iSQAPER task WP 3.3. Soil quality indicators

Influence of soil type and land management on chemical, physical and biological soil parameters assessed visually and analytically.

Output of EU project iSQAPER, work package 3, task 3.

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Summary

Soil quality is one of the most important components of environmental quality and is often defined as "the capacity of a soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994; Doran and Parkin, 1996). Keeping the soil in a 'good condition' is essential for crop and livestock production, but also for other ecosystem services like water quality. Soils often react slowly to changes in management and land use and therefore it is difficult to detect changes in soil quality in short periods of time. Soil parameters which reflect soil quality and soil-based ecosystem services are described as "soil quality indicators".

The project "Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience (iSQAPER)" aims, amongst others, to integrate soil quality-related information and synthesize evidence for agricultural management effects provided by long-term field trials in Europe and China. This report belongs to Work-Package 3 (WP 3), task 3 of iSQAPER: the assessment of interaction of soil type, climatic zone, crop and land management to affect soil quality indicators in 10 long-term field trials in Europe.

In several tasks of iSQAPER WP 3, data of ten long-term field experiments (LTEs) in Europe were used: three trials in Switzerland (CH1, CH2 and CH3), one trial in Spain (ES4), two trials in Hungary (HU1 and HU4), two trials in the Netherlands (NL1 and NL2), one trial in Portugal (PT1) and one trial in Slovenia (SL1). In each of these LTEs, a variety of chemical, physical and biological soil parameters were measured to assess the influence of high *versus* low application rates of organic matter and/or the influence of reduced *versus* conventional tillage. A number of parameters were assessed by the LTE owners (e.g. earthworm numbers, penetration resistance), but most parameters were assessed by analysing soil samples in laboratories. In the spring of 2016, soil sampling and sample storage were done according to a standard protocol.

Minimal statistical analysis was done for the 5 Chinese LTEs. which had different fertilization treatments. Due to a lack of data available and the differences in the experimental set-up of the Chinese LTEs compared with the European LTEs, only limited analyses could be done.

The main conclusions of the data analysis of the 10 European LTEs are as follows:

- Visual soil assessment parameters like those for soil structure did not turn out as sensitive indicators. Also the tea bag test showed only minor sensitivity to reduced tillage and/or high organic matter application.
- Next to the standard analytical methods, a set of parameters was analysed by a commercial provider using Near Infrared Spectroscopy (NIRS), which is a much cheaper and faster alternative to the analytical methods. Linear Regression of the Near Infrared data and the analytical data revealed that the parameters total nitrogen (Ntot), phosphate (P-AL), total organic carbon (TOC) and acidity (pH) were appropriately determined by NIRS (R^2 ranging from 94% to 80%, respectively).
- Effects of climate zone, topography, farm type and crop type on indicator values could not be tested due to the limited number of LTEs representing these different situations. Effects of soil management, soil texture, soil layer and the LTEs as a whole on the value of the soil indicators could be tested.
- The differences in the indicator values caused by the differences in LTEs were much bigger than the differences within LTEs. Soil texture and soil layer showed an influence on the value of the indicators. In the top soil layer (0-10 cm) differences between the values of most indicators were bigger than in the layer 10-20 cm. Moreover, both soil texture and soil layer showed significant interactions with soil management for several indicators.

- Soil management had significant influence on a range of soil quality indicators. The indicators TOC, Ntot, P-AL, potash (K-AL), particulate organic matter (POM), percentage water-stable aggregates (%WSA), basal soil respiration (resp-C) and earthworm number were influenced by both tillage and organic matter input. Averaged over all LTEs, WHC was influenced by organic matter input but not by tillage. Cmic, Nmic and Bulk density were influenced by tillage but not by organic matter input.
- Combining the ability of indicators to make a distinction between LTEs as well as between management practices within an LTE, the indicators TOC, POM, P-AL, K-al and Ntot (all measured in the layer 0-10), performed the best.

1 Introduction

Soil quality is often defined as "the capacity of a soil to function within ecosystem and land use boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health" (Doran and Parkin, 1994; Doran and Parkin, 1996). This broad definition reflects in the first place the complexity of soil ecosystems, each consisting of solid, liquid and gaseous phases. But the definition also indicates that soils are used for a great variety of purposes in a multifunctional way.
Soil is considered to be a 'non-renewable' resource. Once degraded, the restoration of soil quality (and recovery of ecosystem services) is a very slow process taking several decades or even centuries. Maintaining the soil in a 'good condition' is therefore essential, not only for crop and livestock production, but also for other ecosystem services like the purification and provision of water and carbon sequestration.

The quality of a soil is measured through so-called soil quality indicators. These are chemical, physical and biological parameters that should be easily measurable, inexpensive, reproducible, highly sensitive towards soil management and threats, and well correlated with soil functions. This set of requirements for suitable soil indicators was first described by Larson (1994). Thereafter, various sets of indicator considerations and criteria appeared in literature. Bünemann et al. (2018) ranked the indicators according to the frequency with which they were proposed in various soil quality concepts. It was found that total organic matter content of the soil is most frequently used as an indicator for soil quality, followed by pH, available phosphorus and physical indicators like water storage and bulk density. They pointed out that only half of the publications on this subject fulfil the requirement of clear interpretation schemes for a given indicator.

Organic matter is often considered (one of) the most important soil quality indicator(s) since it influences, amongst others, soil structure, water infiltration, nutrient storage, soil life and cation exchange capacity (Stevenson, 1994; Weil and Magdoff, 2004). These parameters are directly related to soil functioning and ecosystem services. Since organic matter is a strong driver for various soil-based ecosystem services, it is considered a meaningful key soil quality indicator. Possible strategies to enhance the soil organic matter content are a more diverse crop rotation by, for example, including ley crops into the rotation, introduction of cover crops and the use of more organic inputs like manure or compost. Organic matter inputs are necessary to compensate for the decomposition of part of the organic matter stock in the soil each year. Also, more recalcitrant fractions of soil organic matter can contribute to stable humus formation.

Next to organic matter addition, reduced tillage can be beneficial for soil quality. During the past decades reduced tillage has become a tool to save energy and improve the quality of the soil. Research has shown that reduced tillage positively affects soil organic carbon while maintaining crop yields (Cooper et al., 2016). Non-inversion tillage is a form of reduced tillage. Loosening the upper soil layer in non-inversion tillage requires less fossil fuel than ploughing. Non-inversion tillage leaves the crop residues and applied manure in the upper layer of the soil. Although soil bulk density increases, the quality of soil pores increases, because existing pores are not destroyed by inversion of the upper 20 or 30 cm of the soil layer. Earthworms and other soil biota are more abundant under reduced tillage, since their habitat is less disturbed (Briones and Schmidt, 2017; D'Hose et al., 2018). Often water infiltration is enhanced after introduction of reduced tillage. The positive influence of reduced tillage, organic matter addition, and crop rotation was recently documented in a literature review by Bai et al. (2018) as part of WP3.2.

Organic matter quantities in soils vary with soil type. Finer textured soils under similar environmental conditions in general contain more soil organic carbon. This was found in different studies around the world (Nichols, 1984; Adhikari, 2015).

Soils often react slowly to changes in management and land use, and for this reason it is often difficult to detect changes in soil quality in short periods of time. Therefore, it is important to assess effects of management practices in the long run. Long-term experiments (LTEs) offer an ideal research platform for this purpose. It is also important to assess soil quality in a reliable and cost-effective way. The assessment of (changes in) soil quality cannot be based on one single parameter only, but should be based on a set of soil parameters that represent the complex relationships in soils, the previously described soil quality indicators.

Aim of the project and this report

Research described in this report is part of the project "Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience (iSQAPER)". Aims of iSQAPER are, amongst others, to integrate existing soil quality information with characterisations of farming systems, synthesise evidence for agricultural management effects provided by long-term field trials and to derive and identify innovative soil quality indicators. The objectives of work package 3 are divided over 4 tasks. Task 1: to critically review existing concepts of soil quality and soil health indicators. Task 2: to document existing field trials across various pedo-climatic zones. Task 3: to assess how soil type, climatic zone, topography and crop and land management interact to affect indicators of soil quality. Task 4: to screen and evaluate a range of newly developed indicators of soil quality in long-term trials.

Tasks 1 and 2 are already finished. In task 1 soil quality and related concepts were reviewed in terms of definition, assessment approaches and indicator selection and interpretation. Results of task 1 are described in Bünemann et al. (2018). Task 2 analysed effects of four paired agricultural management practices (organic matter (OM) addition *versus* no organic matter input, no-tillage (NT) *versus* conventional tillage, crop rotation *versus* monoculture, and organic agriculture *versus* conventional agriculture) on five key soil quality indicators, *i.e.*, soil organic matter (SOM) content, pH, aggregate stability, earthworms (numbers) and crop yield based on long-term experiments in Europe and China and literature review (Bai et al., 2018).

This report is the result of work conducted for task 3. Within task 3 gap-filling research was performed. Soil quality indicators were measured by a set of standard methods in LTEs across Europe and China, since only limited data is available in literature on the previously identified indicators (tasks 1 and 2). We assessed sensitivity and robustness of selected soil chemical, biological and physical indicators to organic matter addition and tillage strategy across a soil and climate gradient in Europe and China. Next to that, standard analytical operation protocols were compared with near infrared spectrometry for selected soil parameters.

2 Materials and methods

2.1 Short description of long-term experiments (LTEs)

2.1.1 European LTEs

In the spring of 2016, ten long-term field experiments (LTEs) were sampled in six European countries: Switzerland (CH), the Netherlands (NL), Portugal (PT), Spain (ES), Slovenia (SI) and Hungary (HU) (Figure 1). The selected LTEs cover three climatic zones (continental, temperate and arid, according to the Köppen classification), three management factors (tillage, fertilization, and farming system), two types of land use (arable and perennial crops), and different soil textures (Figure 2). The availability of previous assessments and the number of experimental years (ideally > 5 years) were additionally considered. The latter could not be met in PT1 (Table 1). In the Mediterranean climate, the focus was on perennial crops.

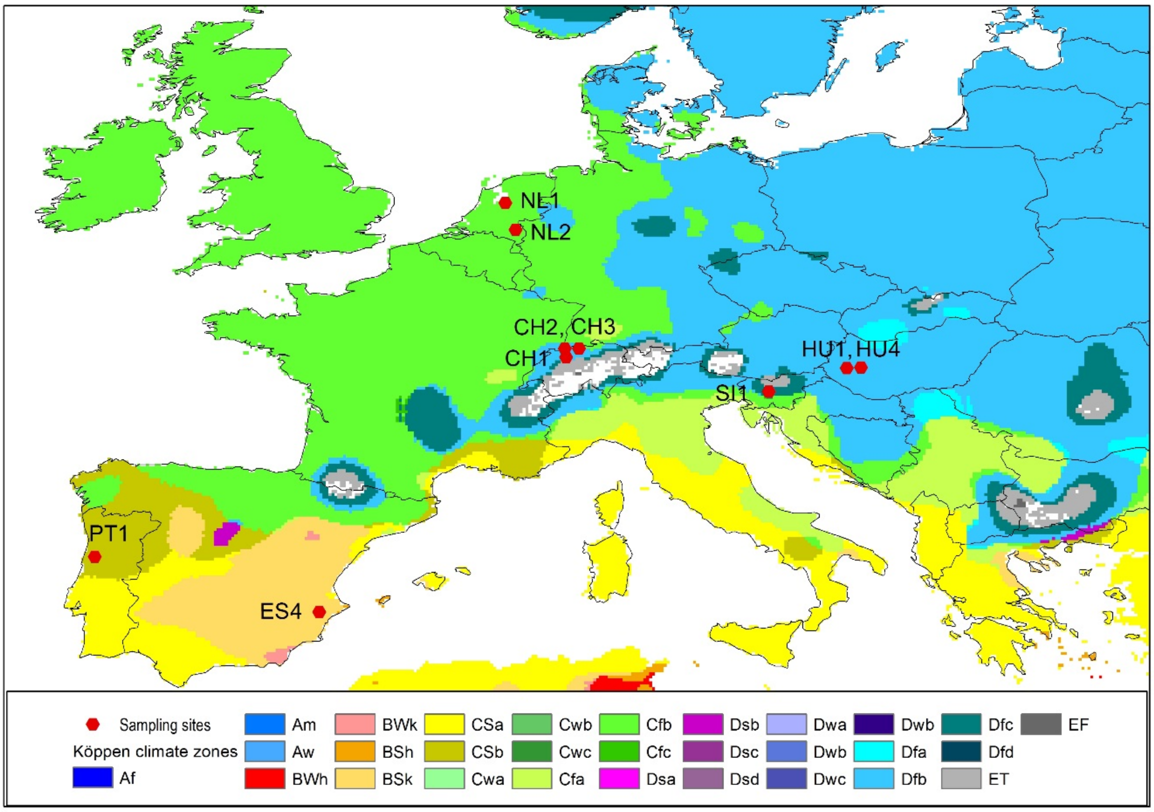

Figure 1. **Sampled long-term field experiments (red dots) and the Köppen climate zones.**

The main experimental factors investigated in the 10 LTEs were tillage and organic matter supply. Different systems were classified according to their level of fertilization by means of organic matter supply in LOW or HIGH. Some LTEs included both tillage treatments and treatments on fertilization with organic matter fertilization, while others were limited to one of the factors (Table 2 and Figure 2).

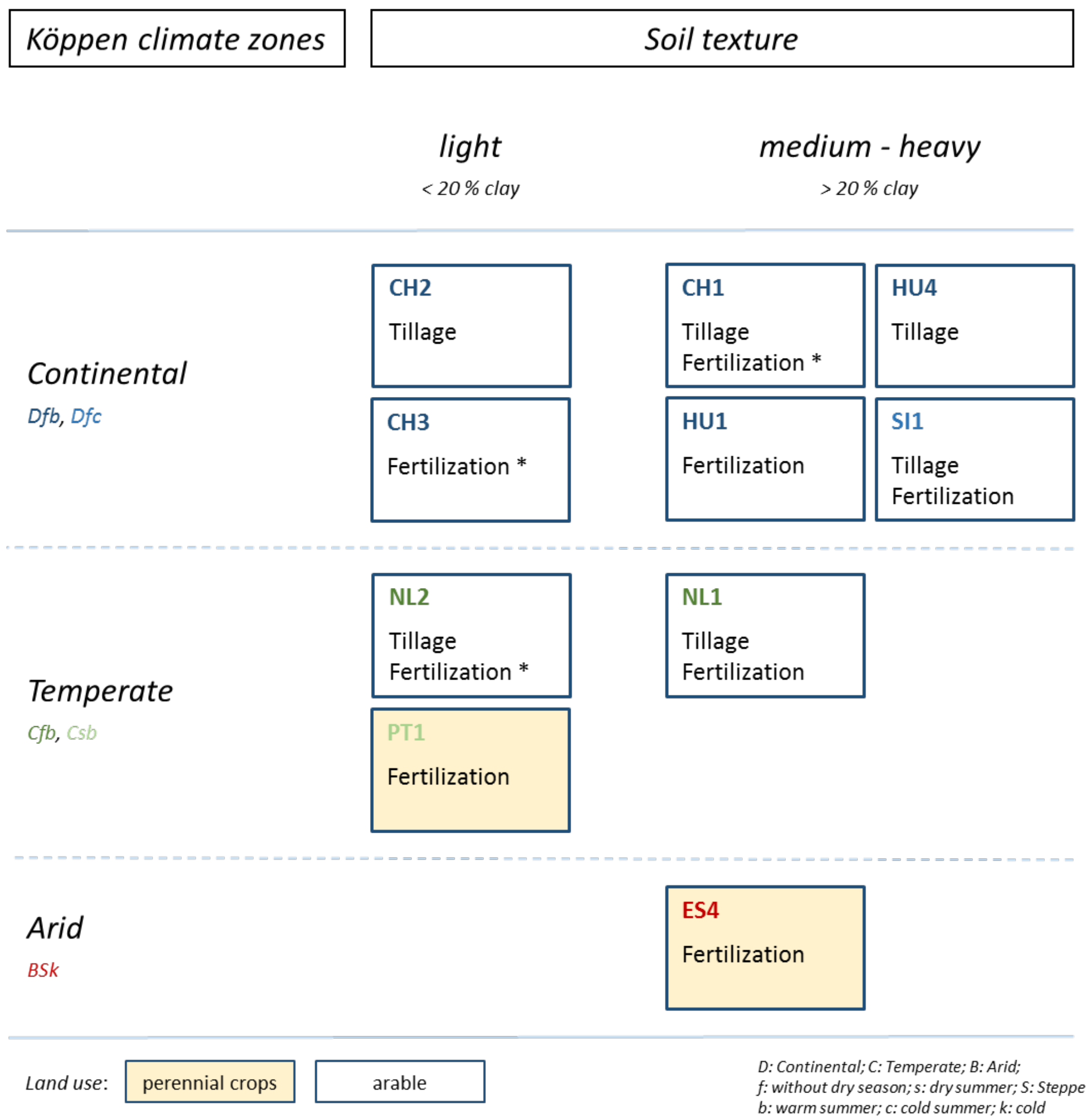

Figure 2. **Classification of sampled LTEs according to Köppen climate zones (Continental, Temperate, Arid) and soil texture (<20% or >20% clay), with additional indications on land use (see legend) and sampled trial factors (Tillage, Fertilization). * =LTEs in which fertilization is part of a farming system, either conventional or organic agriculture. CH= Switzerland, HU= Hungary, SI=Slovenia, NL= the Netherlands, PT=Portugal, ES= Spain.**

Table 1. **Location, coordinates, start year, mean annual temperature (MAT) and mean annual precipitation (MAP), soil type (World Reference Base (WRB), and crop rotation in the selected LTEs.**

LTE	Location	Coordinates	Year	Climate	Soil type (WRB)	Crop rotation	Reference
CH1 Frick	Switzer-land	47° 30' 40'' N 8° 01' 26'' E	2002	MAT: 10.3 °C MAP: 1130 mm	Vertic Cambisol	Winter wheat, maize, spelt, sunflower, rye, grass-clover, grass-clover	Krauss et al. (2010)
CH2 Aesch	Switzer-land	47° 28' 54'' N 7° 34' 46'' E	2010	MAT: 10.6 °C MAP: 992 mm	Haplic Luvisol	Silage maize, winter faba beans, winter wheat, grass-clover, grass-clover	Messmer et al. (2010)
CH3 DOK	Switzer-land	47° 30' 08'' N 7° 32' 25'' E	1978	MAT: 11.2 °C MAP: 700 mm	Haplic Luvisol with Loess	Silage maize, soybean, winter wheat, potatoes, winter wheat, grass-clover, grass-clover	Fließbach et al. (2007)
NL1 De Peel	Nether-lands	52° 27' N 05° 31' E	2008	MAT: 9.5 C MAP: 750 mm	Fluvisol	Potatoes, grass-clover, white cabbage, spring wheat, carrot, mix faba bean	Crittenden et al. (2014)
NL2 BASIS	Nether-lands	51° 32' 27'' N 5° 52' 05'' E	2001	MAT: 10.5 MAP: 775 mm	Gleyic Podzol	Potatoes, fresh peas, leek, spring barley, sugar beet, silage maize	Schrama et al. (2018)
PT1 Vitichar	Portugal	40° 26' 26'' N 8° 26' 23'' W	2013	MAT: 15 °C MAP: 1000-1200 mm	Cambisol	Grapes (permanent)	None.
ES4 Pago	Spain	38° 49' 20'' N 0° 48' 32'' W	2005	MAT: 16.3 ° MAP: 420 mm	Cambisol	Grapes (permanent)	None.
SI1 Tillorg	Slovenia	46° 02' 56'' N 14° 28' 16'' E	1999	MAT: 11.3 °C MAP: 1380 mm	Eutric Gleysol	Winter wheat, soybean, maize for grain, buckwheat	Kaurin et al. (2015)
HU1 Kertstzhely	Hungary	46° 43' 60'' N 17° 13' 49'' E	1984	MAT: 10.5 °C MAP: 683 mm	Eutric Cambisol	Maize, winter wheat, winter barley	Kismányoky und Tóth (2013)
HU4 Kerststzhely	Hungary	46° 44' 5'' N 17° 13' 47'' E	1972	MAT: 10.5 °C MAP: 683 mm	Eutric Cambisol	Winter wheat, winter wheat, maize, maize	Tóth et al. (2012)

Table 2. **Treatments, sampling depth, replicates and total number of samples per LTE. Depth= sampling depth, Repl.= number of replicates, No=total number of samples.**

LTE	Tillage	Fertilization	Depth	Repl.	No	Treatment
CH1	**CT:** inversion tillage, plough, 15-18 cm depth	manure	0-10	4	16	**CT**
	RT : non-inversion tillage, chisel plough, 5-10 cm		10-20			**RT**
CH2	**CT**: inversion tillage, plough, 18 cm depth	manure	0-10	4	16	**CT**
	RT: non-inversion tillage, chisel plough, 10 cm depth		10-20			**RT**
CH3	Inversion tillage, plough, 20 cm depth	**MIN**: NPK	0-20	4	8	**MIN**
		ORG: biodynamic, farmyard manure or composted manure				**ORG**
NL1	**CT**: inversion tillage, plough, 20-22 cm depth	**ORG**$_{-}$: organic system	0-15	3	24	**CT-ORG**$_{-}$
	RT: non-inversion tillage, chisel plough, 8-10 cm depth	**ORG**$_{+}$: organic system, additional cut-and-carry-fertilizer	15-30			**CT-ORG**$_{+}$
						RT-ORG$_{-}$
						RT-ORG$_{+}$
NL2	**CT**: inversion tillage, plough, 20-25 cm depth	**MIN**: NPK	0-10	3	24	**CT-MIN**
	RT: non-inversion tillage, chisel plough, 25 cm depth	**INT**: manure and NPK	10-20			**CT-INT**
						RT-MIN
						RT-INT
PT1	Inversion tillage, plough, 20 cm depth	**CON**: without biochar	0-20	3	9	**CON**
		ORG$_{BC}$: biochar and compost				**ORG**$_{BC}$
		ORG$_{B}$: biochar				**ORG**$_{B}$
ES4	Shallow plough in organic system	**ORG:** slurry (sheep)	0-10	3	12	**ORG**
	Inversion tillage, plough in mineral system	**MIN**: NPK	10-20			**MIN**
SI1	**CT**: inversion tillage, plough, 20 cm depth	**MIN**: NPK	0-10	3	24	**CT-MIN**
	RT: non-inversion tillage, disc harrow, 10 cm depth	**ORG**: biowaste	10-20			**CT-ORG**
						RT-MIN
						RT-ORG
HU1	Inversion tillage, plough, > 25cm depth	**CON**: without organic fertilizer **N0** (0 kg N/ha)	0-20	3	18	**CON-N0**
		ORG$_{F}$: farmyard manure **N1** (210 kg N/ha)				**CON-N1**
		ORG$_{G}$: residues + green manure				**ORG**$_{F}$**-N0**
		(1 per year) + green manure				**ORG**$_{F}$**-N1**
		(every 3 year)				**ORG**$_{G}$**-N0**
						ORG$_{G}$**-N1**
HU4	**CT**: inversion tillage, plough, 27-30 cm depth	mineral N-fertilization	0-10	4	16	**CT**
	RT: non-inversion tillage, disc harrow, 12-15 cm depth	(180 kg N/ha)	10-20			**RT**

2.1.2 Chinese LTEs

In 2017 and 2018, five long-term field experiments (LTE) were sampled in China (Figure 3). The experiments across China cover the warmer/wetter climatic zones in south China (CN1, CN4), the moderate zone in central China (CN7) and the cold zone in north-eastern China. The LTEs were selected to cover two climatic zones (temperate and cold, according to the Köppen classification) and one management factor, i.e., fertilization. The availability of previous assessments and the number of experimental years (ideally > 5 years) were additionally considered. The selected LTEs cover a range of soil types and crop rotations (Table 3).

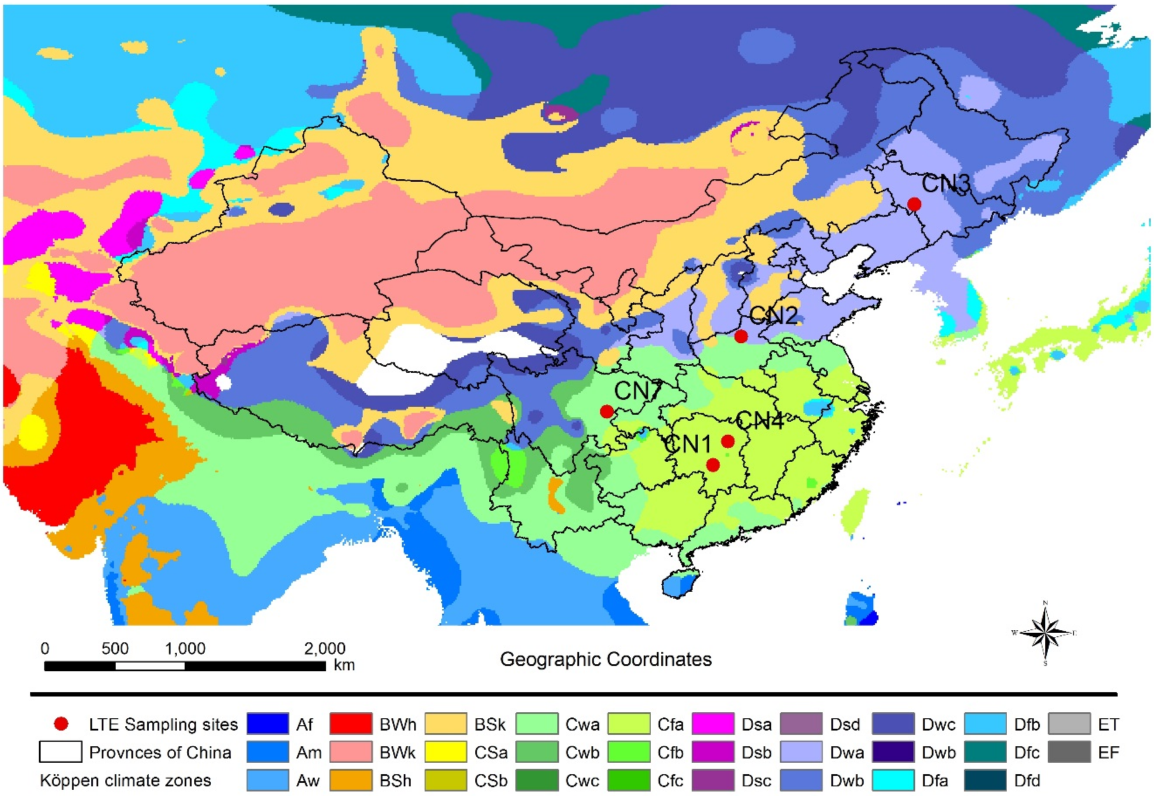

Figure 3. **Sampled long term field experiments in China (red dots) and the Köppen climate zones.**

Table 3. **Location, coordinates, start year, mean annual temperature (MAT) and mean annual precipitation (MAP), soil type (World Reference Base (WRB)), and crop rotation in the selected LTEs.**

LTE	Province	Coordinates	Year	Climate	Soil type (WRB)	Crop rotation	Soil texture % clay	Reference
CN1 Qiyang	Hunan	26° 45' 12" N 111° 52' 32" E	1990	MAT: 18 °C MAP: 1255 mm	Lixisols-Acrisols	Maize, wheat	61.4	Xu et al., 2015
CN2 Zhenhou	Henan	35° 0' 29" N 113° 41' 48" E	1990	MAT: 14.5 °C MAP: 615 mm	Fluvisols-Leptosols	Maize, wheat	29.3	Xu et al., 2015
CN3 Gongzhuling	Jilin	43° 30' 23" N 124° 48' 34" E	1989	MAT: 5 °C MAP: 590 mm	Kastanozems-Chernozems	Maize	31	Xu et al., 2015
CN4 Wangcheng	Hunan	28° 16' 19" N 112° 50' 30" E	1981	MAT: 17 °C MAP: 1370 mm	Anthrosols	Early rice, late rice	38.4	Xu et al., 2015
CN7 Suining	Sichuan	30° 10' 50" N 105° 3' 26" E	1981	MAT: 18.5 °C MAP: 927 mm	Fluvisols-Leptosols	Rice, wheat	28	Xu et al., 2015

All Chinese LTEs have comparable fertilisation treatments, about 10 treatments per LTE, varying from no fertiliser at all to fertilisation with inorganic N, P, and K with or without manure. Details of the treatments per LTE can be found in Annex 7.1. The Chinese LTEs differ in design from the European LTEs; there is no tillage component involved, and organic matter addition only to a small extent.

2.2 Management factors

Tillage treatments differed between LTEs in various intensities, but could be generally categorised in two main tillage groups, conventional tillage (CT) and reduced tillage (RT). Fertilization treatments were identified based on application of organic matter. In some trials the fertilization treatments were part of a farming system (conventional or organic), in other trials there were specific fertilization treatments. All were categorised to the management factor fertilization.

2.2.1 Tillage

For the tillage experiments a distinction was made between conventional tillage (CT) and reduced tillage (RT). Within the CT trials the soil is ploughed and inversed. Ploughing depth ranged from 15-18 cm (CH1) to 20 -25 cm (NL1) cm. In the reduced tillage (RT) application, less intensive tillage has been applied compared to conventional tillage (CT). For the different LTEs there were various non-inversion tillage applications, but in one case also shallow ploughing (ES4; < 15 cm ploughing depth) was applied. Non-inversion tillage depths in the RT treatments varied from a few cm up to 25 cm.
Three LTEs only had tillage as a management factor (CH1, CH2 and HU4). Three LTEs included also fertilization next to tillage as management factor (NL1, NL2 and SL1).

2.2.2 Fertilization

For the fertilization trials, a distinction was made between low and high input of organic matter. The qualification High and Low was given within an LTE. The plots with the higher level of organic matter supply within a LTE were qualified as HIGH and the other plots as LOW. In the LTEs with a comparison between a conventional and an organic farming system (CH3, ES4 and NL2) the conventional system was qualified as LOW, the organic system as HIGH. In general, in the plots classified as LOW, the fertilization strategy was focussed on mineral fertilizers. The plots classified as HIGH had additional sources of organic matter input compared to LOW. The extra source varied from (combinations of) manure, compost or bio-waste to mulching with straw or cover crops. Four LTEs comprised only the management factor fertilization (CH3, PT1, ES4 and HU1). Three LTEs included the management factors tillage as well as fertilization (NL1, NL2 and SL1).
In Table 4, for each LTE the crop(s) in 2016, number of plots per treatment, statistical design, number of replications, treatments and the numbers of sampled layers are presented.

Table 4. Crops, number of plots per treatment per LTE, statistical design number of replications (Nrep) treatments and number of layers measured.

LTE	crop in 2016	number of plots					design[1]	Nrep	treatment[2]	Number of layers
						total				
	tillage	conventional		reduced						
	org. mat. supply	*LOW*	*HIGH*	*LOW*	*HIGH*					
CH1	spelt	-	8	-	8	16	RBD	4	T	2
CH2	faba bean	8	-	8	-	16	RBD	2	T	2
CH3	potato	4	4	-	-	8	RBD	4	OM	1
ES4	barley	6	-	-	6	12	RBD	3	OM	2
HU1	maize	6	12	-	-	18	RBD	3	OM	1
HU4	maize	8	-	8	-	16	RBD	4	T	2
NL1	grass-clover mix	6	6	6	6	24	SBD	3	T/OM	2
NL2	potato/carrot/leek[3]	6	6	6	6	24	SBD	3	OM/T	2
PT1	vineyard	3	6	-	-	9	RBD	3	OM	1
SL1	winter wheat	6	6	6	6	24	SBD	3	T/OM	2
total		53	48	34	32	167				

[1] RBD=Randomize block design, SBD=split-plot block design.
[2] T=tillage, OM= organic matter addition, T/OM= tillage randomized over main plots, organic matter supply

randomized over subplots, OM/T: organic matter supply randomized over main plots, tillage randomized over subplots.
[3] one crop per replication

2.3 Analysed parameters and dimensions

Table 4 gives a brief overview of the soil parameters analysed for per individual LTE. More detailed description of the methods can be found in the paragraphs below.

Table 4. Overview of analysed parameters for all LTEs.

Parameter	Abbreviation	Unit	Method / Reference
Water Stable aggregates	WSA	%	
Particulate organic matter	POM	mg per gram soil	
Texture characteristics: clay, fine silt, coarse silt, total silt, sand		%	SIST ISO 11277
Total organic carbon	TOC	%	
C-total	Ctot	%	SIST ISO 10694
N-total	Ntot	%	SIST ISO 13878
pH	-	-	CaCl2 suspension
Phosphate	P-AL	mg per 100 g soil	ÖNORM L 1087
P-Olsen	Pols	mg per kg soil	SIST ISO 11263-1996
Potassium	K-AL	mg per 100 g soil	ÖNORM L 1087
Cation exchange capacity	CEC	mmolc per 100 g soil	ISO 13536:1995
Microbial biomass C and N	Cmic, Nmic	mg per kg soil	
Basal respiration	respC	µg C per hour, per g soil	
Water holding capacity (water content at field capacity)	WHC	calculated with a using the percentages clay, silt and total organic carbon in the data: $\theta FC = 0.2449 - 0.1887 * (1/(OC+1)) + 0.004527 * Cl + 0.001535 * Si + 0.001442 * Si * (1/(OC+1)) - 0.00005110 * Si * Cl + 0.0008676 * Cl * (1/(OC+1))$ with: θFC: water content at field capacity ($cm^3\ cm^{-3}$). Si: silt content (2-50 µm) (%); Cl: clay content (0-2 µm) (%); OC: organic carbon content (%).Toth et al. (2015).	
Bulk density	Bulk	g per cm^3	
Aggregate size	Aggreg	- (score 1-5)	Spade diagnosis
% Pores		%	Spade diagnosis
Structure quality	struct	- (score 1-5)	Spade diagnosis
Penetration resistance		MPa	
Teabag test		S: stabilisation factor K: decomposition rate	
Earthworms		numbers per m^2 ; weights in g per m^2	
Yield		Tons of dry matter/ha	

2.4 Soil sampling

Soil samples were collected in spring 2016 before any management activities were carried out, such as tillage or fertilization. Per plot, 20 randomly distributed soil samples were taken and combined to one composite sample. In LTEs with tillage as a management factor, two soil layers (0-10 cm and 10-20 cm) were sampled in all treatments, except for NL1 where the sampling depth was 0-15 cm and 15-30 cm. In the absence of tillage treatments, samples were taken in the 0-20 cm layer. The total number of sampled plots was 167 (Table 2). Details on the method of soil sampling can be found in Annex 7.2.

2.5 Analytical analyses

2.5.1 Soil preparation

In the lab, the composite samples were homogenized by moist sieving at 5 mm and stones, macro-fauna and coarse roots were removed. A subsample was air-dried (at room temperature) and another part was stored field-moist at 4 °C. Air-dried samples were sent to University of Ljubljana (Biotechnical Faculty, Centre for Soil Science and Environmental Protection in Slovenia) for determination of general physicochemical soil properties and to FIBL for analysis of aggregate stability and particulate organic matter. Field-moist samples were sent to the University of Trier for determination of microbial biomass and N mineralization, and to the Universidad Miguel Hernandez, Alicante, Spain for determination of soil basal respiration.

2.5.2 Water stable aggregates (WSA)

The amount of water-stable aggregates (>250 µm) was measured by a wet-sieving method (Kemper und Koch, 1966) using an apparatus designed by Murer et al. (1993). Air-dried samples were wet-sieved on steel sieves (mesh size 0.25 mm) and the water-stable aggregates and coarse fraction remaining on top of the sieve were dried overnight at 105 °C and weighed. Aggregates were then destroyed by covering this fraction for 2 h with 0.1 M sodium pyrophosphate ($Na_4P_2O_7$), followed by wet-sieving (0.25 mm). The coarse fraction remaining on top of the sieve was weighed after drying overnight at 105 °C. The aggregate stability as a percentage of water-stable aggregates was calculated as follows:

$$WSA[\%] = \frac{A - B}{IW - B} * 100$$

with *A* standing for the amount of water-stable aggregates and coarse fraction [g], *B* for the coarse fraction after aggregate destruction [g] and *IW* for the initial weight of the dried sample [g].

2.5.3 Particulate organic matter (POM)

The isolation of POM was performed after a modified method by Wyngaard et al. (2016) with a subsequent loss-on-ignition process (Wright et al., 2008). Air-dried soil samples, sieved on 2 mm, were shaken overnight with 1 M NaCl, followed by wet-sieving (63 µm). After one night in the oven by 105 °C, the samples were weighed, put in the muffle oven for 4h at 550 °C for combustion and weighed out again. The POM was calculated by the weight loss before and after the combustion and referred to the whole soil:

$$POM\left[{}^{mg}/_{g}\right] = \frac{A - B}{IW}$$

with A standing for the weight before the combustion [mg], B for the weight after the combustion [mg] and IW for the initial weight of the sample [g].

2.5.4 Particle-size distribution

The amount of clay, silt and sand were determined by sieving and sedimentation (ISO 11277:2009). Organic matter was destructed and soluble salts and gypsum were removed.

Material between 0.063 – 2 mm was wet-sieved. Material < 0.063 mm was determined by sedimentation.

2.5.5 Total C (Ctot), total organic C (TOC) and total N (Ntot)

Total N and total (organic) C were determined by an elementary C and N analysis with combustion > 950 °C by Vario Max Elemental Analyser. In case of calcareous soils, the samples were pre-treated with HCl. The ratio TOC/Clay was calculated according to Dexter et al. (2008).

2.5.6 pH

The pH was measured with a glass electrode WTW pH 538 in 0.01 M $CaCl_2$.

2.5.7 Phosphate (P-AL)

The amount of phosphate (P_2O_5) was determined by ammonium lactate extraction, according to ÖNORM L 1087.

2.5.8 Olsen P

Plant-available P was determined with a sodium bicarbonate extraction (Sims, 2000), followed by colorimetric determination of P in the filtered (Whatman 42) extracts.

2.5.9 Potash (K-AL)

The amount of potash (in this case meaning K_2O) was determined by ammonium lactate extraction (ÖNORM L 1087).

2.5.10 Cation Exchange Capacity

The measurement of potential cation exchange capacity was based on cation extraction using barium chloride solution buffered at pH = 8.1

2.5.11 Microbial biomass (Cmic and Nmic)

Microbial biomass was determined by chloroform-fumigation-extraction after Vance et al. (1987), using 0.01 M $CaCl_2$ as extractant. Concentrations of dissolved C and N in fumigated and non-fumigated subsamples were determined with a Shimadzu TOC Analyzer (V CPN E200V). Results are presented as the difference between fumigated and non-fumigated subsamples, with conversion factors of 0.45 and 0.4 for incomplete extraction of microbial biomass C (Cmic) and N (Nmic), respectively. Cmic was thereafter also used to calculate the Cmic/TOC ratio.

2.5.12 Basal soil respiration

To measure basal soil respiration (respC), moist samples (approx. 60% of WHC) were incubated at 25°C for 72 h in a thermostat bath where all the bottles were connected to the respirometer (Micro-Oxymay, Columbus, OH, USA). The CO_2 rate was determined when it stabilized at 72 h from the beginning of the incubation. respC was thereafter also used to calculate the respC/Cmic ratio.

2.5.13 Water Holding Capacity (WHC)

The water holding capacity was calculated with a formula (Toth et al., 2015) using the percentages clay, silt and total organic carbon.

$$\theta FC = 0.2449 - 0.1887 * \frac{1}{(OC+1)} * 0.004527 * Cl + 0.001535 * Si + 0.001442 * Si * \frac{1}{(OC+1)} - 0.00005110 * Si * Cl + 0.008676 * Cl * \frac{1}{(OC+1)}$$

with: θFC= water content at field capacity (cm^3 cm^{-3}).
Si= silt content (2-50 µm) (%)
Cl= clay content (0-2 µm) (%)
OC: organic carbon content (%)

2.6 Field assessments and yield

Field assessments were done by the LTE owners, according to a standardised protocol which was agreed on by the project consortium. The methods used are described below, details on the methods can be found in Annex 7.3.

2.6.1 Soil bulk density

Soil bulk density was determined with a standardized procedure for volumetric soil sampling. Therefore calibrated sample rings of 100 cm^3 volume were used to take undisturbed soil samples in one or two layers depending on tillage treatment. In the lab, the samples were dried by 105 °C and weighed. The soil bulk density was calculated as follows:

$$Bulk\ density\ [gcm^{-3}] = \frac{dry\ weight\ [g]}{ring\ volume\ [cm^3]}$$

2.6.2 Spade diagnosis

A block of soil was dug out with leaving one side undisturbed. From the undisturbed side the block was opened and broken up, by hand. This was done until it was possible to discover whether there were any distinct layers differing in structure. If so, these were analysed separately.

2.6.2.1 Aggregate size

For each defined layer, the size of soil fragments, clods and aggregates was determined by breaking up the soil into smaller pieces. This was done until the smaller structural units were present, or until breaking got harder. Clods are defined as large, hard, cohesive and rounded aggregates, more than 7 cm in size. Aggregates are defined as smaller structural units, smaller than 7 cm in size. The aggregate size was assessed as follows (Table 5):

Table 5. Explanation of classes addressed for the aggregate size.

Class	Explanation
1	Mostly large clods > 10 cm, very few aggregates < 7 cm.
2	Mostly large clods > 10 cm, less than 30% < 7 cm
3	Aggregates from 2 mm to 7 cm, less than 30% < 1 cm, some clods
4	Aggregates from 2 mm to 7 cm, no clods
5	Only < 6 mm

2.6.2.2 % Pores

The porosity is assessed for the aggregates broken apart and scored as a percentage.
Percentage pores was not assessed in CH3.

2.6.2.3 Structure quality

The structure quality is assessed by the easiness of breaking the aggregates, and it was qualitatively scored from 1 to 5. Explanation of the classes can be found in Table 6.

Table 6. **Explanation of classes addressed for the structure quality.**

Class	Explanation
1	Very compact, almost impossible to break with one hand
2	Compact, difficult to break with one hand
3	Firm, most break with one hand
4	Intact, easy to break with one hand
5	Friable, crumble with fingers

2.6.3 Penetration resistance

The penetration resistance was determined using penetrometer loggers, with different instruments used by the different LTE owners. LTE owners supplied information on the specifications of the type of device used. The soil resistance pressure was measured until 50 cm depth for every 5 cm in 10 replicates per plot. The data were averaged per depth and transformed to MPa if needed. Penetration resistance was not measured in PT1.

2.6.4 Tea bag test

The measurement of plant residue decomposition was based on decomposition of Lipton Green tea and Lipton Rooibos tea. Per plot, four tea bags of each tea type were weighed and buried 8 cm deep. After 90 days, the tea bags were recovered, dried for 48 h at 70 °C and weighed out. Based on the initial weight of the tea bags and the weight after recovering, we calculated the decomposition rate K and the litter stabilisation factor S according to Keuskamp et al. (2013). To get a more precise estimation, the content of the tea bags was combusted at 550 °C and the weight was subtracted from the content weight (Keuskamp et al., 2013).

In CH1 and CH2, fine material entered the tea bags and distorted the results. In CH2 this made that results were not usable for analysis.

2.6.5 Earthworms

Earthworms were sampled in the period that they are most active, with moist soil conditions. Earthworms were collected in sampling plots of 30x30 cm with a mixed method comprising hand sorting of the top 20 cm and irritating the earthworms that were living below 20 cm soil depth with a mustard solution (10 l per plot). Per litre, 6 g of dry powder mustard was mixed with water. In the lab, the earthworms were stored overnight at 15 °C in a jar with moist tissue, to allow them to void their guts. The earthworms were counted and weighed. Counts and weights were averaged over the different ecological groups (Bouché, 1972). When large variation was found between the replicates more plots were sampled per field.

2.6.6 Yield

The aboveground biomass was determined for all crops (including fodder crops and cover crops) at harvest. A representative area of each plot (minimum 10% of plot area) was harvested and the total fresh weight of the harvested material was recorded. A subsample of the harvested material (0.5 to 2 kg fresh weight) was weighed, dried at 60 °C for 48 h and weighed again.

2.7 Ecosystem services

To be able to predict ecosystem services and how they are influenced by either the input level of organic matter or tillage intensity, a number of the assessed parameters were selected to represent these ecosystem services. The ecosystem services considered are: 1. food, feed, fibre and biofuel production, 2. Water quality and supply, 3. Erosion control, 4. Climate regulation, 5. Pest and disease control, 6. Biodiversity conservation, based on Bünemann et al. (2018). 1 was represented by the yield (see paragraph 2.6.6), 2 was assessed by WHC and WSA (see paragraphs 2.5.2 and 2.5.13), 4 was assessed by POM and TOC (see paragraphs 2.5.3 and 2.5.5), 6 was assessed by Cmic and Nmic (see paragraph 2.5.11).

2.8 Statistical analysis

2.8.1 Descriptive statistics (Box-and-whisker diagrams)

Data are visualized in box-and-whisker diagrams, as defined by Tukey (1977). The box spans the interquartile range of the values in the variate, so that the middle 50% of the data lie within the box, with a horizontal line indicating the median. The whiskers extend only to the most extreme data values within the inner "fences", which are at a distance of 1.5 times the interquartile range beyond the quartiles, or the maximum value if that is smaller. Individual outliers are plotted with a green circle. "Far" outliers, beyond the outer "fences" which are at a distance of three times the interquartile range beyond the quartiles, are plotted with a red circle.

2.8.2 Response-ratio analysis

Analysis of variance (ANOVA) was performed on the response variables per LTE and layer 1 (0-10 cm depth) and layer 2 (10-20 cm depth). Subsequently, ratios were calculated using the means from these ANOVAs. The ratio is a measure of the sensitivity of a soil parameter to a management factor as proposed by Bolinder et al. (1999). For the trials with exclusively tillage (CH1, CH2 and HU4), response ratios were calculated as the mean of RT (reduced tillage) over CT (conventional tillage). For the trial with exclusively organic matter and two layers (ES4), response ratios were calculated as the mean of HIGH (high supply of organic matter) over LOW (low or no supply of organic matter) per layer 0-10 and 10-20 cm. In the other three trials with exclusively organic matter and one layer (CH3, HU1 and PT1) response ratios were calculated as the mean of HIGH over LOW for the 0-20 cm layer. The analyses of the trials NL1, NL2 and SL1 were done according to the four combinations of tillage and organic matter (CT LOW, CT HIGH, RT LOW, RT HIGH). ANOVA was performed with these four combinations as treatments. Plotted are the response ratios RT LOW, CT HIGH and RT HIGH calculated as the mean of CT HIGH, RT LOW and RT HIGH over the mean of CT LOW. For this analyses per trial the data were assumed to be normally distributed. The number of observations per trial were too low to test for a deviation from normality. The presented probabilities are from the ANOVA analyses.

To summarize the results from the ten trials, the response ratios discussed above were averaged over all LTEs using ANOVA, and the standard error of these means was calculated. The average effect of RT (reduced tillage) summarized the data from CH1, CH2 and HU4 and the effect of RT in NL1, NL2 and SL1 was included. The average effect of HIGH (high organic matter supply) was summarized using the response ratios of ES4 and the effect of HIGH in NL1, NL2 and SL1 were included. Next to this, the combined effects of RT and HIGH were summarized using the data of NL1, NL2 and SL1. Finally the three LTEs with measurements exclusively over the layer 0-20 cm (CH3, HU1 and PT1) were summarized separately. For this data analysis the range of the parameter values was high, because the levels between the LTEs strongly deviated from each other. Therefore, for this analysis the data were log-transformed. The response ratios were calculated using the back-transformed means.

2.8.3 REML mixed model analysis

A meta-analysis over all ten LTEs was performed using a REML mixed model analysis. The response variates were the parameters, showing significant effects in the ANOVA's performed for the response ratio-analyses: WSA, POM, P-AL, K-AL, Ntot, TOC, Cmic and Nmic. In addition, bulk density and Respiration were added because they depend on soil type. Finally Penetrometer Resistance was added, calculated for layers 1 and 2 to investigate differences in soil structure.

The data have a hierarchical structure; there is information on different levels or strata. Information of the effect of soil type can be analysed between LTEs. Within each trial there are blocks. Within these blocks the effect of tillage and the level of organic matter supply can be assessed on the scores per plot. Within 3 LTEs (NL1, NL2 and SL1) there were subplots within each plot. Within each (sub)plot the score for a number of measured parameters is assessed in 2 layers. Trial, block within trail, plot within block, subplot within plot and layer within (sub)plots are the strata and are random terms within the mixed model. The model is called mixed because next to random terms there are also fixed terms, being soil type, tillage, organic matter supply and layer that are not orthogonal. Only significant interactions with the maximum order are presented or significant main effects when significant interactions are absent. The REML (REsidual Maximum Likelihood) algorithm was used because it is well suited to analyse data with a hierarchical structure with random and fixed terms. Because the measurement levels strongly diverted between LTEs and higher values tend to have a higher variance, the data were log transformed. Back transformed means (medians) are presented with F and pairwise t-test from the analyses on the transformed scale. Means without a common letter differ significantly according to Students pairwise t-test ($P<0.05$). Residuals were identified and removed from the analyses, using GenStat procedure VSOM that applies a variance shift outlier model (Gumedze et al., 2010). In the three LTEs (CH3, HU1 and PT1) with measurements exclusively over the layer 0-20 cm, this measured value was filled in for layer 1 and for layer 2, to make it possible to combine the ten LTEs in one meta-analysis.

2.8.4 Multivariate analysis

2.8.4.1 Principal component analysis (PCA)

Principal component analysis (PCA) was performed on the set of soil parameters (variates) that were significantly influenced by management factors in the response ratio analysis. First, each variate was standardized by subtracting its values with the mean and thereafter dividing its values by the standard error. PCA is a multivariate statistical method to reduce the number of original variables and form new variables, also-called principal components (pc) (Legendre and Legendre, 2012). The first pc, is a linear function of the original variates such that its variance is maximum. Each consecutive pc, is also a linear function of the original variates such that its variance is maximum, with the restriction that it is independent of the already calculated principal components. The roots (eigenvalues) of the correlation matrix show the importance of the original pc's. The percentage variance along axis i in the biplots is calculated as 100 * root i over the sum of all roots. Biplots with the first two pc's are presented. PCA is also performed with the indicator variates formed from factor LTE as covariate (scaling). Objects are designated per LTE and per Treatment in different plots based on the same Principal Component Analysis.

2.8.4.2 Redundancy analysis (RDA)

Redundancy analysis is the direct extension of multiple regression for the modelling of multivariate response data (Legendre and Legendre, 2012). Each of the response variates is regressed on a set of environmental variables. Hence the predictions of the response variates are analysed in a partial PCA (Bocard et al. 2018). In the applied RDA analysis three sets of data are used:

1. Response variates representing ecosystem services: (relative) dry matter yield, TOC, Cmic, Nmic, POM and WHC.
2. Environmental variates that are (rather) 'sensitive' to treatments (tillage and addition of organic matter) in the response ratio (ANOVA) analysis: WSA, P-AL, K-AL, TOC, Ntot, Cmic, Nmic, bulk density, WHC and the ratio TOC/clay%.
3. Variables indicating the levels of the factor LTE formed were covariates, eliminating the LTE effect form the analysis.

2.8.5 Comparison of analytical and NIR data

The content of N-total (%), C/N ratio, K, pH, Toc, P-PAE, P_2O_5, Clay, Silt and Sand were analytically measured by Eurofins on a selection of 29 soil samples and with Near Infrared spectroscopy (NIR). The number of samples per LTE is given in table 7.

Table 7. Number of soil samples per LTE used to compare NIR to the analytical method.

LTE	CH1	CH2	CH3	ES4	HU1	HU4	NL1	NL2	PT1	SL1	Total
Count	2	2	2	12	2	1	2	2	2	2	29

The number of samples per LTE is not equal. To prevent that an LTE with more samples has a larger influence on the results than LTEs with less samples, different weights per LTE were assigned to the samples. A weight of 1/6 was assigned to the ES4 samples and a weight 2 was assigned to the HU4 sample. In this way each LTE had a similar in the regression analysis. Per parameter, the scores for NIR were regressed on the analytical Eurofins scores using simple linear regression. The results are presented in plots. The estimates of the intercepts (a) and slope (b) of the regression lines are in the plots next to their standard error and probability according to their Student t distribution. Also percentage variance accounted for (R_{adj}^2) is given in the plot. In the plots also the line y=x is drawn. When the regression line deviates from the line y=x, the conclusion is that the NIR measurement is inferior to the analytical method that is used as ‘golden standard’ (i.e. a standardised method that is widely used and accepted in the scientific literature).

2.9 Archiving of results

Data of the field trials are stored both on paper and in a digital form. The ‘raw’ and recalculated data, the relevant statistical files and other information of the trials and the report of this project, are kept in a digital form in a folder labelled with the project number 3750318700. After finishing the project the project folder will be archived by Wageningen University & Research for at least fifteen years.

3 Results

3.1 Distribution of data

Boxplots were made for all the measured soil quality indicators (Figure 4). Data are shown per LTE, no discrimination is made for the different treatments, per parameter all data from 1 LTE are shown in 1 boxplot.

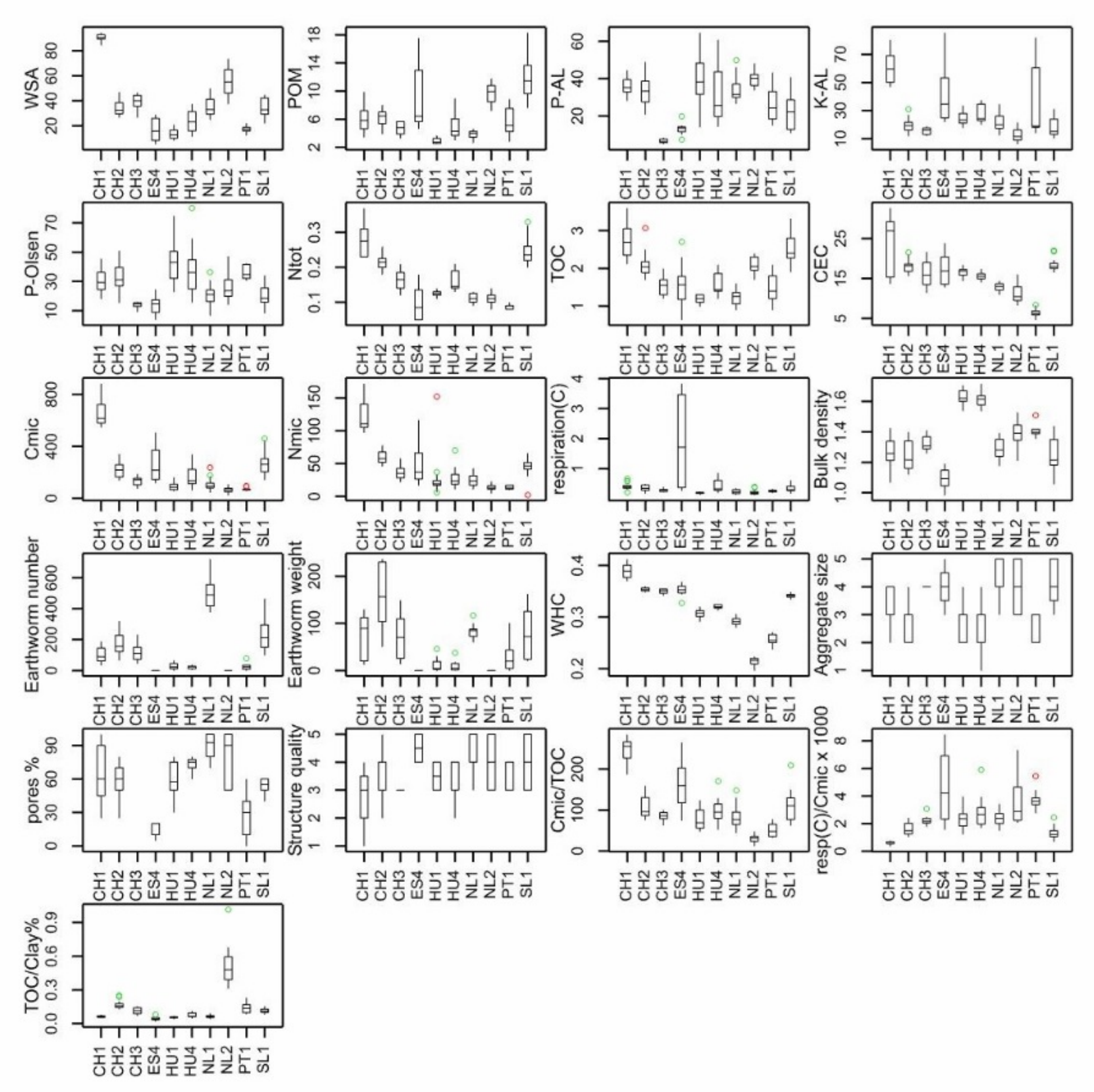

Figure 4. Boxplots showing distribution of the measured soil quality indicators per LTE (units per indictor see table 4).

Figure 4 shows that the level and range of the parameter values vary strongly between the ten LTEs. CH1 has high values (compared to the other LTEs) for nine of the 22 parameters (WSA, K-AL, Ntot, TOC, CEC, Cmic, Nmic, WHC and Cmic/TOC). The level and range of basal respiration is much higher on ES4 than on the other LTEs. There are parameters where the variation within an LTE is almost as high as the variation between LTEs. This is mainly the case for the visual soil assessment parameters aggregate size and structure quality as measured with the spade diagnosis. This variation could be caused by treatments effects. On the other hand, there are parameters where the intra LTE variation is small compared to the inter LTE variation. Examples are WHC and respC except ES4 for respC.

3.2 Effect of management on parameters using response-ratio analysis

In Figure 5 and Figure 6 results of response ratio analyses are given for reduced tillage and/or high supply of organic matter. Values higher than one indicate an increase by reduced tillage relative to conventional tillage and/or by high supply of organic matter relative to low supply of organic matter. Values lower than one indicate a relative decrease of the parameter due to the application of these management strategies.

Results are given averaged over all LTEs (RT: red bars, reduced tillage, HIGH: green bars, high supply of organic matter, RT+HIGH: dark blue bars, reduced tillage and high supply of organic matter, HIGH 0-20: light blue bars, high supply of organic matter in the 0 – 20 cm layer). Figure 5 gives the values of parameters in two layers (layer 1=0-10 cm (left bar), layer 2=10-20cm (right bar)). Figure 6 gives the parameters that are not layer specific, or measured in different layers (penetration resistance).

Above or below the bars, significant F-probabilities are shown with symbol *, ** or *** designating respectively <0.05, <0.01, and <0.001, based on the F-probability of the management in the ANOVA table. The error bars are the standard error of the mean of the ratios. Figure 5 and 6 are a summary of the results of the response ratio analysis of the soil parameters. See Annex 7.4 for a more detailed presentation of the results.

A quick view over Figures 5 and 6 shows that in almost all parameters measured in the top layer are increased by reduced tillage as well as by organic matter addition. Bulk density is reduced by high organic matter addition, but not significantly. The percentage of pores is only influenced in the trials with a high organic matter addition where the measurements were done over the layer 0-20 cm. Looking at the individual LTE data (as presented in Annex 7.4 this is solely caused by PT1. The parameters tea bag test K and S are minimally influenced by reduced tillage and/or high organic matter addition.

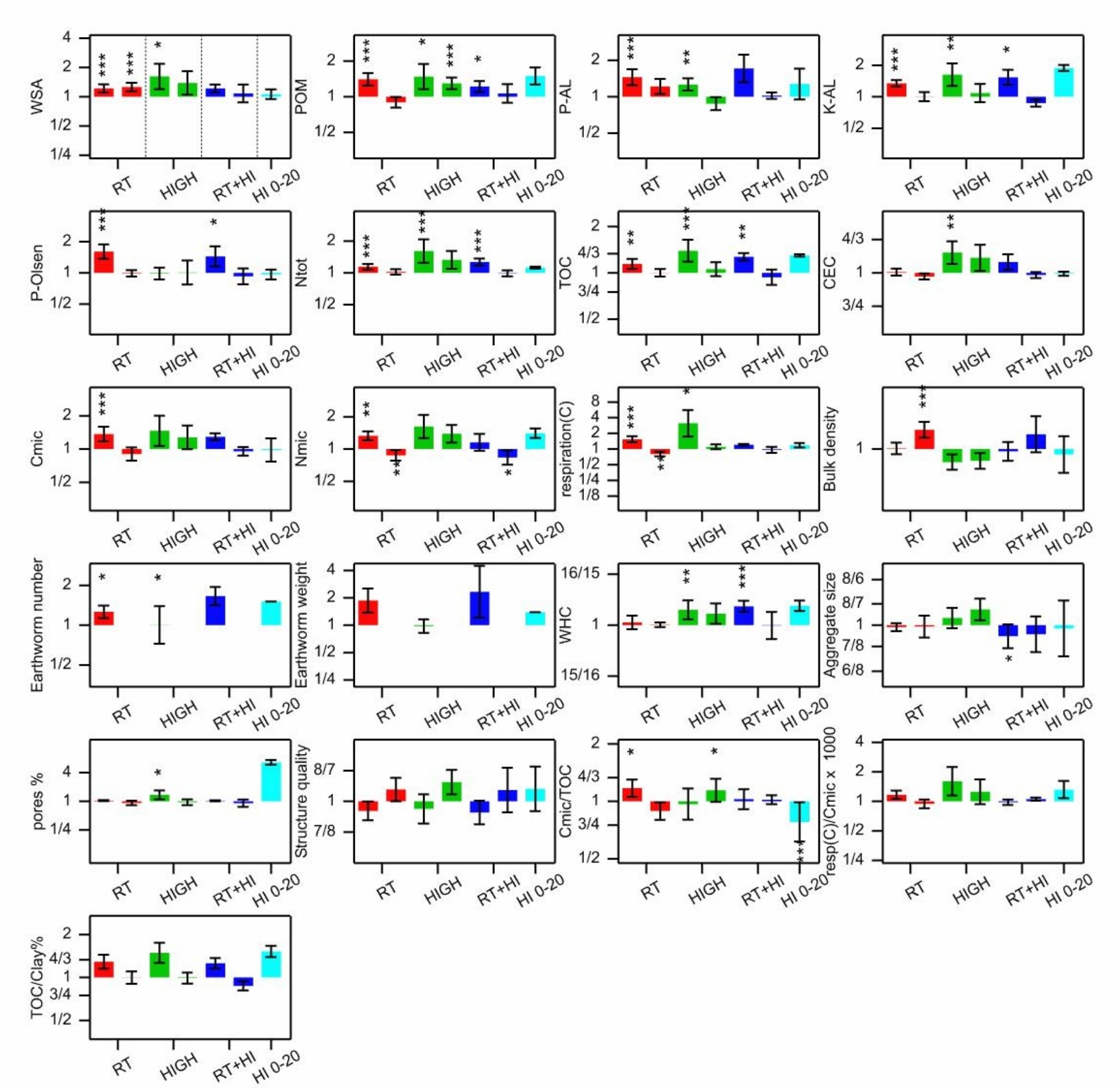

Figure 5. Response ratios per parameter for the different management factors. RT (red)=reduced tillage, HIGH (green)=high organic matter input, RT+HI (darkblue)= combination of reduced tillage and high organic matter input, HI 0-20 (lightblue)= effect of organic matter addition measured in the layer 0-20 cm. First bar per category represents layer 1 0-10 cm, second bar represents layer 2 10-20 cm.

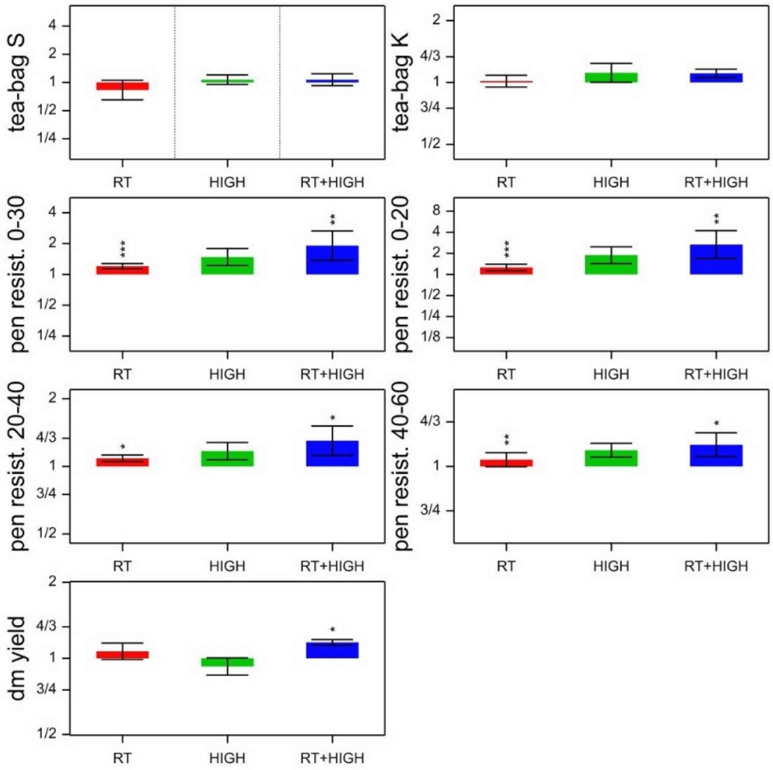

Figure 6. Response ratios per parameter for the different management factors. RT=reduced tillage, HIGH=high organic matter input, RT+HIGH= combination of reduced tillage and high organic matter input.

Table 8 A and B. Overview of the F-probabilities and significance values of the response ratios for parameters determined in the topsoil in layers (A, upper table, 1= 0-10 cm, 2= 10-20 cm) and the other parameters (B, lower table), per management strategy, averaged over the LTEs. Till= tillage (reduced/conventional), org= supply of organic matter (HIGH/LOW), Cmic=microbial carbon, Nmic=microbial nitrogen, resp.=respiration, POM=particulate organic matter, TOC=total organic carbon, P-AL= phosphate, P-Ols=P Olsen, K-AL= potassium, Ntot=total nitrogen, CEC=cation exchange capacity, WSA=percentage water stable aggregates, Bulk=bulk density, WHC=water holding capacity, aggreg=aggregate size, %pores=percentage of pores, struct.=structure quality.

A	mana-		biological			bio-chem		chemical					physical			visual: spade diagnosis			ratio of two parameters:		
	gement	layer	Cmic	Nmic	resp.	POM	TOC	P-AL	P-Ols	K-Al	Ntot	CEC	WSA%	Bulk	WHC	aggreg	%pores	struct.	Cmic/Corg	resp/Cmic	TOC/clay
Average over all LTE's	Till	1	+	+	+	+	+	+	+	+	+		+						+		
		2		-	-								+	+							
	Org	1			+	+	+	+		+	+	+	+		+		+				
		2				+												+	+		
	Org	0-20			+	+	+	+		+	+						+		-	+	+
	Till+Org	1				+	+	+	+	+	+				+	-					
		2		-																	

B	mana-	biological				physical			dry
	gement	tea-bag test		earthworms		penetration resistance			matter
		S	K	number	weight	0-20 cm	20-40 cm	40-60 cm	yield
average	till			+	+	+	+	+	
over all	org			+					
LTE's	till+org			+	+	+	+	+	+

Statistically significant:

not
P < 0.05
P < 0.01
P < 0.001

In Tables 8A and 8B we give an overview of the F-probabilities of the response-ratio analysis. Results per LTE are to be found in annex 7.3. In both tables the (degree of) statistical significance and the effect (increase(+) or reduction(-) of the absolute value) on the parameters is given. Red cells in the table indicate strongly significant effects. Looking at the management factors the most red cells are found for tillage and the most significant increasing effects occur for various parameters in layer 1 (0-10 cm). This means that reduced tillage increases the value of soil parameters in the topsoil when compared to conventional tillage. In layer 2 (10-20 cm) these effects are hardly present, and in some cases reduced instead of increased. Only the percentage water stable aggregates is similarly influenced by tillage in layer 1 and 2. Bulk density is significantly increased by reduced tillage in layer 2. This is confirmed by the penetration resistance measurements for the 0-20 cm layer, which is (highly significantly) increased by reduced tillage, even in the deeper soil layers up to 60 cm. Microbial nitrogen and carbon respiration are reduced in magnitude by reduced tillage in the second soil layer, while both increased in value in the upper 10 cm of the soil.

Organic matter addition results in a significant increase in value for 10 soil parameters in layer 1, with varying p values. In layer 2 only significant effects are found for the parameters particulate organic matter and the visually assessed structure quality. The organic matter trials that were sampled in one layer (0-20 cm) show similar results, with the difference that here no effects were found on the parameters CEC and WSA. So the effects of the organic matter addition are mainly found in the top ten cm of the soil, but the effects are that large that when the layer 0-20 is sampled as a whole most of these significant increasing effects are still present.

The LTEs where organic matter addition and reduced tillage is combined show less significant increasing effects on the soil parameters than the two treatments separately. Seven soil parameters (POM, TOC, P-AL, P-Ols, K-AL, Ntot and WHC) show an increase in value in the top layer, one is reduced (aggregate size). Microbial nitrogen is reduced in the second layer.

Some parameters are more effected by the management factors than others. Particulate organic matter and total nitrogen content are highly significantly influenced by reduced tillage and organic matter addition, POM in both layers, Ntot especially in layer 1. Other soil parameters that show effects of organic matter addition as well as reduced tillage are TOC, P-AL and K-AL. WSA is strongly significantly increased in both layers, but only for the factor tillage.

The tea bag test parameters S and K showed no effect for both of the management factors. Also the visual soil assessment parameters (aggregate size, % pores and structure quality) were not so much influenced by the management factors

3.3 Effect of pedo-climatic conditions and management on parameters using principle component analysis

Based on the results of response-ratio analysis, the following soil parameters were considered to be the most 'sensitive' to management factors in the LTEs: Ntot, P-AL, K-AL, TOC and POM. Moderately sensitive parameters seemed to be Cmic, Nmic, respiration rate, WSA, bulk density and penetration resistance in the layers 0 – 20 cm and 20 – 40 cm. With these twelve parameters principle component analysis (PCA) was done. In Figure 7 and 8 the influences of the LTEs - and thus of environmental circumstances (climate, soil texture and type) of the trial – and management (tillage and/or supply of organic matter) are represented for layer 1 and layer 2, respectively. The penetration resistance (0 – 20 and 20 – 40 cm) was not determined in the same layers as the other parameters (0 – 10 and 10 – 20 cm). Nevertheless the penetration resistance parameters are plotted in figure 7 and 8, to compare their 'sensitivity' with that of the other parameters.

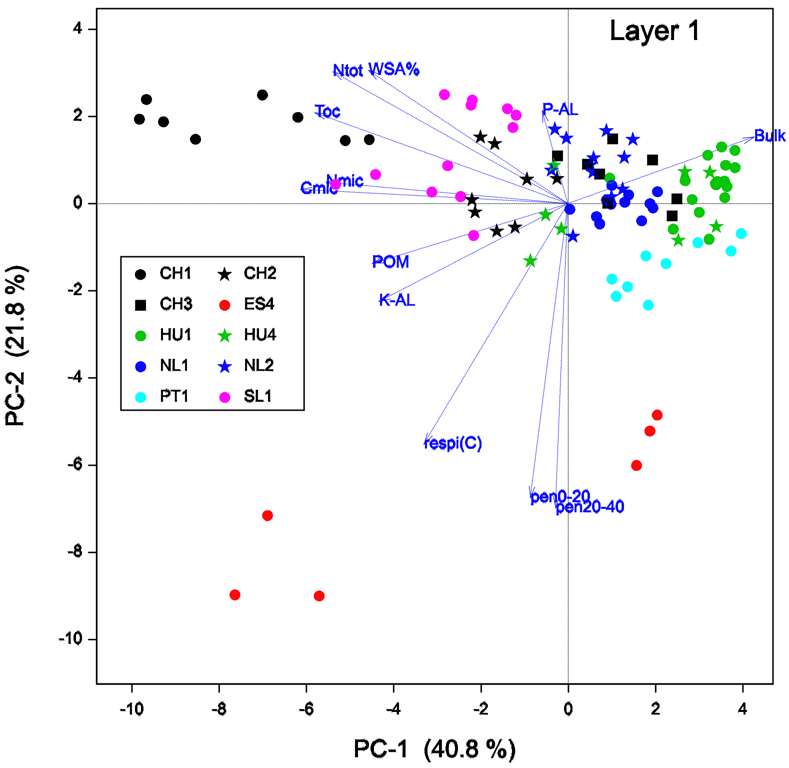

Figure 7. **PCA biplot of 12 'sensitive' soil parameters in soil layer 1, using symbols for the LTEs. Bulk: bulk density; Cmic, Nmic: microbial biomass carbon and nitrogen; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40: penetration resistance in layer 0–20, 20-40 cm; POM: particulate organic matter; resp(C) respiration rate; TOC: total organic carbon; WSA:% water stable aggregates.**

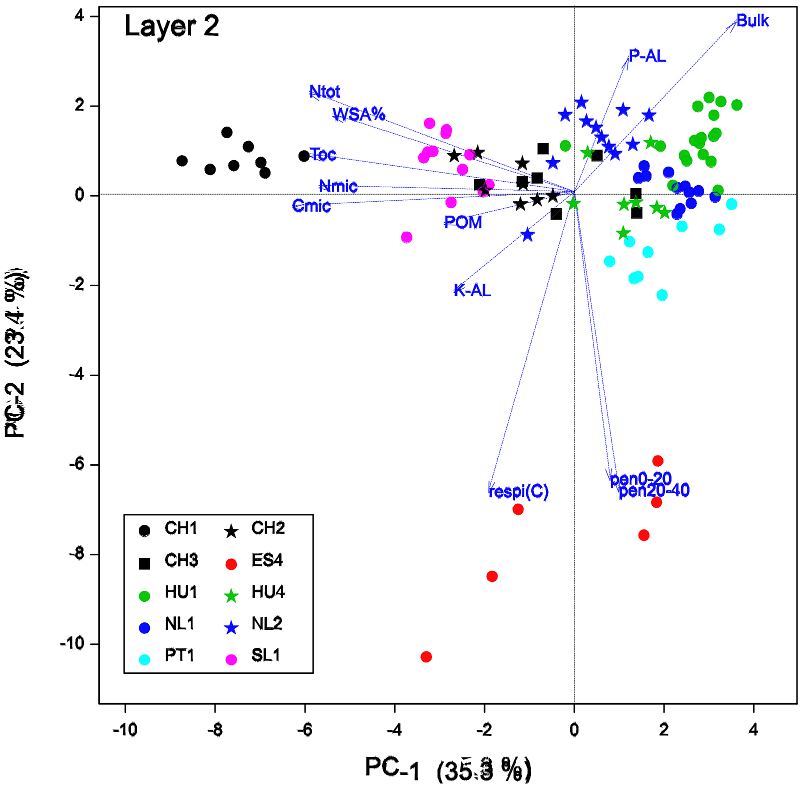

Figure 8. **PCA-biplot of 12 'sensitive' soil parameters in soil layer 2 using LTE symbols. Bulk: bulk density; Cmic, Nmic: microbial biomass carbon and nitrogen; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40: penetration resistance in layer 0–20, 20-40 cm; POM: particulate organic matter; resp(C): respiration rate; TOC: total organic carbon; WSA:% water stable aggregates.**

Looking at the results of the principle component biplots in figures 7 and 8 for layer 1 and layer 2 respectively, it appears that the results of the management treatments of the individual LTEs are clustered and that differences between LTEs are much larger than within LTEs. This implies that the influence of the local conditions on the parameters is much larger than the influence of management (reduced tillage and/or high supply of organic matter). For ES4 a large separation between the data points can be seen. This separation is caused by the different management factors in ES4 (CT LOW versus RT HIGH).

In layer 2 the influence of the specific characteristics of the LTE on the parameters is also larger than the management treatments, but compared to layer 1 the differences between LTEs seem smaller. The LTEs ES4 and CH1 fall outside the cloud of data points of the other LTEs. ES4 has a much higher basal respiration and penetration resistance and lower bulk density, while CH1 has higher Cmic, Nmic, TOC, Ntot and WSA.

Figures 9 to 12 show the same results as Figures 7 and 8, with the difference that here LTE is considered as a covariate factor in the analysis, and therefore its effect is removed in order to show the effect of the management on the soil quality indicators. Figures 9 and 10 show this for layer 1, Figures 11 and 12 for layer 2. Figures 9 and 11 show the LTEs as symbol, while Figures 10 and 12 show the management factors as symbol.

In layer 1 a clear effect of the management factors is visible (Figure 10), especially between the two extremes; CT LOW (black circles) and RT HIGH (green stars). From the parameters involved in the PCA analysis respC, POM, K-AL, P-AL and the penetration resistance show a high sensitivity to the management factors. Cmic, Nmic, Ntot and TOC show a moderate sensitivity. WSA and bulk density show a rather low sensitivity.

In layer 2 the soil parameters can explain less of the variation than in layer 1 (48.3% versus 61.3%). In general in layer 2 the same parameters as in layer 1 show sensitivity to the management factors. The big difference is the response of bulk density. This is much larger in layer 2 than in layer 1. This confirms the result found with the response ratio analysis reported in Table 8A. Here bulk density is significantly influenced by the tillage, but only in the deeper soil layer.

As the length of an arrow in the biplots provides an indication of the sensitivity of the parameter, it appears that respC in layer 1 is very sensitive, irrespective of LTE being in the model as a covariate or not (compare Figure 7 and 9). This seems to be caused by ES4 (red dots in the figures). Bulk density and WSA have a rather high sensitivity in layer 1 when LTE and management are both in the model, but when LTE is used as a covariate, the sensitivity of these parameters is rather low. The opposite applies for P-AL, which is much more sensitive when LTE is used as covariate. This implies that bulk density and WSA are more influenced by LTE (the pedo-climatic conditions) and P-AL more by management.

Considering the results of both soil layers of the twelve sensitive parameters selected after response-ratio analysis, the parameters respiration rate, P-AL, K-AL and POM seem to be the most sensitive to the considered management factors and WSA the least. The penetration resistance at both depths (0-20 and 20-40) is also rather sensitive.

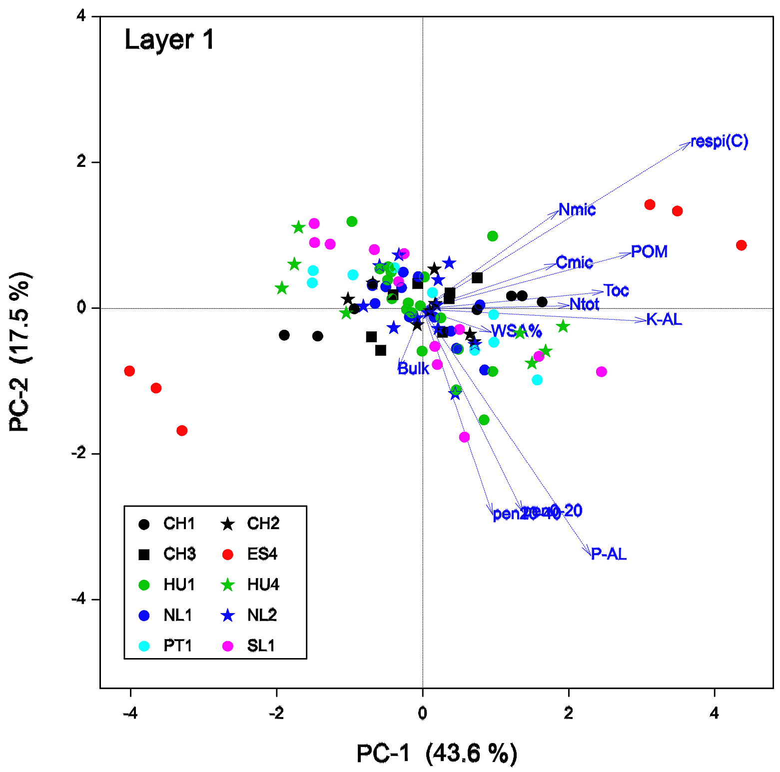

Figure 9. **PCA biplot of 12 soil parameters in layer 1, using LTE symbols and as covariate. Bulk = bulk density; Cmic, Nmic: carbon, nitrogen in micro-organisms; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40: penetration resistance in layer 0–20, 20-40 cm: POM = particulate organic matter; resp(C) = respiration rate; TOC = total organic carbon; WSA = % water stable aggregates.**

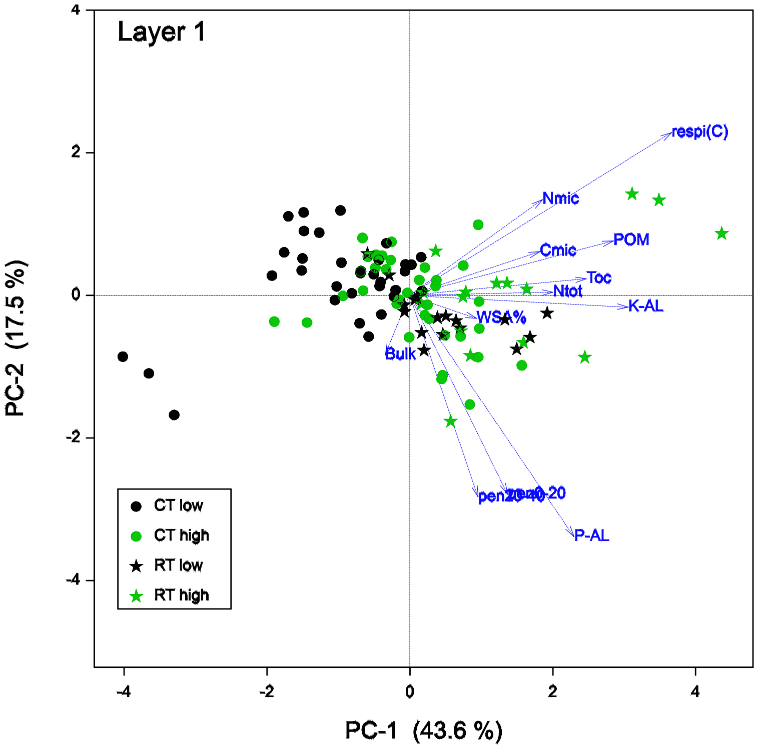

Figure 10 PCA biplot to represent the influence of management on 12 soil parameters in layer 1, using treatment as symbol, LTE is covariate. CT,RT: conventional, reduced tillage; HIGH, LOW: high, low supply of organic matter. Bulk = bulk density; Cmic, Nmic: carbon, nitrogen in micro-organisms; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40: penetration resistance in layer 0–20, 20-40 cm: POM = particulate organic matter; resp(C) = respiration rate; TOC = total organic carbon; WSA = % water stable aggregates.

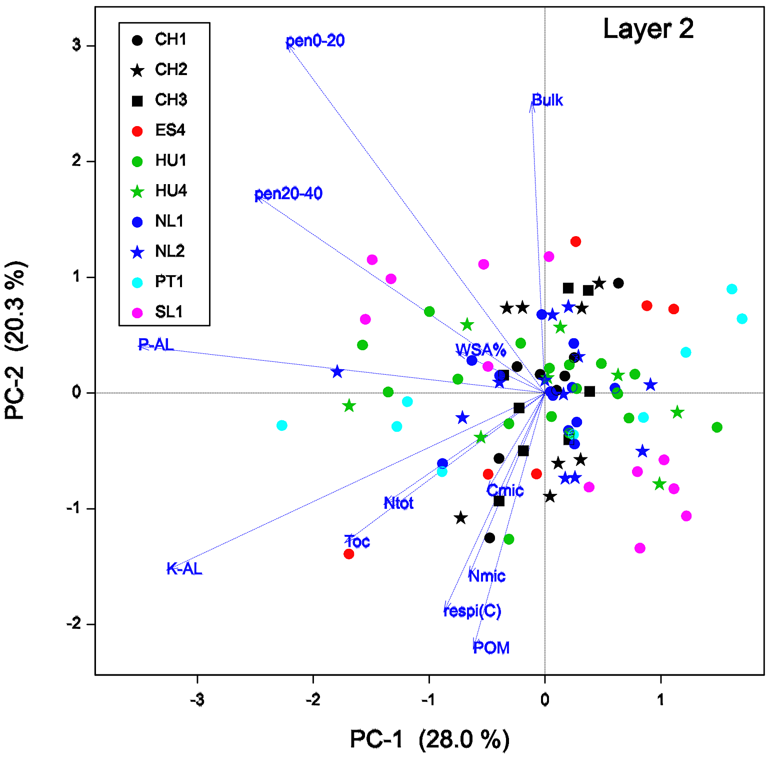

Figure 11. PCA biplot of 12 soil parameters in layer 2, using LTE as symbol and covariate. Bulk = bulk density; Cmic, Nmic: carbon, nitrogen in micro-organisms; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40:

penetration resistance in layer 0–20, 20-40 cm: POM = particulate organic matter; resp(C) = respiration rate; TOC = total organic carbon; WSA = % water stable aggregates.

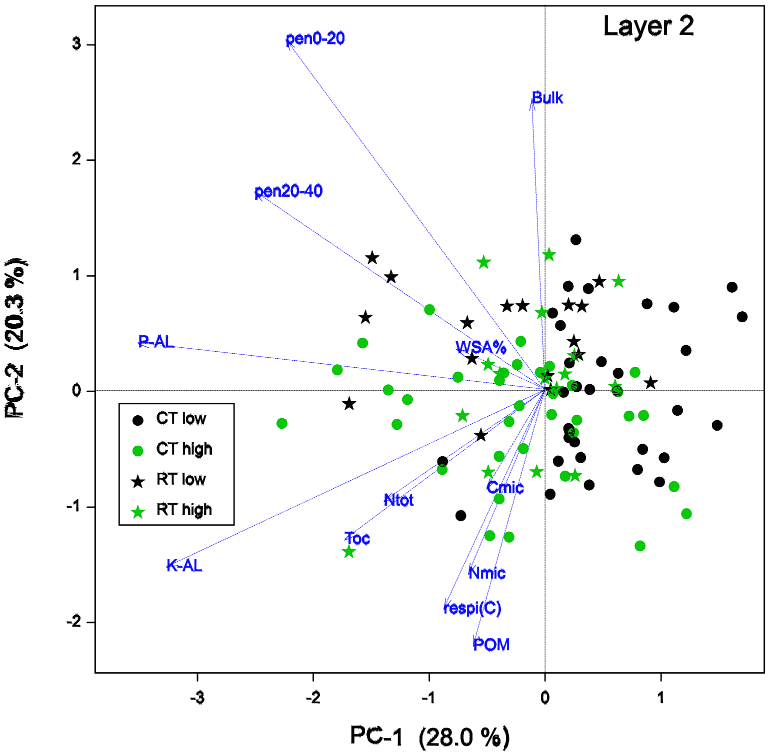

Figure 12. PCA biplot to represent the influence of management on 12 sensitive parameters in layer 2, using treatment as symbol. CT, RT: conventional, reduced tillage; HIGH, LOW: high, low supply of organic matter. Bulk = bulk density; Cmic, Nmic: carbon, nitrogen in micro-organisms; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40: penetration resistance in layer 0–20, 20-40 cm: POM = particulate organic matter; resp(C) = respiration rate; TOC = total organic carbon; WSA = % water stable aggregates.

3.4 Effect of soil type and management on parameters using REML-analysis

There were four influential factors in this study, being soil type, tillage, organic matter supply and soil layer. The data were analysed with a mixed model with main effects and two and three factor interactions of the four influential factors as fixed terms. Only significant interactions with the maximum order are presented, or significant main effects when significant interactions are absent. The data were log transformed. Back transformed means (medians) are presented with F and pairwise t-test from the analyses on the transformed scale. Means without a common letter differ significantly according to Students pairwise t-test ($P<0.05$). Outcomes of statistical tests may differ from those in Table 8a and 8b because here all data are analysed in one, not all analyses are done per treatment.

Table 9. Medians of POM per level of Organic matter supply ($P<0.001$)

Org matter	
HIGH	6.7 b
LOW	5.3 a

POM was higher at the high level of organic matter supply.

Table 10. Medians of Bulk density per level of Organic matter supply ($P = 0.008$).

Org matter	HIGH	LOW
	1.32 a	1.36 b

Bulk density was lower at high organic matter supply ($P=0.008$).

Table 11. RespC per level of Organic matter supply ($P = 0.042$).

Org matter	HIGH	LOW
	0.33 a	0.30 a

RespC was significantly higher in high organic matter supply than in low organic matter supply according to the pairwise t-test and nearly significant according to the sequential F-test.

Table 12. Medians of P-AL per level of Soil type, Organic matter supply and Soil layer (P interaction = 0.027)

Soil layer		1	2
Soil type	Organic matter		
Light	HIGH	23.2 a	21.8 a
	LOW	20.7 a	19.4 a
Medium heavy	HIGH	31.1 a	23.3 a
	LOW	27.5 a	26.9 a

There are no significant pairwise differences between the means in Table 12. However, in medium heavy soil and high organic matter supply the content of P-AL is higher in layer 1 than in layer 2. In the other three combinations of soil type and organic matter supply the differences between layer 1 and 2 are much smaller. This causes the three factor interaction to be significant. So, the high P-AL content, equal to 31.1, in medium heavy soil and high level of organic matter supply in layer 1, causes the three factor interaction to be significant.

Table 13. Medians of K-AL per level of Soil type, Organic matter supply and Soil layer (P interaction = 0.011).

Soil layer		1	2
Soil type	Organic matter		
Light	HIGH	28.2 bc	21.0 bc
	LOW	18.2 b	13.5 a
Medium heavy	HIGH	34.8 c	25.3 bc
	LOW	28.3 bc	28.2 bc

Only at medium heavy soil and low organic matter supply there is no difference between the layers in K-AL content. In other words, only in layer 2 in medium heavy soil K-AL content does not increase from low to high organic matter supply.

Table 14. Medians of Ntot per level of Soil type, Organic matter supply and Soil layer (P interaction = 0.039).

Soil Layer		1	2
Soil type	Organic matter		
Light	HIGH	0.153 a	0.144 a
	LOW	0.127 a	0.120 a
medium heavy	HIGH	0.175 a	0.147 a
	LOW	0.157 a	0.145 a

In medium heavy soil and high organic matter supply, the difference in Ntot content between layer 1 and 2 is highest. This causes the three factor interaction to be significant, although there are no significant pairwise differences within the interaction table (Table 16).

Table 15. Medians of TOC per level of Soil type, Organic matter supply and Soil layer (P interaction <0.001)

Soil layer		1	2
Soil type	Organic matter		
Light	HIGH	2.08 b	1.98 b
	LOW	1.58 ab	1.47 a
Medium heavy	HIGH	1.92 ab	1.54 ab
	LOW	1.72 ab	1.64 ab

In layer 2 and light soil there is an increase in TOC from low to high organic matter supply (P<0.05). Also in layer 1 and light soil there is a strong effect of organic matter supply. In medium heavy soil there is a smaller increase in TOC from low to high organic matter supply in layer 1, and a decrease in TOC in layer 2 from low to high organic matter supply.

Table 16. Medians of WSA per level of Soil type and Tillage level, (P interaction < 0.001).

Tillage	CT	RT
Soil type		
Light	33.2 ab	33.3 ab
Medium heavy	23.2 a	34.9 b

In medium heavy soil WSA was higher in RT than in CT (P<0.05) according to the pairwise t-test, in light soil there was no tillage effect.

Table 17. RespC per level of Soil type and Tillage (P<0.001).

Tillage	CT	RT
Soil type		
Light	0.27 a	0.27 a
medium heavy	0.30 a	0.45 a

The tillage effect on respC was higher in medium heavy soil than in light soil, which caused the interaction effect to be significant.

Table 18. Penetrometer resistance (0-20 cm) per level of Soil type and Tillage (P<0.001).

Tillage	CT	RT
Soil type		
Light	0.56 ab	0.57 ab
Medium heavy	0.52 a	0.79 b

Penetrometer resistance was significantly higher under reduced tillage in medium heavy soils (P<0.05). In light soil there was no tillage effect.

Table 19. RespC per level of Tillage and Soil layer (P interaction <0.001)

Soil layer	1	2
Tillage		
CT	0.29 a	0.29 a
RT	0.47 b	0.26 a

Only in soil layer 1, there was a significant effect of tillage on RespC according to the pairwise Student t-test.

Table 20. Medians of P-AL per level of Tillage and Soil layer (P interaction<0.001).

Soil layer	1	2
Tillage		
CT	22.7 a	22.4 a
RT	28.2 b	22.9 a

Only in soil layer 1, there was a significant effect of tillage on P-AL content of the soil, according to the pairwise Student t-test.

Table 21. Medians of Nmic per level of Tillage and Soil layer (P interaction = 0.006).

Soil layer	1	2
Tillage		
CT	30.2 ab	29.2 ab
RT	36.6 b	24.4 a

In layer 1, Nmic was increased by reduced tillage, in layer two there was a reversed effect.

Table 22. Medians of POM per level of Soil type, Tillage and Soil layer (P interaction = 0.004)

Soil layer		1	2
Soil type	Tillage		
Light	CT	6.3 ab	6.2 ab
	RT	7.2 ab	5.8 ab
Medium heavy	CT	5.0 a	5.1 a
	RT	7.9 b	4.9 a

The difference between layers depended on soil type and tillage. Within CT there is no difference between layer 1 and 2 in both soil types. In RT the level of POM in layer 1 is higher than in layer 2. However, only in medium heavy soil the difference is significant (P<0.05).

Table 23. Medians of K-AL per level of Soil type, Tillage and Soil layer (P interaction = 0.023).

Soil layer		1	2
Soil type	Tillage		
Light	CT	18.1 ab	17.8 ab
	RT	28.3 bc	16.0 a
Medium heavy	CT	26.1 ab	25.0 ab
	RT	37.8 c	28.5 bc

In layer 2 light soil K-AL content is higher in CT than in RT. In layer 2 medium heavy soil K-AL content is higher in RT than in CT.

Table 24. Medians of TOC per level of Soil type, Tillage and Soil layer (P interaction = 0.016).

Soil layer		1	2
Soil type	Tillage		
Light	CT	1.82 ab	1.79 ab
	RT	1.81 ab	1.63 ab
medium heavy	CT	1.55 a	1.53 a
	RT	2.14 b	1.66 b

The difference in TOC content between layer 1 and 2 is highest in medium heavy soil with reduced tillage. Especially in layer 1 in medium heavy soil, there is a strong effect of reduced tillage.

Table 25. Bulk density per level of Soil type, Tillage and Soil layer (P interaction = 0.048).

Soil layer		1	2
Soil type	Tillage		
Light	CT	1.32 ab	1.35 ab
	RT	1.26 a	1.43 b
Medium heavy	CT	1.32 ab	1.35 ab
	RT	1.30 ab	1.41 ab

In layer 1, reduced tillage reduced soil bulk density stronger in light soil than in medium heavy soil. In layer 2, reduced tillage increased bulk density in comparison with conventional tillage.

Table 26. Medians of Ntot per level of Tillage, Organic matter supply and Soil layer (P interaction = 0.045).

Soil layer		1	2
Tillage	Organic matter		
CT	HIGH	0.146 bc	0.143 bc
	LOW	0.132 a	0.130 a
RT	HIGH	0.183 d	0.147 bc
	LOW	0.152 c	0.134 ab

In RT and high organic matter supply difference in Ntot content between layer 1 and 2 is highest.

Table 27. Medians of Cmic per level of soil type, Tillage and Organic matter supply (P interaction = 0.046).

Org matter		HIGH	LOW
Soil type	Tillage		
Light	CT	118 ab	98 a
	RT	106 ab	92 a
medium heavy	CT	147 a	179 b
	RT	253 b	217 ab

Only in medium heavy soil with conventional tillage Cmic content was higher at low Organic matter supply.

Table 29. Medians of Cmic per level of Soil layer (P<0.001)

Soil layer	1	2
	162	124

Cmic content was higher in layer 1 than in layer 2 (P<0.001).

Table 30. Penetrometer resistance (0-20 cm) per Soil layer (P<0.001).

Soil layer	1	2
	0.46 a	0.78 b

The penetrometer resistance was higher in layer 2 than in layer 1 (P<0.001).

3.5 Pearson correlations between parameters

In this section the Pearson correlations between the 12 parameters that showed the highest sensitivity to management in the response ratio analysis are presented (see section 3.2). In the table below (Table 31), correlations between the selected parameters are presented in bold and probabilities in italics. The number of observations for the correlations ranged from n=178 to 202. Correlations between all parameters are given in Annex 7.6 Correlations are also calculated with means over all LTEs and with all the parameters standardised per LTE. These tables are also to be found in Annex 7.6.

Table 31. Pearson correlations and probabilities for the 12 most sensitive parameters. Correlations >0.5 are highlighted in grey.

	WSA	POM	P-AL	K-AL	Ntot	TOC	Cmic	Nmic	bulk	resp. rate	Pen 0-20	Pen 20-40
WSA	**1.00**	*0.000*	*0.055*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.704*	*0.229*	*0.00*
POM	**0.29**	**1.00**	*0.185*	*0.575*	*0.000*	*0.000*	*0.000*	*0.007*	*0.000*	*0.000*	*0.402*	*0.001*
P-AL	**0.14**	**-0.09**	**1.00**	*0.003*	*0.590*	*0.203*	*0.910*	*0.953*	*0.000*	*0.068*	*0.103*	*0.298*
K-AL	**0.27**	**0.04**	**0.21**	**1.00**	*0.000*	*0.000*	*0.000*	*0.000*	*0.010*	*0.000*	*0.000*	*0.021*
N-tot	**0.53**	**0.40**	**0.04**	**0.31**	**1.00**	*0.000*	*0.000*	*0.000*	*0.000*	*0.018*	*0.001*	*0.000*
TOC	**0.65**	**0.72**	**0.09**	**0.28**	**0.80**	**1.00**	*0.000*	*0.000*	*0.000*	*0.002*	*0.014*	*0.350*
Cmic	**0.65**	**0.31**	**0.01**	**0.63**	**0.76**	**0.66**	**1.00**	*0.000*	*0.000*	*0.000*	*0.213*	*0.866*
Nmic	**0.55**	**0.19**	**0.00**	**0.55**	**0.68**	**0.56**	**0.85**	**1.00**	*0.000*	*0.000*	*0.270*	*0.294*
Bulk	**-0.36**	**-0.53**	**0.36**	**-0.18**	**-0.33**	**-0.49**	**-0.42**	**-0.37**	**1.00**	*0.000*	*0.002*	*0.014*
Resp rate	**0.03**	**0.44**	**-0.13**	**0.41**	**0.17**	**0.22**	**0.38**	**0.32**	**-0.34**	**1.00**	*0.000*	*0.000*
Pen 0-20	**-0.09**	**-0.06**	**-0.12**	**0.31**	**-0.25**	**-0.18**	**0.09**	**0.08**	**-0.23**	**0.46**	**1.00**	*0.000*
Pen 20-40	**-0.25**	**0.24**	**-0.08**	**0.17**	**-0.27**	**-0.07**	**-0.01**	**-0.08**	**-0.18**	**0.50**	**0.74**	**1.00**

Most probabilities were below 0.05, meaning statistical significance. P-AL was only significantly correlated to K-AL and bulk density. Penetration resistance showed significance to about half of the involved parameters.

3.6 Ecosystem services and parameters

In this paragraph results are given from partial redundancy analysis to assess the effect of 10 environmental soil parameters on six ecosystem services in layer 1 and 2, where again the LTE is taken is covariate, so the effect of the LTE removed.

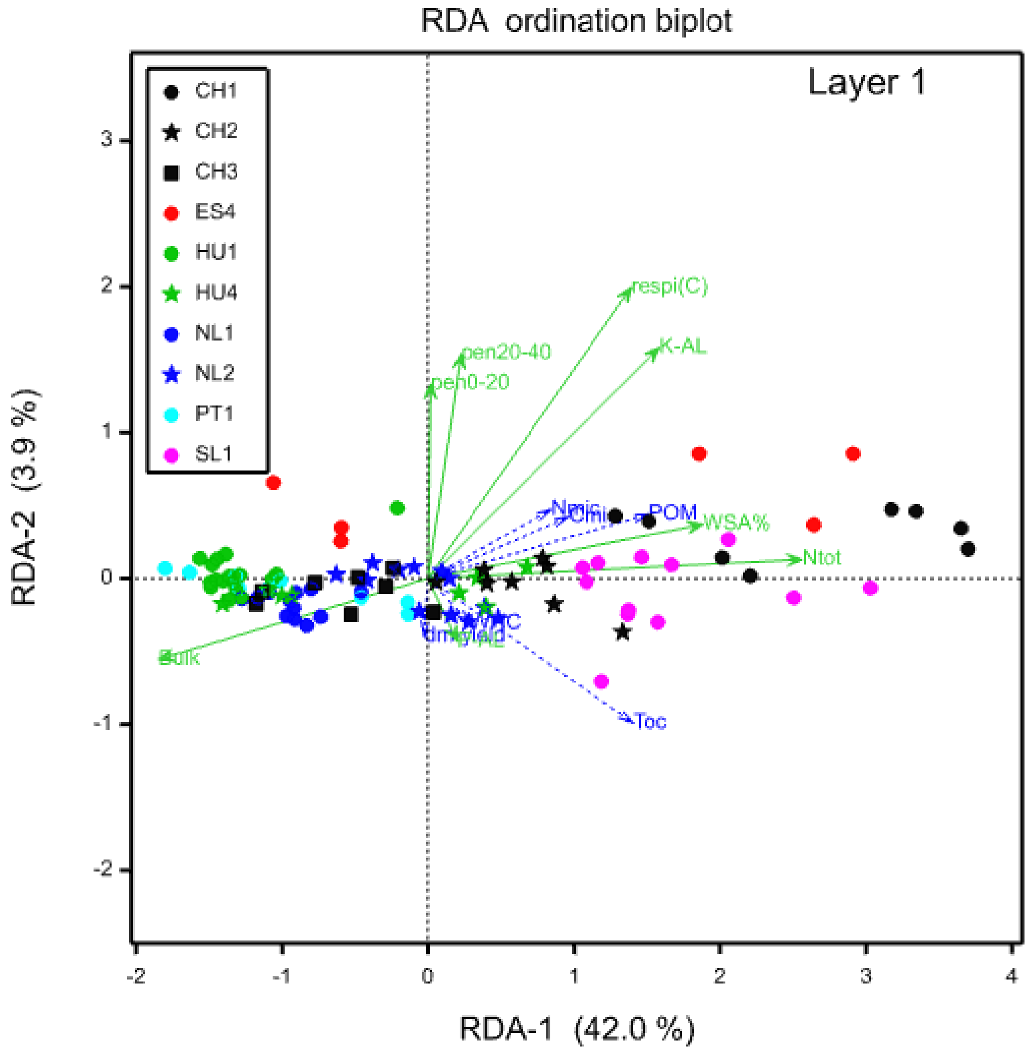

Figure 13. **Partial-RDA triplot of six ecosystem services, ten soil parameters in layer 1, using LTE as symbol and covariate. Cmic, Nmic: microbial biomass carbon and nitrogen; dm_yield: dry matter yield; TOC: total organic carbon; POM: particulate organic matter; WHC = water holding capacity. Bulk: bulk density; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40 = penetration resistance in layer 0–20, 20-40 cm; resp(C) = respiration; WSA =% water stable aggregates.**

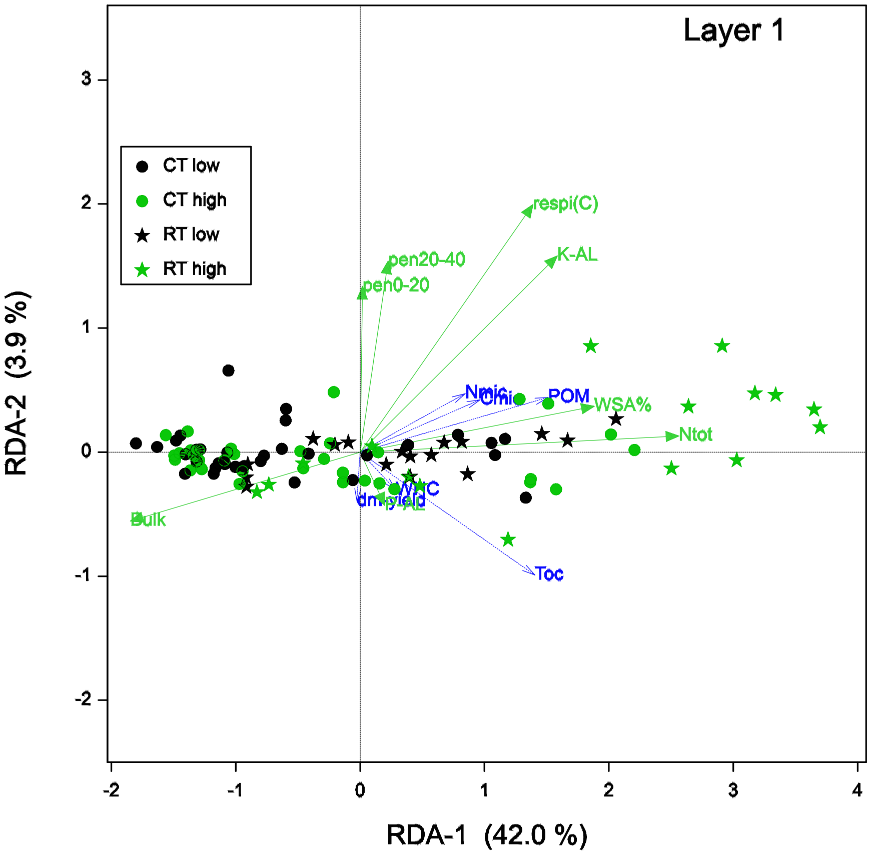

Figure 14. **Partial-RDA triplot of six ecosystem services, ten soil parameters in layer 1, using treatment as symbol and LTE as covariate. Cmic, Nmic: microbial biomass carbon and nitrogen; dm_yield: dry matter yield; TOC: total organic carbon; POM: particulate organic matter; WHC = water holding capacity. Bulk: bulk density; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40 = penetration resistance in layer 0–20, 20-40 cm; resp(C) = respiration; WSA = % water stable aggregates.**

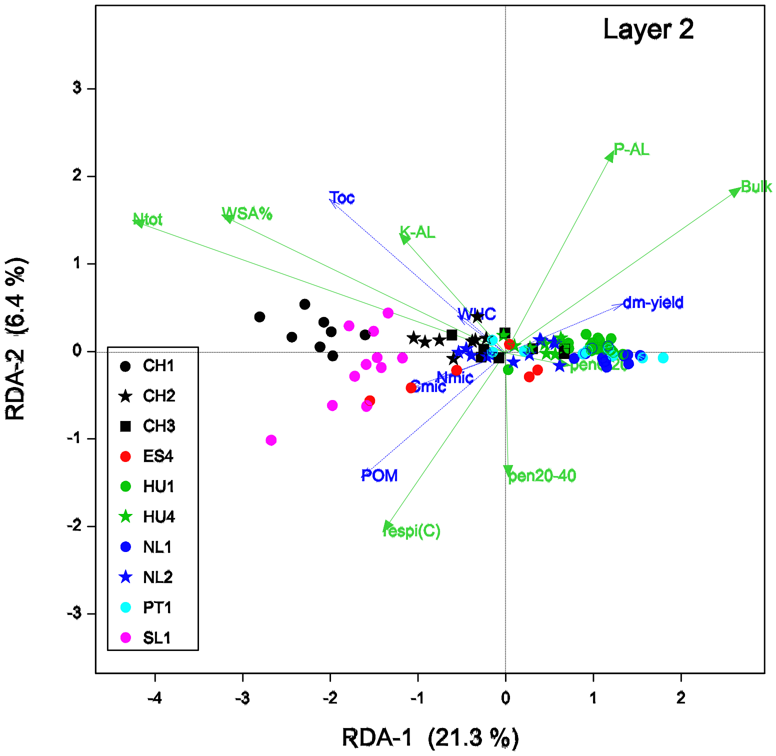

Figure 15. **Partial-RDA triplot of six ecosystem services, ten soil parameters in layer 2, using LTE as symbol and covariate. Cmic, Nmic: microbial biomass carbon and nitrogen; dm_yield: dry matter yield; TOC: total organic carbon; POM: particulate organic matter; WHC = water holding capacity. Bulk: bulk density; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40 = penetration resistance in layer 0–20, 20-40 cm; resp(C) = respiration; WSA = % water stable aggregates.**

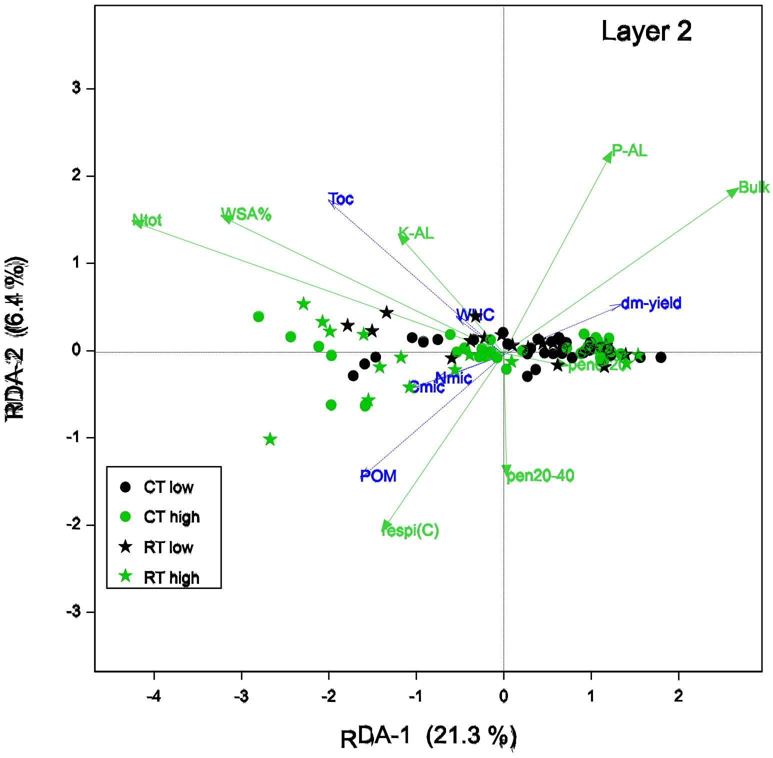

Figure 16. **Partial-RDA triplot of six ecosystem services, ten soil parameters in layer 1, using treatment as symbol and LTE as covariate. Cmic, Nmic: microbial biomass carbon and nitrogen; dm_yield: dry matter yield; TOC: total organic carbon; POM: particulate organic matter; WHC = water holding capacity. Bulk: bulk density; K-AL: total potassium; Ntot: total nitrogen; P-AL: total phosphate; pen0-20, pen20-40 = penetration resistance in layer 0–20, 20-40 cm; resp(C) = respiration; WSA = % water stable aggregates.**

Dry matter yield and the parameters WHC, TOC and POM (as measure of the quantity of carbon in the soil) and Cmic and Nmic (as measure of the microbial life in soil) were considered as representative indicators for ecosystem services.
In layer 1 (Figure 14) the symbols of the combination of reduced tillage and high supply of organic matter are mainly situated on the right side of the biplot, while symbols of the combination of conventional tillage and low supply of organic matter are mainly on the left side of the biplot. The parameters used to represent ecosystem services Cmic, Nmic, POM and TOC seem to be increased in value by the combination of reduced tillage and high supply of organic matter. For WHC and dry matter yield in layer 1 there is hardly any correlation with management. For layer 2 (Figure 16) symbols of tillage and supply of organic matter cannot be discerned clearly from each other and therefore a relation with ecosystem services in this layer doesn't seem to occur.

3.7 NIR-analysis versus analytical methods

In this section for 10 parameters a comparison is made between results determined in the laboratory using the (standard) analytical method (see chapter 2, section 2.5) and the faster and much cheaper near infrared spectroscopy method (NIR or NIRS).

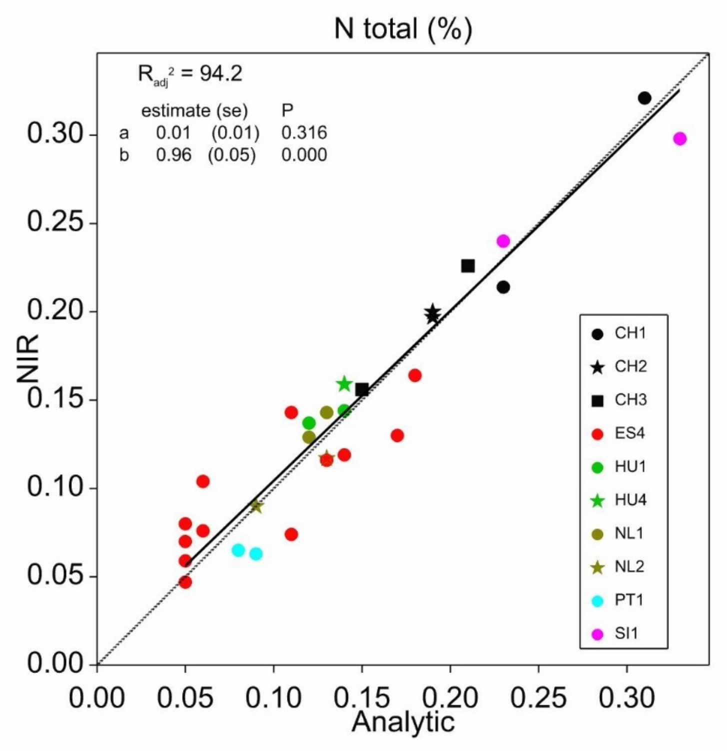

Figure 17. Comparison of N total percentage according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

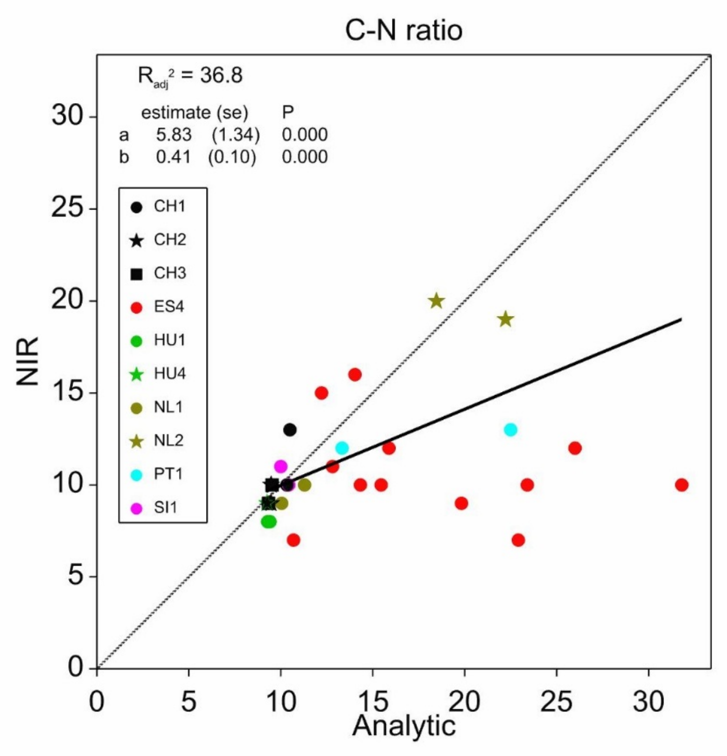

Figure 18. Comparison of C/N ratio according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

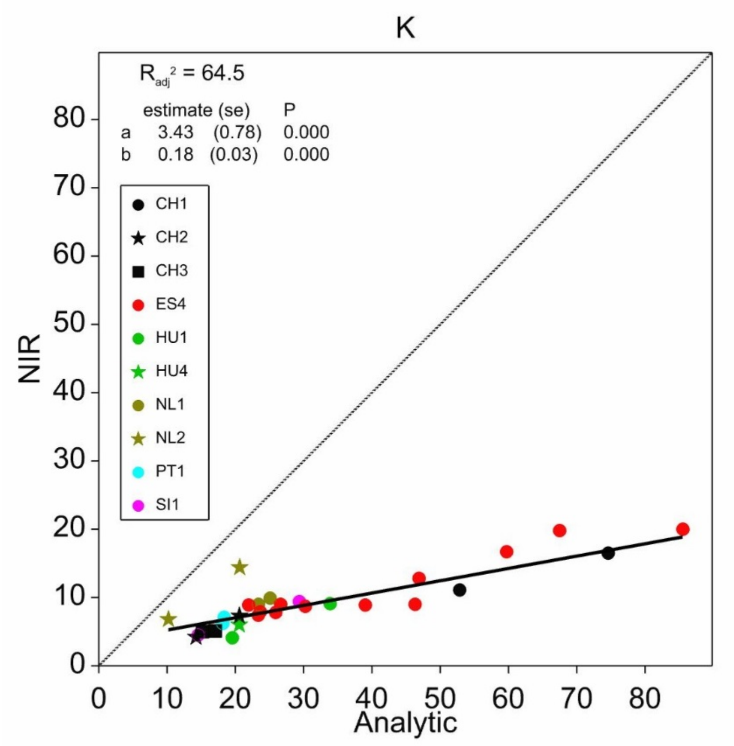

Figure 19. **Comparison of potash (K) according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.**

In figure 19 the measured parameters are not the same for both methods: the NIR results on the Y-axis represents K-available and the analytical results on the X-axis represents K-AL.

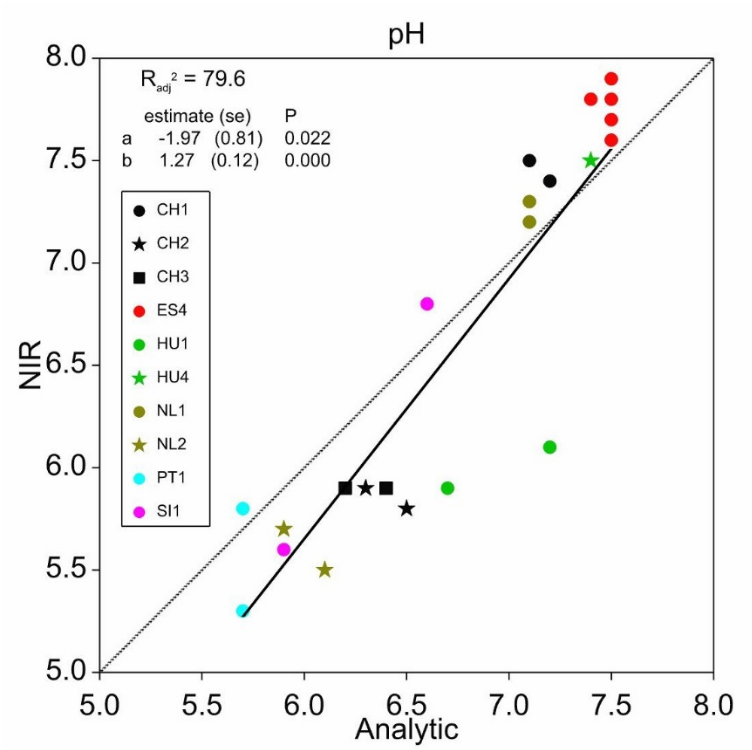

Figure 20. **Comparison of pH according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.**

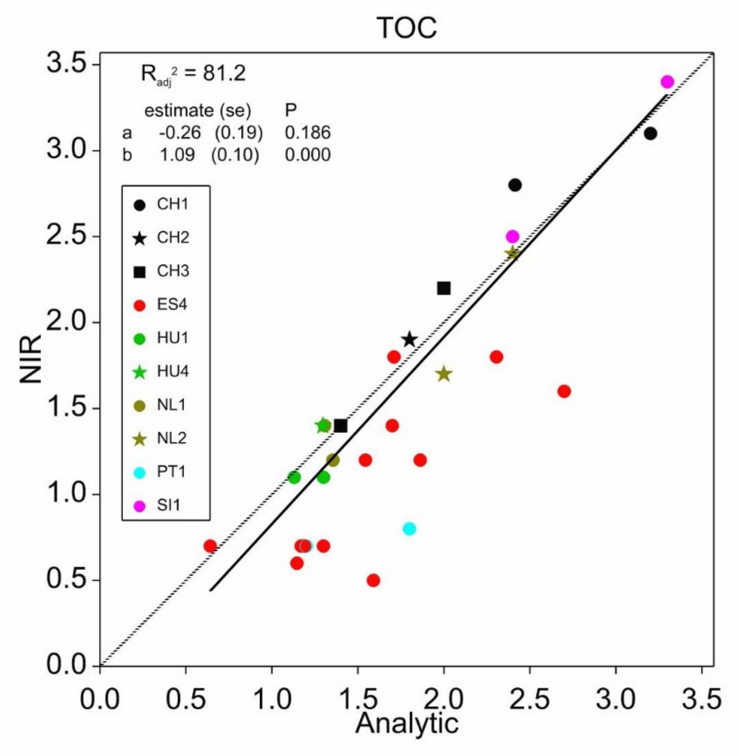

Figure 21. **Comparison of total organic carbon (TOC) according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.**

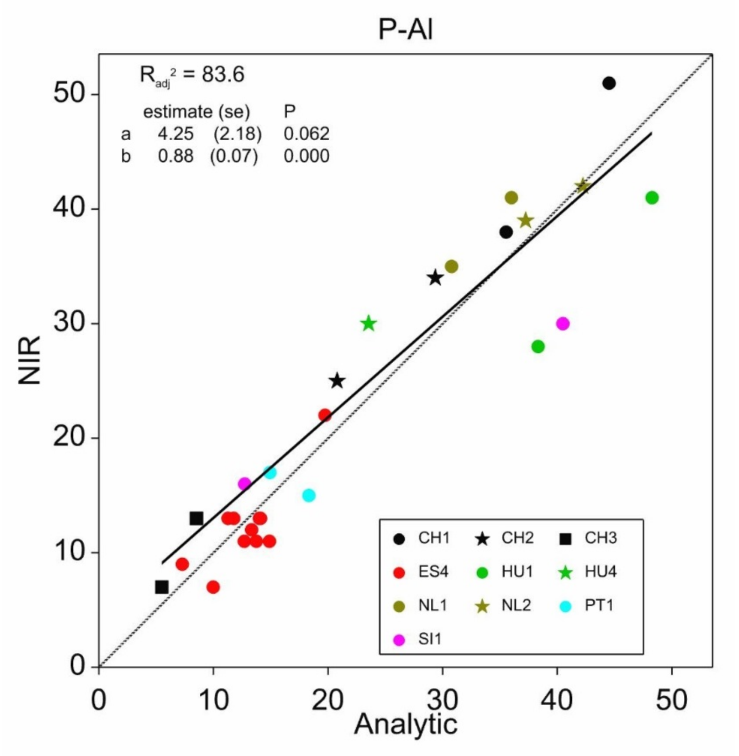

Figure 22. **Comparison of P-AL according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.**

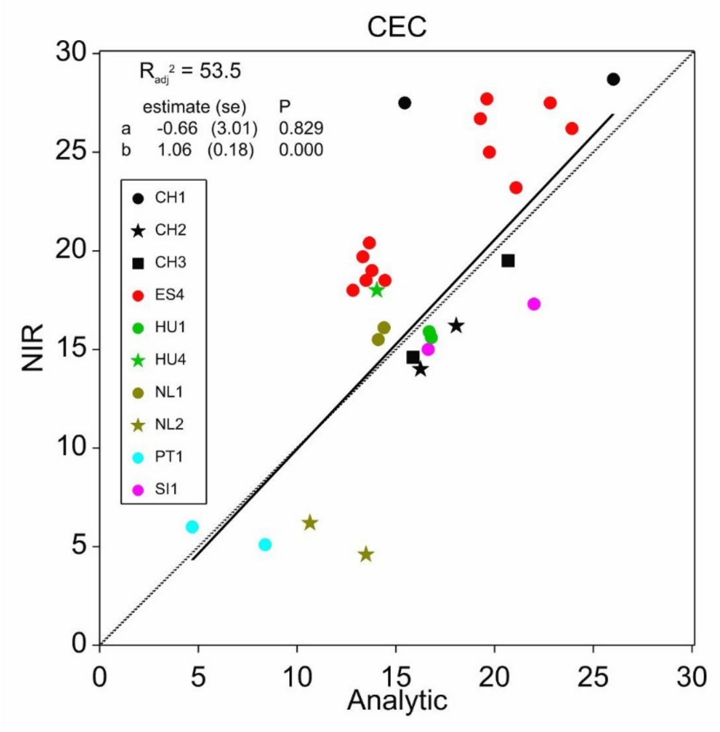

Figure 23. Comparison of cation exchange capacity (CEC) according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

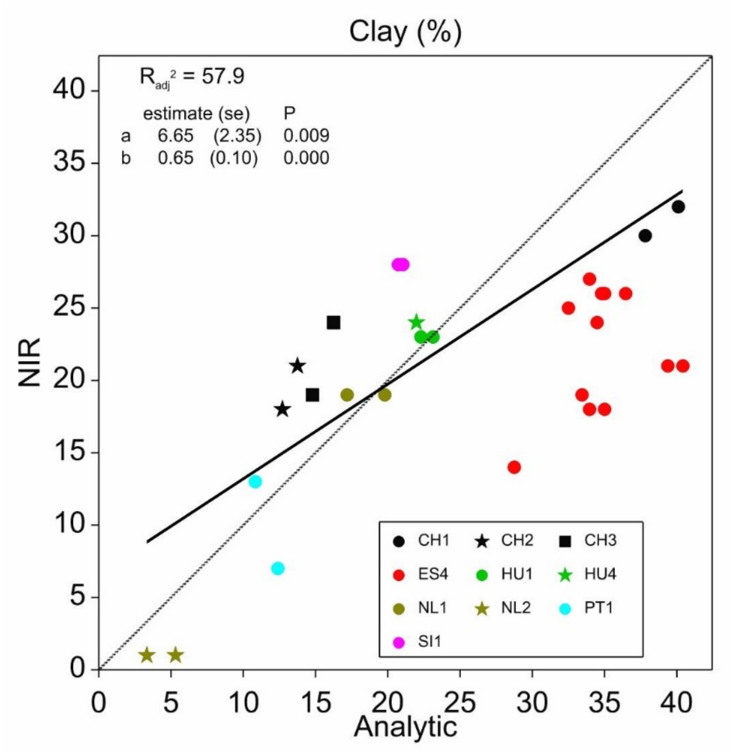

Figure 24. Comparison of percentage clay according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

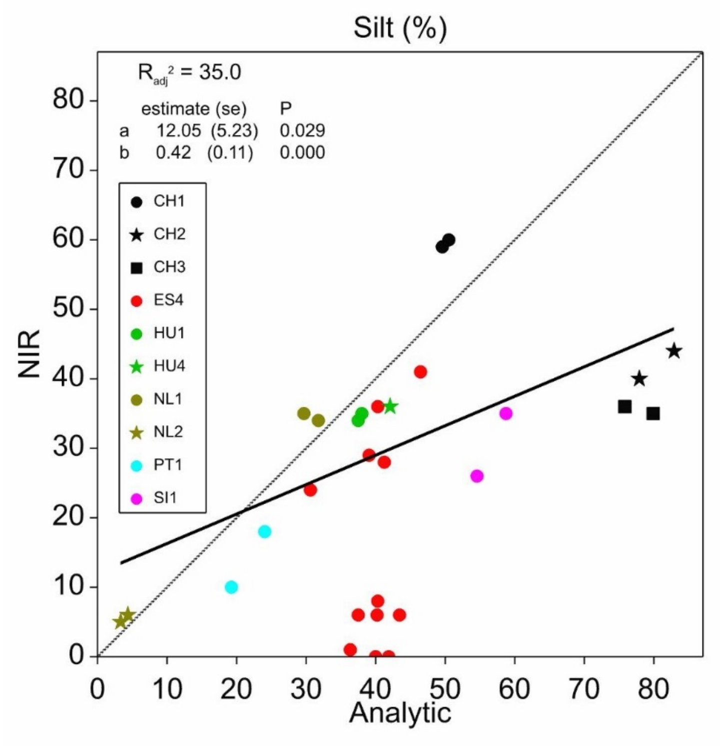

Figure 25. Comparison of percentage silt according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

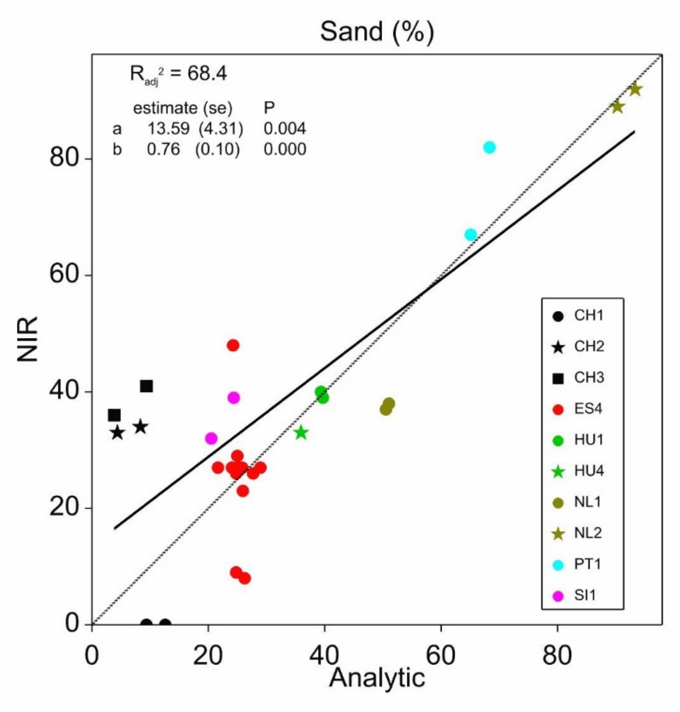

Figure 26. Comparison of percentage sand according to the analytical method (x-axis) and NIR (y-axis) as measured at the European LTEs.

For a number of parameters a comparison was made between their determination using standard analytical methods and the (much cheaper) near infrared method (NIR). This comparison was made for :N-total percentage, C/N ratio, potash (K-AL), pH, total organic carbon

(TOC), phosphate (P-AL), CEC and the percentages clay, silt and sand. For Ntot, assuming a linear relationship between both methods, more than 94 percent of the variance of the analytical method can be explained by NIR. For the C/N ratio no relationship between the analytical and the NIR method was found (R^2 = 37%). Looking at the results of the LTEs, it appears that one plot of PT1 and most plots of ES4 show low results for NIR compared to the analytical method (without ES4 almost 65% of the variance of the analytical method can be explained by NIR). Taking in mind that for potassium the measured parameters are not the same for both methods (NIR results represents K-available, analytical results represents K-AL) the relationship between the analytical method and NIR needs to be assessed with some care. Still 65% of the variation could be explained. For pH almost 80% of the variance of the analytical method can be explained by NIR. Concerning total organic carbon (TOC) over 80% of the variance of the analytical method can be explained using NIR. For TOC it appears that one plot of PT1 and most plots of ES4 show rather low results for NIR compared to the analytical method.
For phosphate (as P-AL) 84% of the variance of the analytical method could be explained by NIR. For CEC about half of the variance (54%) of the analytical method is explained by NIR. Concerning CEC it appears that most plots of ES4 and one plot of CH1 show rather high results and NL2 show rather low results for NIR compared to the analytical method. For percentage clay, silt and sand the relation between the analytical method and NIR varied between 35 (silt) and 69% (sand). For percentage clay, the plots of the LTEs of ES4 and of CH1 show low NIR results. For percentage silt the LTEs ES4, CH2 and CH3 demonstrate low NIR results and for percentage sand some plots of LTE ES4 show low and the LTEs CH2 and CH3 show high NIR results.

3.8 Results from LTEs in China

In this chapter boxplots of data distribution and results of ANOVA analysis on data 5 LTEs in China are given: Gonzhuling, Qiyang, Suining, Wangcheng and Zhengzhou. The treatments codes in the tables have the following meaning: N = nitrogen, P=phosphorus, K=potassium, M=application of manure, 1.5 M= 1.5 times the usual amount of manure, rot=maize and soybean, S=straw incorporation. Details of the amounts of nutrients added per treatment per LTE are to be found in Annex 7.1.

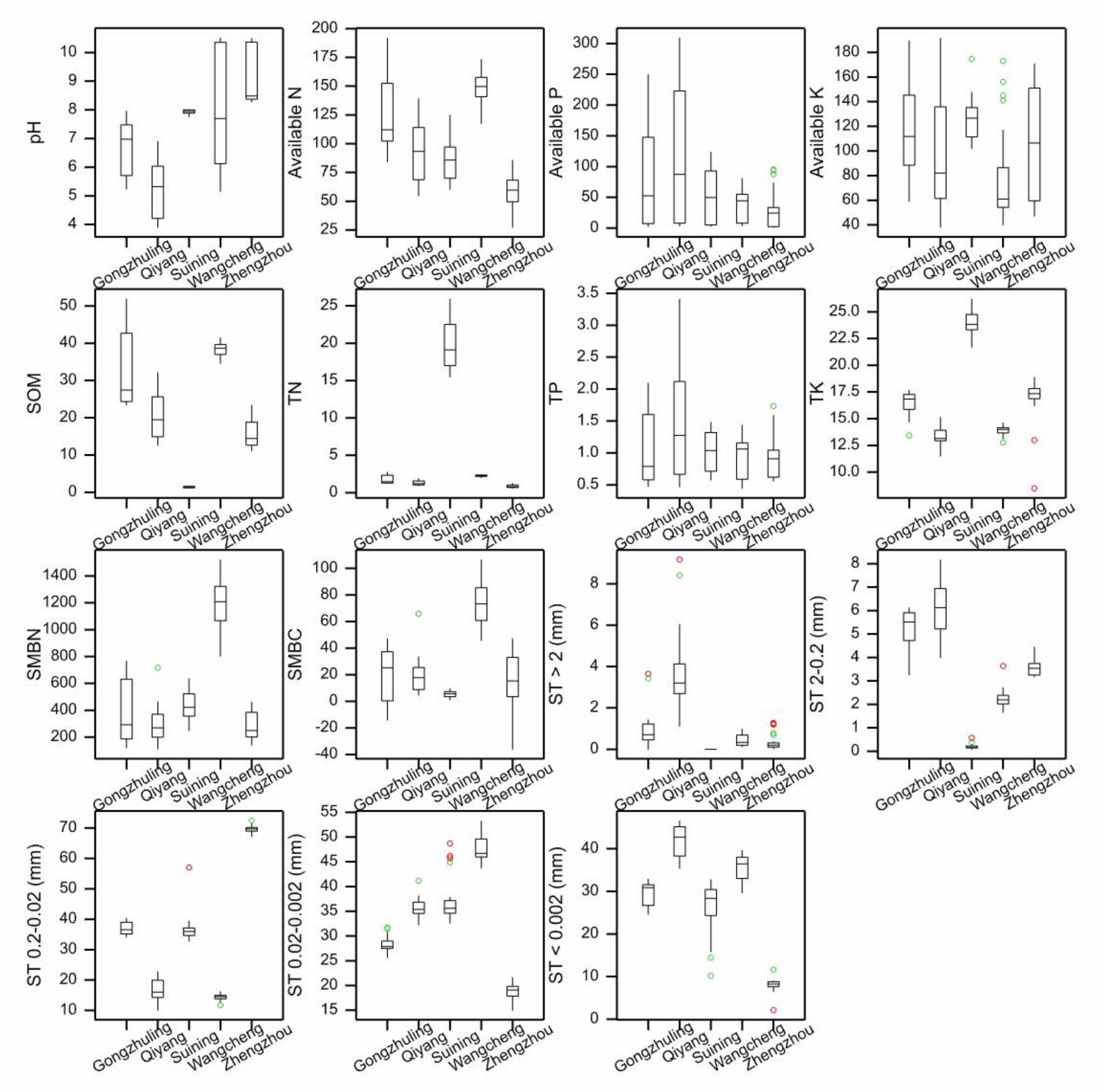

Figure 27. Boxplots showing the distribution of measured soil parameters for Chinese LTEs.

Boxplots were made for all the measured soil quality indicators. Data are shown per LTE, no discrimination is made for the different treatments, per parameter all data from 1 LTE are shown in 1 boxplot.

Figure 27 shows that there is a large variation in the data distribution between LTEs as well as within LTEs. The soil in Suining is high in total N and total K compared to the other LTEs, this trend is not seen for available N and K. Suining is low in soil organic matter compared to the other LTEs. P content is for all the LTEs more or less similar.

Results Gonzhuling

Table 32. Means of pH, available N and available P, Gonzhuling, 2018.

treatment	pH		available N		available P	
Code						
(NPK)1.5	7.1	c	182.3	f	225.6	e
untreated	7.0	bc	88.8	ab	3.2	a
Fallow	7.9	d	109.0	cd	10.7	a
N	5.8	a	106.3	c	4.1	a
NK	5.3	a	122.7	d	4.9	a
NP	5.7	a	103.0	bc	52.3	b
NPK	5.6	a	112.2	cd	46.6	b
NPK+1.5 M	7.5	cd	182.2	f	174.2	d
NPK+1 M	7.1	c	153.2	e	160.2	cd
NPK+M+rot	7.5	cd	152.5	e	138.5	c
NPK+straw	7.9	d	103.9	c	26.9	ab
PK	6.5	b	85.3	a	56.7	b
LSD 5%	0.6		14.99		31.17	
F prob.	<0.001		<0.001		<0.001	

Table 33. Means of available K, SOM, Ntot, Gonzhuling, 2018.

treatment	Available K		SOM		Ntot	
Code			(soil organic matter)		(total nitrogen)	
(NPK)1.5	111.0	abc	50.22	e	2.781	f
untreated	122.5	bcde	24.13	a	1.256	a
Fallow	119.5	abcd	34.19	c	1.852	d
N	105.2	abc	23.74	a	1.291	a
NK	145.2	cde	24.67	a	1.377	b
NP	103.0	abc	25.16	a	1.279	a
NPK	133.0	cde	24.69	a	1.324	ab
NPK+1.5 M	88.5	abc	49.59	e	2.725	f
NPK+1 M	64.0	a	43.24	d	2.330	e
NPK+M+rot	68.2	ab	42.66	d	2.327	e
NPK+straw	177.2	e	29.20	b	1.563	c
PK	171.0	de	24.32	a	1.277	a
LSD 5%	57.43		2.760		0.0776	
F prob.	<0.05		<0.001		<0.001	

Table 34. Means of Ptot, Ktot, Nmic, Gonzhuling, 2018.

treatment	Ptot		Ktot		Nmic	
Code	(total phosphate)		(total potassium)		(soil microbial nitrogen)	
(NPK)1.5	2.054	e	15.09	b	431.1	cd
untreated	0.493	a	17.02	cd	255.1	ab
Fallow	0.646	ab	16.83	cd	596.1	de
N	0.497	a	16.99	cd	153.6	a
NK	0.479	a	16.93	cd	148.9	a
NP	0.754	bc	16.58	c	146.2	a
NPK	0.740	bc	17.32	cd	192.5	a
NPK+1.5 M	1.929	e	14.06	a	736.8	e
NPK+1 M	1.681	d	17.35	cd	669.0	e
NPK+M+rot	1.601	d	15.20	b	693.5	e
NPK+straw	0.813	bc	17.69	d	394.4	bc
PK	0.831	c	16.71	c	279.9	abc
LSD 5%	0.169		0.962		170.9	
F prob.	<0.001		<0.001		<0.001	

Table 35. Means of Cmic, Particles > 2mm, particles 0.2-2 mm, Gonzhuling, 2018.

treatment	Cmic		Particles > 2 mm		Particles 0.2-2 mm	
Code	(soil microbial carbon)					
(NPK)1.5	27.25	de	1.312	abc	5.674	de
untreated	13.07	bc	0.739	abc	4.968	bcd
Fallow	29.71	def	0.401	ab	3.490	a
N	-11.26	a	0.280	ab	4.667	bc
NK	-3.15	a	0.849	abc	5.905	de
NP	-8.56	a	0.758	abc	4.935	bcd
NPK	1.56	ab	0.948	abc	5.442	cde
NPK+1.5 M	35.59	efg	2.429	c	5.960	e
NPK+1 M	42.27	fg	1.205	abc	5.654	de
NPK+M+rot	46.92	g	2.097	bc	5.984	e
NPK+straw	37.30	efg	0.123	a	4.283	ab
PK	19.50	cd	0.624	abc	5.610	cde
LSD 5%	13.73		1.843		0.975	
F prob.	<0.001		n.s.		<0.01	

Table 36. Means of Particles 0.02-0.2 mm, particles < 0.002 mm, particles 0.02-0.002 mm, Gonzhuling, 2018.

treatment	Particles 0.02 – 0.2 mm		Particles < 0.002		Particles 0.02-0.002 mm	
Code						
(NPK)1.5	27.72	abc	26.32	ab	40.29	c
untreated	28.01	abc	31.51	def	35.52	a
Fallow	31.57	d	26.71	b	38.23	b
N	27.67	abc	32.22	ef	35.45	a
NK	26.84	ab	31.51	def	35.75	a
NP	28.91	bc	31.24	de	34.92	a
NPK	28.10	abc	31.59	def	34.87	a
NPK+1.5 M	29.26	c	25.10	a	39.68	bc
NPK+1 M	27.04	ab	28.72	c	38.59	bc
NPK+M+rot	28.46	abc	26.69	b	38.87	bc
NPK+straw	29.24	c	30.38	d	36.10	a
PK	26.47	a	32.67	f	35.25	a
LSD 5%	2.173		1.428		1.993	
F prob.	<0.05		<0.001		<0.001	

Table 37. Means bulk density, penetration resistance, earthworm numbers and earthworm biomass, , Gonzhuling, 2018.

Treatment	Soil bulk density	Penetration	Earthworm	
Code	in grams per cm^3	Resistance	Numbers per	Biomass in grams
			20x20x30 cm	per 20x20x30 cm
CK (untreated)	1.43	942	0	0
F	1.35	3891	0	0
N	1.39	1473	0	0
NP	1.39	1394	0	0
NK	1.36	1542	0	0
PK	1.27	1555	0	0
NPK	1.26	1859	0	0
NPKS	1.37	1097	0	0
NPKM	1.18	859	0	0
NPKMR	1.17	1800	0	0
NPK+1.5M	1.19	1687	0	0
1.5(NPKM)	1.18	911	0	0

1) Statistical analysis was impossible, while there are no data of the plots but only treatment means.

Results Qiyang

Table 38. Means of available N, available P and available K, Qiyang, 2018.

treatment	available N		available P		available K	
Code						
1.5 NPKM	136.3	c	302.3	d	131.0	abc
Untreated	59.2	a	4.3	a	57.0	a
Fallow	82.1	ab	11.0	a	146.2	bc
N	84.8	ab	6.9	a	51.0	a
NK	81.5	ab	5.5	a	126.5	abc
NP	86.7	ab	86.3	b	62.5	ab
NPK	91.0	ab	92.7	b	117.0	abc
NPK+M	113.8	bc	234.7	c	102.5	abc
NPK+M+rot	116.9	bc	238.2	c	172.5	c
NPK+straw	78.5	ab	89.8	b	59.0	a
PK	65.0	a	79.9	b	84.0	ab
LSD 5%	39.13		21.61		85.97	
F prob.	<0.05		<0.001		n.s.	

Table 39. Means of SOM, Ntot and Ptot, Qiyang, 2018.

treatment	SOM		Ntot		Ptot	
Code	(soil organic matter)		(total nitrogen)		(total phosphate)	
1.5 NPKM	30.67	g	1.911	g	3.406	e
Untreated	14.08	a	0.959	a	0.572	a
Fallow	22.90	def	1.356	de	0.598	a
N	13.64	a	1.012	ab	0.603	a
NK	14.43	ab	0.992	ab	0.510	a
NP	17.85	abc	1.152	abc	1.236	b
NPK	19.81	cde	1.239	cd	1.285	b
NPK+M	25.82	f	1.643	f	2.586	d
NPK+M+rot	24.33	ef	1.538	ef	2.241	c
NPK+straw	19.09	bcd	1.158	bcd	1.229	b
PK	14.96	ab	0.982	ab	1.292	b
LSD 5%	4.681		0.198		0.220	
F prob.	<0.001		<0.001		<0.001	

Table 40. Means of Ktot, Nmic and Cmic, Qiyang, 2018.

treatment	Ktot		Nmic		Cmic	
Code	(total potassium)		(soil microbial nitrogen)		(soil microbial carbon)	
1.5 NPKM	13.68	ab	562.1	e	49.86	d
Untreated	13.76	ab	262.5	abc	11.86	ab
Fallow	12.43	a	356.9	cd	20.90	abc
N	12.43	a	160.9	a	5.15	a
NK	13.03	ab	149.6	a	6.76	a
NP	12.65	ab	207.9	a	8.69	a
NPK	14.09	b	271.8	abc	18.40	abc
NPK+M	13.46	ab	417.5	d	25.29	bc
NPK+M+rot	13.02	ab	342.2	bcd	31.25	c
NPK+straw	13.05	ab	215.0	ab	13.19	ab
PK	14.07	b	241.0	abc	16.96	abc
LSD 5%	1.510		132.9		16.25	
F prob.	n.s.		<0.01		<0.01	

Table 41. Means particles > 2mm, particles 0.2-2 mm, particles 0.02-0.2 mm, Qiyang, 2018.

treatment	Particles > 2 mm		Particles 0.2-2 mm		Particles 0.02-0.2 mm	
Code						
1.5 NPKM	3.565	a	7.231	c	35.00	abc
Untreated	2.095	a	6.445	bc	35.88	abc
Fallow	3.752	a	7.520	c	35.51	abc
N	5.140	a	6.227	abc	33.87	a
NK	3.023	a	4.713	ab	36.41	abc
NP	2.955	a	4.393	a	37.69	bc
NPK	3.028	a	5.729	abc	34.24	ab
NPK+M	5.959	a	6.373	bc	34.94	abc
NPK+M+rot	3.221	a	6.239	abc	38.05	c
NPK+straw	2.502	a	5.193	ab	36.28	abc
PK	3.597	a	5.969	abc	35.71	abc
LSD 5%	4.091		1.978		3.706	
F prob.	n.s.		<0.10		n.s.	

Table 42. Means of particles <0.002 mm, particles 0.02-0.002 mm

treatment	Particles <0.002 mm		Particles 0.002-0.02 mm	
Code				
1.5 NPKM	36.25	a	21.51	d
Untreated	42.95	cd	14.73	ab
Fallow	43.03	cd	13.94	ab
N	45.24	d	14.66	ab
NK	45.03	cd	13.84	ab
NP	44.07	cd	13.84	ab
NPK	44.17	cd	15.86	abc
NPK+M	38.52	ab	20.17	cd
NPK+M+rot	36.87	ab	18.84	bcd
NPK+straw	40.77	bc	17.75	abcd
PK	44.86	cd	13.46	a
LSD 5%	4.333		5.308	
F prob.	<0.01		<0.10	

Table 43. Means bulk density, penetration resistance, earthworm numbers and earthworms biomass, , Gonzhuling, 2018.

treatment	bulk density in		penetration		earthworms			
Code	grams per cm^3		resistance		numbers		biomass in grams	
					(20 x 20 x 30 cm)		(20 x 20 x 30 cm)	
untreated	1.422	cd	2326	a	0	a	0.00	a
F	1.492	d	3306	bc	0	a	0.00	a
N	1.307	abc	3084	abc	0	a	0.00	a
NK	1.173	a	3734	c	0	a	0.00	a
NP	1.194	a	2771	ab	0	a	0.00	a
NPK	1.175	a	2220	a	0	a	0.00	a
NPKM	1.361	bcd	2246	a	23	b	4.44	b
NPKM(W+S)	1.432	cd	2928	abc	72	c	15.79	c
NPKS	1.263	ab	2504	ab	0	a	0.00	a
PK	1.282	abc	2871	abc	0	a	0.00	a
Lsd 5%	0.155		896		9		1.95	
F prob.	<0.01		<0.10		<0.001		<0.001	

Results Suining.

In Suining in each plot wheat and rice were planted each year. Rice was planted in May and harvested in September, wheat was planted in October and harvested in May (of the next year).

Table 44. Means of available N, available P and available K, Suining, 2018.

treatment	Available N		Available P		Available K	
Code						
Untreated	74.7	a	2.85	a	143.0	bc
M	80.0	ab	5.51	a	129.4	bc
MN	89.8	ab	4.54	a	122.7	ab
MNP	85.9	ab	83.72	c	108.8	a
MNPK	106.2	b	82.17	bc	146.2	c
N	69.3	a	2.70	a	126.7	abc
NP	91.1	ab	93.38	c	109.3	a
NPK	74.0	a	50.26	b	127.3	bc
LSD 5%	30.75		46.58		22.61	
F prob.	<0.10		<0.001		<0.01	

Table 45. Means of Ntot, SOM and Ptot, Suining, 2018.

treatment	Ntot		SOM		Ptot	
Code	(total nitrogen)		(soil organic matter)		(total phosphate)	
Untreated	1.253	ab	18.67	ab	0.648	a
M	1.328	ab	19.22	ab	0.667	a
MN	1.447	ab	20.71	ab	0.712	ab
MNP	1.426	ab	20.15	ab	1.226	cd
MNPK	1.577	b	22.98	b	1.334	d
N	1.197	a	16.90	a	0.601	a
NP	1.479	ab	20.96	ab	1.253	cd
NPK	1.248	a	17.01	a	1.016	bc
LSD 5%	0.428		6.593		0.358	
F prob.	n.s.		n.s.		<0.001	

Table 46. Means Ktot, Nmic and Cmic, Suining, 2018.

treatment	Ktot		Nmic		Cmic	
Code	(total potassium)		(soil microbial nitrogen)		(soil microbial carbon)	
Untreated	24.07	a	338.0	a	4.357	ab
M	23.55	a	548.6	bc	6.850	ab
MN	23.27	a	632.3	c	8.418	b
MNP	23.76	a	483.5	b	6.431	ab
MNPK	24.64	a	465.3	ab	4.751	ab
N	24.06	a	413.4	ab	5.392	ab
NP	23.15	a	350.5	a	4.248	a
NPK	24.53	a	364.6	a	4.634	ab
LSD 5%	2.280		167.1		4.526	
F prob.	n.s.		<0.01		n.s.	

Table 47. Means of STgt mm, ST2_2 mm and STO_02_002 mm, Suining, 2018.

treatment	Stgt2 mm		ST2_0_2 mm		STO_02_002 mm	
Code	(particles > 2 mm ?)		(particles 2 – 0.2 mm ?)		(particles 0.02-0.002 mm ?)	
Untreated	0	a	0.196	a	34.74	a
M	0	a	0.162	a	41.95	a
MN	0	a	0.292	a	41.54	a
MNP	0	a	0.134	a	38.41	a
MNPK	0	a	0.198	a	38.12	a
N	0	a	0.151	a	35.30	a
NP	0	a	0.176	a	34.14	a
NPK	0	a	0.262	a	35.51	a
LSD 5%	*		0.245		9.046	
F prob.	n.s.		n.s.		n.s.	

Table 48. Means of STlt0_002 mm and STO_2_0_02 mm, Suining, 2018.

treatment	STlt0_002 mm		STO_2_0_02 mm	
Code	(particles < 0.002 mm ?)		(particles 0.2 – 0.02 mm ?)	
Untreated	29.69	a	35.37	ab
M	23.18	a	34.71	ab
MN	22.23	a	35.94	ab
MNP	26.12	a	35.34	ab
MNPK	24.20	a	37.49	ab
N	31.57	a	32.98	a
NP	23.54	a	42.14	b
NPK	28.49	a	35.74	ab
LSD 5%	14.01		9.553	
F prob.	n.s.		n.s.	

Results Wangcheng.

In Wangcheng in each plot rice was planted twice each year. Early rice was planted in April and harvested in July, late rice was planted in July and harvested in October.

Table 49. Means of pH, available N and available P, Wangcheng, 2018.

treatment	pH		available N		Available P	
Code						
Untreated	5.613	a	154.4	b	5.11	a
NK	5.537	a	150.0	ab	3.55	a
NK+M	6.977	b	155.6	b	8.29	a
NP	5.357	a	147.3	ab	50.30	bc
NPK	5.360	a	145.6	ab	44.77	b
NPK+L	5.737	a	135.0	a	47.53	bc
NPKS	7.147	b	147.8	ab	50.52	bc
NPS	7.203	b	159.0	b	60.78	cd
PK	5.400	a	146.4	ab	70.73	d
LSD 5%	0.784		18.31		14.03	
F prob.	<0.001		n.s.		<0.001	

Table 50. Means of available K, SOM and TN, Wangcheng, 2018.

treatment	available K		SOM		TN	
Code			(soil organic matter)		(total nitrogen)	
Untreated	57.3	a	37.60	abc	2.129	a
NK	123.0	b	38.50	abc	2.305	bc
NK+M	65.3	a	40.25	c	2.360	c
NP	45.7	a	37.38	ab	2.206	abc
NPK	73.7	a	38.17	abc	2.282	abc
NPK+L	69.7	a	38.46	abc	2.222	abc
NPKS	71.3	a	39.32	bc	2.333	c
NPS	47.5	a	39.48	bc	2.360	c
PK	139.5	b	35.95	a	2.157	ab
LSD 5%	40.93		2.797		0.157	
F prob.	<0.01		n.s.		<0.05	

Table 51. Means of TP, TK and SMBN, Wangcheng, 2018.

treatment	TP		TK		SMBN	
Code	(total phosphate)		(total potassium)		(soil microbial nitrogen)	
Untreated	0.483	a	13.78	b	1183	a
NK	0.459	a	13.80	b	1200	a
NK+M	0.611	a	14.26	bc	1261	ab
NP	1.098	b	13.19	a	1054	a
NPK	1.097	b	13.90	bc	1425	b
NPK+L	1.090	b	14.18	bc	1142	a
NPKS	1.092	b	14.33	c	1042	a
NPS	1.102	b	13.93	bc	1220	ab
PK	1.327	c	13.99	bc	1181	a
LSD 5%	0.176		0.518		220.4	
F prob.	<0.001		<0.05		<0.10	

Table 52. Means of SMBC, STgt2 mm, ST2_0_2 mm, Wangcheng, 2018.

treatment	SMBC		STgt2 mm		ST2_0_2 mm	
Code	(soil microbial carbon)		particles > 2 mm ?		particles 2 – 0.2 mm ?	
Untreated	64.17	ab	0.348	ab	2.614	a
NK	71.92	bcd	0.700	b	2.303	a
NK+M	72.50	bcd	0.206	a	1.987	a
NP	62.56	ab	0.296	ab	2.141	a
NPK	97.42	e	0.356	ab	2.104	a
NPK+L	91.37	de	0.556	ab	2.232	a
NPKS	51.10	a	0.362	ab	2.243	a
NPS	65.15	abc	0.507	ab	2.281	a
PK	85.17	cde	0.496	ab	2.190	a
LSD 5%	20.2		0.489		0.688	
F prob.	<0.01		n.s.		n.s.	

Table 53. Means of STO_02_0_002, STlt)_002 mm and STO_2_0_02 mm, Wangcheng, 2018.

treatment	STO_02_0_002 mm		STlt 0_002 mm		STO_2_0_02 mm	
Code	(particles 0.02–0.002 mm?		(particles < 0.002 mm ?)		(particles 2 – 0.02 mm ?)	
Untreated	49.60	cd	32.83	ab	14.95	b
NK	49.99	cd	33.10	ab	14.61	ab
NK+M	49.12	bcd	35.43	bc	13.46	ab
NP	50.60	d	32.04	a	15.22	b
NPK	45.75	a	37.74	cd	14.41	ab
NPK+L	46.86	abc	37.79	cd	13.11	a
NPKS	45.67	a	37.67	cd	14.42	ab
NPS	44.95	a	38.53	d	14.25	ab
PK	46.33	ab	36.61	cd	14.87	ab
LSD 5%	3.240		2.780		1.766	
F prob.	<0.01		<0.001		n.s.	

Table 54. Means bulk density, penetration resistance, earthworm numbers and earthworm biomass, Wangcheng, 2018.

treatment	bulk density in		penetration		earthworms			
Code	grams per cm^3		resistance [1]		numbers [1]		biomass in grams [1]	
					(20 x 20 x 30 cm)		(20 x 20 x 30 cm)	
Untreated	1.097	b	1022		0		0	
NK	1.070	a	1131		0		0	
NK+M	1.077	ab	992		0		0	
NP	1.463	d	972		0		0	
NPK	1.070	a	1291		0		0	
NPK+L	1.263	e	1062		0		0	
NPKS	*		1248		0		0	
NPS	*		1175		2		0.25	
PK	1.133	c	1200		0		0	
	0.02							
	< 0.001							

1) Statistical analysis was impossible for penetration resistance, earthworm numbers and earthworm weights, while there were no data of the plots but only treatment means.

2) * no results available (missing).

Results Zhengzhou

In Zhengzhou each plot was planted with wheat and maize. Wheat was planted in October and harvested in June, maize was planted in June and harvested in October.

Table 55. Means of pH, available N and available P, Zhengzhou, 2018.

treatment	pH		available N		Available P	
Code						
1.5 NPK+M	8.33	a	79.15	e	92.23	e
Untreated	10.47	c	34.56	a	2.09	a
F	10.40	c	49.14	b	3.90	a
N	10.33	c	65.38	cd	1.39	a
NK	9.06	b	62.27	cd	1.36	a
NP	10.21	c	59.44	c	24.67	b
NPK	8.34	a	59.69	c	24.90	b
NPK+M	8.39	a	68.64	d	66.37	d
NPK+S	8.41	a	65.98	cd	28.07	b
PK	8.48	ab	42.03	ab	35.10	c
LSD 5%	0.624		7.872		5.875	
F prob.	<0.001		<0.001		<0.001	

Table 56. Means of , Zhengzhou, 2018.

treatment	Available K		SOM		TN	
Code			(soil organic matter)		(total nitrogen)	
1.5 NPK+M	61.5	b	23.34	d	1.309	g
Untreated	57.3	ab	11.99	a	0.596	a
F	134.0	d	14.53	b	0.766	cd
N	54.3	ab	11.82	a	0.685	b
NK	143.8	de	12.46	a	0.711	bc
NP	49.0	a	14.62	b	0.827	d
NPK	86.0	c	14.97	b	0.823	d
NPK+M	166.0	g	19.75	c	1.125	f
NPK+S	157.2	fg	18.73	c	1.027	e
PK	151.0	ef	12.84	a	0.691	b
LSD 5%	12.12		1.091		0.0628	
F prob.	<0.001		<0.001		<0.001	

Table 57. Means of , Zhengzhou, 2018.

treatment	TP		TK		SMBN	
Code	(total phosphate)		(total potassium)		(soil microbial nitrogen)	
1.5 NPK+M	1.536	d	17.85	b	396.2	c
Untreated	0.622	a	18.68	b	176.6	a
F	0.632	a	16.86	ab	204.2	a
N	0.586	a	16.85	ab	183.9	a
NK	0.592	a	17.13	ab	223.0	a
NP	0.907	b	16.68	ab	276.3	b
NPK	0.976	b	14.50	a	276.9	b
NPK+M	1.296	c	15.78	ab	411.7	c
NPK+S	0.917	b	17.87	b	428.2	c
PK	1.039	b	17.78	b	213.6	a
LSD 5%	0.209		3.091		52.65	
F prob.	<0.001		n.s.		<0.001	

Table 58. Means of , Zhengzhou, 2018.

treatment Code	SMBC (soil microbial carbon)		STgt 2 mm (particles > 2 mm ?)		ST2_0_2 mm (particles 2 – 0.2 mm ?)	
1.5 NPK+M	41.33	c	0.522	a	4.235	d
Untreated	15.10	b	0.512	a	3.509	abc
F	8.17	b	0.121	a	3.614	bc
N	-24.83	a	0.421	a	3.443	ab
NK	-19.50	a	0.261	a	3.409	ab
NP	13.56	b	0.418	a	3.413	ab
NPK	12.84	b	0.112	a	3.382	ab
NPK+M	38.26	c	0.071	a	3.657	bc
NPK+S	41.84	c	0.482	a	3.224	a
PK	17.38	b	0.208	a	3.778	c
LSD 5%	13.94		0.649		0.319	
F prob.	<0.001		n.s.		<0.001	

Table 59. Means of , Zhengzhou, 2018.

treatment Code	STO_02_0_002 mm (particles 0.02-0.002 mm ?)		STlt 0_002 mm (particles < 0.002 mm ?)	
1.5 NPK+M	18.60	bc	7.363	ab
Untreated	16.60	a	9.299	b
F	17.50	ab	8.816	b
N	18.52	bc	8.125	ab
NK	18.69	bcd	8.794	b
NP	20.25	def	7.684	ab
NPK	19.62	cdef	7.544	ab
NPK+M	18.71	bcde	8.150	ab
NPK+S	20.35	ef	8.620	b
PK	20.37	f	5.836	a
LSD 5%	1.642		2.443	
F prob.	<0.01		n.s.	

Table 60. Means of bulk density, penetration resistance, earthworm numbers and earthworm biomass, Zhengzhou, 2018.

treatment	bulk density [1] in		penetration		earthworms			
Code	grams per cm^3		resistance [1]		numbers [1]		biomass in grams [1]	
					(20 x 20 x 30 cm)		(20 x 20 x 30 cm)	
1.5 NPK+M	1.33		2628	b	0.67	a	0.07	a
Untreated	1.41		2619	b	0.67	a	0.10	a
F	1.48		1878	a	3.33	a	2.60	a
N	1.35		2353	ab	0.33	a	0.03	a
NK	1.45		2144	ab	0.33	a	0.03	a
NP	1.36		2645	b	0.667	a	0.07	a
NPK	1.45		2553	ab	1.33	a	0.60	a
NPK+M	1.41		2759	b	1.33	a	0.97	a
NPK+S	1.34		2691	b	2.00	a	0.63	a
PK	1.46		2142	ab	3.67	a	2.07	a
LSD 5%	-		707		3.34		2.45	
F prob.	-		n.s.		n.s.		n.s.	

1) Statistical analysis was impossible for bulk density while there were no data of the plots but only treatment means.

4 Discussion

The main objective of iSQAPER task 3 is: *assessing how soil type, climatic zone, topography and crop and land management interact to affect indicators of soil quality*. This report focusses on the effects of 10 long-term experiments across Europe and 5 in China on a selected group of soil quality indicators.
Results of previous research within iSQAPER work package 3 task 1 on soil quality indicators (Bünemann et al., 2018) and effects of management practices on soil quality work package 3 task 2 (Bai et al., 2018) were used for the selection of soil quality indicators and the classification of LTEs.
In this study the effects of pedo-climatic conditions, topography, farming system, crop type and soil management on a comprehensive set of soil quality indicators in 10 European LTEs were investigated. Where relevant, the samples for the assessment of soil quality indicators were taken from two soil layers: layer 1 (0-10 or 0 -15 cm below soil surface) and layer 2 (10-20 or 15- 30 cm below soil surface). The 10 LTEs were located in six countries across Europe with different pedo-climatic characteristics. Next to this, 5 Chinese LTEs with different fertilisation strategies and pedo-climatic conditions were analysed.

Chinese LTEs
The intention was that all the indicators as measured in the European LTEs would also be assessed in China. This has partly happened, and data came only very recently available. Results came too late to be included in the overall analyses. Analyses discussed in the following paragraphs therefore only concern the results of the European LTEs.

Contrasts in European LTEs affecting soil quality indicators
The effects of topography (slope), climatic conditions, crop type (root crops, annual crops, perennial crops) or farming system (integrated *versus* organic) on soil quality parameters could not be analysed separately. These different aspects were either entwined or the groups of LTEs with these specific characteristics were too small (see tables 1 and 2 and figures 1 and 2). The data analyses have been focussed on the effects of LTEs as a whole, the management effects and the effects of soil texture. The effects of LTE on soil quality indicators include a mix of climate, soil type topographic conditions, crops/rotations and farming systems.

Contrasts in soil management in European LTEs affecting soil quality indicators
The soil management treatments in the different LTEs could be divided into two groups, one group of practices was focussed on tillage and one on fertilisation either by mineral fertilizers or by organic matter inputs. However, within these management groups the variation in treatments between LTEs was still quite big.
In the fertilization management group, organic matter input varied strongly between LTEs. To simplify the data for the analysis, all were classified as either LOW or HIGH. These classifications were relative within a trial, and do not reveal information on the absolute values in the different LTEs. An organic matter input classified as LOW in one LTE might be higher than one classified as HIGH input in another LTE and *vice versa*.
Also, in the tillage management group, the variation, especially in the reduced tillage group, was rather big. Not all tillage treatments in the investigated LTEs qualified as reduced tillage or used the same tillage intensity, frequency or depth to work the soil. All treatments that had less intensive tillage than the conventional tillage method (ploughing at more than 20 cm depth) were qualified as reduced tillage. Within the tillage treatments qualified as reduced, there was no zero tillage practiced and neither intensive mixing tillage of more than 15 cm depth. These simplifications in treatment classifications can be an explanation for part of the variation found in the analyses.

Contrasts in soil texture in European LTEs affecting soil quality indicators

As a simplification, we divided soils with differences in soil texture in two groups, only considering clay percentage and thus distinguishing between light and medium to heavy soils. This resulted in the classification as shown in figure 2. The most extreme and clearly distinguishable heavy soils are CH1 and ES4. The most clearly distinguishable light soils are NL2 and PT1. The rest of the soils are all intermediate and similar in clay fraction. However, they do vary in silt fraction. This becomes more clear if we distinguish between fine and coarse silt. For the interaction between soil texture and indicators, focus should be on the extremes in clay content CH1 + ES4 versus NL2 + PT1. To distinguish between the other LTEs, the silt content should be taken into account. The classification of soil types as used in figure 2 qualifies some soil types which have a high percentage of fine silt, as light. In practice, these soils would not be considered as light soils. Another difficulty with this selection is that 4 LTEs are very similar in clay content of around 20% (NL1, HU1, HU4, SL1). These LTEs differ however in their two silt fractions and in the sand fraction.
An alternative division in light and heavy soils could be based on the texture triangle (figure 28) and selecting the right bottom angle area as light to medium light. In this case the division in light and heavy soils could be NL1, PT1, NL2, HU1, HU4 in the light group and the others in the heavy group. The same classification would be reached when using the sum of the percentages of clay and fine silt and classify lower than 50% as light and higher than 50% as heavy.

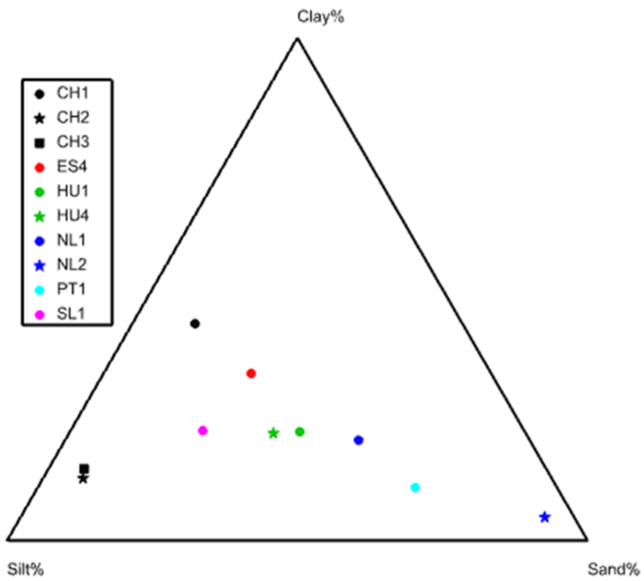

Figure 28. Soil texture of the LTEs represented in a texture triangle

Selection of soil quality indicators for mixed model and multivariate analysis

Based on a response ratio analysis on management effects (chapter 3.2.), 12 indicators were selected for mixed model and multivariate analysis. Some indicators were not further analysed because of their low response to management.
The visually assessed soil quality indicators (aggregate size, pore%, structure quality) showed in general a low variation between LTEs and a high variation within LTEs. The variation within an LTE of these visually assessed soil indicators was however in most cases not caused by the management factors. This does not mean that the visual indicators are not useful. They can be used for education purposes or deliver useful information on sites when done by an experienced person and considering the context.
Indicators based on combinations of the soil indicators (WHC, Cmic/TOC, resp/Cmic, TOC/clay%) were not further analysed in the mixed model and multivariate analysis because they did not show a clear added value over the individual indicators.

Effects of LTE on soil quality indicators

We selected LTEs differing in climate and soil type, to be able to assess the effect of organic matter supply and reduced tillage in a range of environmental conditions. It was shown that the individual LTEs itself (with specific climatic conditions, soil properties and crop type or rotation) were the explanation for the largest part of the variation between all the different data points. Looking at the results of the principle component biplots in figures 7 and 8 for layer 1 and layer 2 respectively, it shows that the different LTEs in general show clear groups of data points. The variation within these groups representing one LTE, is partly caused by the management effects within this group. The variation caused by differences in management within an LTE is much smaller than the variation caused by the differences between LTEs. This implies that the influence of the local conditions on the parameters is much larger than the influence of management (tillage and/or supply of organic matter). The indicators WSA%, Ntot, TOC and to a lower extent Cmic and Nmic, have a strong influence on the differences between most of the LTEs (when excluding ES4). In general the whole group of organic matter related indicators (excluded RespC.) is making the same kind of distinction between most of the LTEs. This common effect of the organic matter related indicators is also reflected in the relative high Pearsons correlations between these indicators (table 31). WSA% seems to be a good discriminative indicator for the differences between LTEs. However its discriminative value seems to be relatively smaller when looking at the management factors (figures 9 to 12).
The indicators respC, Pen 0-20 and Pen 20-40 are very distinctive specifically for ES4. For ES4 a large separation between the data points within this LTE can be seen. This separation is caused by the different management factors in ES4 (CT LOW versus RT HIGH).

The indicators Ntot and WSA% seem to make almost the same distinction between LTEs, the same holds for Nmic and Cmic and for Pen0-20 and Pen 20-40. For Microbial C and N and for Pen 0-20 and 20-40 also the Pearsons correlations are high (0.85 and 0.74; table 31). Both results are plausible: Soil microbial C/N ratio is in general relatively stable and with the absence of subsoil compaction or ploughpan also the penetrometer resistance can be stable over the different soil layers.
Pearson correlation between Ntot and WSA% (0.53) is significant but considerably lower than the correlation between Nmic and C mic and between Pen0-20 and Pen 20-40 .
The above mentioned results are similar for both soil layers although most prominent in the top layer.

Effects of soil texture on soil quality indicators
Medium to heavy soils are more at the left upper quarter of the PCA graphs (Fig 7 + 8) the light soils are more grouped central and at the bottom left quarter.
The heaviest soils CH1 and SL1 are clearly at the left upper quarter and the light sandy soil of PT1 clearly at the right bottom quarter. The heavy soil ES4 has a position that differs both from the light soils as well as the other heavy soils. The heavy soils PT1 and CH1 are distinguished by a higher WSA%, Ntot, Nmic, Cmic and POM. Which is clearly the opposite for the light sandy soil of PT1. NL2 has the lightest soil, but holds a more intermediate position in Ntot, Nmic, Cmic and POM. This intermediate position might be explained that this soil is in fact a former organic soil from which the top peat layer is excavated.
The heavy soil at ES4 holds a separate position because of its high penetrometer resistance and a high respiration.
For several indicator values soil texture also shows an interaction with management and soil layer, this will be discussed at the following paragraphs.

Effects of soil layer on soil quality indicators
Sampling depth had an effect on the value of the indicators. In general the variation in indicator values in layer 1 was larger than in layer 2. The variation within an LTE was in general also higher in layer 1 than in layer two. The LTEs CH1, SL1 and ES 4 in figure 7 and 8 are an example of this. These LTEs are also the ones with the more heavy soil.
Looking at the effect of management factors in the different soil layers (figures 9 to 12), the variation in the indicator values in layer one is in general larger that in layer two. This effect is not random but seems to be mainly caused by the management. This is shown in figure 5 where

most of the significant differences in indicator values caused by treatments are found in layer 1. There is also an interaction between soil texture and soil layer in its effect on certain indicators. The differences in indicator values between soil layers are in general larger in the medium to heavy soils than in the light soils. For example for Ntot and TOC in the HIGH organic matter input (tables 14 and 15) or the effect of reduced tillage on TOC (table 24).

Effect of management on soil quality indicators
In general the visual soil assessment parameters (aggregate size, % pores and structure quality) show a lack of sensitivity to the management factors (chapter 3.2.). Data distribution already showed that the variation for these indicators is high (chapter 3.1.). Apparently, this variation is not caused by the different treatments but by variability in the assessment of the indicator itself. Variation can be caused by differences in human interpretation, methods are quite qualitative and open for own interpretation.
Also the results of the teabag test show on average a low response to either organic matter input or reduced tillage. Looking at the response per individual LTE (figure 43 and 44) there is a response, however not consistently positive or negative and in only a few cases significant.

Organic matter input
Averaged over the ten LTEs, a high level of organic matter input increased TOC, Ntot, P-AL, K-AL, CEC, WHC, POM,%WSA, respiration-C, pores% and earthworm numbers significantly (figure 5 and table 8). These effects where only found in layer 1 (POM excepted). Averaged over all LTEs Cmic, Nmic, P-Ols, bulk density, aggregate size, tea bag test S and K, earthworm weights and penetration resistance were not sensitive to high organic matter addition. Looking at the individual LTEs (figures 29 to 55) POM, TOC and Ntot gave significant differences in a larger number of the LTEs than the other parameters.
The distribution of the Cmic and Nmic data did not show much variation per LTE (figure 4). This could be an indication for a low treatment (in this case organic matter addition) effect. Looking at the individual LTEs (figures 37 and 38) there are in some cases significant differences in Nmic and Cmic between treatments, however mostly with a low probability ($P < 0,5$). In some cases the additional organic matter decreases Nmic or Cmic (Cmic for NL1 and SL1; figure 37). Overall the effect of organic matter input did not affect Nmic or Cmic. Another large analysis of effects of organic amendments on soil quality indicators in several LTEs across Europe did show an increase of microbial biomass (C) due to organic amendments (D'Hose et al., 2018). When the source of organic matter addition is of a low quality or not easily degradable the effects on microbial biomass might be limited. Organic matter amendments in the LTEs were of diverse sources, from manure to compost and biochar, so a range of qualities was evaluated as one treatment. This could be the cause for the lack of sensitivity.

In general for both organic matter addition as well as reduced tillage, the soil quality indicators show most sensitivity in layer 1, 0-10 cm. Some effects continue in layer 2 (10-20 cm), for reduced tillage this is the case for WSA, for organic matter addition for POM. Within some organic matter trials measurements were done over these layers as a whole, 0-20 cm. Increased parameters in this case were respC, POM, TOC, P-AL, K-AL, Ntot and %pores. We found more significantly increased parameters when layer 1 was analysed separately, compared to the layer as a whole. But comparing the whole layer (0-20cm) to layer 2, the whole layer analysis gave more significantly increased parameter values. This is an indication that the effects in layer 1 are large, since even if they are 'diluted' with layer 2 to one larger layer, more than half of the indicators still shows a significant sensitivity.

Reduced tillage
Averaged over the ten LTEs reduced tillage practices increased Cmic, Nmic, respiration-C, POM, TOC, P-AL, P-Ols, K-AL, Ntot, WSA%, bulk density, earthworm number and weight and the penetration resistance significantly (figure 5 and table 8). CEC, WHC, aggregate size, %pores, structure quality and tea bag test S and K were not sensitive to reduced tillage (figure 5 and table 8). Looking at the individual LTEs (figures 29 to 55), TOC and Ntot give significant differences in a larger number of the LTEs than most of the other parameters.

For tillage management there was a strong difference in the effects per soil layer. In the reduced tillage trials Nmic and respC were increased in layer 1, but reduced in layer 2. For these trials the bulk density is increased in layer 2, while there was no effect in layer 1. Cmic was increased in layer 1 but did not show any effect in layer 2. D'Hose et al. (2018) found in their meta-analysis also an increase in microbial biomass in the top 10 cm of soil under reduced tillage. A higher soil respiration and/or microbial biomass in layer 1 due to reduced tillage can be explained by various reasons; reduced tillage keeps the organic matter concentrated in the topsoil and improves soil structure, temperature and moisture (Holland, 2004, Hobbs, 2007), all conditions that make the environment more favourable for soil biota. The difference in soil microbial parameters values between layer 1 and layer 2, or even deeper layers is confirmed by van Capelle et al. (2012). They also found an increased effect in the layer 0-10 cm below soil surface, and saw a decrease in microbial biomass and respiration with depth. It is questionable whether there is a direct relation between respC and bulk density, since soil was incubated, and therefore mixed before respiration measurements, so bulk density probably could not play a role on the respiration measurements. A lower quality of the organic matter in layer 2 might be an explanation for a potential lower soil respiration.

Comparison/ differences organic matter/tillage
For organic matter addition as well as for reduced tillage there is a lack of sensitivity for the visual soil assessment parameters (aggregate size, % pores and structure quality). Data distribution already showed that the variation for these indicators is high. Apparently this variation is not caused by the different treatments. Variation can be caused by differences in human interpretation, methods are quite qualitative and open for own interpretation. For each LTE these measurements were done by different people, causing a lack of consistency in this.

More indicators were sensitive to reduced tillage than to organic matter addition (15 versus 11) and they were more highly significant, for reduced tillage most indicators had a p value lower than 0.001, while for organic matter addition there were various indicators with a p value <0.01 or <0.05.

Combination of organic matter addition and reduced tillage
The combination of organic matter addition and reduced tillage led to a significant increase of the indicators POM, TOC, P-AL, P-Ols, K-AL, Ntot, WHC, earthworm numbers and weight and penetration resistance, compared to the low organic matter plus conventional tillage control plots. All these parameters were also increased by one or both of the individual treatments. Aggregate size is negative influenced by the combination of organic matter addition and tillage, while it was not influenced in the treatments individually.

Interaction of soil texture and management in their effect on soil quality indicators
Soil texture interacts with the effects of reduced tillage and organic matter treatments on the soil quality indicators. A high supply of organic matter had more effect on the indicators on light soils compared to medium/heavy soils. On soils with a higher clay content certain indicators might in itself be higher already, for example the CEC (Brady, 2002). This can be an explanation that an additional organic matter effect has more influence on lighter soils, since there is a bigger improvement still to make.
On medium/heavy soils reduced tillage had a larger positive effect than on light soils on several indicators (WSA, respC, K-AL, penetration resistance, Nmic, POM and TOC). Soils with a heavier texture have a higher initial structure building capacity so might benefit more from reduced tillage practices. Lighter (sandier) soils have the risk of becoming denser (in the subsoil) with less tillage.

NIR analysis versus the analytical method
Linear regression of the NIR data with the analytically measured parameters revealed that the parameters Ntot, pH, TOC and P-AL can be well described by the NIR method, which is a relatively cheap and reliable alternative for the analytical methods. Ntot, TOC and P-AL also discriminated quite well between different LTEs and Management. For the parameters C/N ratio, CEC, percentages clay, silt and sand and K-AL level, the NIR analysis deviates from the analytical analysis, possibly because not enough comparative data are available yet to produce a good calibration curve, made with previously obtained samples which are analysed analytically as well as by NIRS, by Eurofins Agro, an accredited laboratory in the Netherlands. Large parts of the samples used for calibration will be of Dutch origin. Calibration is for most parameters optimised for the Dutch soil conditions. For soils in other European regions which deviate strongly from the dominant Dutch soils there might be less calibration data available and therefore the NIRS results for these soils might be less reliable. This did not directly show from the graphs in paragraph 3.7, but experience has shown that soil types which vary from the NIRS-database collection might be misinterpreted.

Relation of indicators to ecosystem services
Dry matter yield and WHC, TOC, POM, Cmic and Nmic were considered representative parameters for ecosystem services. In the upper soil layer Cmic, Nmic, POM and TOC were increased by the combination of reduced tillage and high supply of organic matter. For WHC and dry matter yield there was hardly any effect of the management.

Summary soil quality indicators
Response-ratio analysis of reduced tillage compared to conventional tillage and high versus low supply of organic matter, delivered twelve parameters that were the most “sensitive” to these management measurements: microbial biomass carbon and nitrogen (Cmic and Nmic), basal soil respiration (respC, measured as carbon dioxide production), particulate organic matter (POM), total organic carbon (TOC), phosphate (P-AL), potassium (K-AL), total nitrogen (Ntot), percentage water stable aggregates (WSA), bulk density and penetration resistance in, respectively, the layers 0 – 20 cm and 20 – 40 cm. Within this group, the parameters POM, TOC, P-AL, K-AL and Ntot seemed to be the most sensitive. Parameters assessed by LTE owners as the teabag test, earthworm abundance and functional groups and parameters determined by ‘spade diagnosis’ showed low sensitivity to management. Nevertheless, on average over all LTEs earthworm populations were significantly affected by reduced tillage and by the combination of reduced tillage and high supply of organic matter.

Principal component analysis with the twelve selected sensitive parameters showed that the influence of pedo-climatic conditions (soil type and climate of the LTEs) had more influence on these parameters than management. After elimination of the influence of the LTEs (and thus of pedo-climatic conditions) it appeared that from these parameters respiration rate, P-AL, K-AL and POM reflected differences in management best and bulk density and WSA reflected it worst. The management effects in ES4 had a strong influence on especially the discriminative value of RespC, Nmic, Cmic, TOC, Ntot and penetration resistance had an intermediate position. Tillage as well the sampling in layer 1 influenced the variation in the indicators the strongest.

Summarised over the different statistical analytical methods (response ratio and multivariate analysis) the effects of reduced tillage and/or high supply of organic matter are best reflected by the parameters total organic carbon (TOC), particulate organic matter (POM), potash (K-AL), phosphate (P-AL), total nitrogen (Ntot), microbial nitrogen (Nmic), microbial carbon (Cmic), respiration rate and penetration resistance. These soil parameters can be regarded as the most sensitive soil quality indicators for reduced tillage and addition of organic matter. Eventually one of the parameters Ntot or TOC might be removed, since they turned out to be strongly correlated. The same counts for the parameters Ntot and Cmic.

5 Conclusions

The research as reported here is focussed on WP 3.3 of the iSQAPER project. The main objective of task 3 was to assess how soil type, climatic zone, topography and crop and land management interact to affect indicators of soil quality.
Originally the intention was to do an analysis on 10 European LTEs together with 5 Chinese LTEs. However the results of the 5 Chinese LTEs came available too late and/or were incomplete. Therefore, the full data analysis has been conducted on the 10 European LTEs only. Only a first general data analysis has been done on the results of the Chinese LTEs. These are presented in this report but a complete analysis on the interactions of indicators with management, soil type and pedo-climatic zone will be reported separately.
Due to the limited number of European LTEs and their distribution over soil type, climatic zone, topography, farm and crop type, no conclusions could be drawn about the separate effect of climatic zone, topography, farm type and crop type. These effects are combined in the conclusions we have drawn across the LTEs. Effects of management, soil texture, soil layer and total LTE, however, could be analysed and are presented in this report.
Additionally for a limited number of LTEs and management factors an extra NIR analysis for some indicators was done. These results were compared to standard analytical methods for soil analysis to get an impression of the value of NIR analysis as a cheap alternative for soil analysis.

The main conclusions of the data analysis are as follows:

Lab analysis, *in situ* analysis and NIR analysis

- In general the indicators assessed in situ by the LTE owners/researchers could not discriminate very well between LTEs and between management practices. An exception to this general conclusion were penetrometer resistance and earthworm number and weight. These indicators were useful for a number of LTEs.
- Indicators based on lab analysis performed in general better than parameters assessed *in situ* and were able to discriminate between LTEs and between management practices.
- For the indicators Ntot, pH, TOC and P-AL the NIR analysis seems to be promising as a reliable and cheap alternative for the analytical methods.

Differences in indicator values between LTEs

- The differences in soil quality indicators observed between LTEs were much bigger than the differences within LTEs as (partly) caused by the management factors.
- For the ten LTEs the combination of the indicators Cmic, Nmic, respC, POM, TOC, P-AL, K-AL, Ntot, WSA%, bulk density and penetration resistance was able to distinguish between the majority of the LTEs. The indicators Cmic, Nmic, TOC and WSA% were quite similar in distinguishing between LTEs.

Effects of climate zone, topography, farm type and crop type

- Effects of climate zone, topography, farm type and crop type could not be tested due to the limited number of LTEs representing these different situations.

Effects of soil texture on indictor values

- Soil texture showed an influence on the value of the indicators. There was a tendency of a higher WSA%, Ntot, Nmic, Cmic and POM for the heavier soils.

Effects of soil layer on indictor values

- The soil layer which was sampled (0-10 cm or 10-20 cm) had an influence on the value of the indicators. In general the differences between LTEs and between management factors were bigger in the layer 0-10 cm than in the layer 10-20 cm. An exception to this rule was bulk density.

Effects of soil management on indictor values

- Soil management had significant influence on a range of soil indicators. The set of indicators influenced by tillage and organic matter input was largely overlapping.
- The indicators TOC, Ntot, P-AL, K-AL, POM, %WSA, resp-C and earthworm number were influenced by both tillage and organic matter input. Averaged over all LTEs, WHC was influenced by organic matter input but not by tillage. Averaged over all LTEs, Cmic, Nmic and Bulk density were influenced by tillage but not by organic matter input.

Interactions between LTE, soil texture, soil management and soil layer

- LTE, soil texture, soil layer and soil management all interacted in their effect on the value of the soil indicators. Specifically, interactions between tillage, soil texture and soil layer were relatively strong**.**

Measuring differences in soil quality between LTEs in general in combination with differences between management practices

- Combining the ability of indicators to make a distinction between LTEs as well as between management practices within an LTE, the indicators TOC, POM, P-AL, K-al and Ntot (measured in the layer 0-10 cm), performed the best.

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7 Annex

7.1 Details of Chinese LTEs

Abbreviation	Explanation
1.5(NPKM)	1.5 (nitrogen +phosphorus + potassium +manure)
CK	no fertilizer
F	fallow
N	nitrogen
NK	nitrogen + potassium
NK+M	Nitrogen + potassium + manure
NP	nitrogen + phosphorus
NPK	nitrogen + phosphorus + potassium
NPS	Nitrogen + phosphorus + straw
NPK+L	Nitrogen + phosphorus + potassium + lime
NPK+1.5M	nitrogen + phosphorus + potassium + 1.5 times the usual amount of manure
NPKM	nitrogen + phosphorus + potassium + manure
NPKMR	nitrogen + phosphorus + potassium + manure + rotation(maize and soybean)
NPKS	nitrogen + phosphorus + potassium + straw
PK	phosphorus + potassium

Treatment information Zhengzhou

Treatment	Maize			Wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(kg/ha)					
CK	0	0	0	0	0	0
N	210	0	0	90	0	0
NP	210	84	0	90	36	0
NK	210	0	84	90	0	36
PK	0	84	84	0	36	36
NPK	210	84	84	90	36	36
NPKM/MNPK	63	84	84	27	36	36
1.5NPKM	95	126	126	40	54	54
NPKMR	63	84	84	27	36	36
NPKS	210	84	84	90	36	36

Treatment	inorganic fertilizer input			manure input		
	N	P	K	N	P	K
CK	0	0	0	0	0	0
N	165	0	0	0	0	0
NP	165	36	0	0	0	0
NK	165	0	68	0	0	0
PK	0	36	68	0	0	0
NPK	165	36	68	0	0	0
MNPK	49.5	36	68	115.5	19	68
1.5(MNPK)	74.25	54	102	173.25	28.7	103
NPKS	112	36	68	53	13	56
NPKMR	49.5	36	68	115.5	19	68
1.5M+NPK	165	36	68	150	24.9	149

Treatment information Wangcheng

Treatment	early rice			late rice		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(kg/ha)					
CK	0	0	0	0	0	0
PK	0	90	120	0	90	120
NP	150	90	0	180	90	0
NK	150	0	120	180	0	120
NPK	150	90	120	180	90	120
NPK+L	150	90	120	180	90	120
NK+M	150	0	120	180	0	120
NPS	150	90	0	180	90	0
NPKS	150	90	120	180	90	120

Treatment information Qiyang

Treatment	Maize			Wheat		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O
	(kg/ha)					
CK	0	0	0	0	0	0
N	210	0	0	90	0	0
NP	210	84	0	90	36	0
NK	210	0	84	90	0	36
PK	0	84	84	0	36	36
NPK	210	84	84	90	36	36
NPKM	63	84	84	27	36	36
1.5NPKM	95	126	126	40	54	54
NPKM(W+S)	63	84	84	27	36	36
NPKS	210	84	84	90	36	36

Treatment information Suining

Treatment	Inorganic			Manure
	N	P2O5	K2O	
	kg/ha			
CK	0	0	0	0
M	0	0	0	30000
MN	240	0	0	30000
MNP	240	120	0	30000
MNPK	240	120	120	30000
N	240	0	0	0
NP	240	120	0	0
NPK	240	120	120	0

Manure: water content 70%, N 20-22 g/kg, P2O5 18-25 g/kg, K2O 13-16 g/kg

7.2 Protocol for soil sampling

This document contains the **protocol for sampling, sample preparation, packaging and transport of samples** for analyses to be done centrally. **Samples should be sent** to four different addresses (see **Table 2**). A fifth portion of air-dried soil of **about 200 g** is to be kept as a **back-up** in dry storage at room temperature or at 4°C **at your own institution**.

Sampling must be done **in spring before ploughing, fertilization** or other major disturbances from management. Field assessments can be done later in the season.

<table>
<tr><td>Principle of the method:</td><td colspan="3">A standardized procedure to get a representative bulk soil sample for the investigated plots (disturbed sampling).</td></tr>
<tr><td>Name:</td><td>Modified from Andreas Fließbach, Karin Schreiner (FertilCrop) by iSQAPER WP3 team</td><td>Date:</td><td>07.03.2016</td></tr>
<tr><td>Reagents</td><td colspan="3">Procedure</td></tr>
<tr><td>Material
(1) Soil sampling equipment (gouge auger), preferably 3cm diameter
(2) Spatula or stick to remove soil from the auger
(3) Basin
(4) Polyethylene (PE) bags
(5) Cooling containers
(6) Labels (water proof)
(7) Material for cleaning</td><td colspan="3">• The reference level of all evaluations is the single field plot. A sample is to be taken representatively (randomly – not crosswise, as this is overestimating the centre of the plot) over the central plot area. A central plot area is defined to avoid border effects (e.g. a distance of 1 m to the plot margins). At least 20 separate soil cores are taken randomly and pooled to one composite sample per field plot and soil layer which should be at least 2,5 kg dry weight equivalent. Samples from field replicates are taken separately. Samples should be taken on 0-20 cm. However, in the case of treatment pairs including non-inversion tillage or reduced tillage, samples should be taken in two separate depths, namely 0-10 cm and 10-20 cm.
• Samples on arable land are taken between the crop plants. Plot margins and compacted field tracks are left out.
• Soil samples are quickly homogenized in the field (if available by passing through a coarse (5 mm) sieve), and visible plant material, soil animals, stones, and coarse organic material are removed.
• The samples are transferred into PE bags, collected in insulation boxes with cooling elements and transported to the laboratory where they are subdivided into the portions detailed in Table B. Subsamples for further storage at different temperatures or drying are taken in the laboratory from the bulked sample taken in the field and labelled properly with date, trial abbreviation (see Table A), depth, plot number.
• Fill in sample information form (Table C) and email it to sandra.wolters@wur.nl. Contact her each time you make a shipment so that she can keep track of samples.</td></tr>
<tr><td colspan="4">Calculations</td></tr>
<tr><td colspan="4">Gouge auger 3 cm Ø: $(1.5\ cm)^2 \times \pi \times 20\ cm = 141\ cm^3$</td></tr>
</table>

Table A. Proposed selection of European LTEs for sampling and analysis in 2016 (selected LTEs in bold).

	Name	Abbrev.	Treatments (total no.)	Soil depths	Repli-cates	Total no. of samples
1	**CH-Frick Tillage trial**	**CH1**	conventional vs. non-inversion tillage (2)	0-10, 10-20	4	16
2	**CH-Tillage trial Aesch**	**CH2**	conventional vs. non-inversion tillage (2)	0-10, 10-20	4	16
3	**CH-DOK trial**	**CH3**	System: MIN/DYN (2)	0-20	4	8
4	**NL-BASIS**	**NL1**	conventional (NPK) vs. organic (ruminant slurry) conventional vs. minimum tillage (4)	0-10, 10-20	4	32
5	**NL-Soil quality on sandy soils (de Peel)**	**NL2**	conventional (NPK) vs. organic (cow slurry) conventional vs. non-inversion tillage (4)	0-10, 10-20	4	32
6	NL-Soil health on sandy soils	NL3				
7	NL-Sustainable soil management fodder crops	NL4				
8	PL-Trzebieszów	PL				
9	EE-Org-Conv system experiment	EE1				
10	EE-Grassland experiment	EE2				
11	EE-Soil forming	EE3				
12	**SI-Tillorg**	**SI1**	NPK vs. biowaste conventional vs. non-inversion tillage (4)	0-10, 10-20	3	24
13	SI-TRAVISTOR	SI2				
14	RO-Braila	RO				
15	**PT-VITICHAR**	**PT1**	Biochar, biochar + compost, no amendment (3)	0-20	3	9
16	PT-VITAQUA	PT2				
17	PT-ESAC: conv vs biol maize	PT3				
18	PT-ESAC: vineyards	PT4				
19	PT-ESAC: conv vs biol grazing	PT5				
20	ES-TEULARET (optional: for central lab and FiBL only)	ES1	Three tillage treatments (3)	0-10, 10-20	3	18
21	ES-ALCOLEJA	ES2	Combination of tillage and fertilization (3)	0-10, 10-20	3	18
22	ES-FERRY	ES3				
23	**ES-PAGO**	**ES4**	Combination of tillage and fertilization (3)	0-10, 10-20	3	18
24	GR-Augeniki, Crete	GR1				
25	GR-Spata, Attiki	GR2				
26	**HU-Organic/inorganic N fertilization (Keszthely)**	**HU1**	Organic vs. inorganic N fertilization (select level where the biggest contrast is expected) (2)	0-20	3	6
27	HU-Mineral fertilization in cont maize cropping (Keszthely)	HU2				
28	HU-Organic/inorganic fert. in rotation (Keszthely)	HU3				
29	**HU-Tillage in maize-wheat bi-culture (Keszthely)**	**HU4**	one fertilization level (either high or low NPK) conventional vs. minimum tillage (2)	0-10, 10-20	4	16

Table B. Sample storage conditions and details for shipment.

Category	Parameters	Sample condition		Amount (g)[1]	Storage	Shipment	Recipient
1.Central analyses	Total organic C	Air-dry (≤ 40°C)		400	Store at room temperature	No special requirements	To be specified later
	Total N						
	pH						
	Plant-available P						
	Cation Exchange Capacity						
	Particle-size distribution						
	Microbial biomass (CFE) including labile C	Field-moist		100	Store at 4°C	4°C if possible	
	N mineralization						
2.FiBL	Aggregate stability	Field-moist		80	Store at 4°C, avoid compaction	Pack carefully to avoid compaction during transport	Else Bünemann FiBL, Department of Soil Science Ackerstrasse 113 CH 5070 Frick Switzerland
	Microbial community by PLFA (selected samples)	Field-moist		20	Ship immediately or else freeze at -20°C	4°C if possible; both portions for FiBL can be shipped as one if shipped immediately after sampling	
3.Giulia Bongiorno	Various new soil biological indicators	0-10 cm and 0-20 cm	Field moist	1000	Store at 4°C	4°C if possible, ship immediately after sampling.	Giulia Bongiorno Wageningen University. Department of Soil Quality. • Postal address: • PO Box 47 6700 AA Wageningen The Netherlands
		10-20 cm	Field moist	500	Store at	4°C if possible, ship immediately after sampling	
4. Various JRC and other	NIR at JRC and possibly contamination with pesticides (Violette Giessen)	Air-dry (≤ 40°C)		2 x 100		No special requirements	To be specified later
5. Backup	-	Air-dry		200	Store at room temperature or 4°C	-	-

[1] **g dry matter equivalent per plot**

Table C. Sample information form.

Name of field experiment	
Trial abbreviation	
Plot numbers and treatment descriptions	
Collection date	
Scientist responsible	
Institution	
Phone number and email address	
Sampling depth (tick appropriate box(es))	☐ **1st layer** (0-10 cm) ☐ **2nd layer** (10-20 cm) ☐ **3rd layer** (0-20 cm)
Total number of samples	
Shipment date	☐ **Central lab:** ☐ **FiBL:** ☐ Giulia Bongiorno: ☐ JRC: ☐ Central lab pesticides:
Comments	e.g. standing crop, special events during sampling etc.

7.3 Protocol for field assessments

This chapter contains the protocols for all required field assessments which (unless stated otherwise) are to be performed per plot. For each assessment, the required materials are summarized and this is followed by a detailed description of procedures that should be followed for the measurement of different parameters.

Table D. Time field assessments should take place, considering activities throughout the year.

	Parameter	Time schedule details
1	Spade diagnosis	In fast growing crop (temperate climate: May to June) according to conditions in your country. This is best done when a maximum growth of roots has been reached (e.g. flowering cereals, flowering potatoes).
2	Soil bulk density	Before disturbance in spring/fall, as close as possible to disturbed sampling
3	Penetration resistance	Before disturbance in spring/fall, at field capacity
4	Soil depth	Spring, summer or fall (only once per site, not in all plots)
5	Earthworms	In maximum activity windows (temperate climate: April, or September)
6	Tea bag test	After disturbance; spring, early summer, fall
7	Yield	At each crop harvest
8	Disease incidence	During the seedling and flowering stages

1. Spade diagnosis

<table>
<tr><td>Principle of the method:</td><td colspan="3">To determine soil structure and root growth</td></tr>
<tr><td>Name:</td><td>Modified from Bruce Ball (VESS) and J. Peigné</td><td>Date:</td><td>15-04-2015</td></tr>
<tr><td>Reagents</td><td colspan="3">Procedure</td></tr>
<tr><td>Material
(1) Spade (long; > 30 cm)
(2) Knife
(3) Meter
(4) Plastic sheet or plastic tray</td><td colspan="3">

Where to sample:

Step one: **Soil removal**

Spade diagnosis will be done once per experimental plot (field replicate). Please note that the spade blade length needs to be below the ploughing depth (>30cm). In soils with a hard surface or under grass, cut out a spade-sized block of soil. Cut down on three sides and then lever the block out leaving one side undisturbed. Alternatively dig out a block and then take a slice from the undisturbed face. Carefully, lay the block on a plastic sheet on the ground or onto a plastic tray. Measure the length of the soil block.




<u>**Soil structure**</u>

Step two: **Soil assessment**

1) Block break-up

Gently open the undisturbed side of the block like a book and start breaking it up.

If the block breaks up easily into small fragments then the structure is likely to be good.
</td></tr>
</table>

If the block is hard to break up then it could either be held together by roots and you will need to pull these apart to expose the soil fragments , or it is compacted and breaks into large lumps.
Break up the block enough to allow you to discover if there are any distinct layers of differing structure. If the block is uniform, then assess as a whole, if there are two or more such layers, then score separately . Measure the depth and thickness of any distinct layers.
For each soil layer assess: the degree of firmness (easy to break) and size of soil fragments, clods and aggregates. Clods are defined as large, hard, cohesive and rounded aggregates (more than 7 cm). See table 1.
A photograph at this stage provides a useful record and, when put together with others, allows for comparisons to be made.

2) Reduced fragments

For each soil layer, break up the soil with your hands into smaller structural units from 1.5 to 2 cm (known as aggregates).
Assess the shape and porosity of soil fragments (see table 1) and evidence of anaerobism (colour, mottles and smell).
Table 1 Soil structure assessment grid for each soil layer identified at block scale and reduced fragment scale.

Indicators	**Assessment**				
Block break-up					
Aggregates and clods mixture - size	Only small aggregates < 6 mm	Aggregates from 2 mm to 7 cm - no clods	Aggregates from 2 mm to 7 cm, less than 30% < 1 cm - some clods	Mostly large aggregates > 10 cm - less than 30% < 7 cm - clods	Mostly large > 10 cm -very few < 7 cm - mostly clods
Breaking up		Easy or Not easy			
Reduced fragments at 1.5 to 2 cm diameter					
Aggregate shape	% of Rounded	% of Angular			
Aggregate porosity	% of Porous	% of less porous with worms hole	% of less porous with cracks	Not Porous	
Anaerobism	% of grey zone with S odour				

3) Step three: Soil scoring

Give a score by matching what you see to the descriptions and the photos in the chart (annex X). A score of Sq1 or Sq2 is good, a score of Sq3 is moderate. Scores of Sq4 and Sq5 are poor and require management action.

Soil scoring: If clods are large, compact lumps that can be broken into non-porous, sub-angular (sharp-edged) aggregates this indicates poor structure and a higher score. Small, rounded aggregates or large aggregates that break down easily into smaller rounded aggregates indicate good structure and a lower score. After assigning a score from comparison with the pictures in the chart, adjust it according to the difficulty of breaking apart of the fragments and their appearance. In grassland, roots make it difficult to break up the block but this is not a factor that will increase the score.

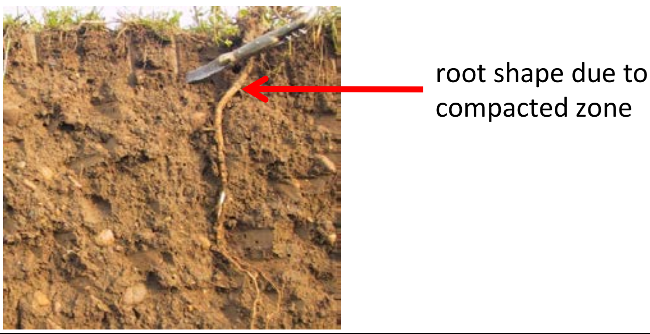
Roots

Two observations will be done : (1) Refresh the face of the spade hole, and observe and assess roots according to table 2 indicators ; (2) complete the observation when you describe soil structure of the block.

Indicators	Assessment			
Clustering	No	If Yes,	where in the block?	How many?
Thickening (root deformation)	No	If Yes, what kind ?	where in the block?	How many?
Defections	No	If yes	where in the block?	
Distribution	Uniform in the block	If not uniform:	presence of an obstacle ?	Where in the block ?

Root deformation

Roots in a cracks in a compacted zone



Calculations	
<u>For the scoring of the spade test</u> Where there are layers present, score each layer separately. If you wish to calculate an overall block score for detailed research or consultancy, multiply the score of each layer by its thickness and divide the product by the overall length. For example, a block 25 cm deep with 10 cm depth of loose soil (Sq 1) over a more compact (Sq 3) layer at 10-25 cm depth has an overall score of: (1 x 10)/25 + (3 x 15)/25 = Sq 2.2. Ball, B. C., Batey, T., & Munkholm, L. J. (2007). Field assessment of soil structural quality - a development of the Peerlkamp test. SOIL USE AND MANAGEMENT, 23(4), 329–337. doi:10.1111/j.1473-2743.2007.00102.x	

<table>
<tr><td>Principle of the method:</td><td colspan="3">A standardized procedure for volumetric or undisturbed soil sampling.</td></tr>
<tr><td>Name:</td><td>Andreas Fließbach</td><td>Date:</td><td>19.10.2011</td></tr>
<tr><td>Reagents</td><td colspan="3">Procedure</td></tr>
<tr><td>Material
(1) Calibrated soil sample rings of 100 cm³ volume with covers
(2) Lubricant
(3) Hammer
(4) Insertion tool
(5) Knife
(6) Field balance 0.01g
(7) Plastic bags
(8) Cooling containers
(9) Labels water proof
(10) Material for cleaning
(11) Drying stove (105 °C)</td><td colspan="3">• For stone-free soils calibrated soil rings of 100 cm³ volume are appropriate. Stony soils are excavated carefully and the hole is filled with sand or water, the volume of which has to be determined.

Stone free soils
• Determine the weight of all soil sample rings in the laboratory. The rings are numbered, thin walled and have a sharpened bottom edge. In order to avoid volume changes during insertion apply a lubricant on the surface.
• A volumetric sample has to be taken in undisturbed soil in the middle of the soil layer of interest (0-20 cm, except for tillage trials which are to be sampled in 0-10 and 10-20 cm separately). The soil surface is levelled out at the upper level. The soil sample ring is inserted vertically with the help of the insertion tool and a hammer without compressing the soil inside the ring. The ring is carefully dug free and taken out of the soil with soil protruding at both sides of the ring. Soil at both ends of the ring is carefully cut off with a sharp knife to obtain a plain and flush surface. In case of soil or stones falling out the procedure has to be repeated. Roots are cut with scissors. Then cover both sides with appropriate lids and put the covered ring in an airtight transport box.
• Make note of the ring number, the plot and the soil layer sampled. A minimum of five replicate samples are to be taken per field plot and the respective soil layer of interest.
• The rings containing soil are weighed with their lids to determine the fresh weight. Then they are dried at 105 °C until weight constancy. The dry weight is determined and after subtracting the weight of the ring and the lids the soil weight of the ring volume is obtained.
  • Alternatively (in case of limited number of rings available) the fresh weight of the soil ring's content is determined in the field. A combined subsample from the five replicate rings (approx. 200 g) is transferred to a plastic bag for dry matter determination in the lab. Samples are transferred to the lab in cooling containers.</td></tr>
</table>

3. Penetration resistance

<table>
<tr><td>Principle of the method:</td><td colspan="3">Measurement of soil penetration resistance</td></tr>
<tr><td>Name:</td><td>Joséphine Peigné</td><td>Date:</td><td>11-02-2015</td></tr>
<tr><td>Reagents</td><td colspan="3">Procedure</td></tr>
<tr><td>Material
(1) Edelman auger
(2) Penetrometer:
(3) Pressure-gauge calibrated: scale from 0 to 1000 Newton, every 20 N
(4) Graduated stem is 50 cm or 100 cm
(5) Cone penetration screwed on a stem
(6) 2 handles for a good grip of the camera
(7) Black arrow indicating the instantaneous value of the measurement
(8) Red arrow indicating the maximum value of the measurement</td><td colspan="3">• Measure the penetration resistance when the profile is at field capacity.

• Choose the most appropriate cone diameter and note it (the more the soil is compacted, the smaller the cone diameter should be)

• The penetrometer is pushed vertically into the soil at an approximate rate of 2 cm per second and with a pressure on each handle. A jerky penetration gives too high and not representative soil resistance values.

• This resistance measured by the cone is indicated on the pressure gauge by the black needle. (Sometimes, the maximum resistance recorded during measurement is indicated by a red arrow)

• Make sub-replicates by measuring 10 times per experimental plot (=field replicate). For each of the 10 sub-replicates: measure and write down every 5 cm depth the soil resistance pressure until 50 cm depth in a table. (optional: Turn the red maximum pointer to 0 after each maximum measurement with the help of the adjusting screw). Calculate the mean of the 10 sub-replicates for each 5 cm depth. Exclude values where you obviously hit a stone (outliers).

• For measuring at greater depth a hole is drilled using an Edelman auger. Place an extension rod.

• The accuracy is ± 8% in the recommended operating range.</td></tr>
<tr><td colspan="4">Calculations</td></tr>
</table>

Table of correspondence : soil resistance measurement in N/cm2 according to the manometer reading and the cone

Projected surface (of the cone)	*1 cm2*	*2 cm2*	*5 cm3*
Manometer reading			
100 N	100	50	20
200 N	200	100	40
300N	300	150	60
400 N	400	200	80
500 N	500	250	100
600 N	600	300	120
700 N	700	350	140
800 N	800	400	160
900 N	900	450	180

Correspondence:

60 $N.cm^{-2}$ =600 $kN.m^{-2}$ = 0.6 MPa = 0.6 x 10^6 Pa

5. Earthworms

Principle of the method:	Counting of worm heads, determination of biomass, and identification at 2 levels (ecological category determination)		
Name:	Joséphine Peigné (according to Y. Capowiez (INRA) and D. Cluzeau (Université de Rennes)) / Ron de Goede	**Date:**	**15-04-2015**
Reagents	**Procedure**		

Material

(1) Pitch fork
(2) Ruler/tape measure
(3) Basin or bucket + disposable gloves (do not rub the face with the glove)
(4) Watering can of 10L + spray bar + a mixing tool (stick)
(5) Water
(6) Commercial Mustard (glasses of 150 g fine and strong AMORA (French one))
(7) Tweezers + flat clear surface for identification (eg tarpaulin or a large size rubbish bag)

Preamble

Ecological categories of earthworms :

They were defined independently by Bouché in France and Lee in Australia in the 70s. Initially based on morphological, demographic, ecological and anatomical criteria and they were extrapolated taking into account behavioural characteristics by Lee and Forster (1991). Originally, the authors had identified three poles between which species were distributed. Over the years, we went to a simplified vision, that is to say, three clearly defined categories and possibly non-overlapping. However, some species may have mixed characteristics, even a certain behavioural plasticity exists in earthworms.

The table gives the main criteria for identifying earthworms from the 3 main ecological categories :

Criteria	**EPIGEIC**	**ANECIC**	**ENDOGEIC**
Size	small (2-8 cm)	big (10-20 cm)	medium (5-15 cm)
Food	litter	litter	Soil organic matter
Skin pigmentation	dark	dark	no
Gallery	no	burrow	path
Longevity	short (cocoons)	long	medium

Typically, earthworms are removed from a defined surface using either hand sorting or irritating (mustard solution, see details below), or **both methods one**

(8) 9 cm petri dishes with small air holes in the lid (use a heated needle) + tissue paper + parafilm + weighing device (9) 96% alcohol solution (or possibly **4% formaldehyde)**	**after the other (called mixed methods)**. Irritant is mainly used to extract anecic earthworms from the soil, whereas epigeic and endogeic earthworms are preferably collected by hand sorting. **Climate Requirements:** a favourable period for the activity of worms, i.e. moist soil with moderate temperatures, so avoid dry and hot conditions (summer), frozen soil (winter), or saturated soil. Most favourable period: end of winter-beginning of spring. Better T (°C): from 6 to 10°C. A part of the day without much sunshine is preferred. **For iSQAPER, we use an adapted mixed method.** A hole is excavated and the earthworms in the excavated soil are collected by hand-sorting. In the bottom of the hole, mustard and water is applied to extract anecic earthworms that are present at greater soil depth. **When: earthworms are collected in fall or at the beginning of spring according to the climate conditions in each country.** **Where: randomly in each plot.**
	• **Mixed method (step 1 and 2):** *Step 1: collecting earthworms from 0-20 cm soil depth:* Manual hand sorting of at least 1 sub-replicate per plot, on a horizontal surface of 30 * 30 cm^2 and a depth of 30 cm (plough depth). Additional sub-replicates need to be done if the variation between field replicates is very large. - Use a pitchfork (rather than a spade which cuts too many earthworms); - Mark the area for sorting (about 30x30cm, i.e. roughly a square with sides equal to 2 times the width of the pitchfork); - Excavate a hole of 30x30 cm soil surface and a depth of 30 cm; - Pour the soil either on a tarpaulin or a large size rubbish bag; - Perform fast enough to limit the escape of some anecic earthworms to depth; - Inspect the sides and bottom of the hole to detect potential earthworms ready to slip away; - Now first continue with step 2, and then continue with step 1; - Carefully sort the collected soil in order to capture all the earthworms; - Place the earthworms in a labelled plastic jar filled with some fine soil. For each sample: The earthworms are stored in a plastic jar with fine soil and brought to the lab. The time required for sorting of such a soil volume varies depending on soil type, moisture, density and land cover (the estimated time is 1 to 2 hours). It is requested to pay particular attention to the root mat, not easy to sort, but often containing

	large amounts of earthworms and soil aggregates. The jar containing the earthworms must be closed after each capture and should ideally be placed in the shade to keep the earthworms cool. *Step 2: Extraction of earthworms from soil layers below 20 cm soil depth:* - Prepare the mustard-tap water solution on-site - for each watering, dilute 2 small commercial mustard pots (150 g *2) in a watering can with 10 L of water; - or 6 g of dry powder mustard for 1 L. - After excavating the hole (see step 1), apply around 2-3 litters of diluted mustard solution; - Continue with hand-sorting the earthworms from the excavated soil (step 1) and regularly check the hole for the presence of earthworms. Check the hole for ≥15 minutes; - Remove any earthworms that are found in the hole immediately and rinse them with tap water (in a dish filled with tap water); - Place the earthworms in a labelled plastic jar (this can be the same jar as for step 1) filled with some fine soil and bring them to the lab.
	In the laboratory: *1. Counting total numbers and numbers per ecological category:* - Remove the earthworms from the jar and transfer them into a dish filled with tap water. - Count all individuals present in the sample. Of specimens that are damaged only the body parts containing the head are counted. Thus, do not count tail or mid-body parts (but still keep them in the sample for further analyses, e.g. biomass estimation). - Classify each earthworm as an adult (with a ring (clitellum) near segment 30-40) or juvenile (no clitellum). *** Start with the adults : - Classify each individual into one of the following ecological groups: - (1) anecic, (2) epigeic and (3) endogeic *** Now continue with the juveniles: Use the same key as for the adults to also classify the juveniles into the ecological categories. Make use of your knowledge obtained from the classification of the adults that were found in the sample when classifying the juveniles. *2. Determination of fresh weight (biomass)*: - After identification, put about maximum of 5-10 earthworms (preferably from the same ecological category) in a labelled petri dish filled with moist tissue and store them overnight at about 15 ^oC, to allow the earthworms to void their gut. Be sure that the petri dish is carefully closed with parafilm to avoid escaping of the earthworms; - After emptying their gut, dry the earthworm with a tissue. Then weigh each individual earthworm. *3. Conservation for species identification and transport:* Earthworm conservation is done as follows: they can be conserved in:

	- Alcohol at 96% (DNA will be preserved), however, if the specimens are not yet classified into the ecological categories, photos must be taken because with time the skin colour will be affected by the alcohol (the earthworms become whitish). **Transportation (by airmail) is done as follows: sending earthworms in a solution of 4% formaldehyde (which should NOT contain any (extra) alcohol).**
Calculations	
Numbers per m^2 = (#complete specimens + #head parts) * 11.1 Biomass in g per m^2 = (#weight of all complete earthworms and fragments) * 11.1	

6. Tea bag test

Principle of the method:	Measuring plant residue decomposition		
Name:	Joost Keuskamp, Bas Dingemans & Mariet Hefting	**Date:**	**02-03-2016**
Reagents	**Procedure**		
Material (1) Green tea and Rooibos tea (see "where to find the materials" below) (2) Pen to mark bags (3) Scale (4) Stick for marking burial places (5) Spade (6) Drying oven	1. Take an unused Lipton Green tea (EAN 87 22700 05552 5) and Rooibos tea (EAN 87 22700 18843 8) bag per replicate. To obtain better estimates of TBI, use three-four replicates of each tea variety per plot. This is to keep in mind that some tea bags might get lost and there is a risk of animal damage. 2. Mark the tea bags on the white side of the label with a permanent black marker and measure the initial weight of the tea bag (.000 g) including the label and the string. 3. Open a few bags and measure the bag weight without content (this is approx. 0.283 g). 4. Bury the teabags in 8 cm-deep, separate holes while keeping the labels visible above the soil. 5. Mark the burial site with a stick. 6. Note the date of burial, geographical position, ecotype and experimental conditions of the site. 7. Recover the tea bags after approximately 90 days 8. Remove adhered soil particles and dry in a stove for 48h at 70°C (not warmer!). 9. Remove what is left of the label but leave the string and weigh the bags (.000 g). 10. Calculate the TBI using the link below. The initial weights (point 2 and 3) are needed only for own calculations.		
Fill in the results to get TBI			
http://decolab.org/tbi/data/index.php			
Materials will be send			

7. Yield

7.1 Above ground biomass

Calculate the aboveground biomass also for crops described in 7.2 and 7.3. Above ground biomass is about **all** crops where aboveground biomass is harvested. Thus, all crops including foddercrops and cover crops, specifically for example harvested foddercrops and cover crops e.g. grassland, silage maize, grass-clover, Lucerne etc.

Principle of the method:	A standardized procedure to get a representative sample of the above-ground (AG) biomass yield.		
Name:	Julia Cooper	**Date:**	**25.11.2011**

Reagents	**Procedure**

Material
(1) suitable harvesting equipment for the crop e.g. plot combine, sickle bar mower, shears
(2) drying oven (80°C)
(3) large capacity electronic balance for use in the field (suggested capacity 100 kg; precision 0.05 kg)
(4) small capacity electronic balance (suggested capacity 2 kg; precision 0.01 g)
(5) pans for drying samples in the oven
(6) plastic bags for storage
(7) aluminium trays for sample drying
(8) waterproof marker pens
	• Select a representative area in the plot that is
	  ◦ removed from the plot borders i.e. in the central area of the plot
	  ◦ large enough to accurately represent the plot; minimum 10% of plot area
	• Harvest the sample area and record the total fresh weight of the harvested material [kg] in the field using the large capacity balance and the harvested area [m²]
	• Take a subsample of the harvested material (0.5 to 2 kg fresh weight) and record the fresh weight of the material using the small capacity balance
	• Dry the sample at 60°C for 48 hours (until constant weight)
	• Record the weight of the dried sample
	• Store the dried material in a tightly sealed bag at room temperature (<=20°C)
	• Label all samples with: Trial short name, crop, plot number, harvest date

Calculations

- $$Fresh\,aboveground\,biomass\,yield\left[t\,ha^{-1}\right]=\frac{harvested\,biomass\left[kg\right]\times 10}{harvested\,area\left[m^{2}\right]}$$
- $$Plant\,dry\,matter\,[\%]=100\times\frac{mass\,dry\,subsample[g]}{mass\,fresh\,subsample[g]}$$
- $$Dry\,aboveground\,biomass\,yield\left[t\,ha^{-1}\right]=\frac{Fresh\,yield\left[t\,ha^{-1}\right]\times plant\,dry\,matter\left[\%\right]}{100}$$

7.2 Crop yield –combinable crops

Principle of the method:	A standardized procedure to get a representative sample of the yield for a combinable crop (e.g. cereals, oilseeds)		
Name:	Julia Cooper	**Date:**	**25.11.2011**

Reagents	**Procedure**

Material
(1) Suitable harvesting equipment for the crop e.g. plot combine, sickle bar mower, knives
(2) Combine balance; precision 0.05 kg (if using a plot combine)
(3) Small capacity electronic balance (suggested capacity 2000 g; precision 0.01 g)
(4) Drying oven (80°C)
(5) Pans for drying samples in the oven
(6) Plastic bags for storage
(7) Aluminium trays for drying
(8) Waterproof marker pens
	• If using a plot combine:
	  • first harvest the border areas of all plots and the areas, where biomass samples were taken
	  • harvest the remaining area of the plot and record the plot area and fresh weight of combined grain (using the combine balance)
	  • collect a subsample of grain and record its fresh weight (using the small capacity balance)
	  • dry the subsample in a 80°C oven and record its dry weight
	• If no crop combine is available:
	  • take a subsample of the above-ground biomass sample (see section 1.1)
	  • dry it at 60°C
	  • record the total weight of the dried sample (A)
	  • thresh the grain from the dried sample and record its weight (B)
	  • determine the grain percentage (grain [%]) of above-ground biomass (B × 100/A)
	• Store the dried grain in a tightly sealed bag at room temperature (<=20°C)
	• Label all samples with: Trial short name, crop, plot number, harvest date

Calculations

Using a plot combine:

- $Fresh\ yield\ (t\,ha^{-1}) = \frac{combine\ yield\ (kg) \times 10}{harvested\ area\ (m^2)}$
- $Plant\ dry\ matter\ [\%] = 100 \times \frac{mass\ dry\ subsample[g]}{mass\ fresh\ subsample[g]}$

7.3 Crop yield –non-combinable crops

Principle of the method:	A standardized procedure to get a representative sample of the yield for a non-combinable crop (e.g. potatoes, onions, carrots, cabbages)		
Name:	Julia Cooper	**Date:**	**25.11.2011**

Reagents	**Procedure**

Material
(1) Suitable harvesting equipment for the crop e.g. potato digger, digging forks, machete
(2) Drying oven (set at 80°C)
(3) Large capacity electronic balance for use in the field (suggested capacity 100 kg; precision 0.05 kg)
(4) Small capacity electronic balance (suggested capacity 2000 g; precision 0.01 g)
(5) Pans for drying samples in the oven
(6) Plastic bags for sample storage
(7) Aluminium trays for sample drying
(8) Waterproof marker pens
	• Select a representative area in the plot that is
	  ◦ removed from the plot borders i.e. in the central area of the plot
	  ◦ large enough to accurately represent the plot; minimum 10% of plot area
	• Harvest the sample area and record the total fresh weight of the harvested material in the field using the large capacity balance
	• Take a large sample (25 - 50 kg) of the harvested material back to the work area for grading
	• Accurately record the weight of the sample to be used for grading
	• Wash a sub-sample of the product (~0.5 - 2 kg) if necessary (e.g. for potatoes, carrots) and chop it using a sharp knife into 2 cm sized chunks
	• Immediately weigh the fresh, chopped material and record the fresh weight using the small capacity balance
	• Dry the sample at 60°C for 48 hours
	• Record the weight of the dried sample
	• Store the dried material in a tightly sealed bag at room temperature (<=20°C)
	• Label all samples with: Trial short name, crop, plot number, harvest date

Calculations

- $Total\ fresh\ yield\left[t\,ha^{-1}\right]=\frac{harvested\ biomass\ [kg]\times 10}{harvested\ area\left[m^{2}\right]}$
- $Plant\ dry\ matter\ [\%]=100\times\frac{mass\ dry\ subsample[g]}{mass\ fresh\ subsample[g]}$
- $Total\ dry\ yield\left[t\,ha^{-1}\right]=\frac{total\ fresh\ yield\left[t\,ha^{-1}\right]\times plant\ dry\ matter\ [\%]}{100}$

Reference

Jahn, R.; Blume, H. P.; Asio, V. B (2003) Students guide for soil description, soil classification and site evaluation. University of Halle/Saale (Germany); University of Kiel (Germany); Leyte State University (Philippines):Germany

Appendix A VESS Chart

Visual Evaluation of Soil Structure

Soil structure affects root penetration, water availability to plants and soil aeration. This simple, quick test assesses soil structure based on the appearance and feel of a block of soil dug out with a spade.
The scale of the test ranges from Sq1, good structure, to Sq5, poor structure.

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Equipment:
Garden spade approx. 20 cm wide, 22-25 cm long.
Optional: light-coloured plastic sheet, sack or tray ~50 x 80 cm, small knife, digital camera.

When to sample:
Any time of year, but preferably when the soil is moist. If the soil is too dry or too wet it is difficult to obtain a representative sample.
Roots are best seen in an established crop or for some months after harvest.

Where to sample:
Select an area of uniform crop or soil colour or an area where you suspect there may be a problem. Within this area, plan a grid to look at the soil at 10, preferably more, spots. On small experimental plots, it may be necessary to restrict the number to 3 or 5 per plot.

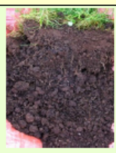
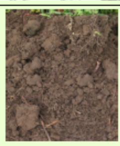
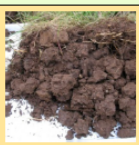
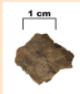
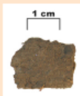
Bruce Ball, SRUC (bruce.ball@sruc.ac.uk),
Rachel Guimarães, University of Maringá, Brazil (rachellocks@gmail.com),
Tom Batey, Independent Consultant (2033@tombatey.f2s.com) and
Lars Munkholm, University of Aarhus, Denmark (Lars.Munkholm@agrsci.dk)

Method of assessment:

Step	Option	Procedure
Block extraction and examination		
1. Extract soil block	Loose soil	Remove a block of soil ~15 cm thick directly to the full depth of the spade and place spade plus soil onto the sheet, tray or the ground
	Firm soil	Dig out a hole slightly wider and deeper than the spade leaving one side of the hole undisturbed. On the undisturbed side, cut down each side of the block with the spade and remove the block as above.
2. Examine soil block	Uniform structure	Remove any compacted soil or debris from around the block
	Two or more horizontal layers of differing structure	Estimate the depth of each layer and prepare to assign scores to each separately.
Block break-up		
3. Break up block (take a photograph - optional)		Measure block length and look for layers. Gently manipulate the block using both hands to reveal any cohesive layers or clumps of aggregates. If possible separate the soil into natural aggregates and man-made clods. Clods are large, hard, cohesive and rounded aggregates.
4. Break up of major aggregates to confirm score		Break larger pieces apart and fragment it until a piece of aggregate of 1.5 - 2.0 cm. Look to their shape, porosity, roots and easily of break up. Clods can be broken into non-porous aggregates with angular corners and are indicative of poor structure and higher score.
Soil scoring		
5. Assign score		Match the soil to the pictures category by category to determine which fits best.
6. Confirm score from:		Factors increasing score:
	Block extraction	Difficulty in extracting the soil block
	Aggregate shape and size	Larger, more angular, less porous, presence of large worm holes
	Roots	Clustering, thickening and deflections
	Anaerobism	Pockets or layers of grey soil, smelling of sulphur and presence of ferrous ions
	Aggregate fragmentaion	Break up larger aggregates ~ 1.5 – 2.0 cm of diameter fragments to reveal their type
7.Calculate block scores for two or more layers of differing structure		Multiply the score of each layer by its thickness and divide the product by the overall depth, e.g. for a 25 cm block with 10 cm depth of loose soil (Sq1) over a more compact (Sq3) layer at 10-25 cm depth, the block score is (1 x 10)/25 + (3 x 15)/25 = Sq 2.2.

Scoring: Scores may fit between Sq categories if they have the properties of both.
Scores of 1-3 are usually acceptable whereas scores of 4 or 5 require a change of management.

16 Oct 2012

Structure quality	Size and appearance of aggregates	Visible porosity and Roots	Appearance after break-up: various soils	Appearance after break-up: same soil different tillage	Distinguishing feature	Appearance and description of natural or reduced fragment of ~ 1.5 cm diameter
Sq1 Friable Aggregates readily crumble with fingers	Mostly < 6 mm after crumbling	Highly porous Roots throughout the soil			 Fine aggregates	 The action of breaking the block is enough to reveal them. Large aggregates are composed of smaller ones, held by roots.
Sq2 Intact Aggregates easy to break with one hand	A mixture of porous, rounded aggregates from 2mm - 7 cm. No clods present	Most aggregates are porous Roots throughout the soil			 High aggregate porosity	 Aggregates when obtained are rounded, very fragile, crumble very easily and are highly porous.
Sq3 Firm Most aggregates break with one hand	A mixture of porous aggregates from 2mm -10 cm; less than 30% are <1 cm. Some angular, non-porous aggregates (clods) may be present	Macropores and cracks present. Porosity and roots both within aggregates.			 Low aggregate porosity	 Aggregate fragments are fairly easy to obtain. They have few visible pores and are rounded. Roots usually grow through the aggregates.
Sq4 Compact Requires considerable effort to break aggregates with one hand	Mostly large > 10 cm and sub-angular non-porous; horizontal/platy also possible; less than 30% are <7 cm	Few macropores and cracks All roots are clustered in macropores and around aggregates			 Distinct macropores	 Aggregate fragments are easy to obtain when soil is wet, in cube shapes which are very sharp-edged and show cracks internally.
Sq5 Very compact Difficult to break up	Mostly large > 10 cm, very few < 7 cm, angular and non-porous	Very low porosity. Macropores may be present. May contain anaerobic zones. Few roots, if any, and restricted to cracks			 Grey-blue colour	 Aggregate fragments are easy to obtain when soil is wet, although considerable force may be needed. No pores or cracks are visible usually.

Annex : Mansonia-Field Sheet

Visual evaluation of soil structure (Ball et al., 2007).

		Observation number:	
Date:			
Described by:		**Location:**	
Plot:		**Depth (cm) of the block:**	
Crop:		**Difficulty of extraction**	

Layers (cm)	**Layer 1 layer 2 layer 3**
Block extraction	Loose soil / Firm soil
Examine soil block	Uniform structure / horizontal layers
Block break -up	
	Clods are large, hard, cohesive and rounded aggregates
	Aggregates shape
	Aggregate porosity
	Roots
	Easily of break-up
	Anaerobism
Appearance of reduced fragment	
Aggregate shape and size	Large / small / held by roots / rounded/ angular / less porous / porous / presence worm holes
Roots	
Clustering	Few / Common / Many
Thickening (root deformation)	None / weak / Common
Defections	None / Weak / Strong
Distribution	Uniform / surface layer
Score	
Match the soil to the pictures category	**Layer 1 layer 2 layer 3**
Confirmed score	

Appendix B Disease incidence form

	Attribute	Not detected	<25%	25%-50%	50%-75%	75%-100%
1	Lesions (general)					
2	Damping-off					
3	Loss of root cortical tissue					
4	Rotting of root tips and fine lateral roots					
5	Swellings (galls, knots, and clubs)					
6	Necrosis					

7.4 Response ratio results for individual LTEs

For the LTEs CH1, CH2, ES4, HU4, NL1, NL2 and SL1 two bars appear in the graphs: the left bar indicates layer 1, and the right bar indicates layer 2. For the LTEs CH3, HU1 and PT1 there is only one bar, since in these LTEs sampling was done in the layer 0 – 20 cm as a whole. Above or below the bars, significant F-probabilities from the ANOVA are shown with symbol *, ** or *** designating respectively <0.05, <0.01, and <0.001, designating .

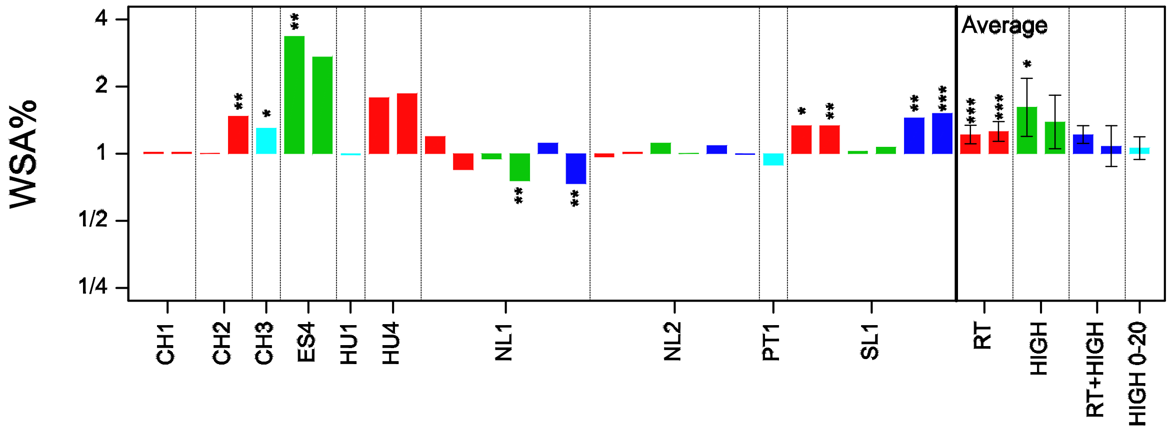


Figure 29. Response ratios of water stable aggregates (WSA) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both factors (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased WSA in both layers in SL1 and in layer 2 in CH2. High supply of organic matter increased WSA in ES4 in layer 1, but decreased it in NL1 in layer 2. High supply of organic matter increased WSA in layer 0-20 cm in CH3. The combination of reduced tillage and high supply of organic matter reduced WSA in NL1 in layer 2, but increased it in SL1 in both layers. On average over the LTEs, reduced tillage increased WSA in both layers. High supply of organic matter increased WSA in layer 1. The combination of reduced tillage and high supply of organic matter had no significant effects.

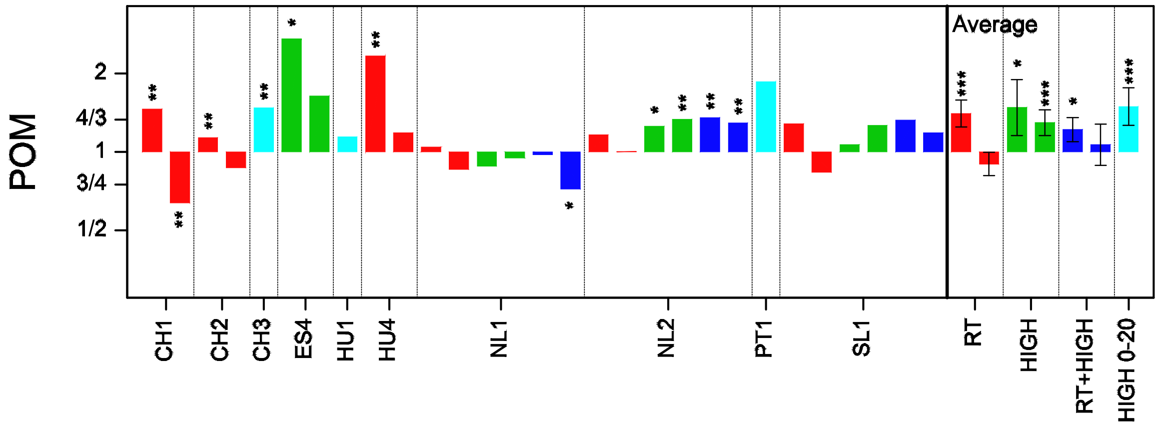


Figure 30. **Response ratios of particulate organic matter (POM) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both management factors (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased POM in layer 1 of CH1, CH2 and HU4, but decreased it in CH1 layer 2. High supply of organic matter increased POM in ES4 layer 1, in NL2 in both layers and in CH3 in layer 0-20 cm. The combination of reduced tillage and high supply of organic matter decreased POM in NL1 in layer 2 and increased it in NL2 in bot layers. On average over the LTEs, reduced tillage increased POM in layer 1. High supply of organic matter increased POM in both layers and in the layer 0-20 cm. The combination of reduced tillage and high supply of organic matter increased POM in layer 1.

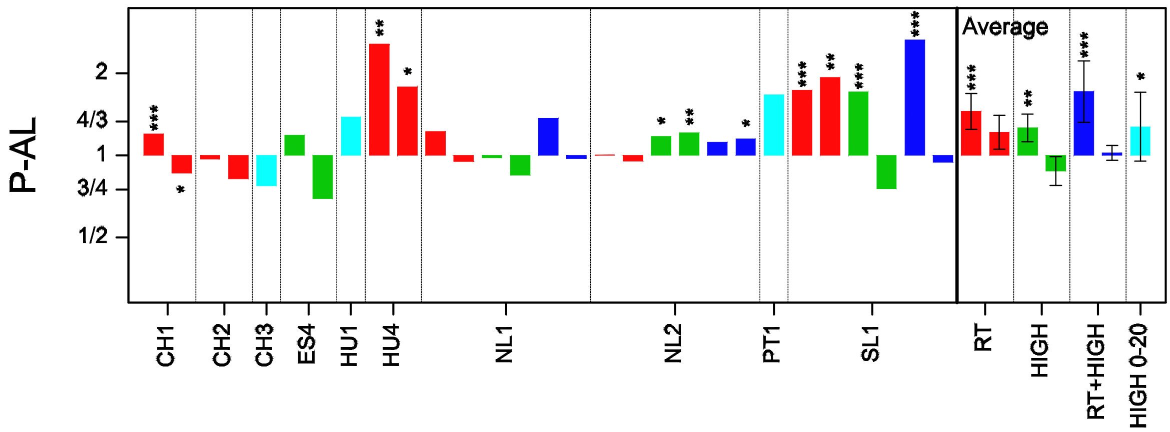


Figure 31. **Response ratios of total phosphate (P-AL) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased P-AL in CH1 in layer 1 and in both layers of HU4 and SL1, but decreased it in CH1 in layer 2. High supply of organic matter increased P-AL in NL2 in both layers and in SL1 in layer 1. On average over the LTEs, reduced tillage, high supply of organic matter and the combination of both increased P-AL in layer 1 and had no significant effects in layer 2. High supply of organic matter also increased P-Al in the layer 0 - 20 cm.

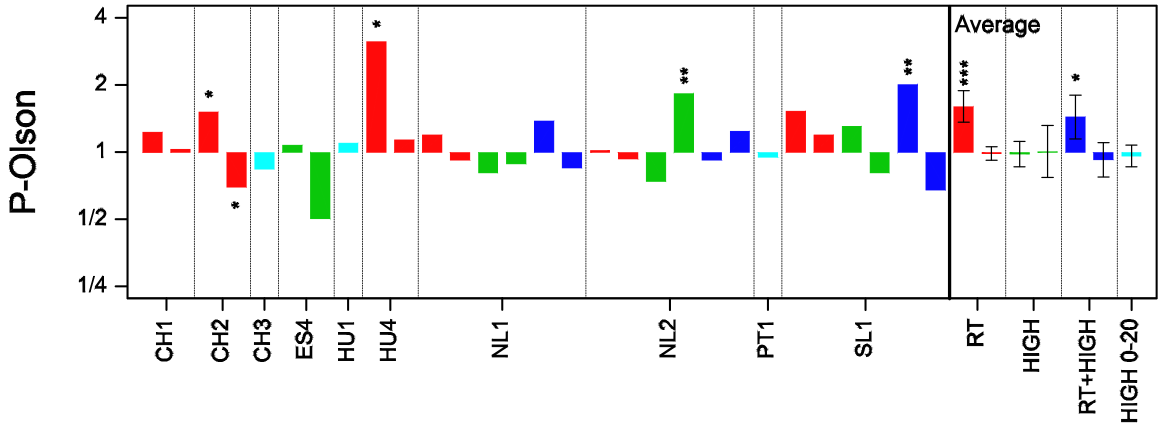


Figure 32. Response ratios of available phosphate (P-Olsen) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased P-Olsen in layer in CH2 and in HU4 in layer 1, but decreased it in CH2 layer 2. High supply of organic matter increased P-Olsen only in NL2 in layer 2. The combination of reduced tillage and high supply of organic matter increased P-Olsen in SL1 layer 1.
On average over the LTEs, reduced tillage and the combination of reduced tillage and high supply of organic matter increased P-Olsen in layer 1.

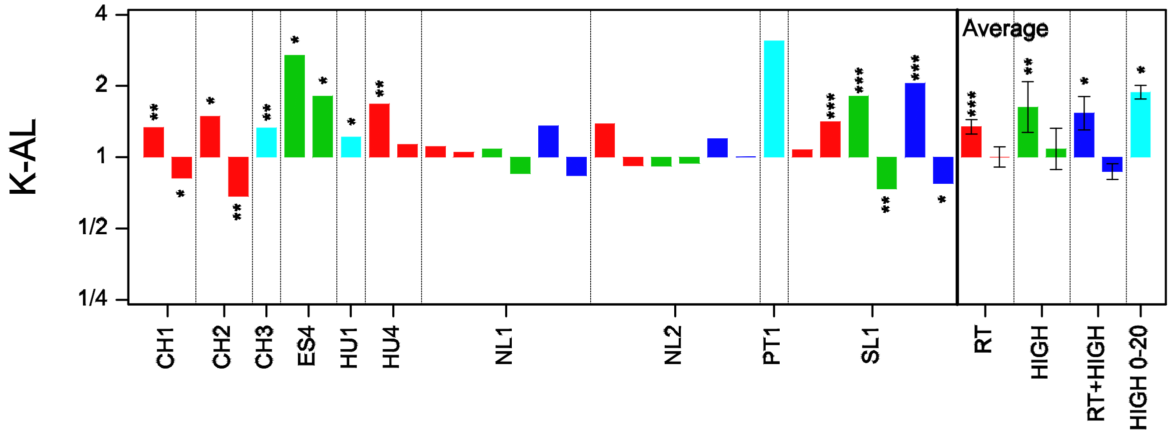


Figure 33. Response ratios of K-AL for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased K-AL in layer 1 in CH1, CH2 and HU4 and increased it in SL1 in layer 2, but decreased K-AL in layer 2 in CH1 and CH2. High supply of organic matter increased K-AL in both layers in ES4 and in SL1 in layer 1, but decreased it in SL1 in layer 2. High supply of organic matter also increased K-AL in CH3 and HU1 in layer 0 – 20 cm. The combination of reduced tillage and high supply of organic matter increased K-AL in SL1 in layer 1 but decreased it there in layer 2. On average over the LTEs, reduced tillage, high supply of organic matter and the combination of both increased K-AL in layer 1 and had no significant effects in layer 2.
High supply of organic matter increased K-AL in the layer 0 – 20 cm.

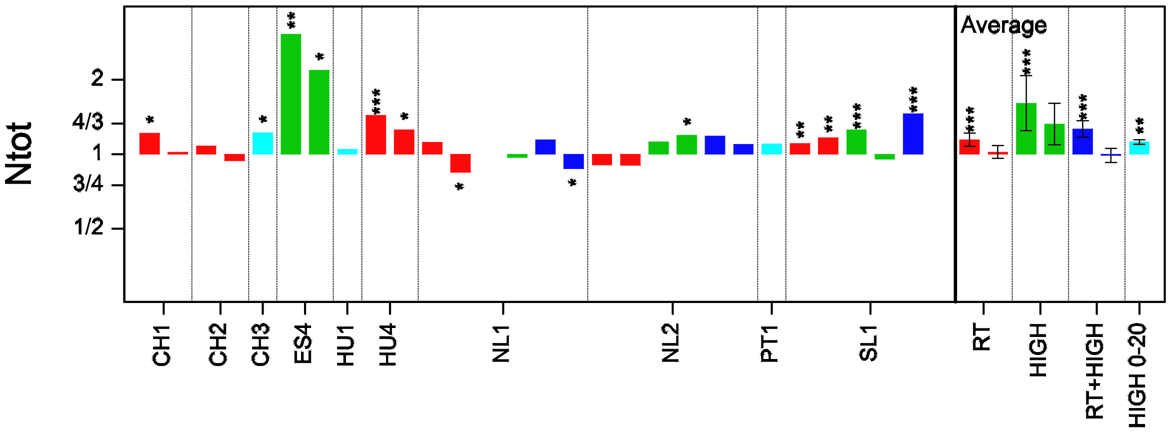


Figure 34. **Response ratios of total nitrogen (Ntot) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased Ntot in CH1 in layer 1 and in both layers of HU4 and SL1, but decreased it in NL2 in layer 2. High supply of organic matter increased Ntot in ES4 in both layers, in NL2 in layer 2, in SL1 in layer 1 and in CH3 in the layer 0 – 20 cm. On average over the LTEs, reduced tillage, high supply of organic matter and the combination of both increased total nitrogen in soil layer 1 and had no significant effects in layer 2. High supply of organic matter increased Ntot in layer 0 – 20 cm.

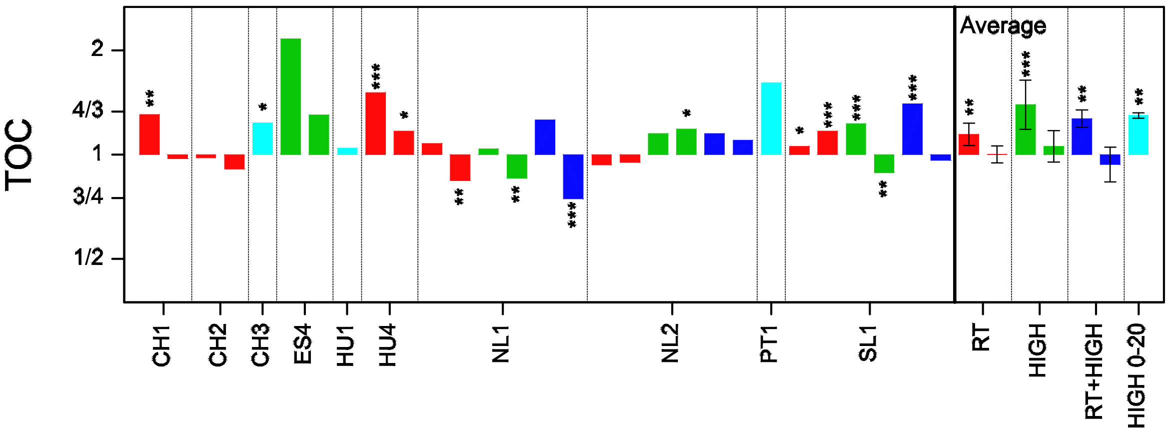


Figure 35. **Response ratios of total organic carbon (TOC) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased TOC in CH1 in layer 1 and in HU4 and SL1 in both layers, but decreased in NL1 in layer 2. High supply of organic matter increased TOC in NL2 in layer 2 and SL1 layer 1, but decreased in NL1 layer 2 and SL1 layer 2. Combination of reduced tillage and high supply of organic matter increased TOC in SL1 layer 1, but decreased it in NL1 layer 2. Like Ntot, in NL1 TOC in layer 2 was decreased by reduced tillage and by the combination of reduced tillage and high supply of organic matter, which was contrary to what was expected from other measurements in this trial in 2016 and earlier. On average over the LTEs, reduced tillage, high supply of organic matter and the combination of both increased TOC in layer 1. High supply of organic matter also increased TOC in layer 0 – 20 cm.

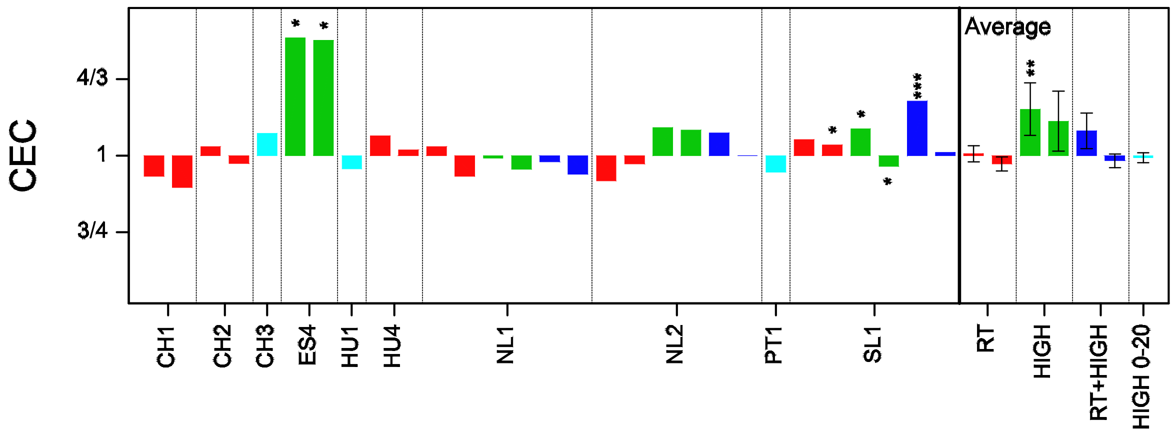


Figure 36. **Response ratios of cation exchange capacity (CEC) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased CEC only in SL1 in layer 2. High supply of organic matter increased CEC in both layers of ES4 (substantially) and in SL1 in layer 1, but decreased it there in layer 2. The combi-nation of reduced tillage and high supply of organic matter increased CEC in SL1 in layer 1. On average over the LTEs, high supply of organic matter increased CEC in layer 1.

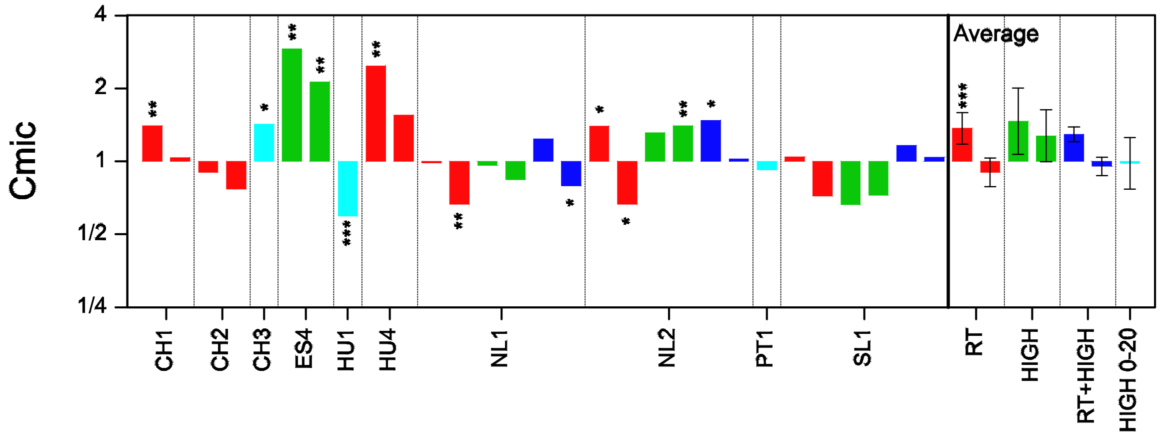


Figure 37. **Response ratios of carbon content of micro-organisms (Cmic) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased Cmic in layer 1 of CH1, HU4 and NL2, but decreased it in layer 2 of NL1 and NL2. High supply of organic matter increased Cmic in ES4 in both layers, in NL2 in layer 2 and in CH3 in layer 0 – 20 cm, but decreased Cmic in HU4 in layer 0 – 20 cm. On average over the LTEs reduced tillage increased Cmic in layer 1.

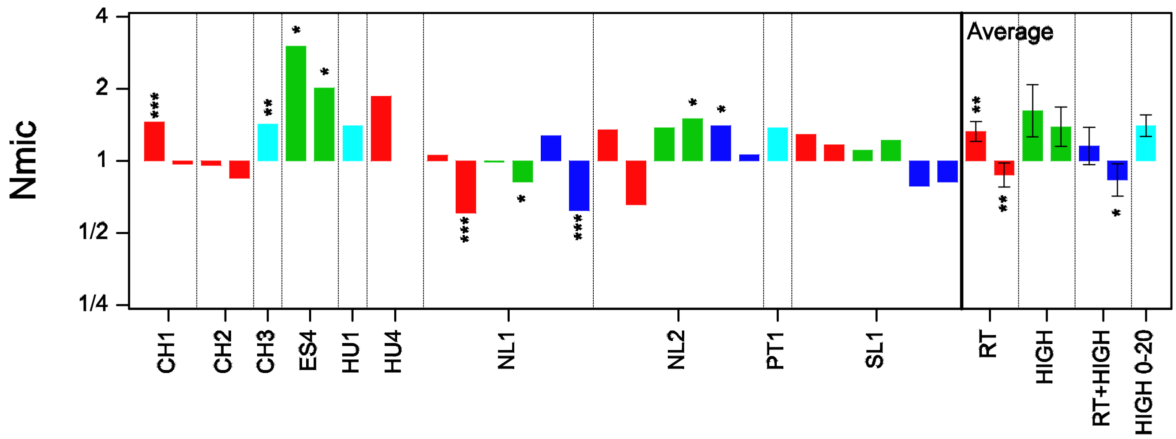


Figure 38. Response ratios of nitrogen content of micro-organisms (Nmic) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased Nmic in CH1 layer but decreased in NL1 in layer 2. High supply of organic matter increased Nmic in CH3 in 0 – 20 cm, in both layers of ES4 and in NL2 in layer 2, but decreased Nmic in NL1 in layer 2. Like Ntot, Ctot, TOC and Cmic effects of reduced tillage and/or high supply of organic matter in NL1 decreased Nmic in layer 2. Remarkable at SL1 is that it seems that Nmic was decreased by the combination of reduced tillage and high supply of organic matter, where reduced tillage and high supply of organic matter alone both seem to have increasing effects. Averaged over the LTEs reduced tillage increased Nmic in layer 1, but decreased it in layer 2 and the combination of reduced tillage and high supply of organic matter decreased Nmic in layer 2.

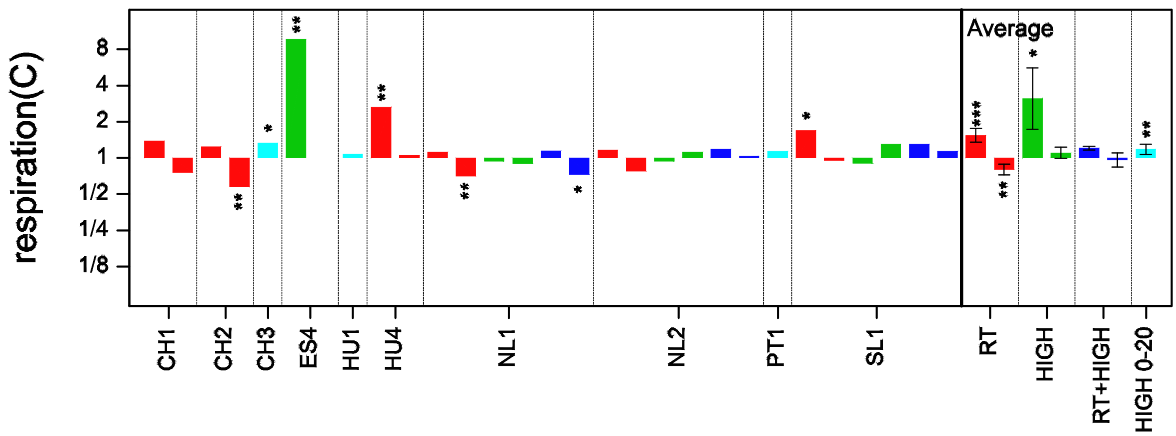


Figure 39. Response ratios of soil respiration for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased respiration in layer 1 in HU4 and SL1, but decreased respiration in layer 2 of CH2 and NL1. High supply of organic matter increased respiration in ES4 layer 1 substantially and also increased it in CH3 in layer 0 – 20 cm. On average over the LTEs, reduced tillage increased respiration in soil layer 1 and reduced it in soil layer 2. High supply of organic matter increased respiration in soil layer 1 and in layer 0 – 20 cm.

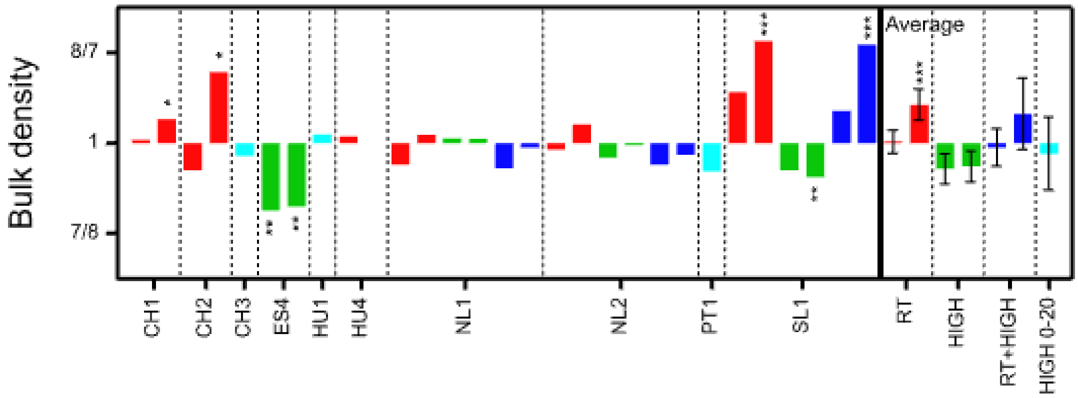


Figure 40. **Response ratios of bulk density (Bulk) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased bulk density in layer 2 in CH1, CH2 and SL1 and had no significant effects on layer 1 in those locations. High supply of organic matter decreased bulk density in ES4 in both layers and in SL1 in layer 2. On average over LTEs, reduced tillage increased bulk density in layer 2.

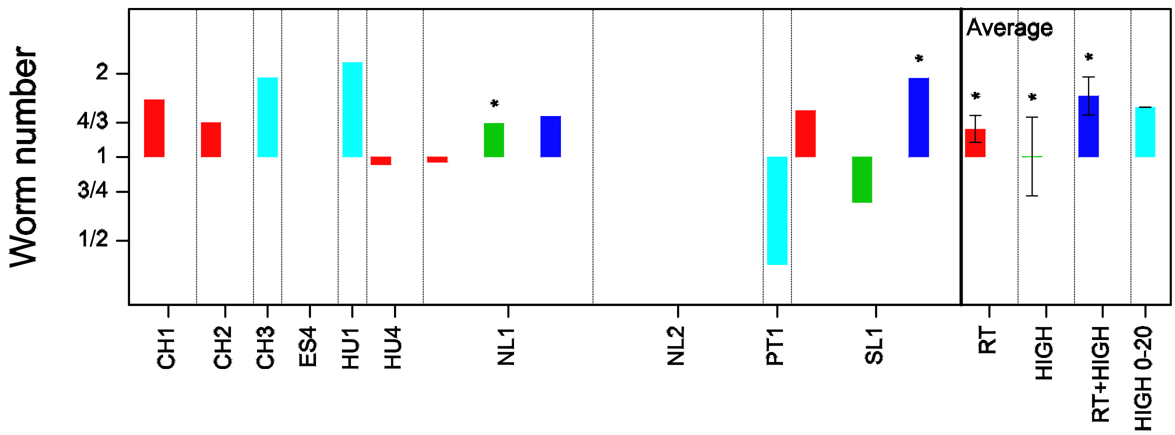


Figure 41. **Response ratios of the number of earthworms for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Earthworms were not found in ES4 and NL2. In CH1, CH2, HU4, NL1 and SL1, earthworm numbers were only counted in soil layer 1 (0 - 10 cm). Only in HU4, earthworm numbers and weights were determined in two layers. Reduced tillage had no significant effects on the earthworm numbers in the individual LTEs. High supply of organic matter seem to have great effects in the three LTEs were the layer 0 – 20 cm was determined, but these effects were not significant. High supply of organic matter increased the number of earthworms in NL1 in layer 1. The combination of reduced tillage and high supply of organic matter increased number of earthworms in SL1 in layer 1. On average over all LTEs reduced tillage, high supply of organic matter and the combination of both increased the number of earthworms in layer 1. The effect of high supply of organic matter in layer 1 was very small, but nevertheless significant. However high supply of organic matter had no significant effects on earthworm numbers in the layer 0 – 20 cm.

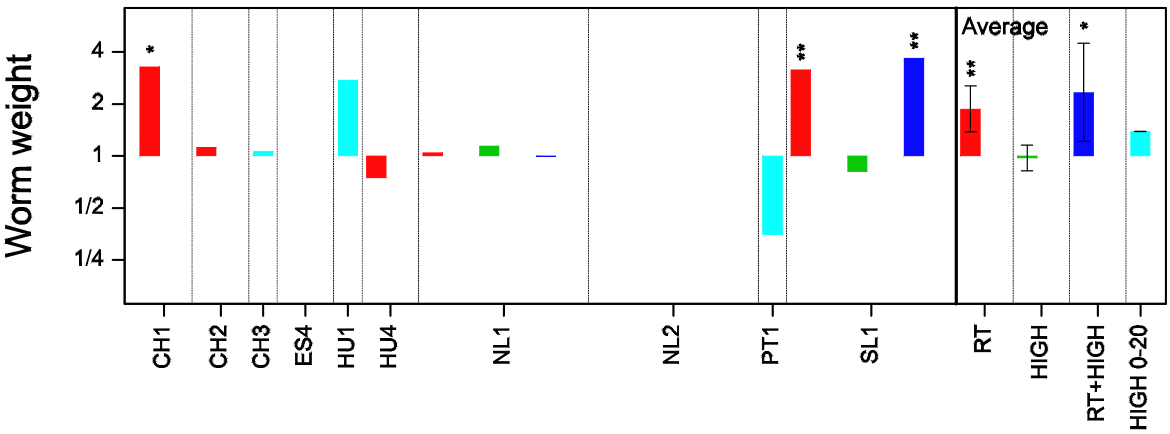


Figure 42. Response ratios of weight of earthworms for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Earthworms were not found in ES4 and NL2. Earthworm weights were only determined in LTEs CH1, CH2, HU4, NL1 and SL1 in soil layer 1. Reduced tillage increased weight of earthworms in layer 1 in CH1 and SL1. High supply of organic matter did not have significant effects on earthworm weight. The effect of organic matter addition seems to have a large effect in HU1 and PT1, but the effects are opposite for the two LTEs. The combination of reduced tillage and high supply of organic matter increased weight of earthworms in SL1 in layer 1. On average over all LTEs, reduced tillage and the combination of reduced tillage and high supply of organic matter increased weight of earthworms in layer 1.

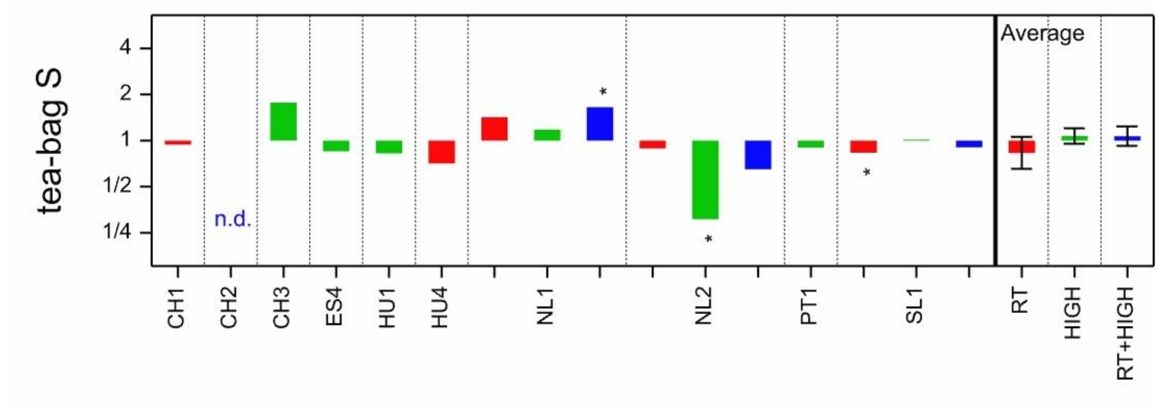


Figure 43. Response ratios of teabag test parameter S (stabilisation factor) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage decreased teabag parameters S in SL1 and high supply of organic matter decreased this parameter in NL2. However the combination of reduced tillage and high supply of organic matter increased teabag parameter S in NL1.
On average over the LTEs there were no significant effects on this parameter.

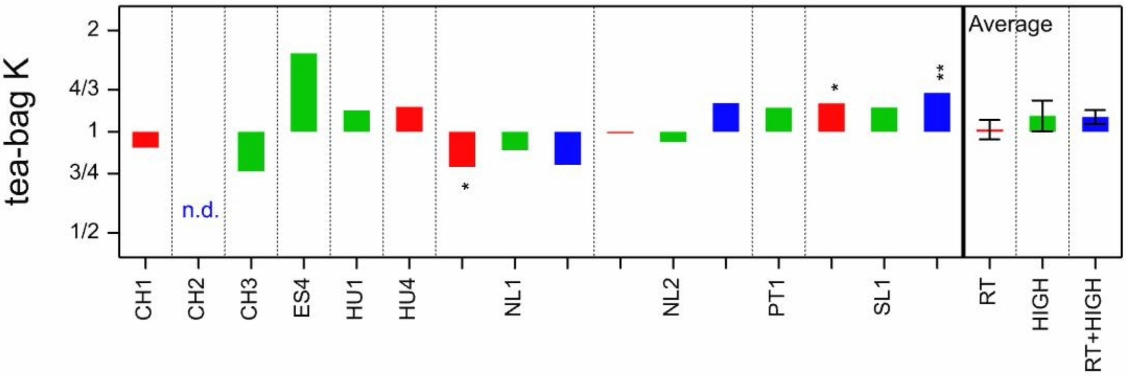


Figure 44. Response ratios of teabag test parameter K (decomposition rate) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage decreased parameter K in NL1 but increased it in SL1. The combination of reduced tillage and high supply of organic matter increased parameter K in SL1. Averaged over the LTEs there were no significant effects of reduced tillage and/or high supply of organic matter on parameter K of the teabag test.

As could be expected the effects of management on the parameters S and K are more or less the mirror image of each other: effect which increase decomposition will imply a higher decomposition rate (higher K), but also less stabilisation (lower S).

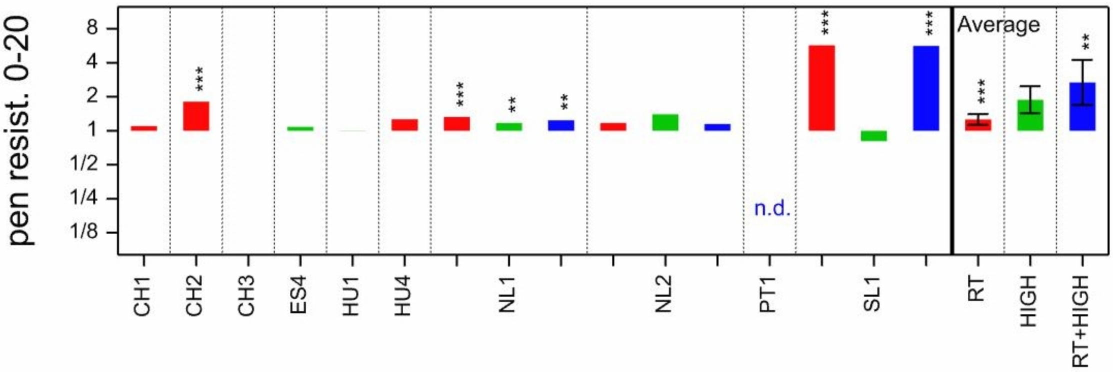


Figure 45. Response ratios of penetrometer resistance between 0 to 20 cm for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased penetration resistance between 0 and 20 cm in CH2, NL1 and SL1. Supply of organic matter increased this parameter in NL1. Combination of reduced tillage and high supply of organic matter increased the parameter in NL1 and SL1. On average, over the LTEs reduced tillage and the combination of reduced tillage and high supply of organic matter increased penetration resistance between 0 and 20 cm.

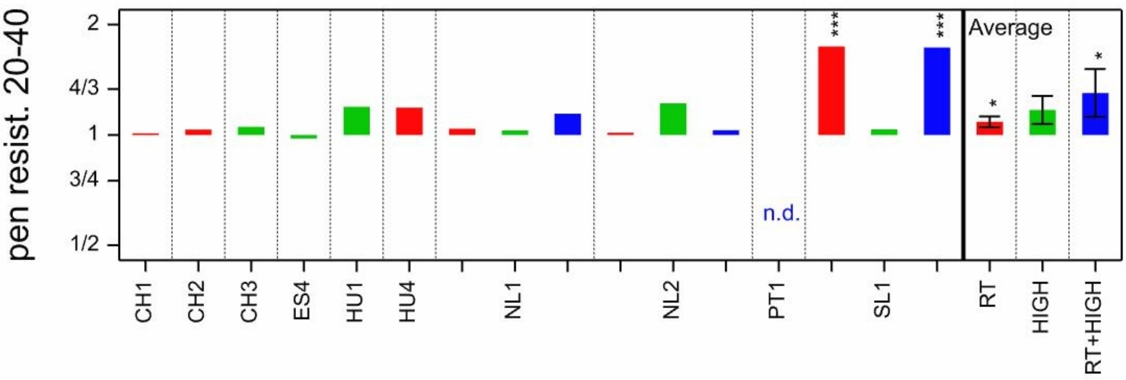


Figure 46. Response ratios of penetrometer resistance between 20 to 40 cm for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased penetration resistance between 20 and 40 cm in SL1. High supply of organic matter had no significant effects in the LTEs. The combination of reduced tillage and high supply of organic matter increased this parameter in SL1. On average over the LTEs reduced tillage and the combination of reduced tillage and high supply of organic matter increased penetration resistance between 20 and 40 cm.

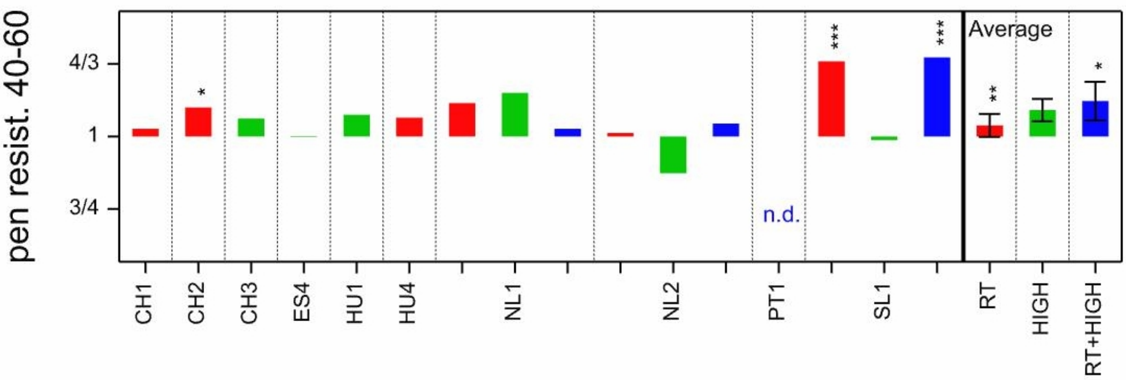


Figure 47. Response ratios of penetrometer resistance between 40 to 60 cm for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased penetration resistance between 40 and 60 cm in CH2 and SL1. High supply of organic matter had no significant effects on this parameter. The combination of reduced tillage and high supply of organic matter increased this parameter in SL1. On average over the LTEs reduced tillage and the combination of reduced tillage and high supply of organic matter increased penetration resistance between 40 and 60 cm.

The pattern is more or less the same for the penetration resistance in the three layers (0 -20 cm, 20 – 40 cm and 40 – 60 cm): significant increased penetration resistance by reduced tillage and the combination of reduced tillage and high supply of organic matter, and not significant increase by high supply of organic matter.

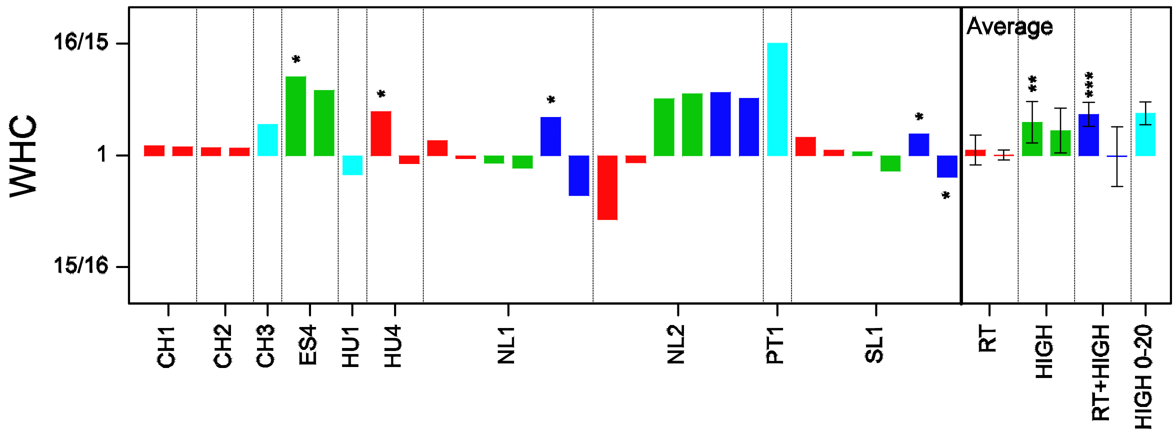


Figure 48. Response ratios of water holding capacity (WHC) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased WHC in HU4 layer 1. High supply of organic matter increased WHC in ES4 in layer 1. The combination of reduced tillage and high supply of organic matter increased WHC in NL1 layer 1 and in SL1 layer 1, but decreased it in SL1 in layer 2. On average over the LTEs reduced tillage had no significant effects on WHC but high supply of organic matter and the combination of reduced tillage and high supply of organic matter increased WHC in layer 1. Although effects were (rather) small (see the scale of the Y-axis), effects of high supply of organic matter were significant.

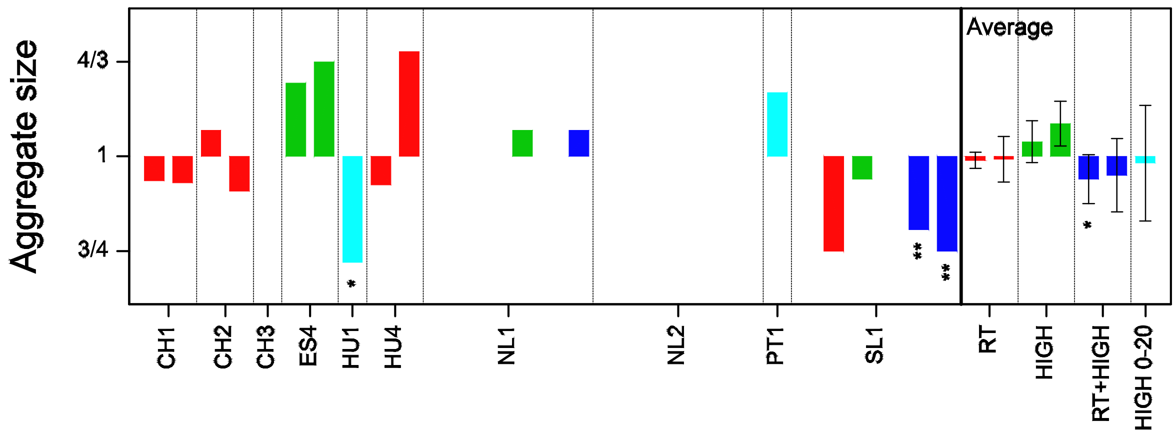


Figure 49. Response ratios of aggregate size and clod mixture (in the spade diagnosis) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

In CH3, values of aggregate size were the same on all plots and in NL2 the values were the same in each layer, therefore response ratios equal one in these LTEs. Reduced tillage had no significant effects in the LTEs. High supply of organic matter decreased the aggregate score in HU1. The combination of reduced tillage and high supply of organic matter had a decreasing effect on aggregate score in SL1 in both layers. On average over the LTEs, the combination of reduced tillage and supply of organic matter decreased the aggregate score (a lower score means a larger aggregate size and more clods) in layer 1.

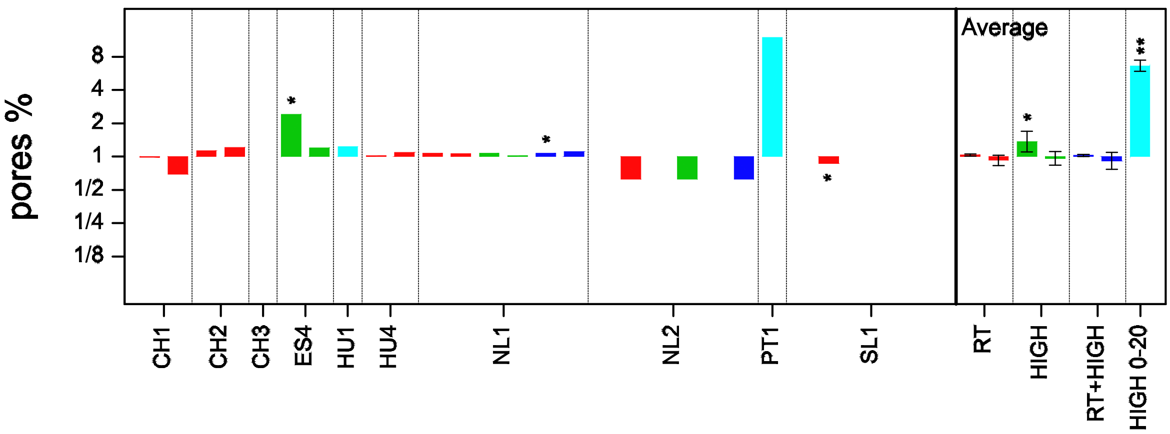


Figure 50. **Response ratios of percentage pores in the soil (in the spade diagnosis) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage decreased percentage pores in SL1. High supply of organic matter increased percentage pores in ES4 layer 1 and the combination of reduced tillage and high supply of organic matter increased percentage pores in NL1 layer 1.
Remarkable is that there seemed to be great increasing effect by high supply of organic matter in PT1, but that this effect was not statistically significant. On average over all the LTEs high supply of organic matter increased percentage porous soil in layer 1 and in the layer 0 – 20 cm.

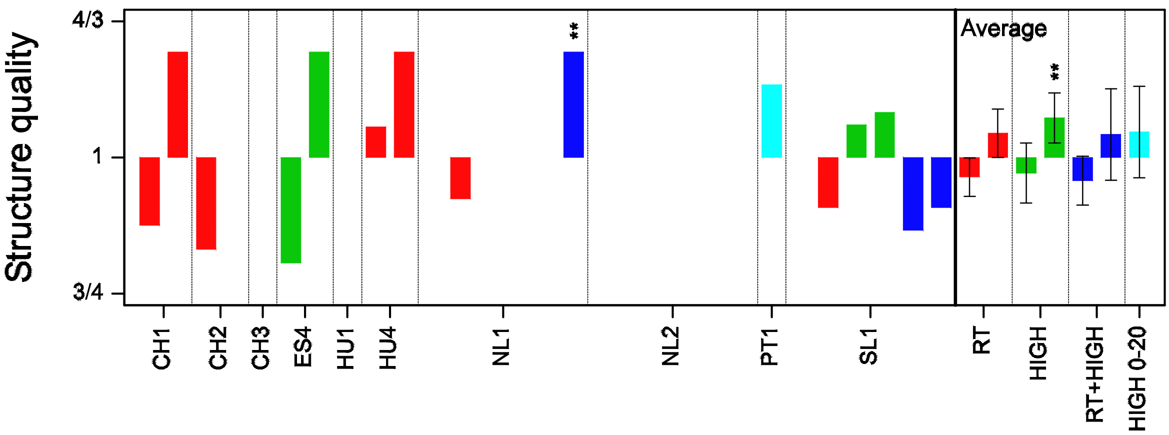


Figure 51. **Response ratios of soil structure quality (in the spade diagnosis) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

In CH3 structure quality on all plots had the same value (response ratio in this LTE is one).
In LTE NL2 all score per layer were the same and therefore there was no effect of reduced tillage and/or high supply of organic matter in this LTE. The combination of reduced tillage and high supply of organic matter increased structure quality only in NL1 in layer 2. On average over the LTE s high supply of organic matter increased structure quality in layer 2.

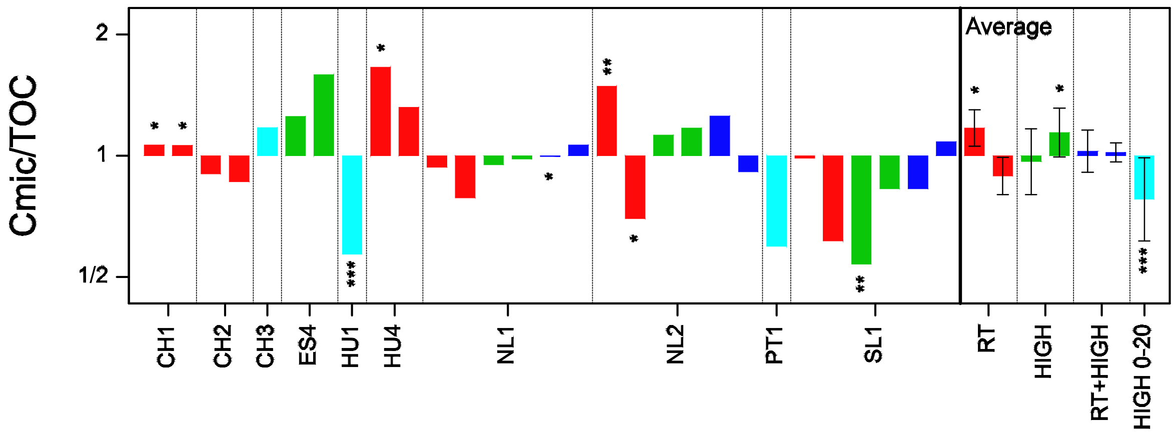


Figure 52. Response ratios of the ratio of microbial carbon and total organic carbon (Cmic/TOC) for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased this ratio in CH1 in both layers, in HU4 and in NL2 in layer 1, but decreased it in NL2 in layer 2. High supply of organic matter decreased the ratio in HU1 in layer 0 – 20 cm and in SL1 layer 1. The combination of reduced tillage and high supply of organic matter had a very small but significant increasing effect on this ratio in NL1. On average over all LTEs, reduced tillage increased the ratio in layer 1 and high supply of organic matter increased it in layer 2.

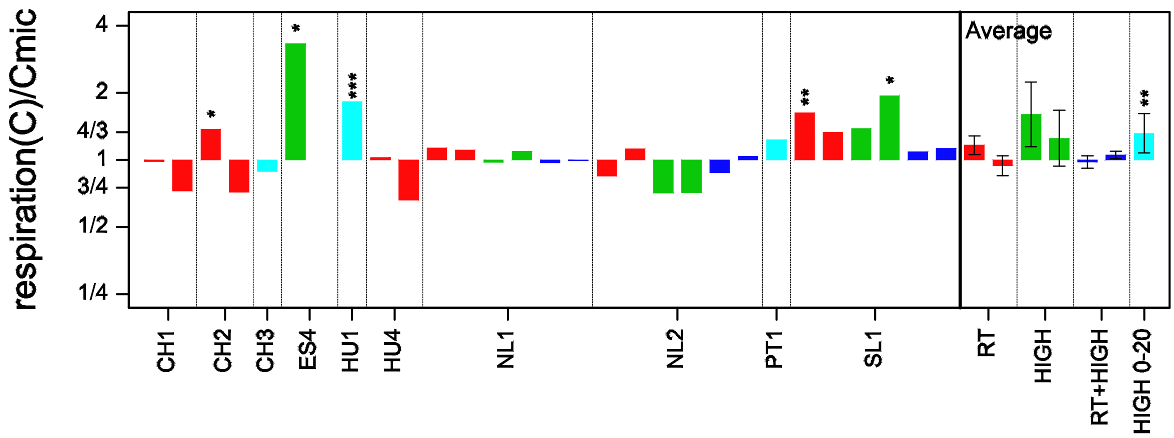


Figure 53. Response ratios of the ratio of respiration and carbon content of micro-organisms for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.

Reduced tillage increased this ratio in layer 1 in CH2 and SL1. High supply of organic matter increased this ratio in ES4 in layer 1, in HU1 in layer 0 – 20 cm and in SL1 in layer 2. The combination of reduced tillage and high supply of organic matter had no significant effects on this ratio. On average over all LTEs there were no significant effects of reduced tillage and the combination of reduced tillage and high supply of organic matter on this ratio, but high supply of organic matter increased this ratio in the layer 0 – 20 cm.

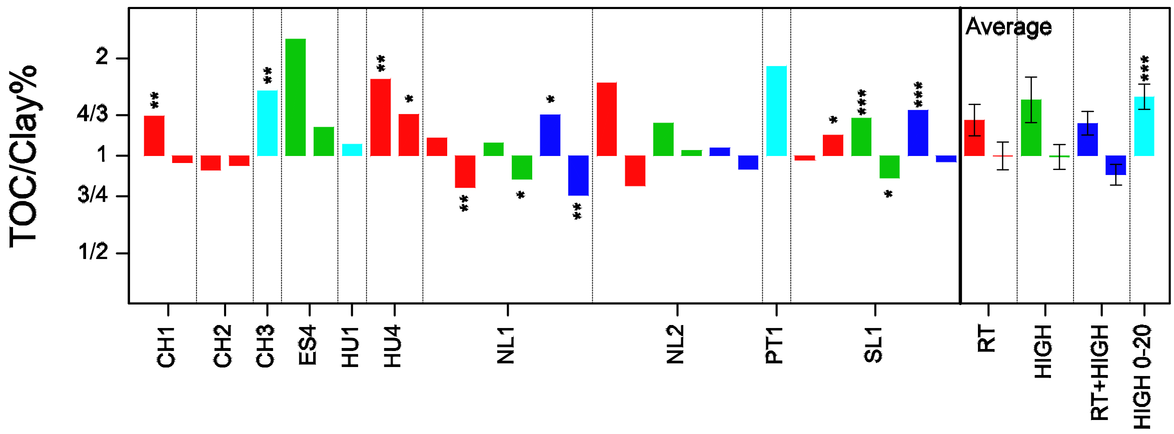


Figure 54. **Response ratios of the ratio of total organic carbon and clay percentage for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Reduced tillage increased this ratio in CH1 in layer 1, in HU4 in both layers and in SL1 in layer 2, but decreased it in NL1 in layer 2. High supply of organic matter increased this ratio in CH3 in layer 0 – 20 cm and in SL1 in layer 1, but decreased it in layer 2 in NL1 and SL1. The combination of reduced tillage and high supply of organic matter increased the ratio in layer 1 in NL1 and SL1, but decreased it in NL1 in layer 2. On average over all LTEs there were no significant effects of reduced tillage and the combination of reduced tillage and high supply of organic matter, but high supply of organic matter increased the ratio in the layer 0 – 20 cm.

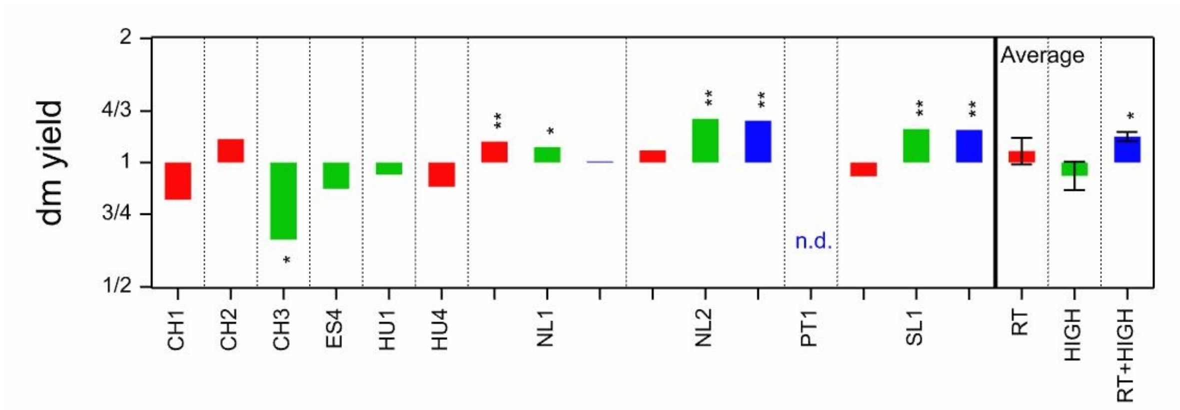


Figure 55. **Response ratios of dry matter yield for reduced tillage (RT, red bars), high supply of organic matter (HIGH, green and lightblue bars) and the combination of both (dark blue bars) per LTE and averaged over LTEs.**

Dry matter yield was not determined in PT1. Reduced tillage increased dry matter yield in NL1. High supply of organic matter decreased dry matter yield in CH3, but increased it in NL1, NL2 and SL1. The combination of reduced tillage and high supply of organic matter increased dry matter yield in NL2 and SL1. On average over the LTEs only the combination of reduced tillage and high supply of organic matter increased dry matter yield.

7.5 Overview of F-probabilities for response ratios per LTE

LTE	mana-		biological			bio-chem		chemical					physical			visual: spade diagnosis			ratio of two parameters:		
	gement	layer	Cmic	Nmic	resp.	POM	TOC	P-AL	P-Ols	K-Al	Ntot	CEC	WSA%	Bulk	WHC	aggreg	%pores	struct.	Cmic/Corg	resp/Cmic	TOC/clay
Average over all LTE's	Till	1	+	+	+	+	+	+	+	+	+		+						+		
		2		-	-								+	+							
	Org	1			+	+	+	+		+	+	+	+		+		+				
		2				+												+	+		
	Org	0-20			+	+	+	+		+	+						+		-	+	+
	Till+Org	1				+	+	+	+	+	+				+	-					
		2		-																	
CH1	till	1	+	+		+	+	+		+	+								+		+
CH1	till	2				-		-		-				+					+		
CH2	till	1				+			+	+										+	
CH2	till	2			-				-	-			+	+							
CH3	org	-	+	+	+	+	+			+	+		+								+
ES4	org	1	+	+	+	+				+	+	+	+	-	+		+			+	
ES4	org	2	+	+						+	+	+		-							
HU1	org	-	-							+						-			-	+	
HU4	till	1	+		+	+	+	+	+	+	+				+				+		+
HU4	till	2					+	+			+										+
NL1	till	1																			
NL1	till	2	-	-	-		-				-										-
NL1	org	1																			
NL1	org	2		-			-						-								-
NL1	till+org	1													+		+		+		+
NL1	till+org	2	-	-	-	-	-				-		-					+			-
NL2	till	1	+																+		
NL2	till	2	-																-		
NL2	org	1				+		+													
NL2	org	2	+	+		+	+	+	+		+										
NL2	till+org	1	+	+		+															
NL2	till+org	2				+		+													
PT1	org	-																			
SL1	till	1			+		+	+			+		+							+	
SL1	till	2					+	+		+	+	+	+	+			-				+
SL1	org	1					+	+		+	+	+							-		+
SL1	org	2					-			-		-		-						+	-
SL1	till+org	1					+	+	+	+	+	+	+		+	-					+
SL1	till+org	2								-			+	+	-	-					

layer:
1 = 0 - 10 cm
2 = 10 - 20 cm

Management:
till=tillage (reduced/conventional)
org=supply organic matter (high/low)

Statistical significant:

not
P < 0.05
P < 0.01
P < 0.001

The **effect** of reduced tillage and/or supply of organic matter:
+ : enhanced
- : reduced

LTE	mana-gement	biological				physical			dry matter yield
		tea-bag test		earthworms		penetration resistance			
		S	K	number	weight	0-20 cm	20-40 cm	40-60 cm	
average	till			+	+	+	+	+	
over all	org			+					
LTE's	till+org			+	+	+	+	+	+
CH1	till				+				
CH2	till	*	*			+		+	
CH3	org								-
ES4	org								
HU1	org								
HU4	till								
NL1	till		-			+			+
NL1	org			+		+			+
NL1	till+org	+				+			
NL2	till								
NL2	org	-							+
NL2	till+org								+
PT1	org					*	*	*	*
SL1	till	-	+		+	+	+	+	
SL1	org								+
SL1	till+org		+	+	+	+	+	+	+

Management:
till=tillage (reduced/conventional)
org=supply organic matter (high / low)

Statistical significant:

not
P < 0.05
P < 0.01
P < 0.001

The **effect** of reduced tillage and/or supply of organic matter:
+ : enhanced
- : reduced

*: not determined

7.6 Correlations between all parameters and correlations averaged over LTEs and standardized per LTE

Parameter	WSA%	POM	POM2	CaCO3	PH	P-AL	P Olson	K-AL	Not	Ctot	TOC	clay%	fsilt%	csilt%	tot silt%	sand%	Cammol	Mg mmo	K mmol	Na mmo	H mmol	CEC
WSA%	1.000																					
POM	0.288	1.000																				
POM2	0.343	0.228	1.000																			
Caco3	-0.140	0.119	-0.030	1.000																		
PH	-0.126	-0.251	-0.015	0.446	1.000																	
P_AL	0.136	-0.094	-0.383	-0.261	0.093	1.000																
P_Olson	-0.171	-0.242	-0.237	-0.283	0.016	0.634	1.000															
K_AL	0.269	0.040	0.100	0.255	0.294	0.212	0.223	1.000														
Ntot	0.529	0.403	0.631	-0.234	0.125	0.038	0.018	0.308	1.000													
Ctot	0.154	0.411	0.164	0.897	0.362	-0.207	-0.314	0.349	0.121	1.000												
Toc	0.647	0.722	0.455	-0.110	-0.164	0.090	-0.077	0.284	0.798	0.318	1.000											
Clay%	0.239	-0.084	0.172	0.418	0.616	-0.069	-0.016	0.567	0.446	0.491	0.198	1.000										
Fsilt%	0.033	0.095	0.808	-0.003	0.215	-0.439	-0.197	0.012	0.623	0.120	0.284	0.247	1.000									
Csilt%	-0.123	-0.263	0.696	-0.080	0.240	-0.306	-0.010	-0.036	0.345	-0.101	-0.057	0.109	0.804	1.000								
Tsilt%	-0.034	-0.057	0.800	-0.037	0.237	-0.403	-0.125	-0.009	0.533	0.030	0.149	0.199	0.965	0.931	1.000							
Sand%	-0.069	0.082	-0.739	-0.139	-0.449	0.367	0.111	-0.223	-0.627	-0.224	-0.205	-0.573	-0.908	-0.823	-0.917	1.000						
Camm	-0.035	-0.132	0.025	0.595	0.893	0.003	-0.123	0.304	0.111	0.529	-0.101	0.656	0.169	0.132	0.162	-0.402	1.000					
Mgmm	0.577	0.156	0.280	0.057	0.234	0.015	0.009	0.534	0.669	0.292	0.539	0.798	0.214	0.004	0.133	-0.435	0.226	1.000				
Kmm	0.304	0.119	0.202	0.432	0.466	0.090	0.159	0.737	0.431	0.544	0.362	0.760	0.141	0.038	0.103	-0.395	0.539	0.664	1.000			
Namm	0.127	-0.104	0.142	0.167	0.195	-0.224	-0.389	0.047	-0.073	0.126	-0.117	0.092	0.107	0.050	0.087	-0.110	0.314	-0.111	-0.017	1.000		
Hmm	0.340	0.436	0.232	-0.494	-0.880	-0.042	-0.019	-0.251	0.252	-0.270	0.478	-0.409	-0.018	-0.150	-0.077	0.231	-0.805	0.073	-0.297	-0.295	1.000	
CEC	0.320	0.115	0.514	0.073	0.444	-0.002	-0.011	0.293	0.728	0.260	0.434	0.681	0.493	0.362	0.461	-0.662	0.425	0.702	0.593	-0.053	-0.062	1.000

Figure 56. Pearson correlations between all parameters (1: WSA - CEC)

Parameter	WSA%	POM	POM2	CaCO3	PH	P-AL	P Olson	K-AL	Not	Ctot	TOC	clay%	fsilt%	csilt%	tot silt%	sand%	Cammol	Mg mmo	K mmol	Na mmo	H mmol	CEC
Cmic	0.649	0.308	0.477	0.164	0.311	0.008	-0.034	0.627	0.760	0.442	0.664	0.714	0.386	0.150	0.303	-0.543	0.346	0.822	0.710	0.026	-0.039	0.649
Nmic	0.550	0.191	0.510	0.099	0.262	0.004	0.013	0.550	0.683	0.342	0.558	0.622	0.430	0.259	0.377	-0.568	0.265	0.728	0.628	0.026	-0.022	0.609
WC%	0.236	0.147	0.596	0.025	0.431	-0.169	-0.144	0.131	0.698	0.183	0.366	0.506	0.715	0.525	0.669	-0.765	0.409	0.443	0.366	0.195	-0.158	0.666
Wetsoil	0.058	-0.173	-0.334	0.037	0.151	0.326	0.139	-0.153	-0.206	-0.046	-0.147	-0.031	-0.387	-0.214	-0.331	0.289	0.082	-0.005	-0.011	-0.252	-0.075	0.007
respiration_C	0.027	0.436	0.213	0.566	0.236	-0.131	-0.068	0.414	0.168	0.600	0.222	0.248	0.143	0.036	0.103	-0.184	0.355	0.152	0.540	-0.001	-0.191	0.248
bulk	-0.359	-0.526	-0.488	-0.398	0.007	0.355	0.508	-0.182	-0.331	-0.593	-0.493	-0.197	-0.362	-0.025	-0.233	0.279	-0.184	-0.182	-0.265	-0.384	-0.093	-0.187
worm_nr	0.203	0.041	0.193	-0.099	0.197	-0.015	-0.200	-0.048	0.294	-0.032	0.144	0.087	0.287	0.124	0.227	-0.221	0.231	-0.023	0.006	0.468	-0.188	0.118
worm_wgt	0.230	0.100	0.566	-0.176	0.032	-0.093	-0.090	0.041	0.518	-0.044	0.309	0.052	0.551	0.426	0.519	-0.449	0.027	0.075	0.013	0.239	0.051	0.260
blocextr	-0.266	-0.040	-0.010	-0.357	-0.177	0.052	0.217	-0.329	-0.066	-0.386	-0.092	-0.328	-0.004	0.186	0.079	0.067	-0.287	-0.176	-0.250	-0.367	0.210	-0.048
soil_block	-0.557	0.014	-0.500	0.061	-0.129	-0.176	-0.078	-0.375	-0.561	-0.149	-0.463	-0.337	-0.380	-0.340	-0.382	0.457	-0.094	-0.451	-0.378	0.007	-0.060	-0.450
aggregate_size	0.234	0.368	0.078	0.183	0.001	-0.182	-0.476	-0.109	0.014	0.239	0.160	-0.050	-0.003	-0.182	-0.081	0.088	0.157	-0.026	0.006	0.364	0.011	-0.059
clodbreak	0.012	-0.096	0.115	0.108	0.233	0.061	-0.015	-0.114	0.014	0.082	-0.050	0.096	0.046	0.174	0.104	-0.126	0.238	0.028	0.193	-0.041	-0.148	0.260
round%	-0.236	0.046	-0.362	0.304	0.199	0.061	-0.193	-0.330	-0.387	0.169	-0.274	-0.183	-0.292	-0.263	-0.297	0.308	0.268	-0.350	-0.103	0.162	-0.251	-0.149
angular%	0.236	-0.046	0.362	-0.304	-0.199	-0.061	0.193	0.330	0.387	-0.169	0.274	0.183	0.292	0.263	0.297	-0.308	-0.268	0.350	0.103	-0.162	0.251	0.149
pores%	0.306	-0.036	-0.102	-0.370	0.096	0.410	-0.019	-0.173	0.079	-0.314	0.085	-0.170	-0.189	-0.118	-0.170	0.204	0.046	-0.031	-0.162	0.170	-0.041	-0.007
porhol%	0.470	-0.081	0.625	-0.121	0.224	0.128	0.110	0.377	0.711	0.056	0.436	0.454	0.562	0.481	0.543	-0.615	0.103	0.585	0.339	0.000	-0.014	0.531
porcrack%	0.189	-0.102	0.753	-0.203	0.116	0.150	0.215	0.111	0.632	-0.065	0.340	0.184	0.740	0.718	0.754	-0.655	-0.013	0.224	0.162	-0.121	0.088	0.469
anaerob%	0.036	0.211	0.097	-0.069	-0.074	-0.153	-0.149	-0.083	0.224	0.022	0.203	0.068	0.200	0.019	0.136	-0.134	-0.047	0.091	-0.038	0.006	0.191	0.125
struct_quality	-0.134	0.194	-0.239	0.253	0.127	0.119	-0.135	-0.172	-0.184	0.219	-0.063	-0.118	-0.179	-0.248	-0.218	0.231	0.257	-0.270	-0.049	0.176	-0.193	-0.161
cluster	0.167	-0.225	-0.069	-0.750	-0.305	0.394	0.290	-0.319	0.180	-0.723	0.023	-0.309	-0.027	0.051	0.005	0.129	-0.473	-0.026	-0.436	-0.110	0.308	-0.120
roortdefec	0.090	-0.307	-0.111	-0.549	-0.245	0.325	0.239	-0.398	0.064	-0.529	-0.048	-0.250	-0.027	0.062	0.009	0.100	-0.418	-0.060	-0.498	-0.089	0.229	-0.208
rootunif	-0.267	-0.411	0.063	-0.430	0.400	0.053	0.244	-0.025	0.287	-0.503	-0.199	0.195	0.487	0.559	0.547	-0.514	0.173	0.055	-0.030	0.112	-0.328	0.247
WHC	0.167	-0.018	0.663	0.224	0.526	-0.292	-0.098	0.365	0.683	0.349	0.308	0.746	0.803	0.676	0.788	-0.962	0.507	0.599	0.571	0.115	-0.273	0.753

Figure 57. Pearson correlations between all parameters (2: Cmic - CEC)

Test/P	Colour
r<=0.6	(white)
r>0.6-0.7	(green)
r>0.7-0.8	(orange)
r>0.8-0.9	(red)
r>0.9	(violet)

Parameter	Cmic	Nmic	Wat	wetsoil	resp.rate	bulk	worm nr	worm wgt	blockext	soil-block	aggreg_si	clodbreak	round %	angular %	pores%	por hol%	porcrack%	anaerob%	struc_qua	root clust	root defe	root unif	WHC
Cmic	1.000																						
Nmic	0.847	1.000																					
WC%	0.546	0.556	1.000																				
Wetsoil	-0.183	-0.150	-0.159	1.000																			
respiration_	0.379	0.324	0.213	-0.122	1.000																		
bulk	-0.416	-0.370	-0.374	0.425	-0.340	1.000																	
worm_nr	0.174	0.172	0.439	-0.266	-0.022	-0.409	1.000																
worm_wgt	0.348	0.354	0.522	-0.396	0.012	-0.413	0.647	1.000															
blocextr	-0.332	-0.284	-0.148	0.227	-0.163	0.429	-0.167	-0.082	1.000														
soil_block	-0.649	-0.661	-0.408	0.094	-0.041	0.286	-0.061	-0.408	0.315	1.000													
aggregate_s	0.053	0.035	0.101	-0.072	0.186	-0.518	0.457	0.151	-0.015	0.210	1.000												
clodbreak	-0.021	0.033	0.128	0.211	0.055	0.003	0.125	0.077	0.360	-0.066	0.200	1.000											
round%	-0.385	-0.363	-0.112	0.242	0.114	-0.091	0.279	-0.143	0.267	0.491	0.571	0.432	1.000										
angular%	0.385	0.363	0.112	-0.242	-0.114	0.091	-0.279	0.143	-0.267	-0.491	-0.571	-0.432	-1.000	1.000									
pores%	-0.030	-0.028	0.124	0.260	-0.191	0.098	0.387	0.114	0.270	0.007	0.413	0.317	0.413	-0.413	1.000								
porhol%	0.683	0.679	0.506	-0.110	0.012	-0.157	0.039	0.398	-0.182	-0.737	-0.167	0.069	-0.437	0.437	0.120	1.000							
porcrack%	0.413	0.523	0.537	-0.174	-0.016	-0.173	0.085	0.520	-0.053	-0.744	-0.297	0.110	-0.374	0.374	-0.031	0.610	1.000						
anaerob%	0.097	0.037	0.171	0.009	-0.018	-0.029	0.019	-0.034	-0.099	0.059	-0.025	-0.239	-0.197	0.197	-0.089	0.043	0.218	1.000					
struct_quali	-0.171	-0.208	-0.060	0.003	0.048	-0.293	0.325	-0.023	0.067	0.216	0.594	0.261	0.691	-0.691	0.393	-0.251	-0.238	-0.116	1.000				
cluster	-0.128	-0.088	0.034	0.151	-0.950	0.363	0.168	0.177	0.265	-0.115	-0.114	-0.072	-0.226	0.226	0.465	0.188	0.192	0.046	-0.137	1.000			
roortdefec	-0.193	-0.152	-0.022	0.198	-0.950	0.339	0.136	0.142	0.214	-0.093	-0.184	-0.058	-0.221	0.221	0.367	0.152	0.155	0.037	-0.147	0.809	1.000		
rootunif	0.034	0.068	0.496	-0.180	-0.222	0.316	0.336	0.275	0.103	-0.099	-0.232	-0.021	-0.252	0.252	0.100	0.249	0.274	0.097	-0.143	0.419	0.339	1.000	
WHC	0.675	0.664	0.782	-0.254	0.245	-0.332	0.233	0.396	-0.151	-0.492	-0.063	0.140	-0.286	0.286	-0.183	0.607	0.565	0.134	-0.197	-0.208	-0.181	0.431	1.000

Figure 58. Pearson correlations between all parameters (3: Cmic - WHC)

Test/P	Colour
r<=0.6	
r>0.6-0.7	
r>0.7-0.8	
r>0.8-0.9	
r>0.9	

Table 55. Pearson correlations and probabilities between the 12 most sensitive parameters layer 1 + 2. Means over all LTEs are used.

	WSA	POM	P-AL	K-AL	Ntot	TOC	Cmic	Nmic	bulk	resp. rate	Pen 0-20	Pen 20-40
WSA	**1.00**	*0.000*	*0.039*	*0.026*	*0.000*	*0.000*	*0.000*	*0.076*	*0.350*	*0.000*	*0.000*	*0.000*
POM	**0.25**	**1.00**	*0.002*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.089*	*0.668*
P-AL	**0.15**	**0.21**	**1.00**	*0.000*	*0.000*	*0.000*	*0.001*	*0.184*	*0.726*	*0.099*	*0.009*	*0.000*
K-AL	**0.16**	**0.44**	**0.49**	**1.00**	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.251*	*0.255*
N-tot	**0.36**	**0.58**	**0.44**	**0.54**	**1.00**	*0.000*	*0.000*	*0.000*	*0.000*	*0.000*	*0.056*	*0.118*
TOC	**0.28**	**0.64**	**0.38**	**0.48**	**0.82**	**1.00**	*0.000*	*0.000*	*0.000*	*0.000*	*0.061*	*0.151*
Cmic	**0.35**	**0.65**	**0.23**	**0.44**	**0.57**	**0.54**	**1.00**	*0.000*	*0.000*	*0.000*	*0.251*	*0.273*
Nmic	**0.13**	**0.40**	**0.09**	**0.31**	**0.31**	**0.34**	**0.44**	**1.00**	*0.001*	*0.000*	*0.691*	*0.942*
Bulk	**0.07**	**-0.36**	**0.03**	**-0.30**	**-0.35**	**-0.36**	**-0.27**	**-0.23**	**1.00**	*0.005*	*0.000*	*0.003*
Resp rate	**0.27**	**0.62**	**0.12**	**0.42**	**0.45**	**0.41**	**0.58**	**0.38**	**-0.20**	**1.00**	*0.160*	*0.689*
Pen 0-20	**0.37**	**0.13**	**0.19**	**0.09**	**0.14**	**0.14**	**0.09**	**0.03**	**0.30**	**0.11**	**1.00**	*0.000*
Pen 20-40	**0.38**	**0.03**	**0.40**	**0.08**	**0.12**	**0.11**	**0.08**	**0.01**	**0.22**	**0.03**	**0.69**	**1.00**

Table 56. Pearson correlations and probabilities between the 12 most sensitive parameters layer 1 + 2. Each parameter is standardized per LTE (by subtracting the average).

	WSA	POM	P-AL	K-AL	Ntot	TOC	Cmic	Nmic	bulk	resp. rate	Pen 0-20	Pen 20-40
WSA	**1.00**	*0.647*	*0.447*	*0.295*	*0.051*	*0.013*	*0.019*	*0.020*	*0.456*	*0.516*	*0.413*	*0.211*
POM	**0.17**	**1.00**	*0.584*	*0.786*	*0.507*	*0.048*	*0.620*	*0.832*	*0.114*	*0.346*	*0.995*	*0.327*
P-AL	**0.27**	**-0.20**	**1.00**	*0.920*	*0.847*	*0.715*	*0.921*	*0.906*	*0.181*	*0.157*	*0.322*	*0.359*
K-AL	**0.37**	**-0.10**	**0.04**	**1.00**	*0.504*	*0.461*	*0.012*	*0.028*	*0.560*	*0.266*	*0.275*	*0.515*
N-tot	**0.63**	**0.24**	**0.07**	**0.24**	**1.00**	*0.004*	*0.010*	*0.006*	*0.554*	*0.546*	*0.228*	*0.203*
TOC	**0.75**	**0.64**	**0.13**	**0.26**	**0.82**	**1.00**	*0.017*	*0.026*	*0.238*	*0.865*	*0.389*	*0.593*
Cmic	**0.72**	**0.18**	**0.04**	**0.75**	**0.77**	**0.73**	**1.00**	*0.000*	*0.238*	*0.530*	*0.814*	*0.932*
Nmic	**0.71**	**0.08**	**0.04**	**0.69**	**0.79**	**0.69**	**0.98**	**1.00**	*0.233*	*0.639*	*0.840*	*0.768*
Bulk	**-0.27**	**-0.53**	**0.46**	**-0.21**	**-0.21**	**-0.41**	**-0.41**	**-0.41**	**1.00**	*0.097*	*0.175*	*0.308*
Resp rate	**-0.23**	**0.33**	**-0.48**	**0.39**	**-0.22**	**-0.06**	**0.23**	**0.17**	**-0.55**	**1.00**	*0.001*	*0.000*
Pen 0-20	**-0.31**	**0.00**	**-0.37**	**0.41**	**-0.45**	**-0.33**	**0.09**	**0.08**	**-0.50**	**0.91**	**1.00**	*0.004*
Pen 20-40	**-0.46**	**0.37**	**-0.35**	**0.25**	**-0.47**	**-0.21**	**-0.03**	**-0.12**	**-0.38**	**0.95**	**0.85**	**1.00**

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