020box

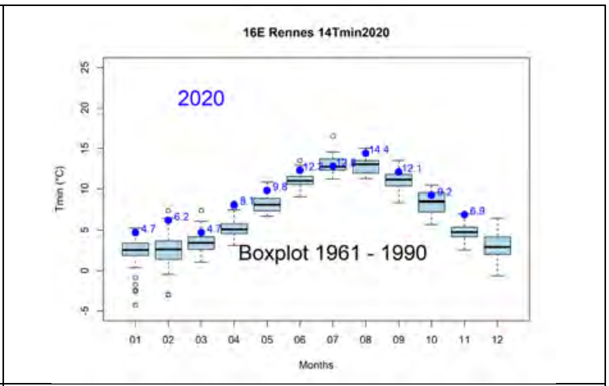

Figure 16: 16E Rennes 14Tmin2020box

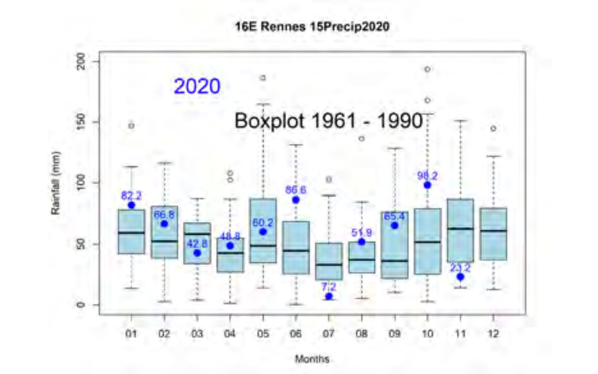

Figure 17: 16E Rennes 15Precip2020box

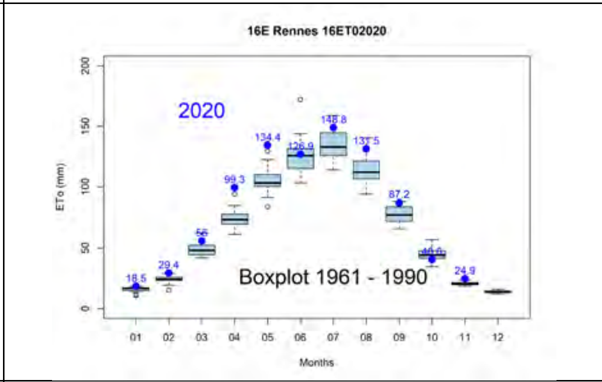

Figure 18: 16E Rennes 16ET02020box