The effect of soil measures on ecosystem services in the long-term experiment 'Bodemkwaliteit Veenkoloniën'

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Summary
Several measures were tested to improve the soil quality on a reclaimed peatsoil in the North-East of the Netherlands in the period 2014-2021. The effects of the measures on the crop yields, crop quality, soil fertility, nutrient balances, soil nematodes, soil biology, soil structure, plant available water and weeds were monitored. Replacing spring barley by Marigold in the crop rotation was the most successful in increasing the crop yields of potatoes, by reducing the population of the plant parasitic nematode P. penetrans. The cultivation of Marigold once every four years was more successful than once every eight years. The application of compost increased the yield of sugar beet. The application of compost was also associated with nutrient surpluses and a increase in soil nutrients. The application of compost also led to an increase in some aspects of the soil biology. The other measures, including non-inversion tillage, the Base-Cation saturation ratio and applying rockdust were not successful in increasing the crop yields. Overall, large improvements in the soil quality as a result of the measures was not found.

Keywords: arable cropping, soil quality, sustainable crop production, tillage, fertilisation, compost, Marigold

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Foreword

In 2013 the question was raised whether the soil quality of the reclaimed peatlands in the North East of the Netherlands could be improved within the common crop rotation of the region. The experiment '*Bodemkwaliteit Veenkoloniën*' was set up, in the same year, to answer this question. With the help of regional farmers and the sector measures were selected that potentially could improve soil quality, yields and farmers income. This report describes the results of the measures in this experiment over the years 2014-2021.

This experiment and its outcomes were not only used to write this report, but for many other occasions as well. Farmers, advisors, researchers and students visited the experiment and had discussions with the involved researchers about the results. Soil from the experiment was taken to the laboratory for deepening investigations on for example soil biology, and results of the experiment were used as input for nematode schemes in Best4Soil.

We could never have written this report without Gerard Hoekzema and his staff from the experimental farm (*'t Kompas*) in Valthermond whom made sure the experiment was carried out and that data were gathered all these years. Next to that we want to thank the group of involved farmers and representatives of the sector, known as '*de begeleidingscommissie*' for their yearly reflections on the outcomes of the experiment. This experiment could not have been possible without financing, therefore we would like to thank all the partners within the PPS Beter Bodembeheer.

With this report the experiment *Bodemkwaliteit Veenkoloniën* comes to an end. The different measures in the experiment have been evaluated thoroughly, research questions were answered, and no new questions popped up that could be answered by this experiment in its current set up. There are ideas to start a new experiment for new research questions.

On behalf of the authors,
Marie Wesselink
August 2023

Summary

Introduction

Arable agriculture on reclaimed peatlands in the Northeast of the Netherlands faces several challenges related to the soil quality. These are related to the soil structure, wind erosion, a limited water holding capacity, high weed pressure and plant parasitic nematodes. The profitability of arable farming in this region is under pressure while at same time the demand for soil improving measures is growing. Together with the agricultural sector in the region a long-term experiment was initiated to test measures with the aim to improve the soil functioning and economic perspective.

Material and methods

Six treatments were tested:

1. Non-inversion tillage (NT) instead of conventional tillage (T), with the aim to improve the soil structure and reduce soil erosion.
2. The cultivation of Marigold instead of spring barley and black oat, to reduce the plant parasitic nematode *P. penetrans*.
3. The application of compost was initiated to increase the supply of organic matter which potentially has a positive impact on several soil quality aspects.
4. The method of base-cation saturation ratio (BCSR) aims at optimal ranges and ratios for several soil nutrients at the cation exchange complex, potentially increasing the soil fertility, soil structure and crop yields.
5. The application of rockdust was developed to enhance the status and availability of soil nutrients.
6. To maximise the potential effects, all treatments were combined into one combined treatment.

The six treatments were tested in a common four-year arable crop rotation consisting of 1) spring barley with black oats as a cover crop – 2) starch potato – 3) sugar beet – 4) starch potato. The treatments started in 2013-2014 and monitored until 2021. The monitoring programme aimed at providing an integral insight in the soil quality and its effect on crop yield. Monitoring included crop development, soil nutrients, soil structure, soil biology and weed pressure. The crops were visually observed during the growing season, the biomass was determined with a crop sensor and the yield and nutrient content was determined. The soil nutrient status was analysed annually for several treatments. The soil structure was analysed in terms of penetration resistance, plant available water, the bulk density and the water holding capacity. The penetration resistance was measured two times a year. The soil moisture content was continuously measured during the growing season. The bulk density and water holding capacity was determined once during the experiment. Parameters of the soil biology were measured at the start, once during the experiment and more extensively at the end of the experiment. Indicators included the total microbial biomass and indicators related to the subgroups of soil bacteria, fungi and nematodes. Plant parasitic nematodes were monitored annually. The weed pressure was analysed in terms of the number of seeds in the seedbank and was determined only at the end of the experiment.

Results and discussion

<u>Non-inversion tillage</u>
The effect of NT on marketable yield was minor when averaged over the crops, but still negative for spring barley (-1.8%). The exact reason why spring barley was impacted remains unclear, but the moisture content of the yield was higher for NT than for T. Apart from the spring barley, NT did not affect any quality aspects of the crops. As a direct result of a lower yield for spring barley, the nutrient removal was lower. Seen over a crop rotation, the effect of NT on the nutrient balance was small. NT affected the soil structure. Compared to T, NT was associated with more crop residues in the soil surface, a lower penetration resistance, a lower bulk density and root hindrance occurred at a greater depth. The values found for both T and NT were within the target range, and therefore NT did not necessarily improve the soil structure. It is not likely that the difference in soil structure between the treatments impacted the crop yield. NT did not affect soil biological indicators as soil fungi and bacteria and plant parasitic nematodes. To conclude, NT reduced crop yield of spring barley and did not improve soil functioning. The effect is, however, dependent on the field circumstances. The field conditions should therefore determine whether it would be better to apply T or NT.

<u>Marigold</u>
The cultivation of Marigold successfully reduced the population of *P. Penetrans* in the soil. The population remained low for the five to six subsequent years. As a result, the starch potatoes benefitted in the first two to three cultivations. Therefore, the yield effect on the susceptible crops, potato in this case, is larger when Marigold was grown every four years compared to once every eight years. Growing Marigold once every four years resulted in a yield increase of 8.3 and 13.7% respectively for Festien and Seresta, which was 5.3 and 9.9% when grown every eight years. The yield of sugar beet was not affected. Furthermore, Marigold is a poor host for Meloidogyne and Trichodoridae, since Marigold replaced a rather good host for these nematodes, the densities decreased. The densities remained low for both the treatments as the control. Effects on other soil functions were studied only to a limited extend. Financially, the increased yield of potatoes outweighed the loss of spring barley. This depends, however, largely on the return on spring barley. The impact of the measure is dependent on several factors. An important factor is the presence of *P. penetrans* in the soil. Insight in the population densities is key to decide whether or not to grow Marigold. Besides, the cultivation of Marigold should be successful, in which the timing and presence of weeds are important. Summarised, the cultivation

of Marigold successfully reduced harmful nematode populations and increased potato yields which was financially attractive.

Compost

Compost contains substantial amount of nutrients, which was (partly) compensated for in the artificial fertilization of phosphate and potassium. The application of compost was associated with a yield increase of the sugar beet (+3.6%). Besides, the application of compost impacted the ripening of spring barley. It was therefore decided to switch from an application of 15 ton compost ha^{-1} yr^{-1} for each crop to an application of 20 ton ha^{-1} yr^{-1} for sugar beet and the potatoes. Compost led to a lower starch content in Seresta. This could be due to a (non-significant) higher field yield (as the starch content is negatively correlated with yield) or a direct effect of the increase in K supply (as the starch content is negatively correlated with potassium applications). The starch yield (kg ha^{-1} yr^{-1}) was still comparable to the control. Averaged over all crops, Compost led to the overconsumption of phosphate and magnesium but led to lower concentrations for some of the micronutrients in the crop leaves of the potato. Altogether, this resulted in a nutrient surplus for nitrogen, phosphate, potassium and magnesium when compared to the control. These surpluses led to a higher soil nutrient concentration of phosphate, magnesium and calcium. The latter was surprising, as less calcium was applied with compost. An increase of total nitrogen and potassium was expected, but not found. Along with nutrients, the application of compost is accompanied with the supply of organic matter. Organic matter is the main source of food for soil life. The soil organic matter content correlated positively with the number of bacteria and fungi. The application of organic matter in the form of compost only increased the number of protozoa and the fungi/bacteria ratio. Previous studies make it plausible that the application of compost increase soil life, but the effect of compost is dependent among other things on the type of compost and compost age. Obtaining qualitatively good compost can be a challenge. The application of compost did not affect the soil structure in terms of penetration resistance. Financially, the costs of compost were higher than the savings on artificial fertiliser and the increased yield of sugar beet. In short, the application of compost did improve some aspects of soil functioning, including yield and soil life. These effects were however limited. Since the application of compost is not financially attractive, it should be considered whether or not applying compost is the most strategic way to apply a sufficient amount of organic matter.

BCSR

BCSR targets optimum saturation levels for calcium, magnesium and potassium in the soil. With the applications, the optimum magnesium saturation and calcium/magnesium ratio was reached after 4-7 years. The calcium saturation level did not reach the level which is considered as optimal, but the calcium status in the soil did increase. It is likely that magnesium and possibly potassium have replaced the hydrogen ions at the cation exchange capacity, rather than calcium. Another reason might be that the pH was not sufficiently high. The altered soil nutrient levels did not affect crop yield. BCSR only had a positive effect on the field yield of starch potatoes, but the chloride in Kali-60 reduced the starch content, resulting in marketable yields similar to the control. The yield of other crops was not affected by BCSR. The treatment led to overconsumption of potassium, magnesium and sulfur but still resulted in large nutrient surpluses of potassium, magnesium, calcium and sulfur, which can be seen as inefficient nutrient use. BCSR did not affect the soil structure in terms of PR. To conclude, BCSR altered the soil nutrient status towards levels that are considered as optimal. This did however not increase crop yields, did not alter the soil structure and led to lower nutrient use efficiencies. BCSR therefor did not improve the soil functioning. Together with the increase in costs, BCSR is not advised as an useful measure.

Rockdust

The annual application of Rockdust did not affect crop yields and was therefore discontinued in 2017. Furthermore, Rockdust did not affect any of the quality aspects of the crops. Since large amounts of potassium, magnesium and calcium were applied and the crop yields were unaltered, Rockdust resulted in large nutrient surpluses. The soil nutrient status was not measured. All-in-all, it is not likely that the application of Rockdust improved the soil functioning, but rather led to inefficient nutrient use and increased costs.

Combination

In the Combi-NT treatment, all treatments were combined. The idea behind it was to maximize the possible effects. The combination resulted in a yield increase, but the increase was lower than for the sum of the separate treatments. Marigold (both 1:4 and 1:8) increased the yield of Festien and Seresta more than Combi-NT did. This is probably due to similar effects on the population of *P. penetrans*, but the negative effect of Kali-60 on the starch content. For sugar beet, the yield increase of Combi was equal to compost. The cultivation of spring barley was replaced every eight years, for the other years an effect on the yield of spring barley was not observed. It is not plausible that synergistic effects between any of the treatments on the crop yield occurred for any of the crops. Compost, Rockdust and BCSR resulted in large nutrient surpluses. A combination of these treatments resulted in even larger surpluses. As a result, higher soil nutrient levels were found for phosphorous (P-Al), potassium (K-number), total potassium, magnesium, calcium and the cation exchange capacity saturation. For phosphorus (P-Al), potassium (K-number) and magnesium this effect is desirable, for the other elements a proper target value is not available. The application of compost as part of Combi-NT led to an increased supply of organic matter. In combination with NT, a positive effect on the soil life was expected. Combi-NT increased the number of fungi, the fungal biomass and the fungi/bacteria ratio. This might be an effect of the combination of compost with NT, or caused by any of the other treatments. These effects are difficult to disentangle, because not all of the treatments were analysed separately. Regarding the soil nematodes, Combi-NT did not affect the communities. For the soil structure, it is likely that the effect of Combi-NT was a result of NT. Combi-NT resulted, like NT, in a lower PR and a greater depth at which root hindrance occurred, while this was not the case for Compost-T nor BCSR-T. However, Combi-NT did not seem to be associated with higher water availability. The water availability seemed to be linked to the soil organic matter level but could not be ascertained with data. All-in-all, a combination of treatments increased the soil nutrient level but was associated with a lower nutrient use efficiency, increased some aspects of the soil fungi and reduced *P. penetrans* but did not affect other aspects of the soil biology, altered the soil structure but did not improve the water availability, and most of all, was not associated with higher yields than some of the treatments. Together with the associated costs, Combi-NT is not a realistic strategy to improve soil functioning.

Conclusion

Several treatments were investigated on their effects on crop yields and soil quality aspects. The cultivation of Marigold instead of spring barley and black oat turned out to be the most feasible treatment to improve crop yields, by reducing the plant parasitic nematode *P. penetrans*. Another interesting treatment includes the application of compost. Compost showed to increase the yield of sugar beet. The application of compost was also associated with large nutrient surpluses, which should be paid attention to in case of long-term annual application in terms of mineralisation and potential nutrient leaching. Compost is associated with an increase in costs, it should therefore be considered whether compost is the best choice to apply organic matter to the soil.

Apart from Marigold and compost, none of the treatments increased the yields substantially. NT altered the soil structure, but none of the crops strongly benefited from this change in soil structure. NT could reduce costs and could therefore still be interesting. The effect of NT is largely related to specific field conditions, which have to be kept in mind. BCSR and Rockdust mainly resulted in inefficient nutrient use, without improving crop yield, and are therefore not interesting treatments.

Although Marigold affected the nematode population, Compost and BCSR affected the soil nutrient status, and NT affected the soil structure, large improvements in the integral soil quality were not observed. The applied treatments ranged from experimental to more common ones, but were all unable to improve the integral soil quality substantially. It can therefore be concluded that improving the integral soil quality and crop yields within the current crop rotation is not easy. Especially since other potential measures are limited.

Summary (NL)

Inleiding

De akkerbouw in de Veenkoloniën heeft te maken met verschillende uitdagingen rondom bodemkwaliteit. Dit omvat onder andere de hoge variabiliteit in het bodem organisch stof gehalte in percelen, een beperkt watervasthoudend vermogen, ontmenging van de bodem met stuiven en verslemping als gevolg, een hoge onkruiddruk en de aanwezigheid van plantparasitaire nematoden. Maatregelen om de bodemkwaliteit te verbeteren zijn daarom wenselijk, terwijl tegelijkertijd het economisch perspectief in de regio onder druk staat. Samen met de agrarische sector in het gebied is er daarom gekeken naar maatregelen die zowel bodemfuncties als het economisch perspectief versterken. Dit heeft geleid tot een lange termijn experiment (acht jaar) waarin verschillende bodemmaatregelen zijn getest in een standaard Veenkoloniaal bouwplan.

Materiaal en methode

De volgende zes maatregelen zijn aangelegd:

1. Niet kerende grondbewerking (NKG). NKG is uitgevoerd met een vaste tand op een diepte van 20 tot 25 cm en een ondergrondwoeler (vijf tanden) op een diepte van 40 cm. NKG wordt vergeleken met spitten. Spitten is gedaan tot een diepte van 25 tot 30 cm en ook voorzien van een ondergrondwoeler (vijf tanden) op een diepte van 35 cm. Deze maatregel is uitgevoerd met het oog op het verbeteren van de bodemstructuur.
2. De teelt van Tagetes als vervanger van zomergerst met Japanse haver. Hierin zijn twee varianten aangebracht. Bij Tagetes(4) is elke teelt van zomergerst met Japanse haver in de rotatie vervangen. Bij Tagetes(8) is enkel de eerste teelt van zomergerst met Japanse haver in de rotatie vervangen, waardoor het effect van Tagetes op een langere termijn kan worden gevolgd. Het doel van deze maatregel was om de populatie van het plantparasitaire aaltje P. penetrans te verminderen.
3. Het toedienen van compost. Elk jaar is er voorafgaand aan de teelt 15 ton ha^{-1} jr^{-1} groencompost uitgereden. In 2017 is dit bijgesteld naar 20 ton ha^{-1} jr^{-1} met uitzondering van de zomergerst. Deze maatregel was gekozen om de aanvoer van organische stof te verhogen.
4. Het toepassen van de calcium-magnesium (Ca/Mg) methode. Deze methode bestaat uit een aanvullende kali, calcium en magnesium bemesting om te komen tot een optimale Ca/Mg verhouding in de bodem. Deze methode zou leiden tot een optimale nutriëntenvoorziening en gewasgroei.
5. Het toedienen van steenmeel. In de periode 2014-2017 zijn er jaarlijks twee soorten steenmeel toegediend voorafgaand aan de teelt. Met de toediening worden spoorelementen aan de bodem toegevoegd en wordt er gestreefd naar het verbeteren van de bindingscapaciteit van de bodem.
6. Een combinatie. Alle bovenstaande maatregelen zijn gecombineerd om tot een maximaal effect te komen.

Daarnaast is er een standaard object aangelegd, waarbij de gangbare praktijk wordt gevolgd. De twee grondbewerkingsmethoden zijn over de andere maatregelen heen gelegd, hierdoor ontstonden er 14 objecten. De objecten zijn vergeleken met de controle (standaard-spitten). Bij de controle is het stro afgevoerd, bij de overige objecten is het stro ingewerkt. De maatregelen zijn getest in een standaard Veenkoloniaal bouwplan bestaande uit 1) zomergerst met Japanse haver als groenbemester; 2) zetmeelaardappel, ras Festien; 3) Suikerbiet en 4) zetmeelaardappel, ras Seresta. De proef ligt in vier herhalingen. De maatregelen zijn ingezet in 2013-2014 en gemonitord tot en met 2021. Er is met name gekeken naar de gewasontwikkeling, bodemvruchtbaarheid, bodemstructuur en bodembiologie. Van elk object is jaarlijks de gewasopbrengst en -kwaliteit bepaald. Aanvullend zijn voor enkele maatregelen metingen verricht aan de nutriënten in het geoogste product, gewasresten en het plantsap. Wat betreft de bodemvruchtbaarheid is er jaarlijks gemeten aan de standaard, combinatie, Ca/Mg en steenmeel, aanvullend is er in twee jaar gemeten aan de compost objecten. Het effect op de bodemstructuur is met name gemeten in de grondbewerkingsvarianten. Twee keer per jaar is de indringingsweerstand bepaald, gedurende het groeiseizoen is het bodemvocht bepaald middels een sensor en in 2020 zijn er bepalingen gedaan aan de bulkdichtheid en het watervasthoudend vermogen van de bodem. Het microbiële bodemleven is geanalyseerd bij aanvang van de proef en aan het eind van de proef, voor zowel de standaard als de NKG en compost behandeling. Plantparasitaire nematoden zijn jaarlijks geanalyseerd, milieu-aaltjes enkel bij aanvang van de proef in 2013 en in 2020. De onkruiddruk (het aantal onkruidzaden in de bodem) is bepaald aan het einde van de proef en enkel voor de grondbewerkingsvarianten.

Resultaten en discussie

<u>Niet kerende grondbewerking</u>
Wanneer bekeken over de gehele gewasrotatie was het effect van NKG op de gewasopbrengsten beperkt, al had NKG een negatief effect op de opbrengst van zomergerst (-1,8%; zie figuur 1). De precieze reden waarom NKG leidde tot een lagere opbrengst voor zomergerst is niet duidelijk. NKG had geen effect op de gewasopbrengsten of kwaliteitsaspecten van de andere gewassen. Door de lagere opbrengst van zomergerst was de nutriëntenafvoer lager, wanneer bekeken op bouwplanniveau was het effect van NKG op de nutriëntenbalans beperkt. NKG had wel een effect op de bodemstructuur. In vergelijking met spitten ging NKG gepaard met meer gewasresten in de bovengrond, een lagere indringingsweerstand, een lagere bulkdichtheid en de diepte waarop de grenswaarde voor de maximale indringingsweerstand werd bereikt was dieper. De gevonden waarden voor zowel spitten als NKG vielen binnen de streefwaarden. Het is daarom niet aannemelijk dat de verschillen in bodemstructuur de gewasopbrengst hebben beïnvloed. Bovendien had NKG geen effect op verschillende aspecten van het bodemleven, zoals schimmels, bacteriën en plantparasitaire nematoden. Kort samengevat leidde NKG tot een lagere opbrengst van zomergerst en leidde niet tot een verbeterde bodemkwaliteit. Hierbij dient vermeld te worden dat het effect van de grondbewerkingsvarianten beïnvloed

worden door de specifieke omstandigheden van de bodem op het moment van uitvoeren. In de praktijk bepalen de bodemomstandigheden of NKG of spitten gewenst is. Daarnaast heeft een dergelijke maatregel mogelijk een meerwaarde in een ander systeem, waarin minder rooivruchten worden geteeld.

Tagetes
De teelt van Tagetes was succesvol in het reduceren van het plant-parasitaire aaltje P. penetrans. De populatie bleef laag in de vijf tot zes opvolgende jaren. De zetmeelaardappelen profiteerden daar in de eerste twee tot drie teelten van. De opbrengst van de zetmeelaardappels was daarom hoger wanneer Tagetes eens in de vier dan eens in de acht jaar werd geteeld. De teelt van Tagetes elke vier jaar leidde tot een opbrengststijging van 8,3 en 13,7% voor Festien en Seresta respectievelijk. Dit was 5,3 en 9,9% wanneer Tagetes elke acht jaar werd verbouwd (zie Figuur 0-1). Bovendien daalde de populatie aan Trichodoridae, omdat Tagetes een slechte waardplant is en een goede waardplant in de rotatie verving. De opbrengst van suikerbiet werd niet beïnvloed door de teelt van Tagetes. Het effect van Tagetes op andere bodemfuncties is beperkt onderzocht. Samengevat leidde de teelt van Tagetes tot een opbrengstverhoging van de zetmeelaardappelen, waarbij het effect groter was bij de teelt eens in de vier dan eens in de acht jaar. Financieel gezien compenseerde de opbrengststijging van de aardappels voor het wegvallen van de zomergerst. Dit is echter sterk afhankelijk van de (variabele) prijzen van graan. Het effect zou mogelijk nog groter zijn geweest wanneer het gevoeligere ras Seresta direct na de Tagetes was geteeld. De effectiviteit van de maatregel hangt sterk samen met de besmetting in de bodem. Inzicht in de besmetting helpt daarom bij de keuze of de teelt van Tagetes wel of niet zinvol is. Daar komt bij dat er bij de teelt van Tagetes rekening gehouden moet worden met het onkruid vrij houden van de grond.

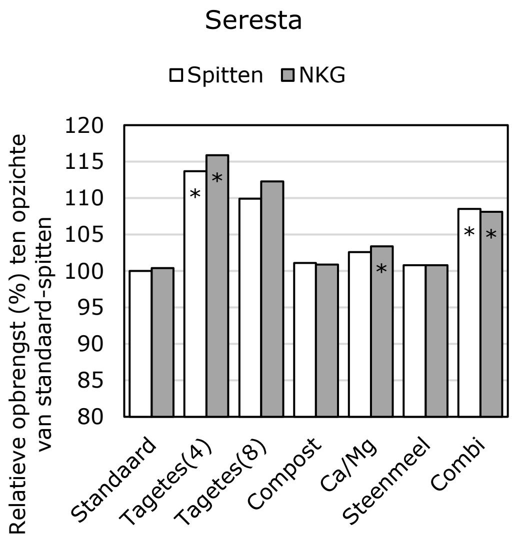
Compost
Met de aanvoer van compost zijn er substantiële hoeveelheden nutriënten aangevoerd. Hiervoor is slechts gedeeltelijk gecorrigeerd in de bemesting met kunstmest van fosfaat en kali. De aanvoer van compost ging gepaard met een opbrengstverhoging van suikerbiet (+3,6%). Daarnaast had de aanvoer van compost invloed op het rijpingsproces van de zomergerst. Er is daarom in 2017 besloten geen compost meer aan te voeren voorafgaand aan de teelt van zomergerst. Compost leidde tot een lager zetmeelpercentage in Seresta. Dit is mogelijk een effect van een (niet significant) hogere opbrengst of een direct gevolg van verhoogde kali toediening. De zetmeelopbrengst was uiteindelijk even hoog na het wel of niet toedienen van compost. Gemiddeld over alle gewassen leidde de toediening van compost tot de luxe-consumptie van fosfaat en magnesium. Ondanks deze luxe-consumptie leidde de aanvoer van compost tot nutriënt overschotten van stikstof, fosfaat, kalium en magnesium. Nutriëntoverschotten werden deels teruggevonden in de bodem. Hogere nutriëntconcentraties zijn gevonden voor fosfaat (P-Al), magnesium en calcium. Dat laatste is verrassend, omdat er met compost niet meer calcium werd aangevoerd dan bij de standaard. Op basis van de nutriëntoverschotten werd een toename van stikstof en kali in de bodem verwacht, maar niet gevonden. Naast nutriënten gaat de aanvoer van compost gepaard met de aanvoer van organische stof. Organische stof is een belangrijke voedselbron voor het bodemleven. De aanvoer van compost leidde tot een hoger aantal protozoa en een hogere schimmel/bacterie ratio. Eerdere studies maken het aannemelijk dat compost inderdaad een effect had op het bodemleven, al is dit onder meer afhankelijk van kwaliteitsaspecten van de compost. Uit een analyse over alle veldjes heen bleek dat naast de vers aangevoerde organische stof ook het bodem organisch stof gehalte sterk verband houdt met het bodemleven. Gezien veldjes met een hoger bodem organisch stof gehalte doorgaans lager liggen, kan dit effect mede beïnvloed worden door de vochtvoorziening. De aanvoer van compost had geen effect op de bodemstructuur in termen van indringingsweerstand. Financieel gezien compenseerde de opbrengststijging van de suikerbiet en de besparingen op kunstmest de kosten van de compost niet. In deze proef is vrij prijzige compost gebruikt. In de praktijk is goedkoper compost beschikbaar, waardoor het gebruik van compost financieel beter uitpakt. Praktisch gezien is de aanvoer van compost niet ingewikkeld, enkel het verkrijgen van compost van voldoende kwaliteit kan een uitdaging zijn. Kort samengevat had de aanvoer van compost dus effect op een beperkt aantal bodemfuncties, waaronder de gewasopbrengst, nutriëntenbalans en het bodemleven. Gezien de kosten moet per situatie de afweging gemaakt worden of compost de juiste manier is om voldoende organische stof aan te voeren.

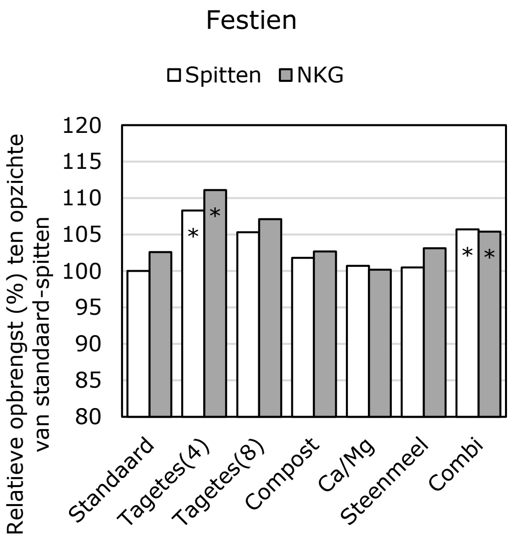
Ca/Mg
Met de calcium/magnesium methode wordt er gestreefd naar een optimale verhouding van deze nutriënten in de bodem. Met een aangepaste bemesting werd de verhouding die wordt gezien als optimaal bereikt na vier tot zeven jaar. De calcium bezetting aan de CEC bereikte echter niet het optimum, maar de calcium voorraad in de bodem steeg wel. Mogelijk hebben magnesium en kalium de waterstofionen aan de CEC vervangen, in plaats van calcium. Een andere mogelijke reden is dat de pH relatief laag was. De veranderde nutriënten situatie in de bodem had nauwelijks effect op de gewasopbrengsten (zie Figuur 1). De maatregel had een effect op de veldopbrengst van de zetmeelaardappels, maar de chloride in Kali-60 had een negatief effect op het zetmeelpercentage, waardoor de uiteindelijke zetmeelopbrengst gelijk was aan de controle. De opbrengst van zomergerst en suikerbiet werd niet beïnvloed door de Ca/Mg maatregel. De maatregel leidde tot een luxe-consumptie van kali, magnesium en zwavel, maar leidde desondanks tot nutriëntoverschotten van kali, magnesium, calcium en zwavel. Dit kan gezien worden als een inefficiënt gebruik van nutriënten. De Ca/Mg methode had geen effect op de bodemstructuur in termen van indringingsweerstand. Daarnaast is het toepassen van de maatregel enigszins ingewikkeld. Bodemnutriënten dienen gemonitord te worden en de bemesting daarop aangepast. Daarbij komt dat deze aangepaste bemesting duurder is. Omdat het effect op de financiële opbrengst beperkt is, is deze maatregel niet aantrekkelijk. Kort samengevat leidde de Ca/Mg methode tot de gewenste calcium-magnesium verhoudingen in de bodem, dit had geen effect op de marktopbrengsten maar leidde wel tot hogere nutriënten inefficiëntie, in combinatie met de kosten is de Ca/Mg methode daarom niet aantrekkelijk.

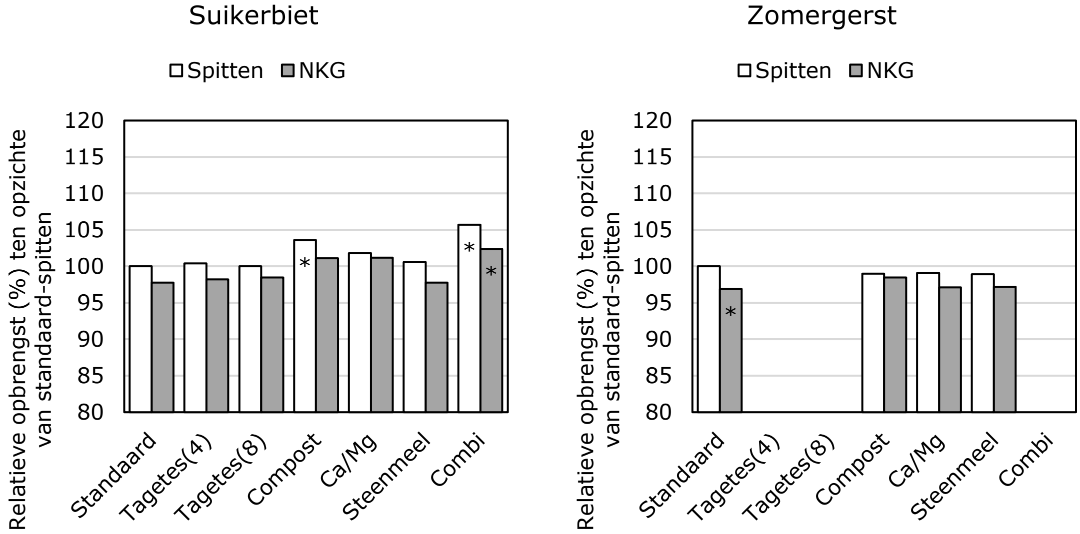
Steenmeel
De aanvoer van steenmeel leidde niet tot verhoogde gewasopbrengsten in de periode 2014-2017 en de aanvoer van het materiaal is daarom in de jaren daarop niet voortgezet. Ook in de periode 2017-2021 had deze maatregel geen effect op de gewasopbrengsten (zie Figuur 1). Met de aanvoer van steenmeel werden er aanzienlijke hoeveelheden kali, magnesium en calcium aangevoerd. Omdat de maatregel geen effect had op de gewasopbrengsten, leidde dit tot verhoogde nutriëntoverschotten. Het effect op de bodemvruchtbaarheid is niet gemeten. Het is niet aannemelijk dat steenmeel heeft geleid tot een verbeterde bodemkwaliteit. Omdat

de maatregel resulteerde in een inefficiënt gebruik van nutriënten en verhoogde kosten maar niet tot verhoogde opbrengsten, wordt deze maatregel niet aanbevolen aan de praktijk.

Combi-NKG
In deze maatregel zijn alle bovenstaande maatregelen gecombineerd tot één object. Het idee hierachter was om alle mogelijke potentiële positieve effecten te maximaliseren. Deze maatregel leidde tot een opbrengststijging. Deze toename was echter kleiner dan de som van alle onderliggende maatregelen, een synergie trad dus niet op. De teelt van Tagetes leidde tot een sterkere toename van de zetmeelopbrengst van Festien en Seresta dan Combi-NKG. Het positieve effect van Tagetes op de aardappelopbrengst werd in de Combi-NKG maatregel waarschijnlijk teniet gedaan door het effect van de kali aanvoer op het zetmeelgehalte. Voor suikerbiet was de toename in de suikeropbrengst vergelijkbaar met de compost maatregel. Als onderdeel van de Combi-NKG maatregel is de teelt van zomergerst eens in de vier jaar vervangen, opbrengsteffecten op zomergerst zijn daarom niet geanalyseerd. De maatregelen compost, Ca/Mg en steenmeel leidden tot hoge nutriëntoverschotten, een combinatie van deze maatregelen leidde tot nog hogere overschotten. Als gevolg werd een hogere nutriëntconcentratie in de bodem gevonden voor fosfaat (P-Al), kali, magnesium, calcium en de CEC-bezetting. Voor fosfaat, kalium en magnesium is dit effect wenselijk, voor de overige elementen zijn geen goed onderbouwde streefwaarden beschikbaar. In vergelijking met de standaard werd er meer organische stof aangevoerd bij Combi-NKG ten gevolge van de compost, in combinatie met NKG werd een positief effect verwacht op het bodemleven. Combi-NKG leidde tot meer schimmels, een hogere schimmel biomassa en schimmel/bacterie verhouding. Het effect op de schimmels zou een gevolg kunnen zijn van de combinatie van de aanvoer van compost en NKG, aangezien dit effect niet optrad bij de afzonderlijke maatregelen. Ook kan dit een gevolg zijn van één van de andere maatregelen als onderdeel van Combi-NKG. Dit is moeilijk uit elkaar te halen, omdat het bodemleven niet voor elke maatregel apart is geanalyseerd. Op de milieuaaltjes had Combi-NKG geen effect. Wat betreft de bodemstructuur leidde Combi-NKG tot een lagere indringingsweerstand, het is aannemelijk dat dit het gevolg is van NKG. Het leek er niet op dat Combi-NKG gepaard ging met een betere vochtvoorziening. Mogelijk hield de vochtvoorziening beter verband met het bodem organisch stof gehalte, al is dat op basis van de data niet met zekerheid te zeggen. Kort samengevat leidde de combinatie aan maatregelen tot een verhoogde bodemvruchtbaarheid maar een lagere nutriënt efficiëntie, een lagere populatie P. penetrans maar geen effect op de milieuaaltjes, had de combinatie een effect op de bodemstructuur maar niet op de vochtvoorziening, leidde de combinatie tot meer schimmelbiomassa maar had het geen effect op bacteriën, en tot slot leidde de combinatie van maatregelen niet tot een hogere opbrengst dan enkele maatregelen afzonderlijk. Aangezien de combinatie aan maatregelen gepaard gaat met een enorme kostenstijging is het combineren van alle maatregelen geen geschikte strategie om de bodemkwaliteit te verbeteren of gewasopbrengsten te verhogen.







Figuur 0-1 De relatieve opbrengst van de vier gewassen voor de verschillende maatregelen over de periode 2014-2021. Opbrengst is weergegeven in zetmeelopbrengst voor de aardappels, suiker voor de suikerbiet en de korrelopbrengst gecorrigeerd voor het vochtgehalte voor de zomergerst. Voor Tagetes is de data opgenomen van 2014-2021 voor Festien, 2015-2021 voor de suikerbiet en van 2016-2021 voor Seresta. Significante verschillen worden weergegeven met een sterretje (*), significanties voor Tagetes(8) zijn niet getoetst.

<u>Conclusie</u>
Het effect van verschillende maatregelen op gewasopbrengsten en de bodemkwaliteit is onderzocht in de proef 'Bodemkwaliteit Veenkoloniën'. De teelt van Tagetes in plaats van zomergerst met Japanse haver bleek de meest interessante maatregel te zijn om de gewasopbrengsten te verhogen, door de populatie van *P. penetrans* te reduceren. In hoeverre deze maatregel effectief is, hangt af van de besmetting op het betreffende perceel. Een andere interessante maatregel is het aanvoeren van compost, dit bleek een positief effect te hebben op de opbrengst van suikerbiet. De aanvoer van compost ging gepaard met een verhoogde aanvoer van nutriënten. Er dient rekening gehouden te worden met de mineralisatie van deze nutriënten en mogelijke effecten op uitspoeling. Daarbij komt dat de aanvoer van compost gepaard gaat met een toename van kosten, het is daarom van belang de afweging te maken of de aanvoer van compost de meest geschikte maatregel is om organische stof aan te voeren. Naast de teelt van Tagetes en de aanvoer van compost leidde geen enkele andere maatregel tot een toename in gewasopbrengsten. NKG had een effect op de bodemstructuur, maar geen enkel gewas profiteerde hiervan. Het is afhankelijk van de veldomstandigheden of het zinvol is om te kiezen voor NKG in plaats van spitten. De Ca/Mg methode en steenmeel leidde tot een inefficiënt gebruik van nutriënten en leidde niet tot opbrengstverhoging, en zijn daarom geen zinvolle maatregelen.

Tagetes een effect had op P. penetrans, compost en Ca/Mg op de nutriënten gehalten in de bodem en NKG op de bodemstructuur. Echter, grote effecten van de maatregelen op de integrale bodemkwaliteit bleven uit. De maatregelen varieerden van gebruikelijk tot experimenteel, maar waren allen niet in staat om de integrale bodemkwaliteit aanzienlijk te verbeteren. Er kan daarom geconcludeerd worden dat het niet eenvoudig is om de integrale bodemkwaliteit en gewasopbrengsten binnen de huidige gewasrotatie te verbeteren. Overige maatregelen om zowel de gewasopbrengsten als de bodemkwaliteit te verbeteren zijn beperkt voorhanden.

1 Introduction

Arable agriculture on reclaimed peatlands in the North East of the Netherlands are characterised by a four year crop rotation consisting of starch potato – sugar beet – starch potato – spring barley with a cover crop. The soils are associated with a relatively high organic matter percentage with a high spatial variability, and face challenges such as soil segregation[1], wind erosion, a limited water holding capacity, high weed pressure, and the presence of crop yield influencing numbers of plant parasitic nematodes. All-in-all, the profitability of arable farming in this region is under pressure. At the same time, there is increasing attention for improving the soil quality and societal challenges.

Already in 2012, a program was initiated by *de Commissie Landbouw Veenkoloniën* to improve the soil quality and reduce the dependence of the sector on public funds. The main focus was on the soils capacity to produce crops. Together with the sector, the idea arose to start a long-term experiment in which several soil treatments would be tested to enhance the perspective of the arable agriculture in the region. This led to the start of the long-term experiment '*Bodemkwaliteit Veenkoloniën*' in 2013, as part of a public private partnership, the *PPS Beter Bodembeheer*.

The main goal of this experiment was to develop and test feasible soil treatments to improve the soil quality, improve the profitability and meet societal challenges. Researchers together with the sector made an overview of all the challenges and have formulated possible solutions. The most promising were later turned into six treatments. These include:

1. Non-inversion tillage instead of conventional tillage, with the aim to improve the soil structure and reduce soil erosion.
2. The cultivation of Marigold instead of spring barley and black oat, to reduce the plant parasitic nematode *P. penetrans*.
3. The application of compost was initiated to increase the supply of organic matter which potentially has a positive impact on several soil quality aspects.
4. The method of base-cation saturation ratio (BCSR) aims at optimal ranges and ratios for several soil nutrients at the CEC, potentially increasing the soil fertility, soil structure and crop yields.
5. The application of rockdust was developed to enhance the status and availability of soil nutrients.
6. To maximise the potential effects, all treatments were combined into one treatment.

All of the treatments were analysed in comparison to a control treatment. The effects of the soil treatments were monitored in terms of crop yield and additional soil quality aspects were monitored. The results of the period 2014-2021 are presented within this report.

1.1 Aim of the report

Results gathered in the period 2014-2017 are already presented in a previous report by de Haan et al. (2020). This report is an update with data of the period 2018-2021. Research questions were formulated at the start of the experiment, and expanded during the execution thereof. Some of these questions remained unanswered with the data collected in 2014-2017. Therefore, additional measurements have been carried out in the past few years, to provide an integrated understanding on the effect of the soil measures on the soil functions.

1.2 Research questions

In this report, the following questions will be answered:

1. What is the effect of non-inversion tillage on soil functions compared to the control?
    - What is the effect of non-inversion tillage on yields?
    - What is the effect of non-inversion tillage on nutrient uptake by crops?
    - What is the effect of non-inversion tillage on the soil structure?
    - What is the effect of non-inversion tillage on the soil biology?
    - What is the effect of non-inversion tillage on the weed pressure?
    - What is the practical applicability of non-inversion tillage?
2. What is the effect of Tagetes Patula on soil functions compared to the control?
    - What is the (long-term) effect of Tagetes Patula on yields?
    - What is the (long-term) effect of Tagetes Patula on the population of nematodes?
    - To what extent does the effect differ between the cultivation once every four or once every eight years?
    - What is the practical applicability of Tagetes Patula?
3. What is the effect of compost application on the soil functions compared to the control?
    - What is the effect of compost on yields?
    - What is the effect of compost on the nutrient balance?

[1] Reclaimed peatlands, especially under dry conditions, often lack aggregate stability. Soil particles at the surface lie apart from each other, without any adhesion.

- What is the effect of compost on soil fertility?
- What is the effect of compost on the soil structure?
- What is the effect of compost on the soil biology?
- What is the practical applicability of compost?

4. What is the effect of an optimized BCSR situation on the soil functions compared to the control?
    - What is the effect of BCSR on yields?
    - What is the effect of BCSR on nutrient uptake?
    - What is the effect of BCSR on the nutrient balance?
    - What is the effect of BCSR on the soil fertility?
    - What is the effect of BCSR on the soil structure?
    - What is the practical applicability of BCSR?
5. What is the effect of rockdust on the soil functions compared to the control?
    - What is the effect of rockdust on yields?
    - What is the effect of rockdust on nutrient uptake?
    - What is the effect of rockdust on the nutrient balance?
    - What is the practical applicability of BCSR?
6. What is the effect of the combination of five measures on the soil functions compared to the control?
    - What is the effect of the combination of measures on crop yields?
    - What is the effect of the combination of measures on the nutrient uptake?
    - What is the effect of the combination of measures on the nutrient balance?
    - What is the effect of the combination of measures on the soil fertility?
    - What is the effect of the combination of measures on the nematode population?
    - What is the effect of the combination of measures on the soil biology?
    - What is the effect of the combination of measures on the soil structure?
    - What is the effect of the combination of measures on plant available water?
    - Is the availability of water linked to the soil organic matter content?
    - Are the (possible) effects a result of a sum of the individual measures or due to the combination?

2 Method

2.1 Field characteristics

The experiment is located on reclaimed peatlands in the North-East of the Netherlands (52.87N, 6.92E). Reclaimed peatlands are a sandy soil from which most of the peat has been excavated and covered with a layer of sand. Remains of old peat can still be found in the soil. A picture of the soil profile is presented in **Error! Reference source not found.**. The remains of peat are present below 30 cm, and are visible in both pictures. The pictures clearly show the heterogeneity of the soils, as the pictures are taken within the same field. The oxidation of old peat, which is spatial not evenly distributed, resulted in differences in soil level within fields. A map is presented in Appendix 1. Characteristics of reclaimed peatlands are a low pH (around 5), high (old) organic matter (6-14%) and 80% of the soil is >50 µm. The reclaimed peatland area in the North-East of the Netherlands is characterized by arable agriculture, mainly cultivating potatoes for the processing industry, sugar beet, barley and wheat.

Figuur 2-1 Peaty podzol of two different places at field 71-2 in Valthermond, 22th of July 2021.

2.2 Crop rotation

The experiment follows the most common crop rotation in the region:

1. Starch potato (Festien),
2. Sugar beet,
3. Starch potato (Seresta),
4. Spring barley with black oats as a cover crop.

Because of a mistake in the N fertilization in 2020, spring barley was replaced by spring wheat. The experiment consists of 4 fields, so each crop is grown each year. An overview is presented in Table 2-1.

Table 2-1 Overview of the crop rotation, the start of Marigold and the successive crops are indicated in grey.

		Year								
		2013	2014	2015	2016	2017	2018	2019	2020	2021
Field	71-2	B/M	F	SB	S	B/M	F	SB	S	B
	70-4	S	B/M	F	SB	S	B/M	F	SB	S
	71-1	SB	S	B/M	F	SB	S	B/M	F	SB
	70-3	F	SB	S	B/M	F	SB	S	W/M	F

B=spring barley, W=wheat, SB=sugar beet, F=Festien, S=Seresta, M=marigold.

2.3 Treatments

An overview of the treatments is presented in Table 2-2. The treatments are elaborated below.

1. Two forms of tillage were applied: conventional tillage (T) and non-inversion tillage (NT). T was done by rotary spading at a depth of 25-30 cm plus a subsoiler to a depth of 35 cm (5 tines) in combination with a cultipacker. NT was done by a rigid tine cultivator at a depth of 20-25 cm and a subsoiler (5 tines) at a depth of 40 cm. With NT, the soil is loosened but not turned, which leads to a less loosened soil and crop residues remaining the soil surface. All crop residues were left in the field, except for straw which was removed from the control.
2. Marigold(4) refers to the replacement of spring barley and black oats by Marigold (*Tagetes Patula*, groundcontrol) each time in the crop rotation, so Marigold is grown every 4 years. Marigold was sown when the conditions were suitable, after the last frost and when the soil was not too dry (usually between June and August). With Marigold(8), spring barley and black oats were replaced by Marigold only in the first crop rotation, so Marigold was grown every 8 years. The aim of these treatments is to reduce the population of *P. penetrans* and positively affect potato yields.
3. Applying compost was done to increase the supply of organic material. Compost was applied in addition to slurry, only the application of artificial P_2O_5 and K_2O were (partly) corrected for the nutrients in the compost. In the period 2013-2016 15 ton ha^{-1} jr^{-1} was applied annually, in the period 2017-2021 20 ton ha^{-1} jr^{-1} was applied for the potatoes and sugar beet.
4. The theory of BCSR focusses on realizing a ratio between Ca- and Mg-saturation of 5.7. Soil analyses were performed annually by Soiltech Solutions and HortiNova to determine the appropriate Ca, Mg and K applications.
5. For the treatment with rockdust, 3 ton ha^{-1} jr^{-1} zeolite and 3 ton ha^{-1} jr^{-1} biolit were applied on top of the standard fertilization in the period 2014-2017. Zeolite (Natrolite-phonolite) originates from volcanic rocks, and is associated with a high CEC. Biolit is a kind of lava that is produced under high pressure, and mainly contains MgO, CaO, Na_2O and several other micronutrients.
6. In the Combi treatment, Marigold(8), BCSR and compost were combined. Rockdust was part of the Combi treatment in the period 2014-2017.

T and NT are applied in strips over all other treatments, resulting in 14 treatments (see Table 2-2). The experiment has a completely randomized block design, in which each treatment had 4 replicates, resulting in 224 objects (see Appendix 2 for an overview).

Each treatment was compared to the control (standard-T). The straw of spring barley was incorporated in the soil for all treatments, except for the control. In the control (standard-T), the straw of the spring barley was exported from the field, the fertiliser regime was not corrected for the export of nutrients.

Crop protection and irrigation was done following common agricultural practice in the region. Irrigation was somewhat postponed, to provide an opportunity for the treatments to show their effects on crop growth during stress conditions.

Table 2-2 Overview of treatments.

Treatment	**Tillage**	**Abbreviation**
Standard	Tillage (spading)	Control
Standard	Non-inversion tillage	Standard-NT
Compost	Tillage (spading)	Compost-T
Compost	Non-inversion tillage	Compost-NT
Marigold-4	Tillage (spading)	Marigold(4)-T
Marigold-4	Non-inversion tillage	Marigold(4)-NT
Marigold-8	Tillage (spading)	Marigold(8)-T
Marigold-8	Non-inversion tillage	Marigold(8)-NT
BCSR	Tillage (spading)	BCSR-T
BCSR	Non-inversion tillage	BCSR-NT
Rockdust	Tillage (spading)	Rockdust-T
Rockdust	Non-inversion tillage	Rockdust-NT
Combi	Tillage (spading)	Combi-T
Combi	Non-inversion tillage	Combi-NT

2.4 Measurements

2.4.1 Crop development

2.4.1.1 Crop observations

During the growing season the crops were assessed visually every two weeks. Crop growth stages were noted, as well as visual differences in crop growth between the plots, and the presence of weed

s, pest and diseases. In 2014-2016. For sugar beet, the number of plants was noted for five meters at five randomly selected spots for each plot. For the potatoes, the number of stems were noted for five plants per plot.

2.4.1.2 CropScan measurements

The CropScan is a MultiSpectral Radiometer which measures radiation reflectance from crop canopies. The percent reflection of radiation in various wavelengths is influenced by any condition that influences the normal growth of plants. The radiometer is therefore particularly useful as an objective and efficient means of estimating the effects of any condition that affects plant health, yield, or quality of the crop.

In this experiment the Cropscan MSR16R is used, which measure reflectance in the wavelengths stated below. In the field the radiometer is held level by a support pole about 3m above the soil surface to measure the crop canopy. The diameter of the field of view is one half of the height of the radiometer above the canopy. The radiometer is directed to the sun and perpendicular to the direction of the crop rows. For each plot at about a quarter of the length of the plot three consecutive measurements are taken swinging from left to middle to right of this position. This is repeated at position about three quarters of the length of the plot to get six readings in total. These readings are then averaged to get a mean reflectance percentage for each wavelength for the plot.

The reflectance percentages are used to calculate the following vegetation indices:

- NDVI: $(r_{810}-r_{670})/(r_{810}+r_{670})$ Deering (1978)
- WDVI green: $r_{810}-r_{560}*(r_{810}/r_{560})_{soil}$ Clevers et al. (1989)
- WDVI red: $r_{810}-r_{670}*(r_{810}/r_{670})_{soil}$ Clevers et al. (1989)
- N-content potato plant[2] Evert et al. (2012)
- NDRE $(r_{780}-r_{730})/(r_{780}+r_{730})$ Fitzgerald et al. (2006)
- CIred $(r_{810}/r_{670})-1$ Gitelson et al. (2003,2006)

The weighted difference vegetation index (WDVI) uses a correction factor for bare soil. During each day of measurement a plot of bare soil was measured and these correction factors were calculated. The normalized difference vegetation index (NDVI) indicates growing vegetation. An area without crop growth will have a NDVI of zero and an area with healthy vegetation will have a value close to one. Since measurements were carried out twice a year, crop status was assessed during the growing season (July/August) and during decay (September). The latter is an indication of which crop in which treatments remained vital for a longer period of time.

Table 2-3 MSR16R spectral wavelengths

Centre of wavelength [nm]	Bandwidth [nm]
460 (blue)	10.0
490	7.3
510	10.0
560 (green)	9.4
670 (red)	10.0
700	12.3
720	12.6
730 (red edge)	12.9
740	13.1
760	10.0
780	10.0
810 (infrared)	10.0
870	12.2
900	12.7
970	10.0
1080	14.8

2.4.1.3 Cover crops

The crop development of the cover crops was observed in terms of biomass production during the growing season, and biomass production was determined in some of the years. The above ground biomass was harvested and dried, and the fresh biomass (kg ha^{-1}), dry matter content (g kg^{-1}) and the dry biomass (kg ha^{-1}) were determined. The biomass of black oats was determined in 2017, 2018, 2019 and 2021, and the biomass of Marigold was determined in 2013, 2015, 2017, 2019 and 2020.

[2] https://doi.org/10.1016/j.eja.2012.05.005

2.4.2 Yield

Two different terms are used for yield: the field yield and the market yield. The field yield is related to the net yield. The gross fields are 12x12 meters, except of the Marigold 1:4 and Marigold 1:8 that are 6×12 meters (because of the split plot). The net fields are 3x10 meters for the potato fields (Festien and Seresta) and sugar beet fields. The net fields of the crop spring barley are 2,75x9 meters. The field yield is the yield that is harvested in the net fields and recalculated to hectares. In the case of sugar beet, the tare sugar beet has been removed to calculate the net field yield.

The market yield is calculated as the amount of marketable products. For the potatoes (Festien and Seresta), the marketable product is the quantity of produced starch. The net yield is therefore multiplied by the starch content of the potatoes. The amount of starch is recalculated by the underwater weight (UWW) by the calculation $Starch\ (\%) = UWW * 0.0527 - 5.769$. For sugar beet, the marketable product is the quantity of sugar. The net yield is therefore multiplied by the sugar content of the sugar beet. For spring barley, the marketable yield is the net yield corrected for a moisture content of 15%.

2.4.2.1 Parameters

The underwater weight of the potatoes Festien and Seresta is determined with a Perten NIR Analyser at the experimental farm of WUR "'*t Kompas*" in Valthermond, The Netherlands. The quantity of sugar from the sugar beets is determined at Instituut voor Rationele Suikerproductie (IRS), Centre for research and knowledge for sugar beet production in Dinteloord, The Netherlands. The moisture content, protein content and the hectoliter weight of spring barley is determined at Agrifirm, Apeldoorn, The Netherlands.

2.4.3 Nutrient concentration

2.4.3.1 Product

The nutrient concentration in the product has been measured several times during the period 2014-2021, an overview can be found in Appendix 3. Analyses were performed by Eurofins Agro (Wageningen, The Netherlands). Macronutrients (N, P, K, Ca, Mg and S) have been measured in 2014 and 2015, and from 2016 onwards only NPK have been measured. Until 2017 all treatments were measured (except for Marigold-8), and from 2018 onwards only Standard-T and Combi-NT have been measured. In the period 2014-2017 each replicate has been measured, from 2018 onwards samples of each treatment were mixed. Since no replicates were available from 2018 onwards, no statistical analysis was performed on the data of 2018-2021.

Additionally, Nova Crop Control (Oirschot) performed plant sap analyses on various elements (pH, EC, K, Ca, Mg, Na, NH4, NO3, total N, Cl, S, P, Si, Fe, Mn, Zn, B, Cu, Mo and Al). These data are not taken into account in the analysis as they cannot be used to calculate total removal of nutrients with harvest.

2.4.3.2 Leaf tissue

The nutrient concentration in plant sap in leaves has been measured 3-4 times during the growing season in the period 2014-2021, both in young and old leaves. Analyses were performed by Nova Crop Control (Oirschot). Compost-NT and Rockdust-NT were not analysed every year and therefore assessed separately.

2.4.3.3 Soil

Soil nutrients were analysed by two laboratories: Eurofins Agro (Wageningen, the Netherlands) and van Iersel (Biezenmortel, the Netherlands).

Eurofins
Soil nutrients were measured annually (2013-2022) for Combi-NT and the control, and for Compost-T in the period 2021-2022. Samples were taken per plot separately for each of the fields. Collecting the samples was done in spring (the end of March) in the layer 0-30 cm. Analyses were performed on dried samples. Eurofins Agro is a Laboratorium which performs analyses accredited by *de Raad van Accreditatie* (www.rva.nl). N-status, K-status, K-availability, Mg-status, S, pH, CEC, soil organic matter were analysed by Nearly Infra-Red techniques (NIR). P-Al was determined following a method similar to NEN 5793. P-PAE and Mg-availability were analysed using a calcium chloride solution.

Van Iersel
Soil nutrients were measured annually (2013-2021) for BCSR-T, BCSR-NT, Rockdust-T, Rockdust-NT, Standard-NT, Combi-NT and the control. Each plot was measured individually for field 71-2. For the other fields, samples were mixed per treatment. Samples were collected in spring (the end of March) in the layer 0-30 cm. Only Ca-, Mg- and H+ saturation, pH were reported. pH was determined by water 1:1, and the quantities of Ca and Mg are determined using the Mehlich III extraction.

2.4.4 Nutrient balance

The soil nutrient balance was calculated based on the supply (fertilization) and removal (yield). Supply consisted of artificial and organic fertilizers. The nutrient concentration in the manure and compost was determined by Eurofins Agro (Wageningen). For removal, the nutrient concentration (see 2.4.3.1) was multiplied by the dry matter of the exported products. Average nutrient concentrations from the measurements in the period 2014-2021 were taken for the years that the nutrient concentration was not measured.

2.4.5 Organic matter balance

For each treatment the organic matter balance was calculated. The balance comprises the supply of organic material and the degradation of soil organic matter. The supply consists of manure (including compost), crop residues and cover crop residues. The supply is expressed as effective organic matter, which is the amount that remains after one year. The amount remaining after one year can be calculated with the humification coefficient (HC), which is available in Handboek Bodem en Bemesting (HBB). The organic matter content of manure was assumed to be 60 kg ton^{-1} with a HC of 0.33. The organic matter content of compost was determined each year in the laboratory. The organic matter of the cover crops was determined in some years, averaged values were used for the remainder of the years. The crop residues were not determined, and standard values were used from HBB. For the estimation of the decomposition of soil organic matter the fourth approach described by de Haan et al. (2020) was used. The bulk density and soil organic matter level were not determined for each plot, and therefore average values were used to calculate the initial soil organic matter content. The final soil organic matter level (2021) was calculated by adding the cumulative soil organic matter balance to the initial soil organic matter level.

2.4.6 Soil structure

2.4.6.1 Penetration resistance

Soil compaction can be characterized by the penetration resistance (PR) of the soil which is measured with a hand held sensor called a 'penetrometer' (Eijkelkamp, 2020). A penetrometer measures the resistance in MPa at every 1 cm in the soil layer 0-80 cm. Average PR is calculated for the soil layer 0-20 and 20-40 cm. Additionally, the depth at which roots experience hindrance (1.5 MPa) and inhibition (3.0 MPa) are derived. PR is measured twice a year (March and June) for Combi-NT and the control in the period 2014-2021, for Standard-NT in 2014, 2015, 2020 and 2021, and for Compost-T and BCSR-T in 2021. A baseline measurement has not been executed.

PR is strongly influenced by the soil texture and soil moisture content, and therefore mainly suitable for comparative studies at the same site at the same moment. Because PR is also related to bulk density and soil organic matter and these are highly variable at this specific type of soil, results should be utilized with caution (Kuang et al., 2012).

2.4.6.2 Bulk density and pF curve

Information about the bulk density and pF curve are derived from soil sample rings (Eijkelkamp, 2019), which were collected once in 2020. Rings with a volume of 100 cm^3 were hammered in the soil profile. Eight samples were collected per plot, four at a depth of 10-15 cm and four at a depth of 30-35 cm. Results were averaged per plot. Samples were only taken in field 71-2, for the control (plots 65, 71, 86, 92), standard-NT (plots 53, 59, 74, 80) and Combi-NT (49, 56, 76, 82).

The rings were saturated with water, and weighted at pF 0 (saturation), pF 0.4, pF 1.0, pF 1.5, pF 1.8, pF 2.0 and dried at 105℃. The bulk density is the dry weight, expressed as g cm^{3-1}. The moisture content at field capacity was determined by the weight at pF 2.0 minus the dry weight.

2.4.7 Soil moisture content

Soil water and temperature control soil functions such as nutrient cycling, seed emergence and crop growth, as well as timing of soil management operations such as tillage, seeding, and harvesting (Crittenden, 2015). Under optimal conditions, both hydrogen and oxygen are available in the root zone at sufficient quantities so the water in the large and immediate pores can be easily used by crop roots. After rainfall, the top layer will be saturated for several hours and then the water will infiltrate to deeper soil layers. When evapotranspiration increases the soil moisture content in the top layer will first decrease, and then be refilled by capillary rise. Soil water is dynamic: removal of water occurs due to drainage, evaporation, and transpiration and addition of water occurs with dewdrops, rainfall, and irrigation. Soil management (including non-inversion tillage) may affect soil water availability due to modifications in soil structure.

Sensors
Soil moisture content was measured at a depth of 15 cm with a sensor during the growing season between 2015 and 2021 at 2x3 spots for Combi-NT and the control, both at a plot with low and high organic matter percentage (see Table 2-4). These measurements were done with Eijkelkamp PlantCare Mini-Loggers (version 1.31). Calibration is done by placing the sensor in the desired position and depth and the soil is watered until it is saturated. After 2-3 days the field capacity is reached and the first measurement has to be done, which will then be considered as a reference value. The sensor provides an indication of the plant available water. Thus, 100% represents the volumetric soil moisture content at field capacity (pF 2.0) minus wilting point (pF 4,2), and 0% then represents the wilting point (pF 4.2).

Table 2-4 Overview of soil moisture measurements

Plot (#)	Treatment	Soil organic matter level
71	Control	High
65	Control	Low
56	Combi-NT	Low
82	Combi-NT	High

2.4.8 Soil biology

2.4.8.1 Fungi and bacteria

Several microbiological parameters can be used as indicators of soil health, such as microbial biomass and fungal and bacterial biomass. A higher microbial biomass and activity indicate a more rapid decomposition and consequentially more available nutrients for plant growth. At the same time an active soil life can contribute to suppressiveness of soil-borne pathogens. Soil bacteria are thought to be mainly responsible for the decomposition of simple compounds, while fungi can degrade more recalcitrant compounds. The presence of recalcitrant material therefore promotes the amount of soil fungi. Bacterial and fungal biomass can be measured by both PLFA and classic microscopic methods. Classic microscopic method, which make use of dyes, can be used to measure the number of soil bacteria and fungi. With dyes active (stained) and dead (unstained) fungal hyphae can be differentiated.

With PLFA the total biomass of bacteria was determined, and several subgroups: gram-negative bacteria, gram-positive bacteria and actinobacteria. Gram-negative bacteria are associated with faster growth in the presence of easily degradable compounds. Most gram-positive bacteria are slow growing and able to degrade more recalcitrant material. An increase in the ratio of gram-positive and gram-negative bacteria thus indicates a decrease in carbon availability. Several species within the group of actinobacteria are known for their antagonistic activity against pathogens.

PLFA was used to determine fungi biomass, the amount of mycorrhiza (i.e. AMF) and saprophytic fungi. AMF are important symbionts for a number of plants. Saprophytic fungi are often positively correlated with the C/N ratio en these fungi are also responsible for the decomposition of complex compounds.

PLFA was also used to assess the amount of protozoa. Protozoa are a diverse group of unicellular eukaryotes, such as ciliates, flagellates, and amoeba. Protozoa mostly play a role as predators for bacteria. It has also been found that some species graze selectively on bacteria with for example a specific cell volume, etc.

Both HWC (hot water extractable carbon) and PMN (potential mineralizable nitrogen) are an indicator of respectively the amount of C and N in the microbial biomass, which are easily decomposable and available for plants. HWC is also assumed to be an early indicator for the increase of organic matter in soil. PCM (potential carbon mineralization) and PNM (potential nitrogen mineralization) are indicators for short term changes in soil organic C and N.

In 2013, three mixed samples were taken from the fields 70.3, 70.4 and 71.1. Additionally, in 2013 and 2020 fungal and bacterial biomass were measured with classic methods. In 2022, PLFA analysis was carried out by Eurofins Agro (Wageningen). Table 2-5 shows an overview of the sampled treatments in field 71.2.

Table 2-5 Overview of sampled treatments and microbiological measurements.

Parameters	Year	Treatments
Classic microbiological measurements (Soil Biology Lab, Wageningen), Bemestingwijzer (Eurofins Agro, Wageningen)	2013	Combi-NT, Standard-T
Classic microbiological measurements (Soil Biology Lab, Wageningen), Bemestingwijzer (Eurofins Agro, Wageningen)	2020	Combi-NT, Standard-T
PLFA	2022	Standard-T, Compost-T, Combi-NT, Standard-NT

2.4.8.2 Nematode community

Soil contains a large diversity of nematodes that easily can reach up to 40-100 different species. Besides plant-feeding or plant-parasitic nematodes, of which some are known as pests of crops in agriculture, many other nematodes are found that feed on other food sources (Yeates et al., 1993). Nematodes are important as grazers of bacteria, fungi and plant roots and therewith contribute to the mineralization of organic matter. Some nematodes predate on other nematodes and protists, whereas other nematodes are omnivorous and feed on a variety of food sources. Due to their omnipresence, numerousness and diversity, they have long been used as an indicator for soil fertility and the level of disturbance of soils.

Free-living nematodes, except for plant feeders, can be classified according to their CP-value (Colonizer-Persister value) that ranges from 1 to 5. These values are assigned based on the life strategy of the nematodes. Nematodes with a low CP-value have a short life cycle, produce many offspring and are able to quickly respond to an increase in food sources. On the other hand, nematodes with a high CP-value have a longer life cycle, produce a small number of offspring and are sensitive to chemical as well as physical disturbances (Ferris et al., 2001; Du Preez et al., 2022). Analogous to CP-values, PP-values ranging from 2 to 5 have been assigned to plant-feeding nematodes. Shifts among CP-groups can be expressed in indices, such as the Maturity Index (MI; Bongers, 1990). The MI is a weighted average of the CP-values and is based on all nematode groups except the plant feeders. The Maturity Index 2-5 (MI2-5) is calculated in the same way as the MI, but leaves out nematodes with a CP-value of 1 (Bongers and Korthals, 1994). The Plant Parasitic Index (PPI) is calculated in the same way as the MI, but is a weighted average of the PP-values of the plant-feeding nematodes (Bongers and Korthals, 1994). Other indices focus on the importance of specific nematode groups (Ferris, et al., 2001). The Basal Index (BI) is an indicator for the level of occurrence of nematodes with a high tolerance to stress (CP-value 2). The Enrichment Index (EI) is a measure of the occurrence of nematodes that quickly respond to an increase in food availability (decomposing organic matter). The Channel Index (CI) specifies the share of fungal-feeding nematodes within the groups that quickly responds to food availability. High numbers indicate that fungal-feeding nematodes are dominant, whereas low numbers indicate the dominance of bacterial-feeding nematodes. In general, CI-values in soils of arable fields are low. The Structure Index (SI) is a measure for the complexity, structure and interactions among nematode in the soil. Lower values of SI indicate that the food web is basal and mainly contains bacterial en fungal feeders with low CP-values. In contrast, high values of SI indicate a more complex food web containing groups that feed on other food sources, such as predators and omnivores, and which have higher CP-values. The values of EI and SI often are presented together in a food web analysis diagram that is divided into four quadrats (Figure 2-1; Ferris et al., 2001). Observations from arable fields often are found in the upper part of the diagram (high fertility), observations from grasslands and forests on the right side (high SI) and observations from polluted areas in the lower left corner.

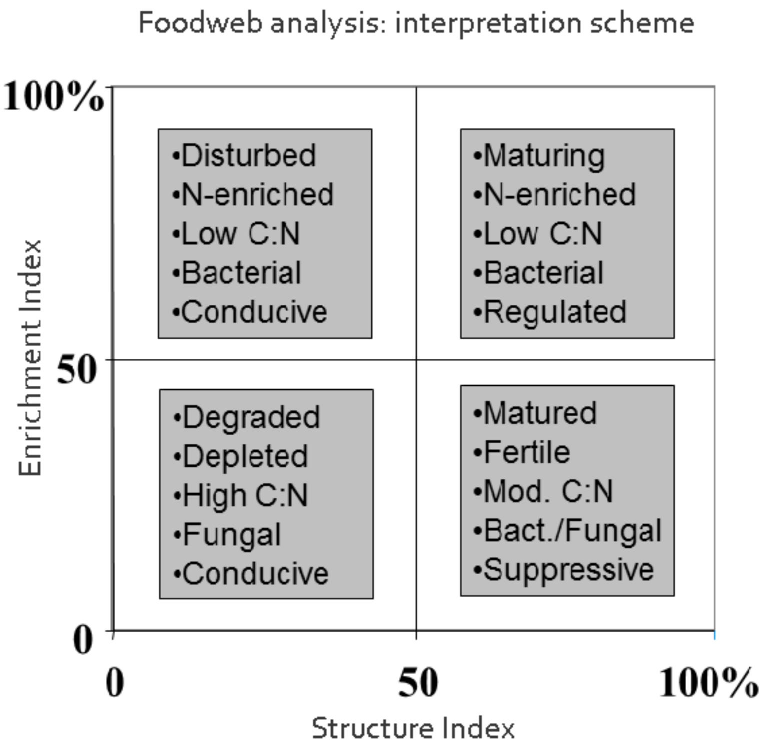


Figure 2-1 Interpretation of the quadrats in the food web analysis diagram (from Ferris et al., 2001).

Samples for determination of the nematode community were collected until a depth of 20 cm in April 2013 and March 2020 from the treatments Combi-NT and Control in field 71-2 (see Appendix 2). In 2013, before application of the treatments, combined samples were taken from fields 70-3, 70-4 and 71-1. For measurement of soil moisture, a subsample of about 100 mL was weighed, dried at 105°C for 40-48 hours, the weighed again. The moisture content of the soil was calculated as ((moist soil weight)-(dry soil weight))/(dry soil weight).

In 2013, determination of the nematode community was performed at the former laboratory BLGG AgroXpertus (now Eurofins), while in 2020, it was performed at WUR Field Crops. For determination of the soil nematode community, a subsample of about 100 mL soil was weighed. The soil was sieved on a 180 µm sieve to remove coarse organic material (>180 µm) as a means to obtain a cleaner nematode suspension. The nematodes in the caught suspension with particles <180 µm were extracted by Oostenbrink elutriation (van Bezooijen, 2006) and the supernatant was sieved on a set of three 45 µm sieves. The material on the sieves was transferred to a double filter (Tork Heavy duty cleaning cloth 530137) and incubated in a dish with tap water for three days at 20°C. After that, the nematode suspension of 100 mL was tapped and the total number of nematodes was counted in a subsample of 10 mL. The remainder of the suspension was fixed with formalin for identification. The suspension was concentrated, transferred to 25-30 mL vials, left to settle for 24 hours, after which the liquid was extracted down to 2 mL. To fix the nematodes, 4 mL formalin (7.6 mL formaldehyde 37% and 92.4 mL distilled water) of 90°C was added and immediately after 4 mL of 20°C formalin. At random, about 150 nematodes were identified to family, genus or species at a magnification of 400-1000× (Bongers, 1988). Dauer larvae, which are resting stages of nematodes (often bacterial feeders, but also insect parasites) that cannot be identified, were counted, but not included in the number of nematodes to be identified.

Counts of the nematode community were analyzed with Ninja (24-08-2022; Sieriebrienikkov et al., 2014). Dauer larvae, which are resting stages of nematodes (often bacterial feeders, but also insect parasites) that cannot be identified, were not incorporated in the analysis.

2.4.8.3 Plant parasitic nematodes

Samples for analysis of plant parasitic nematodes were taken from a selected number of treatments because sampling of all plots was not financially feasible. Table 2-6 shows an overview of the sampled treatments. Soil samples were collected in March each year. Each soil sample (1.5L) was collected by 40 cores (diameter 13 mm) taken in a regular pattern within the net of each plot from the top 25 cm of the soil.

Free living nematodes were extracted by means of Oostenbrink elutriation (see description in section 2.4.8.2). After elutriation of the suspension with particles <180 µm, the material that was caught on the 180 µm sieve was added to the filter for incubation. The nematodes were tapped after 3 days and again after four weeks to facilitate hatching of eggs of endoparasitic nematodes (mainly *Meloidogyne* spp. and *Pratylenchus* spp.). The nematodes were counted at 25-40× magnification. In every one out of four samples, up to 20 nematodes in the groups *Meloidogyne*, *Pratylenchus* and Trichodoridae were identified to species. Potato cyst nematode (PCN) infestation was determined on a second subsample of 500 mL of soil. The cysts were extracted by Seinhorst elutriation and collected on a 210 µm sieve. The number of cysts was counted. The cysts were crushed and the number of living and dead eggs was determined. The PCN infestation was only determined for the treatments Combi+ NT and Standard+ T, from 2013 until 2017.

Table 2-6 Overview of sampled treatments for the determination of plant parasitic nematodes.

		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
70-3	Standard-T	x	x	x	x	x	x	x	x	x	x
70-3	Combi-NT	x	x	x	x	x	x	x	x	x	
70-3	Marigold(4)-T								x	x	x
70-3	Marigold(8)-T								x	x	x
70-4	Standard-T	x	x	x	x	x	x	x	x	x	x
70-4	Combi-NT	x	x	x	x	x	x	x	x	x	
70-4	Marigold(4)-T		x	x	x		x	x	x	x	x
70-4	Marigold(8)-T						x	x	x	x	x
70-4	Marigold(4)-NT		x	x	x		x	x			
70-4	Marigold(8)-NT						x	x			
71-1	Standard-T	x	x	x	x	x	x	x	x	x	x
71-1	Combi-NT	x	x	x	x	x	x	x	x	x	
71-1	Marigold(4)-T							x	x	x	x
71-1	Marigold(8)-T							x	x	x	x
71-2	Standard-T	x	x	x	x	x	x	x	x	x	x
71-2	Standard-NT								x	x	x
71-2	Combi-NT	x	x	x	x	x	x	x	x	x	
71-2	Marigold(4)-T		x	x	x	x	x	x	x	x	x
71-2	Marigold(8)-T					x	x	x	x	x	
71-2	Marigold(4)-NT		x	x	x	x	x	x	x	x	x
71-2	Marigold(8)-NT					x	x	x	x	x	

2.4.8.4 Soil weed seedbank

The number of weeds in the soil seedbank and their species composition was estimated. The main objective was to determine the effect of soil tillage on the density and composition of the weed seedbank, comparing NT with T after a period of nine years. In addition, the number of weeds and the species present give an indication of the weeds that can be expected during the growing season, as well as the periods during the season in which germination is most likely to occur based on species characteristics.

Annual weeds reproduce and spread by seeds, resulting in soil weed seedbank build up. This weed seedbank is the main source for weed infestations in later seasons. Therefore, farmers need to control weeds to prevent crop-weed competition and the reproduction of weeds. Apart from direct control measures such as chemical and mechanical weeding, cultural control measures among others are an important part of the toolbox for weed management.

To estimate the soil weed seedbank, soil samples were collected in the field from two different layers of the topsoil: 0-10 and 10-30 cm depth. Only the four replicates of standard-T and standard-NT were included for each field. In each plot, 96 soil cores were randomly collected using a 25 mm width auger and combined into one soil sample for each layer per plot. This resulted in a total of 64 soil samples. Soil sampling was done on 21 and 22 March, shortly before the first tillage operations in 2022.

The soil samples were taken to a greenhouse in Lelystad and assessed using direct greenhouse germination. During the period between March and October, the weed seeds were germinated in the greenhouse and weed seedlings were determined on species level. After each germination flush, the soil was mixed again and rewatered to let the remaining seeds germinate. In total, six cycles were completed by the end of the assessment.

For practical reasons, the larger soil samples originating from the 10-30 cm layer were reduced to 10 kg of moist soil. To be able to compare densities between layer and treatments, the number of weeds were recalculated using the dry weight of each sample in the greenhouse and average soil bulk densities from earlier bulk density determinations.

2.5 Statistical analysis

Crop yields, the nutrient concentration in the leaves, soil nutrient concentrations and the penetration resistance data were analysed with Genstat Windows 19^{th} edition. Data was analysed with a linear model (Anova), the student T test was used to compare treatments. The soil biology data was analysed with R version 4.2.1 (R Core Team, 2022) and RStudio® version 2022.07.0 (RStudio Team, 2022). For the data from T2 (2022), differences between the four measured objects (Combi-NT, Standard-NT, Compost-T and Standard-T) were analysed with a linear mixed model with treatment as a fixed factors and block nested in crop as a random factor. In addition the soil organic matter content in six categories (5-7.5%, 7.5-10%, 10-12.5%, 12.5-15%, 15-17.5%, 17.5-20%) was added as a random variable to account for variation within the experimental setup. Correlations between the measured parameters were calculated with the spearman method.The plant parasitic nematode data were statistical analysed using Genstat Windows 22nd edition. Data of nematode counts were 10log transformed to stabilize the variance (meet normal distribution) and analysed with ANOVA to assess the effect of the treatments on the population of plant parasitic nematodes. The means obtained after 10log transformation are back transformed. These back transformed means (called medians) are less influenced by extremes.

The soil nematode data was analysed with a linear model (Anova) with treatment (Combi-NT and Control) and block (1-4) as fixed factors. The analysis was performed in R version 4.2.1 (R Core Team, 2022) and RStudio® version 2022.07.0 (RStudio Team, 2022).

Results of statistical analyses are indicated with letters or with font style (bold or underlined). A confidence interval of 95% was used.

3 Results

3.1 Crop development

3.1.1 Potato

The crop development of Festien and Seresta are presented in Appendix 4. In general, the differences in NDVI between the treatments for Festien were limited. Compared with the control, only BCSR-NT performed slightly less in 2020. For the other years, no significant differences were found between the treatments and the control. For the N-uptake, some differences were found. Combi-T was associated with a higher N-uptake in 09-2014 and Marigold(4)-NT and Combi-NT in 09-2015, indicating that the crop remains vital for a longer period of time. For Seresta, BCSR-T and Combi-T were associated with a higher NDVI in 09-2015, Marigold(4)-T and Combi-T in 08-2018 and a lower NDVI for Marigold(8) in 07-2020. For the N-uptake, no differences were found between the treatments and the control. The NDVI was not directly related to the yield levels.
The crop development of Marigold is crucial for its suppression on *P. penetrans*. Its biomass production of some years is presented in Figure 3-1.

3.1.2 Cover crops

In 2013, Marigold was sown in the end of June in field 71-2. Some regrowth of potatoes and barley became visible. Marigold covered the soil in mid-August. The soil profile was assessed, revealing an intense root system through the top layer. The above ground biomass reached an average height of 99 cm. In 2014, Marigold was sown on 24-06 in field 70-4. Marigold covered the soil in Mid-August, flowered extensively, but the above ground biomass was slightly less than the year before. In 2015, Marigold was sown and irrigated at 16-06 in field 71-1, and germinated mid-June. The seedlings did not grow well, and the Marigold was resown the 10th of July. Eventually the crop developed well, leading to a relatively high amount of biomass (see Figure 3-1). In 2016, Marigold was sown mid-June in field 70-3. The crop developed well, and covered the soil completely mid-August. In 2017, Marigold was sown 27-06 in field 71-2, only for Marigold 1:4. The crop reached a height of ~50 cm at the end of August. Although the crop seemed to develop well, the biomass production was relatively low (see Figure 3-1). In 2018, Marigold was grown in field 70-4. Due to drought, sowing was postponed until the 20th of August. During the growing season, weeds were present. Due to frost early in the season (03-10) and decision to use herbicides (as the presence of weeds increased), Marigold had a very short growing period. In 2019, Marigold was sown at 09-08 in field 71-1. In 2020, Marigold was sown on 18-06 in field 70-3. Marigold developed well and weeds were hardly present. Figure 3-1 shows that the cultivation did not result in large quantities of biomass. In 2020, Marigold was sown mid-June in field 70-4. The crop developed well. In general the Marigold developed well, except for 2018 (70-4) and in 2019 (71-1) due to the dry conditions.

The biomass production of black oats is presented in Table 3-1. The dry biomass production was 2363 kg ha^{-1} on average. In most years the black oat developed well. Chickweed (*Stellaria media*) was present in 2014, 2015, 2016 and 2017. In 2016 Melde (*Chenopodium album*) was present as well. In 2018 the circumstances for cover crops were not optimal, and biomass production was relatively low.

Table 3-1 Biomass production of black oats, averaged over 2017-2018-2019-2021.

		Fresh biomass	Dry matter content	Dry biomass
		kg ha^{-1}	g kg^{-1}	kg ha^{-1}
Standard	T	26186	102	2511
Compost		24502	110	2592
BCSR		24231	103	2340
Rockdust		24367	103	2366
Combi		24296	105	2419
Standard	NT	24475	101	2336
Compost		25249	99	2370
BCSR		22762	104	2212
Rockdust		23784	103	2267
Combi		23255	103	2218

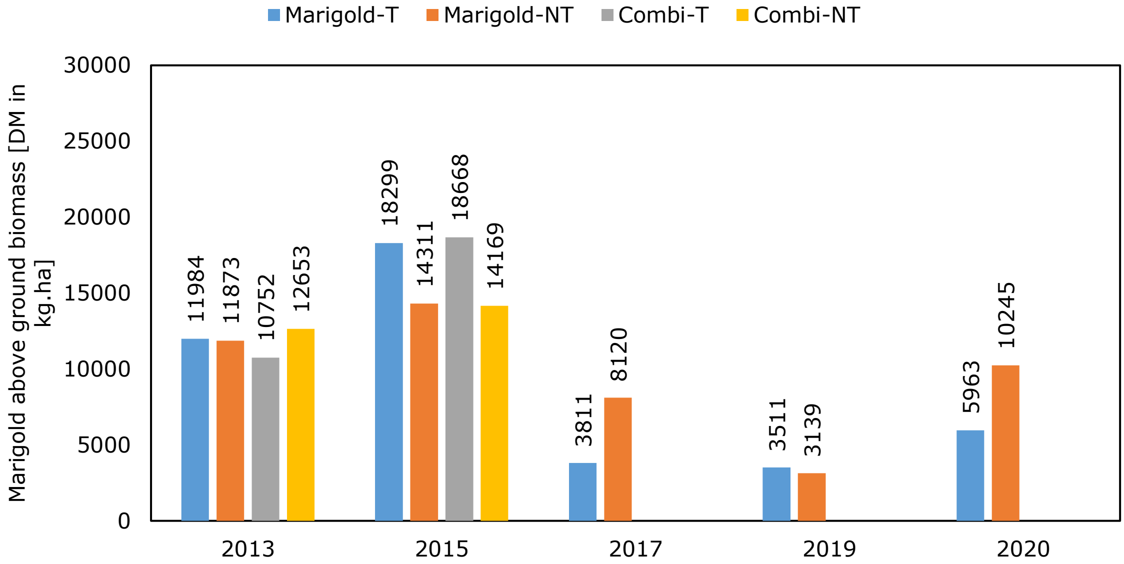


Figure 3-1 Above ground biomass production in DM of Marigold in 2013, 2015, 2017, 2019 and 2020.

3.2 Yield

Farmers get rewarded for the marketable yield, rather than the field yield. Therefore, the marketable yield is presented in this section, and the field yield is presented separately in Appendix 4. The marketable product is expressed in tons of sugar per hectare for the sugar beet, in tons of starch per hectare for the potatoes and tons per hectare converted to 15% moisture for spring barley. The effect of Compost, BCSR, Rockdust and Combi on the yield is presented in Table 3-2, the effect of NT compared to T is presented separately in Table 3-3, and the effect of Marigold is presented in Table 3-4 and will be discussed in Paragraph 3.2.1.

The Combi treatment (both T and NT) resulted in the largest yield increase for the starch potatoes and the sugar beet (up to 8.5%). For the starch potatoes this is mainly an effect of Marigold, which was grown once every 8 years in the Combi treatment. For sugar beet, the effect was probably due to the application of compost, since the yield of Compost-T was significantly higher than for the control but did not significantly differ from Combi-T. Just the application of compost improved the marketable yield of sugar beet (+3.6%), but did not affect the marketable yield of any of the other crops. The application of compost did however impact the ripening of spring barley. The N mineralising from Compost had a delaying effect on the ripening of spring barley. It was therefore decided to switch from an application of 15 ton compost ha^{-1} yr^{-1} for each crop to an application of 20 ton ha^{-1} yr^{-1} for sugar beet and the potatoes.

Whereas BCSR-T improved the field yield of Seresta and Festien, the marketable product was not higher than the control. This is due to a lower starch percentage, which is an effect of the K fertilization in BCSR. In combination with NT, however, the marketable yield of BCSR was slightly higher than for the control for Seresta. The yield of the other crops was not affected by BCSR. Rockdust did not increase the marketable yield in any of the crops. The yield of spring barley was negatively affected by NT, none of the other treatments did affect the yield of spring barley.

NT had a negative effect on the marketable yield of spring barley (-1.8%), but a positive effect on Festien (+1.4%). For sugar beet, the difference between NT and T was 304 kg sugar which was almost significant (LSD=309). When looking at the standard treatments, no significant differences were found in the yield between T and NT, except for spring barley. It is therefore not likely that the yield of Festien or sugar beet is substantially affected by NT compared to T. For Festien, the difference in yield between T and NT over all the treatments might be a result of the NT effect in Marigold. Marigold(4)-NT was associated with a higher yield than Marigold(4)-T, which was included in the average yield of T and NT. For the other treatments, even for the standard, there was no difference in yield between T and NT. Taking this into account, the effect of NT on the marketable yield was minor when averaged over the crops, but still negative for spring barley.

In short, there are limited possibilities to improve the yield of the starch potatoes by reduced tillage or adding more nutrients or organic matter, the largest positive effect was found for the cultivation of Marigold (see section 3.2.1). The yield of sugar beet can be improved by the application of compost. None of the measures was able to improve the marketable yield of spring barley, whereas NT affected the marketable yield of spring barley adversely.

Table 3-2 Average yield in relative numbers over the years 2014-2021. The relative numbers are based on yield in terms of tons of starch per hectare for Seresta and Festien, in tons of sugar per hectare for sugar beet, and in tons of yield corrected for moisture for spring barley.

	Seresta		Festien		Sugar beet		Spring barley		Average
Standard T	100	a	100	a	100	ab	100.0	b	100.0
Standard NT	100.4	ab	102.6	ab	97.8	a	96.9	a	99.4
Compost T	101.1	ab	101.8	a	103.6	cd	99.0	ab	101.4
Compost NT	100.9	ab	102.7	ab	101.1	bc	98.5	ab	100.8
BCSR T	102.6	ab	100.7	a	101.8	bc	99.1	ab	101.1
BCSR NT	103.4	b	100.2	a	101.2	bc	97.1	ab	100.5
Rockdust T	100.8	ab	100.5	a	100.6	abc	98.9	ab	100.2
Rockdust NT	100.8	ab	103.1	ab	97.8	a	97.2	ab	99.7
Combi T*	108.5	c	105.7	bc	105.7	d			106.6
Combi NT*	108.1	c	105.4	bc	102.4	cd			105.3
100% (ton/ha)	11.0		11.7		15.8		7.21		

*Marigold is 1:8 years in the Combi object.

**Wheat was cultivated instead of spring barley in 2020, in all treatments.

Table 3-3 Average yield tillage and average market yield non- inversion tillage in relative numbers over the years 2014-2021.The relative numbers are based on yield in terms of tons of starch per hectare for Seresta and Festien, in tons of sugar per hectare for sugar beet, and in tons of yield corrected for moisture for spring barley.

	Seresta		Festien		Sugar beet		Spring barley		Average
Average T	103.5	a	102.8	a	102.1	a	99.2	b	101.9
Average NT	103.9	a	104.2	b	100.1	a	97.4	a	101.4
Effect NT (%)	0.4		1.4		-1.9		-1.8		-0.5

3.2.1 Yield effect of Marigold 1:4 and 1:8

A comparison of the marketable yield between Marigold(4), Marigold(8) and the control is presented in Table 3-4. Annual data is presented in Appendix 5.

The cultivation of Marigold had a large beneficial effect on the marketable yield of Seresta and Festien. The marketable yield of sugar beet was not affected by Marigold(4) nor Margigold(8). The effect of Marigold on the marketable yield was stronger when combined with NT, this was only the case for Festien and not for Seresta. Averaged over 2014-2021 (Festien) and 2016-2021 (Seresta), both Marigold(4) and Marigold(8) had a positive effect on the marketable yield. This effect was stronger for 1:4 than for 1:8. As a result of the experimental set-up, a difference can be expected in the yields between Marigold(4) and Marigold(8) from 2018 (Festien), 2019 (sugar beet) and 2020 (seresta). For Festien no differences were found in the marketable yield between Marigold(8) and the control for the period 2018-2021. Compared to Marigold(4), the marketable yield of Marigold(8) was lower in 2019 but equal in the other years. For Seresta, the treatments Marigold(4) and Marigold(8) and the control resulted in equal marketable yield in 2020, but Marigold(8) led to a significant lower marketable yield in 2021, both compared to the control and Marigold(4). This was not the case when combined with NT. As can be seen from Figure 3-2, Marigold(8) only led to a lower yield when compared to Marigold(4) on field 70-4.

Overall, the cultivation of Marigold had a positive effect on the marketable yield of starch potatoes, which was stronger when cultivated 1:4 than 1:8. After 4 years the difference between 1:4 and 1:8 became apparent, and Marigold(8) was associated with lower to equal yields compared to the control and Marigold(4). This indicates that the effect of Marigold on the crop yield only lasts for the two subsequent potato cultivations. Seen over the two crop rotations, Marigold(4) resulted in a higher yield increase than Marigold(8), but both led to a yield increase when compared to the control.

Table 3-4 Average market yield of Marigold (1:4) and Marigold (1:8) in relative numbers. The relative numbers are based on yield in terms of tons of starch per hectare for Seresta and Festien, in tons of sugar per hectare for sugar beet, and in tons of yield corrected for moisture for spring barley.

	Seresta		Festien		Sugar beet		Average
	2016-2021		2014-2021		2015-2021		
Standard T	100.0	a	100.0	a	100.0	abc	100.0
Standard NT	101.1	a	102.6	a	96.6	a	100.1
Marigold(4) T	113.7	b	108.3	c	100.4	abcd	107.4
Marigold(4) NT	115.9	b	111.1	d	98.2	ab	108.4
Marigold(8) T	109.9		105.3		100.0		105.1
Marigold(8) NT	112.3		107.1		98.5		106.0
100% (ton/ha)	10.4		11.7		15.8		

3.2.2 Annual yield and trends

Improving soil quality is a slow process and therefore the effects on the yield are expected to show, and even increase, over time. For the treatments Compost, BCSR and Rockdust one might expect that the effect becomes notable after a few years and increases over time. Additionally, some treatments are expected to have a larger impact under stress conditions. For example, compost might have a larger impact on the crop yield under dry conditions. To gain insight in the annual effects and trends, the annual crop yields are presented in Appendix 5.

The results did not reveal upward (or downward) trends in crop yields when compared to the control. The yields of all treatments show year-to-year variability when compared to the control, and do not seem to be related to specific years. None of the treatments resulted in consistently lower or higher yields when compared to the control.

Bijker et al. (2022) studied the trends in yield and yield stability of this experiment in more detail. They found a negative trend, which is due to the relatively dry years in the end of the period, generally leading to lower yield levels. Regarding the yield stability Bijker et al. (2022) found that NT led to a slightly higher variation coefficient in crop yields, due to the year-to-year variability in the soil conditions which make NT more or less suitable. Marigold(4) led to a slightly improved yield stability for Seresta. This can be explained by the reduced *P. penetrans* population and subsequent lower damage to the root system, making the potato crop less sensitive to year-to-year variations in climatic circumstances. Applying compost, BCSR and Rockdust did not affect the stability of crop yields.

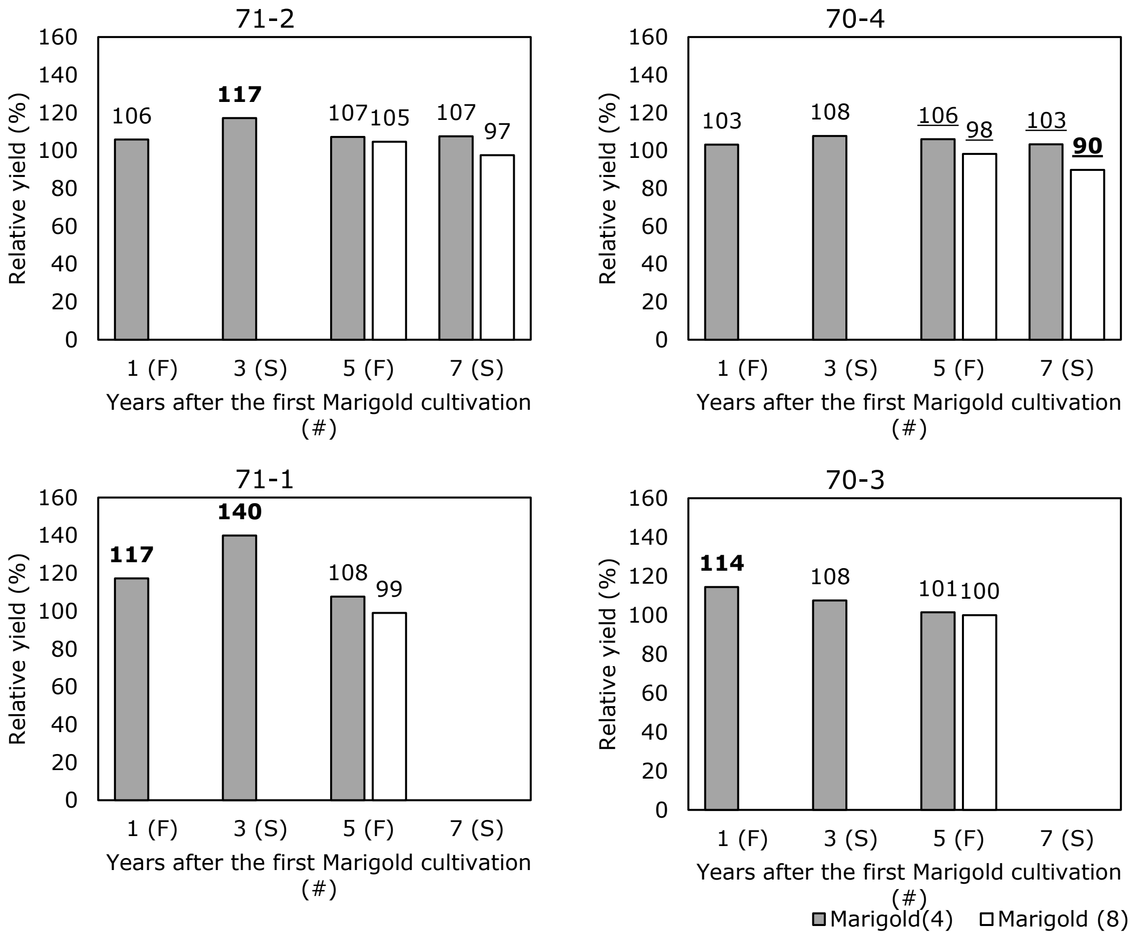


Figure 3-2 The yield effect of Marigold-T on the potato yields, Festien (F) and Seresta (S), for the four individual years. Significant differences from the control are indicated in bold, significant differences between Marigold(4) and marigold(8) are underlined. The yield of Marigold(8) is expected to be equal to Marigold(4) in the first three years.

3.3 Quality aspects

3.3.1 Potatoes

The main quality aspects of the starch potatoes are presented in Table 3-5. Additional characteristics were reported from 2017 onwards and are provided in Appendix 6. The starch content can be considered as the most important quality aspect. Compared to the control, no significant higher starch contents were found for any of the treatments. BCSR (and Combi) have led to the highest reduction in the starch content, both for Festien and Seresta. To a lesser extent, Compost led to a lower starch content in Seresta and Marigold(4) in a lower content in Festien. The UWW of potatoes is another important quality aspect. The BSCR method (and the combination of treatments) resulted in a significant lower UWW. To a lesser extent, Compost led to a lower UWW for Seresta. Other treatments did not affect the UWW. Other quality aspects include physiological aspects. No differences were found in physiological growth disorders between the treatments, both for Festien and Seresta. Corky ringspot is a sign of Tobacco rattle virus, which is spread by Trichodorus or Paratrichodorus or introduced via infected seed potatoes. No differences were found in the presence of corky ringspot between the treatments in Seresta. For Festien the presence of corky ringspot was negligible for all treatments. This is a variety characteristic, Festien is less susceptible to corky ringspot than Seresta.

Table 3-5 Quality aspects of the potatoes, averaged over 2014-2021.

		Underwater weight (g)				Starch content (%)			
		Festien		Seresta		Festien		Seresta	
Standard	T	560	f	566	g	23.8	f	24.1	g
	NT	559	f	562	fg	23.7	f	23.9	fg
Compost	T	557	f	555	ef	23.6	f	23.5	ef
	NT	556	f	559	efg	23.5	f	23.7	efg
BSCR	T	536	bc	540	bc	22.5	bc	22.7	bc
	NT	539	c	542	cd	22.6	c	22.8	cd
Rockdust	T	557	f	562	fg	23.6	f	23.8	fg
	NT	555	ef	558	ef	23.5	ef	23.6	ef
Combi	T	529	a	530	ab	22.1	a	22.2	ab
	NT	532	ab	530	a	22.3	ab	22.2	a

Table 3-6 Starch content in potatoes for the Marigold treatments, averaged over 2014-2021 Festien and averaged over 2016-2021 Seresta.

		Underwater weight (g)				Starch content (%)			
		Festien		Seresta		Festien		Seresta	
Standard	T	560	f	526	a	23.8	f	22.0	a
	NT	559	f	531	a	23.7	f	22.2	a
Marigold(4)	T	545	d	525	a	23.0	d	21.9	a
	NT	549	de	531	a	23.1	de	22.2	a
Marigold(8)	T	547		525		23.0		21.9	
	NT	549		528		23.2		22.0	

3.3.2 Sugar beet

The main quality aspects of sugar beet are the extractability and the sugar concentration. Results are presented in Table 3-7. Applying compost, BSCR and the combination of all treatments were associated with a lower extractability compared to the control. Rockdust and Marigold did not affect the extractability. Furthermore, there were no significant differences in extractability between tillage and non-inversion tillage. The sugar concentration is an even more important quality aspect. The variation between the years was larger than between the treatments. The average sugar concentration over de period 2014-2021 did not show large differences between the treatments, only BSCR was associated with a significant higher sugar concentration, both for tillage and non-inversion tillage.

Table 3-7 Quality aspects of the sugar beet, averaged over 2014-2021.

		Extractability (-)		Sugar concentration (%)	
Standard	T	92.1	c	18.4	a
	NT	92.1	c	18.5	a
Compost	T	91.6	b	18.4	a
	NT	91.7	b	18.4	a
BSCR	T	91.7	b	18.6	b
	NT	91.8	b	18.8	b
Rockdust	T	92.0	c	18.4	a
	NT	92.0	c	18.5	a
Combi	T	91.3	a	18.5	a
	NT	91.3	a	18.5	a

Table 3-8 Quality aspects of the sugar content of sugar beet for the Marigold treatment, averaged over 2015–2021.

		Extractability (-)		Sugar concentration (%)	
Standard	T	100.0	a	18.4	a
	NT	100.0	a	18.5	a
Marigold(4)	T	100.0	a	18.3	a
	NT	99.9	a	18.4	a
Marigold(8)	T	99.9		18.3	
	NT	99.8		18.4	

3.3.3 Spring barley

The main quality aspects of spring barley are provided in Table 3-9 and additional aspects are provided in Appendix 6. In 2020 the cultivation of spring barley was replaced by wheat. The protein content of wheat is higher than for barley, and therefore excluded from the averages. The protein content was significantly higher for non-inversion tillage than for conventional tillage, but was not affected by any of the other treatments. The percentage plump grains (>2.5mm) was negatively affected by Compost and BCSR. The highest percentage of plump grains was found for the control. The opposite was true for screenings (<2.2mm). The percentage screenings was the lowest for standard-T and standard-NT. BSCR had a significant higher percentage of screenings. Compost did not affect this quality aspect. The hectolitre weight was around 63 kg, and no significant differences were found between the treatments and the control. The protein content was positively affected by NT, this effect was significant for the standard treatment as well as seen over all treatments (data not shown).

Table 3-9 Quality aspects of spring barley (2014-2019 and 2021).

		Moisture (%)		Protein (%)		Plump grains (%)	
Standard	T	14.44	bc	11.18	a	97.40	c
	NT	14.79	d	11.54	c	97.35	c
Compost	T	14.28	ab	11.42	abc	96.77	ab
	NT	14.56	c	11.56	c	96.82	ab
BSCR	T	14.07	a	11.23	ab	96.59	a
	NT	14.45	bc	11.43	abc	96.63	a
Rockdust	T	14.40	bc	11.20	ab	97.33	c
	NT	14.61	cd	11.47	bc	97.15	bc

3.4 Nutrient management

3.4.1 Nutrient supply

The nutrient application per source and per treatment is presented in Appendix 7. Compost was applied on top of the standard fertilization with slurry. Compost contains substantial amounts of nutrients, which was (partly) compensated for in the artificial fertilization of P_2O_5 and K_2O, the amount of artificial N applied was not reduced. This resulted in 150, 9, 66 and 67 kg more N, plant available nitrogen (PAN)[3], P_2O_5 and K_2O respectively for Compost than for the control. The additional amount of PAN is thus small. The amount of P_2O_5 applied in Compost was twice the amount applied in the control, and twice the amount that is legally permitted. Also for Combi the amount of artificial P_2O_5 was compensated for the amount of compost applied. This was also done for K_2O, but additional K_2O was applied because of BSCR. In total, more K_2O was applied in Combi than for BCSR. With BSCR large amounts of K_2O, MgO, CaO and SO3 were applied with artificial fertilization. Especially for MgO, CaO and SO_3 the difference with the control was large (246, 385 and 288 kg ha^{-1} yr^{-1} respectively).

[3] The sum of the organic nitrogen and inorganic nitrogen in applied organic material (e.g. manur or compost) that is available for crop uptake in the year of application.

The artificial fertilization was not compensated for Rockdust, resulting in larger amounts of K_2O, MgO and CaO compared to the control.

3.4.2 Nutrient content

The nutrient concentration in the products over the period 2014-2017 is presented in de Haan et al. (2020), including statistics. From 2018 onwards the number of measurements were reduced: only Standard-T and Combi-NT were measured, product samples of the four replicates were mixed, and Mg, Ca, S and Na were no longer measured. Therefore, data from 2014-2017 and 2018-2021 were presented separately in Table 3-10 until Table 3-13, and no statistical analysis was performed for the data between 2018 and 2021.

In the period 2014-2017 no differences were found in the N concentration between the control and the treatments for all 4 crops. In the period 2018-2021, the N concentration was higher for Combi-NT than for the control in all four crops. The differences between Combi-NT and the control were larger than in the period 2014-2017 for Festien and sugar beet.

In the period 2014-2017 the amount of P was higher for Marigold(4) and Combi than for the control (both for T and NT) in Festien, this was not the case for Seresta. For Seresta, the amount of P was significant lower for BSCR than for the control, but the differences were small. For sugar beet and spring barley no differences in the P concentration were found between the treatments and the control. In the period 2018-2021 the amount of P was similar for Combi-NT as for the control, only for sugar beet the P concentration was higher.

In the period 2014-2017 significant higher K concentrations were found for BCSR and Combi (both T and NT) in the Festien and sugar beet, this was not the case for Seresta and spring barley. In the period 2018-2021 higher concentrations of K were found in Combi-NT compared to the control for Festien and Sugar beet, which is probably related to BCSR. This was, again, not the case for Seresta and spring barley.

Ca concentrations in the products did not seem to differ between the treatments. No Ca deficiencies were observed during the experiment.

Table 3-10 Nutrient concentration (g kg^{-1} dm) in Festien (product).

Treatment		N	P	K	Mg	Ca	S	Na
Years		2014-2015-2016-2017			2014-2015			
Standard	T	13.3	2.1	16.3	0.8	0.2	1.2	0.1
Marigold-4	T	13.4	2.4	17.8	0.9	0.3	1.4	0.1
Compost	T	13.5	2.2	17.8	0.8	0.3	1.3	0.1
BSCR	T	13.6	2.1	19.1	0.9	0.2	1.4	0.1
Rockdust	T	13.4	2.1	17.1	0.8	0.2	1.3	0.1
Combi	T	13.4	2.5	20.7	1.0	0.3	1.5	0.1
Standard	NT	13.5	2.0	16.4	0.7	0.2	1.2	0.1
Marigold-4	NT	13.5	2.4	18.0	0.9	0.2	1.3	0.1
Compost	NT	13.3	2.1	17.6	0.8	0.2	1.3	0.1
BSCR	NT	13.4	2.0	19.8	1.0	0.2	1.4	0.1
Rockdust	NT	13.7	2.1	17.2	0.8	0.3	1.3	0.1
Combi	NT	13.6	2.4	19.7	1.0	0.3	1.4	0.1
Years		2018-2019-2020-2021						
Standard	T	12.6	1.8	17.9				
Combi	NT	13.8	1.8	18.2				

Table 3-11 Nutrient concentration (g kg^{-1} dm) in Sugar beet (product).

Treatment		N	P	K	Mg	Ca	S	Na
Years		2014-2015-2016-2017			2014-2015			
Standard	T	4.6	1.4	5.9	1.2	0.8	0.3	0.3
Marigold-4	T	4.7	1.4	6.2	1.2	0.9	0.4	0.3
Compost	T	4.8	1.4	6.0	1.2	0.8	0.4	0.3
BSCR	T	4.7	1.4	6.8	1.2	0.8	0.4	0.3
Rockdust	T	4.7	1.4	6.1	1.2	0.9	0.4	0.3
Combi	T	4.9	1.4	7.2	1.3	0.8	0.4	0.3
Standard	NT	4.7	1.4	6.0	1.2	0.8	0.3	0.2
Marigold-4	NT	4.8	1.4	6.4	1.4	0.9	0.4	0.3
Compost	NT	4.8	1.4	6.2	1.3	1.0	0.4	0.3
BSCR	NT	4.5	1.3	6.7	1.2	0.8	0.4	0.2
Rockdust	NT	4.6	1.4	6.3	1.3	0.8	0.4	0.3
Combi	NT	4.9	1.5	6.7	1.2	0.7	0.4	0.3
Years		2018-2019-2020-2021						
Standard	T	5.9	1.0	6.7				
Combi	NT	6.3	1.2	8.4				

Table 3-12 Nutrient concentration (g kg^{-1} dm) in Seresta (product).

Treatment		N	P	K	Mg	Ca	S	Na
Years		2014-2015-2016-2017			2014-2015			
Standard	T	14.1	2.1	17.0	0.9	0.2	1.4	0.1
Marigold-4		13.9	2.1	16.6	0.8	0.2	1.3	0.1
Compost		14.0	2.1	16.6	0.8	0.2	1.2	0.1
BSCR		13.6	1.9	17.7	1.0	0.2	1.4	0.1
Rockdust		14.4	2.0	16.2	0.8	0.2	1.3	0.1
Combi		13.8	2.0	17.9	0.9	0.2	1.4	0.1
Standard	NT	13.9	2.1	16.7	0.8	0.2	1.3	0.1
Marigold-4		14.5	2.2	16.1	0.8	0.2	1.2	0.1
Compost		14.1	2.1	15.8	0.7	0.2	1.1	0.1
BSCR		13.6	1.9	17.1	0.9	0.2	1.4	0.1
Rockdust		13.7	2.0	15.0	0.7	0.2	1.1	0.1
Combi		13.9	2.0	17.6	0.9	0.2	1.3	0.1
Years		2018-2019-2020-2021						
Standard	T	14.9	1.6	16.2				
Combi	NT	15.0	1.7	15.9				

Table 3-13 Nutrient concentration (mg kg^{-1} dm) in Spring barley (product).

Treatment		N	P	K	Mg	Ca	S	Na
Years		2014-2015-2016-2017			2014-2015			
Standard	T	17.6	4.0	5.5	1.2	0.5	1.2	4.0
Marigold-4								
Compost		17.7	4.0	5.4	1.1	0.5	1.2	4.0
BSCR		17.8	3.9	5.4	1.2	0.5	1.2	3.9
Rockdust		17.3	3.9	5.4	1.1	0.5	1.1	3.9
Combi								
Standard	NT	18.0	4.0	5.4	1.2	0.5	1.2	4.0
Marigold-4								
Compost		17.7	4.0	5.4	1.1	0.5	1.2	4.0
BSCR		18.1	3.9	5.4	1.2	0.5	1.2	3.9
Rockdust		17.7	3.9	5.4	1.2	0.5	1.2	3.9
Combi		19.1						
Years		2018-2019-2020						
Standard	T	17.1	3.4	5.3				3.4
Combi	NT	18.2	3.6	5.4				3.6

The nutrient concentration in the crop leaves were measured for the potatoes and presented in Table 3-14 and Table 3-15. The nutrient concentration was for some years measured for the treatments Compost and Rockdust and presented separately in Appendix 8. The nutrient concentrations were measured in NT for each of the treatments.

Differences in nutrient concentrations in the leaves between the treatments BCSR and Combi were found for K, Ca, Mg, S, Cl, Mn and Mo. The BCSR method resulted in higher K concentrations, both in young and old leaves and both for Festien and Seresta. Contrary to the expectations, the Combi treatment was not associated with higher concentrations of K, this was only the case for Festien. BCSR led to lower concentrations of Ca in the leaves, although this was not significant for the young leaves of Festien. BCSR and Combi generally led to higher concentrations of Mg in the leaves (although not all significant), but also to a lower concentration in the young leaves of Seresta. BCSR also affected the S content in the leaves, which is additionally supplied in BCSR and not in Combi.

Applying rockdust had mainly an effect on Ca, which led to lower concentrations compared to the standard. Rockdust also influenced Mg in the Festien, which led to a higher concentration in the young leaves and a lower concentration in the older leaves. In Festien, rockdust led to a lower concentration of N in the leaves, both the young and old, while the N supply was unaltered. This was not the case for Seresta.

The effect of compost on the leave nutrient concentration was only measured for Seresta. Applying compost had an effect on the uptake of Ca, Cl, S, Mn, Fe, Zn and B. The application of compost led to higher concentrations of Cl, and to lower concentrations of Mn, Fe, N, Ca, Zn and B. Compost led to higher concentrations of S in the older leaves, but to lower concentrations in the younger leaves.

Table 3-14 Nutrient concentration (ppm) crop leaves of Festien, average over 2018-2020-2021. Significant differences compared to the control are indicated in bold.

Treatment		K	Ca	Mg	Na	N	Cl	S	P	Si	Fe	Mn	Zn	B	Cu	Mo	Al
Young leaves																	
Standard	NT	3675	1066	557	6.9	1254	815	281	235	30	5.1	13.8	2.0	4.0	0.6	0.1	0.6
BCSR	NT	**4105**	907	623	7.7	1249	789	**405**	209	28	6.8	9.8	2.2	4.1	0.6	0.1	0.6
Combi	NT	3681	1026	**659**	8.1	1157	966	211	218	28	4.8	8.5	2.1	3.8	0.5	**0.1**	0.6
Old leaves																	
Standard	NT	3415	2194	584	4.7	1351	540	200	80	19	6.2	24	2.7	3.0	0.2	0.0	2.0
BCSR	NT	**3948**	**1812**	**766**	4.5	1277	562	**314**	86	19	7.8	16	2.5	3.3	0.2	0.0	2.4
Combi	NT	3189	2236	**880**	6.0	1404	**798**	176	80	19	6.0	**14**	2.2	3.3	0.2	**0.1**	1.8

Table 3-15 Nutrient concentration (ppm) crop leaves of Seresta, average over 2015-2016-2017-2018-2019-2020-2021. Significant differences compared to the control are indicated in bold.

Treatment		K	Ca	Mg	Na	N	Cl	S	P	Si	Fe	Mn	Zn	B	Cu	Mo	Al
Young leaves																	
Standard	NT	3591	1203	669	8.1	1254	1092	218	205	18	5.9	14.0	2.0	3.1	0.7	0.1	0.6
BCSR	NT	**4411**	**845**	**611**	7.5	1254	1174	**288**	189	16	5.7	**10.5**	1.9	2.9	0.7	0.1	0.6
Combi	NT	**3990**	**978**	689	8.0	1239	**1358**	237	198	17	5.6	**9.7**	1.9	2.8	0.7	0.1	0.6
Old leaves																	
Standard	NT	3235	1582	649	7.2	1189	683	133	78	16	5.8	17	1.9	2.1	0.3	0.0	3.0
BCSR	NT	**3930**	**1133**	672	6.2	1159	**823**	**166**	72	14	5.4	**13**	2.0	2.1	0.3	0.0	2.6
Combi	NT	**3467**	**1390**	**755**	6.7	1214	**973**	141	72	14	5.2	**12**	1.8	2.0	0.3	0.1	2.2

3.4.3 Nutrient balance (supply-removal)

The average soil nutrient balance is presented in Table 3-16, the nutrient balances per crop can be found in Appendix 9.

All treatments resulted in a larger surplus of N compared to the control. The higher surplus for the treatments rockdust and BCSR was a result of a lower removal, because the same amount of N was supplied as in the control. For marigold the higher surplus was a result of a lower supply and an even lower removal. With compost a large amount of N was supplied, which did not result in a higher removal and thus in a larger surplus. In terms of mineral N, compost led to a surplus twice the amount of the control.

The control is associated with a strict P_2O_5 equilibrium fertilisation. Treatments with an additional P_2O_5 fertilisation (compost and combi) resulted in a P_2O_5 surplus. The surplus was smaller than could be expected based on the supply, because of an increased removal. The additional removal was higher than the increase in yield, which suggests that the crops overconsumed[4] P_2O_5. The remainder of the treatments (marigold, BCSR, rockdust) resulted in a surplus or shortage close to 0.

Treatments with additional K_2O fertilisation (compost, BCSR, rockdust and combi) resulted in large surpluses of K_2O, the control and marigold resulted in shortages. Compared to the control, treatments with additional K_2O fertilisation led to an increase in K_2O concentration in the crop yields, only BCSR and Combi led to a higher removal. For BCSR and Combi, the increase in removal was higher than the increase in yield, which indicates overconsumption.

With BCSR, Rockdust and Combi large amounts of CaO were applied. The removal of all the treatments was similar to the control, which led to increased surpluses of CaO for BCSR, Rockdust and Combi.

Compared to the control, additional MgO fertilization did not result in higher removal and therefore led to surpluses. For Combi, the supply was 15-fold of the removal, leading to a large surplus (340kg ha^{-1}). For combi and BCSR the surplus of MgO was on purpose, to alter the Ca/Mg balance in the soil. Also compost was associated with large surpluses (67 kg ha^{-1}).

Contrary to all other treatments, straw was exported from the field in Standard-T. Exporting or incorporating straw is the main difference between Standard-T and Standard-NT. The removal for Standard-T was higher than for Standard-NT, the differences were 7 kg N, 3 kg P_2O_5, 15 kg K_2O and 1 kg SO_3 ha^{-1} yr^{-1} when averaged over the whole crop rotation.

Overconsumption of nutrients becomes visible in Table 3-17. Overconsumption occurs when nutrients are supplied excessively and lead to higher concentrations in products but not to higher yields. Overconsumption of N did not occur. The greatest overconsumption was found for MgO in BCSR, for P_2O_5 in Compost and of SO_3 in BCSR.

[4] Overconsumption: in case the application of nutrients do not result in a higher yield, but do result in higher concentrations in crop yields.

Table 3-16 Average nutrient supply and removal in the period 2014-2021, expressed in kg ha^{-1} yr^{-1}.

Treatment			N-tot	PAN	P_2O_5	K_2O	MgO	CaO	SO_3
Standard	T	Supply	186	169	60	181	35	44	28
		Removal	158	158	61	208	22	9	32
		Balance	28	11	0	-27	12	35	-4
Marigold-4		Supply	173	157	60	181	34	44	23
		Removal	133	133	57	204	22	9	31
		Balance	40	24	3	-22	12	35	-8
Marigold-8		Supply	187	171	60	181	35	44	28
		Removal	145	145	63	205	23	10	33
		Balance	42	26	-3	-24	11	34	-5
Compost		Supply	336	178	126	248	91	37	13
		Removal	157	157	66	207	23	10	32
		Balance	179	21	60	41	68	28	-19
BCSR		Supply	186	169	60	264	281	429	316
		Removal	156	156	63	219	25	9	36
		Balance	31	13	-3	44	256	420	281
Rockdust		Supply	186	169	66	265	108	137	28
		Removal	154	154	64	197	23	10	33
		Balance	32	15	2	67	86	127	-5
Combi		Supply	338	180	132	386	364	474	214
		Removal	152	152	67	237	24	9	33
		Balance	187	28	65	150	340	464	181
Standard	NT	Supply	186	169	60	181	35	44	28
		Removal	151	151	64	193	22	9	31
		Balance	35	18	-4	-12	12	35	-3
Marigold-4		Supply	173	157	60	181	34	44	23
		Removal	136	136	58	204	22	9	30
		Balance	36	21	2	-23	11	35	-8
Marigold-8		Supply	187	171	60	181	35	44	28
		Removal	150	150	65	205	24	9	32
		Balance	37	21	-5	-24	11	34	-4
Compost		Supply	336	178	126	248	91	37	13
		Removal	152	152	66	197	24	11	31
		Balance	184	26	60	51	67	27	-18
BCSR		Supply	186	169	60	264	281	429	316
		Removal	153	153	63	220	25	9	36
		Balance	33	16	-3	43	256	420	280
Rockdust		Supply	186	169	66	265	108	137	28
		Removal	151	151	64	192	23	9	31
		Balance	35	18	3	72	85	128	-3
Combi		Supply	338	180	132	386	364	474	214
		Removal	156	156	60	221	24	9	33
		Balance	182	24	72	166	340	465	181

Table 3-17 Relative nutrient uptake and field yield (2014-2021) on the level of crop rotation.

		Relative nutrient uptake							Relative field yield*
		N	NAC	P_2O_5	K_2O	MgO	CaO	SO_3	
T	Marigold-4	0.84	0.84	0.94	0.98	0.97	1.00	0.96	0.95
	Marigold-8	0.92	0.92	1.04	0.99	1.04	1.06	1.03	1.01
	Compost	0.99	0.99	1.09	0.99	1.05	1.07	1.01	1.03
	BCSR	0.98	0.98	1.04	1.05	1.11	0.97	1.11	1.02
	Rockdust	0.97	0.97	1.06	0.95	1.02	1.09	1.04	1.03
	Combi	0.96	0.96	1.10	1.14	1.06	1.00	1.03	1.04
NT	Standard	0.96	0.96	1.06	0.93	0.99	0.94	0.97	1.00
	Marigold-4	0.86	0.86	0.96	0.98	1.00	0.97	0.95	0.95
	Marigold-8	0.95	0.95	1.08	0.99	1.07	1.03	1.02	1.00
	Compost	0.96	0.96	1.09	0.95	1.07	1.17	0.97	1.02
	BCSR	0.97	0.97	1.04	1.06	1.13	1.01	1.12	1.03
	Rockdust	0.96	0.96	1.05	0.92	1.03	0.98	0.97	1.01
	Combi	0.99	0.99	0.99	1.06	1.06	0.94	1.04	1.01

* Relative to the control.

3.5 Soil quality

3.5.1 Soil nutrients

3.5.1.1 Soil nutrient parameters

The chemical soil fertility for Combi-NT and Compost-T compared to the control is presented in Table 3-18. Results per field and per year are presented in Appendix 10.

Averaged over 2021-2022 and over the fields, Compost-T resulted in a significant higher pH, CEC, CEC saturation, P-Al, Mg and Ca. Compost-T was associated with an average annual surplus of 60 kg P_2O_5 ha^{-1} jr^{-1}, while the supply and removal were equal for the control. A higher P-Al for Compost-T compared to the control is therefore in line with the expectations. Compost also contains Mg and Ca, which led to higher concentrations in the soil compared to the control. With compost, great amounts of N are supplied compared to the control, resulting in a higher surplus of N (179 vs 28 kg N ha^{-1} yr^{-1}). Although not significant, differences in N status were found between Compost-T and the control.

Apart from compost, Combi-NT includes additional supply of Ca, Mg and K applied as part of BCSR and Rockdust. Averaged over 2014-2022 and over the fields, Combi-NT resulted in a significant higher pH, CEC saturation, P-Al, K-status, Mg and Ca. The results are in line with the expectations. Liming is done as part of Combi-NT, resulting in an increased pH, which enables cations to replace H+ at the CEC and increase the CEC saturation. Also CEC increased, albeit only significant for one field (70-3). This is probably a result of compost and the incorporation of straw, which increases the soil organic matter and therewith the CEC. Combi-NT is associated with an surplus of 72 kg P_2O_5 ha^{-1} yr^{-1}, while for the control the supply and removal were equal. As a result, P-Al was higher for Combi-NT than for the control. High quantities of K, Mg and Ca measured in Combi-NT compared to the control can be attributed directly to the high surpluses because of the large quantities that are supplied with Combi-NT. Larger quantities of total N were supplied in Combi-NT than in the control, and the NAC applied was twice as high for Combi-NT as for the control. Hence, a higher N status can be expected. Table 3-18 shows a higher N-status, but the difference was not significant. Combi-NT was also associated with a higher supply of S, which did not result in a significant increase in the soil compared to the control.

Differences between fields and trends are presented in Appendix 10. An average annual surplus of 72 kg P_2O_5 ha^{-1} yr^{-1} with Combi-NT led to a higher P-Al compared to the control which did not have a surplus. However, a sharp increase in P-Al over time did not become visible for Combi-NT. For the control, P_2O_5 supply and removal were equal, which did not result in a strong decrease of P-Al. Plant available phosphate (P-PAE) decreased slightly for the control, and decreased a bit more for Combi-NT. The control is associated with a lower annual supply than removal of K_2O, surprisingly, the K status did not decrease in the period 2014-2022 (see Appendix 9). Combi-NT was associated with a large surplus of K_2O, which resulted in a slightly higher K-status.

Table 3-18 Average soil fertility parameters, measured annually for the period 2014-2022 for the control and Combi-NT and for the period 2021-2021 for Compost-T. Significant differences with the control are indicated in bold.

		2014-2022				2021-2022			
		Control		Combi-NT		Control		Compost-T	
C:N ratio	-	22.9	a	22.9	a	23.9	a	23.7	a
pH	-	4.9	a	5.2	b	4.9	a	5.1	b
Soil organic matter	%	10.6	a	11.2	a	10.4	a	11.4	a
Lutum	%	1.7	a	1.8	a	2.0	a	2.1	a
CEC	mmol kg^{-1}	145	a	163	a	141	a	159	b
CEC saturation	%	87	a	92	b	86.5	a	90	b
C:S ratio	-	113	a	110	a	105	a	115	a
Total N	mg N kg^{-1}	2756	a	2916	a	2545	a	2918	a
P-PAE	mg P kg^{-1}	4.4	a	3.9	a	4.3	a	4.6	a
P-Al	mg P_2O_5 $100g^{-1}$	24	a	28	b	24	a	27	b
Total K	mmol kg^{-1}	2.7	a	3.1	b	3.1	a	3.3	a
K-number	-	8.0	a	11.1	b	8.7	a	9.0	a
Total S	mg S kg^{-1}	554	a	614	a	570	a	593	a
Total Mg*	mg Mg kg^{-1}	10.6	a	15.7	b	9.3	a	11.4	b
Total Na*	kg Na ha^{-1}	1.1	a	1.2	a	1.1	a	1.1	a
Total Ca	kg Ca ha^{-1}	6022	a	7096	b	6294	a	7325	b
Available Ca	kg Ca ha^{-1}	111	a	107	a	98	a	99	a

** Only measured in 2019-2022.*

3.4.1.1. Ca/Mg ratios following the BCSR-method

The Ca and Mg saturation and Ca/Mg ratio are presented in Figure 3-3 and the pH and H+ in Figure 3-4. The results are averaged over the four fields, results per field are presented in Appendix 10.
Liming is done as part of BCSR, the effect on the pH becomes visible only to a limited extend. The effect becomes more clearly visible in the H+ saturation (see Figure 3-4). The H+ saturation was lower for BCSR than for the control, making space available for cations to adsorb to the CEC. The CEC in 2021 was somewhat

higher for BCSR than for the control, and was more or less stable in the period 2014-2021. The Mg-saturation was between 6-7% at the start of the experiment[5], and this level was maintained in the following years for the control. For BCSR, the Mg saturation increased up to 11-13%. BCSR reached the desired Mg saturation after 5 to 6 years. Both for the control and BCSR, the Ca saturation varied between 53 and 68% in the period 2014-2021. The Ca saturation both for BCSR and the control did move slightly towards the desired saturation (68%). It is remarkable that, even though large quantities of Ca are applied with the BCSR strategy, the Ca saturation did not strongly increase. Although the desired Ca saturation was not reached, the Ca/Mg ratio of BCSR moved towards the desired ratio, which was reached in 2018-2021. The Ca/Mg ratio of the control remains more or less at the initial level, only for field 71-2 the Ca/Mg ratio moved towards the desired ratio in the period 2014-2019 and increased afterwards, which is due to the decreasing Mg saturation. It is not clear why the Mg saturation suddenly decreased.

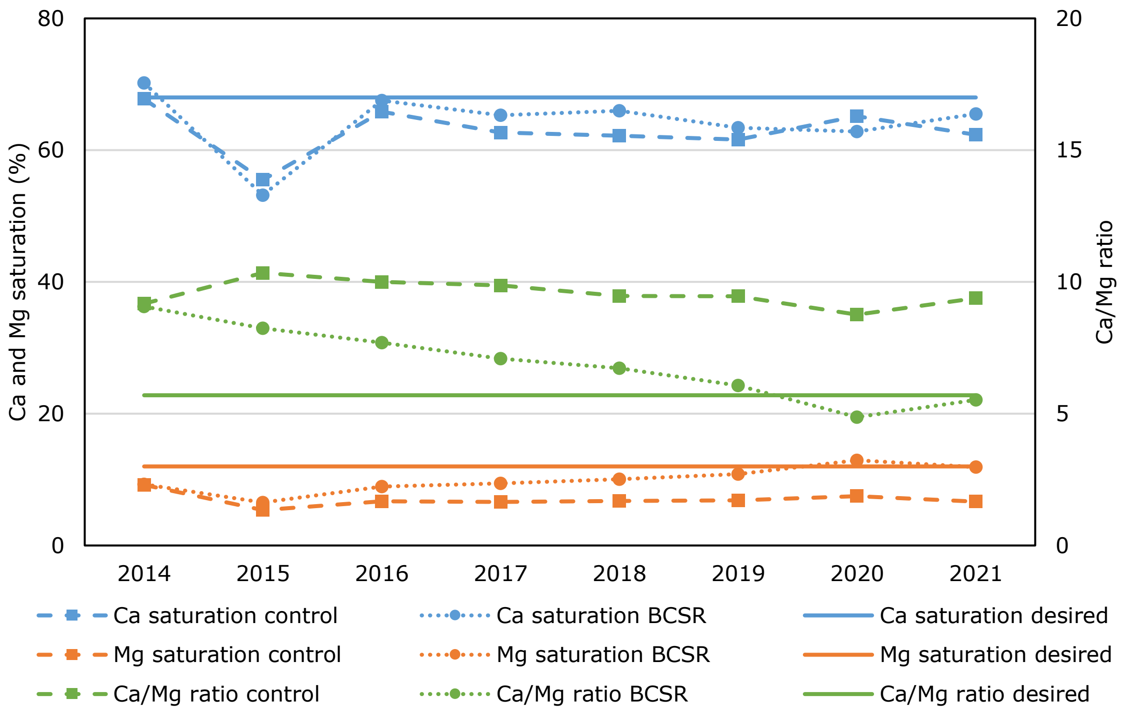
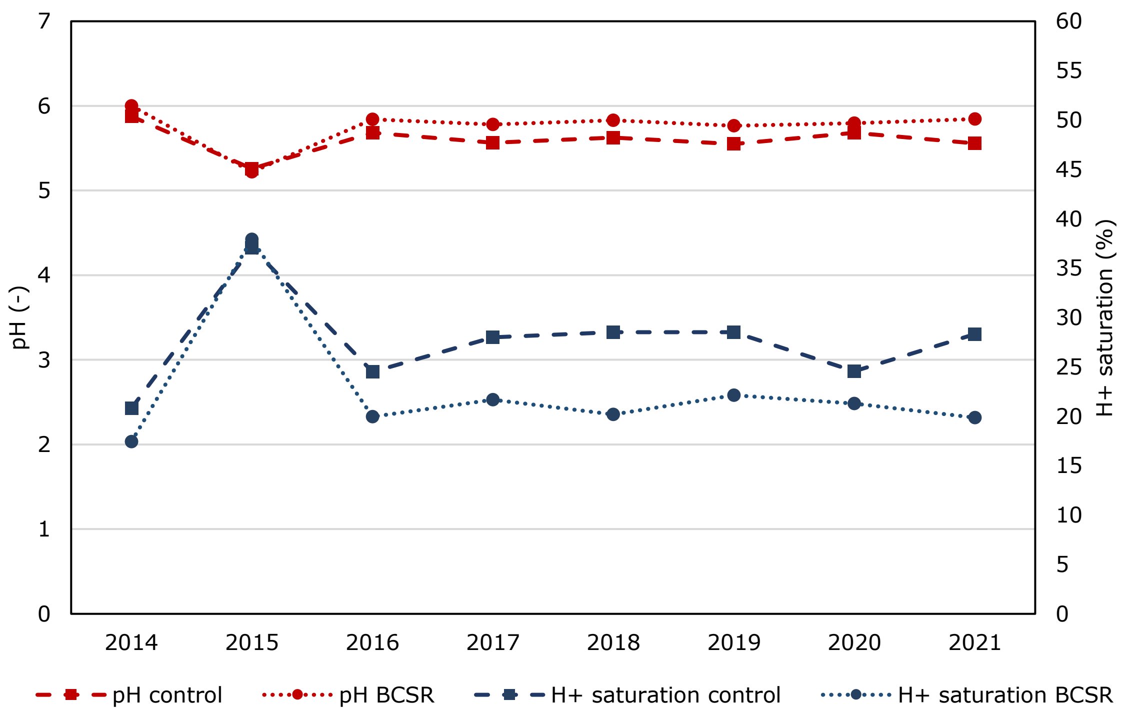


Figure 3-3 Ca and Mg saturation and the Ca/Mg ratio for BCSR-T and the control in the period 2014-2021, averaged over the four fields.



[5] Relative high Mg-saturation values were found for field 71-1 (17-18%) in 2014, for all the individual plots. These results are considered as not reliable, since the values in the subsequent years were between 5-7%. In line with the high Mg-saturation in 2014 was the low saturation of H+ in 2014.

Figure 3-4 pH and H+ saturation for BCSR-T and the control in the period 2014-2021, averaged over the four fields.

3.5.2 Soil organic matter

In Table 3-19 the initial and final soil organic matter content are presented, including the annual balance. The annual decomposition of soil organic matter was estimated at 2082 kg ha^{-1} jr^{-1} for each treatment. The control was associated with a higher decomposition than supply of organic matter, resulting in a negative balance and a declining soil organic matter content. The soil organic matter content dropped with 0.1 percentage point in 8 years. Although there were small differences, Marigold, BCSR and Rockdust resulted in a very similar soil organic matter content in 2021. Only compost and Combi were associated with a surplus on the organic matter balance, resulting in an increase in the soil organic matter content. Compost and Combi resulted in an increase of 0.7 percentage point in the soil organic matter.

Table 3-19 The annual supply of organic matter (OM), annual decomposition of soil organic matter (SOM), and OM balance averaged over 2014-2021, and the estimated initial and final SOM content.

		Supply of effective OM	Decom-position of SOM	OM balance	Initial SOM content	Calculated SOM content in 2021	Initial SOM content	Calculated SOM content in 2021
		kg ha^{-1} jr^{-1}			kg ha^{-1}		%	
Control	T	1371	2082	-711	346928	341242	11.3	11.2
Marigold(4)	T	1264	2082	-815	346928	342394	11.3	11.2
Marigold (8)	T	1621	2082	-458	346928	344982	11.3	11.3
Compost	T	4539	2082	2458	346928	366591	11.3	12.0
BCSR	T	1682	2082	-399	346928	343733	11.3	11.2
Rockdust	T	1681	2082	-401	346928	343721	11.3	11.2
Combi	T	4578	2082	2497	346928	366901	11.3	12.0
Standard	NT	1681	2082	-400	346928	343726	11.3	11.2
Marigold(4)	NT	1325	2082	-754	346928	342431	11.3	11.2
Marigold (8)	NT	1694	2082	-385	346928	345111	11.3	11.3
Compost	NT	4518	2082	2437	346928	366420	11.3	12.0
BCSR	NT	1661	2082	-421	346928	343560	11.3	11.2
Rockdust	NT	1672	2082	-409	346928	343655	11.3	11.2
Combi	NT	4530	2082	2449	346928	366519	11.3	12.0

3.5.3 Soil structure and water availability

3.5.3.1 Penetration resistance

Soil compaction can be characterized by the PR. The results are shown in Table 3-20. Since measurements were not executed at the same moment (indicated in the second row), comparisons can only made pair-wise between the treatments and the control. Additionally, the PR is available for the period 2014-2021 for combi-NT and the control and shown in Figure 3-5. The depth at which root hindrance occurs is determined. The depth at which PR exceeds 1.5 MPa is classified as 'root hindrance' (Zwart et al., 2011). The depth at which PR exceeds MPa>3.0 is classified as 'root inhibition' (Zwart et al., 2011).

On average, root hindrance occurred at a depth of 24-32cm. Root inhibition occurred at a depth of >40cm for all treatments. The depth at which roots experienced inhibition did not differ between inversion and non-inversion tillage. Non-inversion tillage resulted in a significant lower PR in 0-20 and 20-40cm. Roots of crops that are grown in a non-inversion tillage system experienced hindrance at a greater depth when compared to the control. Compost or BCSR did not result in lower PR or depth at which root hindrance or inhibition occurs.

The combination of all treatments (Combi-NT) resulted in a significant lower PR in 0-20 and 20-40cm, and roots were hindered at a greater depth compared to the control. The depth at which roots experienced inhibition did not differ between Combi-NT and the control. Figure 3-5 shows that the difference in PR between Combi-NT and the control is larger at 20-40 cm than in 0-20 cm (average difference of 8 and 21% respectively). The difference at 20-40 cm is rather constant for the complete period (except for the second measurement in 2015), a trend did not occur (data not shown).

Table 3-20 Soil compaction at two soil layers, root hindrance (MPa 1.5) and root inhibition (MPa 3.0) for standard-NT, compost-T, Ca/Mg-T compared to the control (2021); and for combi-NT compared to the control (2014-2021). Significant differences with the control are indicated in bold.

		Standard-NT	Control	Compost-T	Control	BCSR-T	Control	Combi-NT	Control
		2014, 2015, 2020, 2021		2021		2021		2014-2021	
0-20cm	MPa	**0.71**	0.75	0.70	0.70	0.70	0.70	**0.70**	0.75
20-40cm	MPa	**1.99**	2.37	1.40	1.40	1.42	1.40	**1.72**	2.22
MPa 1.5	cm	**28.98**	23.62	30.62	26.59	27.65	26.59	**31.65**	24.26
MPa 3.0	cm	44.71	43.32	46.43	44.74	43.40	44.74	51.21	46.66

3.5.3.2 Bulk density and moisture content at field capacity

Reduced tillage systems generally have higher soil density than conventionally tilled soil because of lack of loosening from inversion tillage and natural reconsolidation (Crittenden, 2015). On the longer term, however, reduced tillage systems maintain continuous macropores better than conventional tillage since their continuity

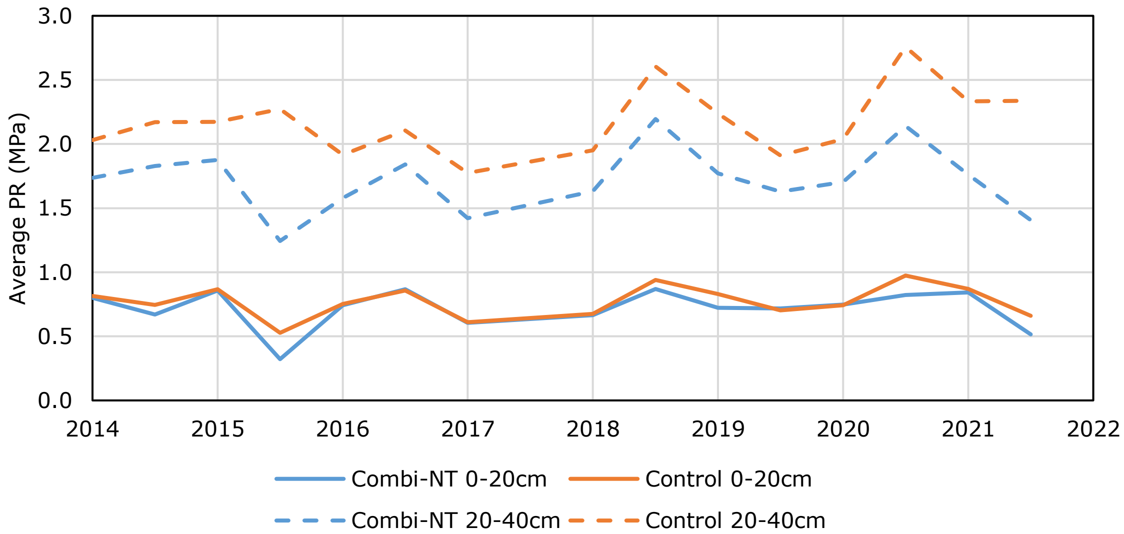


Figure 3-5 Average PR in the period between 2014 and 2021. In 2013 only field 71-2 was measured and could therefore not be included in this figure.

is not or less disrupted.

The bulk density is presented in Table 3-21. The variation in bulk density was relative high, varying between 0.33 and 1.72 g $cm^{3\ -1}$. However, the differences in bulk density between the treatments were relatively small.

Table 3-21 shows that NT is not necessarily associated with a higher bulk density. Also the moisture content at field capacity (FC) were relatively small between the treatments. As can be seen in Figure 3-6, the water holding capacity (moisture content at FC) is for a large extent related to the bulk density. However, the bulk density is not the only determinant, and the pore sizes and distribution throughout the soil profile might also be of importance when looking at the water holding capacity.

Table 3-21 Bulk density and soil moisture content at field capacity at a depth of 15cm.

	Bulk density	Moisture content at FC
	(g $cm^{3\ -1}$)	(%)
Control	1.23	43.21
Standard-NT	1.19	42.20
Combi-NT	1.09	43.65

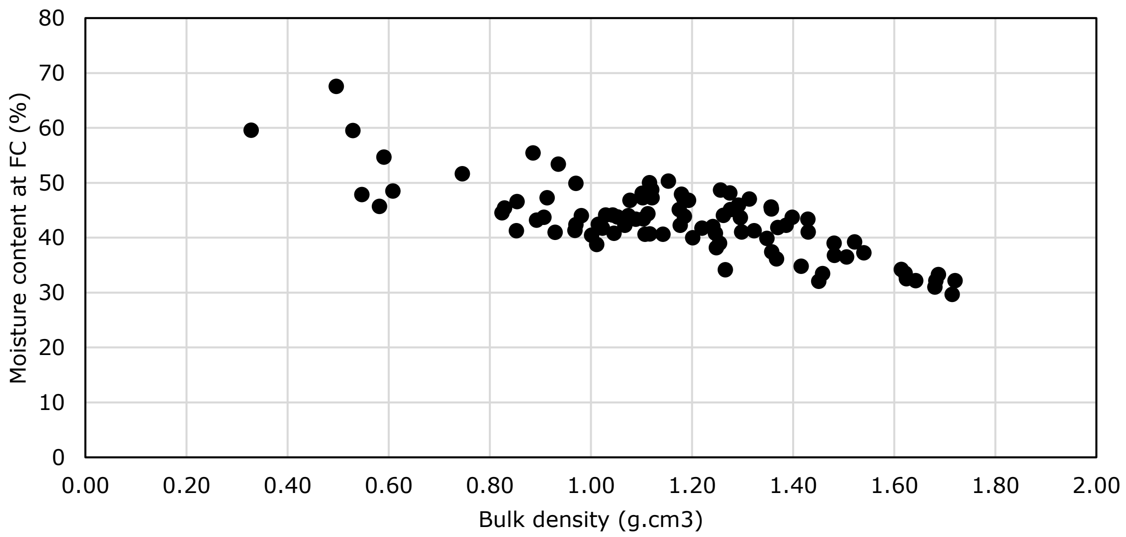


Figure 3-6 The relation between the bulk density and the moisture content at FC.

3.5.3.3 Plant available water

The plant available water was measured for the control and Combi-NT at two organic matter level intervals, seeTable 3-22.

Plant available water was determined for a subset of plots described in 3.5.3.2, and presented in Appendix 11. As can be seen from the graphs in Appendix 11, the plant available water follows a similar pattern during the growing season for each of the plots, for most of the years. These results indicate that there was no or limited difference in soil water retention between the plots (i.e. amount of time for precipitation or irrigation water to infiltrate into or remain in the soil). However, differences could be observed in the amount of plant available water.

At the low soil organic matter interval (<10%) no difference between Combi-NT and the control became clear. In some years the control was associated with more plant available water than Combi-NT, and for others Combi-NT was associated with more plant available water. This did not seem to be linked to years classified as dry. At the high soil organic matter interval (≥10%) the difference between Combi-NT and the control became even less clear. Only in 2018 Combi-NT was associated with more plant available water than the control.

For the control, a difference in plant available water between the soil organic matter levels became visible for some of the years, with the plot at a high organic matter level having a higher percentage of plant available water. For Combi-NT, the difference between the low and high organic matter interval became less clear and did even show less consistency during and between the years.

Table 3-22 Water availability in the period 2015-2021 between the first of June and the first of September.

Plot	Treatment	Organic matter level		Bulk density	Moisture content at FC	Average plant available water	
(#)		Class	(%)	(g $cm^{3\ -1}$)	(%)	(%)	Variance
65	Control	Low	8.5	1.18	43.13	54.92	799
56	Combi-NT	Low	7.2	1.37	41.85	55.39	831
71	Control	High	10.3	1.29	43.12	58.41	813
82	Combi-NT	High	15.6	0.84	48.20	58.35	807

3.5.4 Soil biology

At the beginning of the experiment, there were no significant differences between the plots in field 71-2 with the intended treatments (see Appendix 12). However, it cannot be excluded that there were differences in parameters that were not measured at this moment (e.g. AMF or protozoa). The results of the measurement in 2020 are presented in Table 3-23. As can be derived from the results, there were no significant differences between the treatments in any of the parameters measured. In 2022 more extensive measurements were done, covering the four fields. Soil organic matter was found to have a strong impact on soil biology aspects. Significant positive correlations were found between the amount of organic matter and several microbiological parameters: microbial biomass ($R=0.8$, $p<0.01$), the bacteria number ($R=0.8$, $p<0.01$), Gram-positive bacteria ($R=0.73$), Actinobacteria ($R=0.71$), total fungal numbers ($R=0.74$), saprophytes ($R=0.6$), AMF ($R=0.76$), protozoa ($R=0.55$), microbial biomass C ($R=0.79$), bacterial biomass C ($R=0.79$), and fungal biomass C ($R=0.78$), see Figure 3-7 and Appendix 12. Therefore, soil organic matter was included as a co-variable in the statistical analysis to evaluate the effects of the treatments. The results are presented in Table 3-24. The results of several measurements differed significantly between the treatments. Pairwise analyses showed that the number of fungi, saprophytes, protozoa, fungi/bacteria ratio, diversity, fungal biomass and AMF measured by PLFA analysis were sensitive to the treatments (see Appendix 12). It needs to be mentioned, however, that Eurofins indicates that their method of calculating the diversity is still under development. To conclude, soil organic matter strongly affects soil biology, but soil treatments can still have an effect on some parameters. Standard-NT did not significantly affect any of the soil biodiversity indicators compared to Standard-T. Applying compost increased the amount of protozoa and led to a higher fungal/bacterial ratio. Combi-NT led to a higher fungal number, more fungal biomass, a higher fungal/bacterial ratio, and more diversity compared to the control.

Table 3-23 Average values of the parameters measured in 2020 by Jaap Bloem (upper part) and Eurofins (bottom part) in the treatments Combi-NT and Standard-T in field 71-2, and the results of a linear model.

Parameter	Unit	Treatment	Average	F	P
Analysed by the Soil Biology Lab					
Fungal biomass	µg C/g	Combi-NT	7.34	6.51	0.08
		Standard-T	4.37		
Bacterial biomass	µg C/g	Combi-NT	14.38	6.01	0.09
		Standard-T	46.50		
PMN		Combi-NT	34.15	0.00	0.93
		Standard-T	34.55		
HWC		Combi-NT	1732	0.10	0.77
		Standard-T	1651		
Analysed by Eurofins Agro					
Microbial biomass	mg C/kg	Combi-NT	329	0.13	0.74
		Standard-T	347		
Bacterial biomass	mg C/kg	Combi-NT	145	0.25	0.65
		Standard-T	158		
Fungal biomass	mg C/kg	Combi-NT	101	0.51	0.53
		Standard-T	117		
Fungi/Bacteria	mg C/kg	Combi-NT	0.70	0.60	0.50
		Standard-T	0.75		

Table 3-24 Average values of the parameters measured in 2022 of the treatments Combi-NT, Standard-NT, Compost-T and Standard-T and the results of a linear mixed model.

Variable	Unit	Treatment	Average	Sig.	Chisq	p
Microbial biomass	mg PLFA/kg	Combi-NT	12.38		2.97	0.40
		Standard-NT	12.31			
		Compost-T	12.94			
		Standard-T	12.94			
Total bacterial number	mg PLFA/kg	Combi-NT	10.81		4.52	0.21
		Standard-NT	10.94			
		Compost-T	11.31			
		Standard-T	11.63			
Grampositive bacteria	mg PLFA/kg	Combi-NT	4.19		2.82	0.42
		Standard-NT	4.18			
		Compost-T	4.29			
		Standard-T	4.46			
Actinobacteria	mg PLFA/kg	Combi-NT	0.96		1.67	0.64
		Standard-NT	0.96			
		Compost-T	0.99			
		Standard-T	1.03			
Gramnegative bacteria	mg PLFA/kg	Combi-NT	6.59		6.54	0.09
		Standard-NT	6.70			
		Compost-T	6.96			
		Standard-T	7.08			
Total fungal number	mg PLFA/kg	Combi-NT	1.12	c	17.23	**<0.01**
		Standard-NT	0.90	a		
		Compost-T	1.04	bc		
		Standard-T	0.93	ab		
Saprophytes	mg PLFA/kg	Combi-NT	0.41		9.81	**0.02**
		Standard-NT	0.36			
		Compost-T	0.39			
		Standard-T	0.35			
AMF	mg PLFA/kg	Combi-NT	0.70	b	14.67	**<0.01**
		Standard-NT	0.54	a		
		Compost-T	0.66	b		
		Standard-T	0.59	ab		
Protozoa	m mg PLFA/kg	Combi-NT	0.13	ab	8.84	**0.03**
		Standard-NT	0.11	ab		
		Compost-T	0.12	b		
		Standard-T	0.10	a		
Fungi/bacteria ratio	-	Combi-NT	0.82	c	117.37	**<0.01**
		Standard-NT	0.66	a		
		Compost-T	0.71	b		
		Standard-T	0.64	a		
Grampositive/Gramnegative bacteria	-	Combi-NT	0.65		1.92	0.59
		Standard-NT	0.63			
		Compost-T	0.63			
		Standard-T	0.64			
Diversity	-	Combi-NT	3.15	b	9.96	**0.02**
		Standard-NT	3.11	a		
		Compost-T	3.12	ab		
		Standard-T	3.11	ab		
Microbial biomass C	mg PLFA/kg	Combi-NT	268.38		3.02	0.39
		Standard-NT	265.56			
		Compost-T	278.31			
		Standard-T	281.31			
Bacterial biomass C	mg PLFA/kg	Combi-NT	102.13		4.71	0.19
		Standard-NT	103.75			
		Compost-T	107.44			
		Standard-T	110.00			
Fungal biomass C	mg PLFA/kg	Combi-NT	81.63	b	17.62	**<0.01**
		Standard-NT	64.88	a		
		Compost-T	75.06	ab		
		Standard-T	67.75	a		

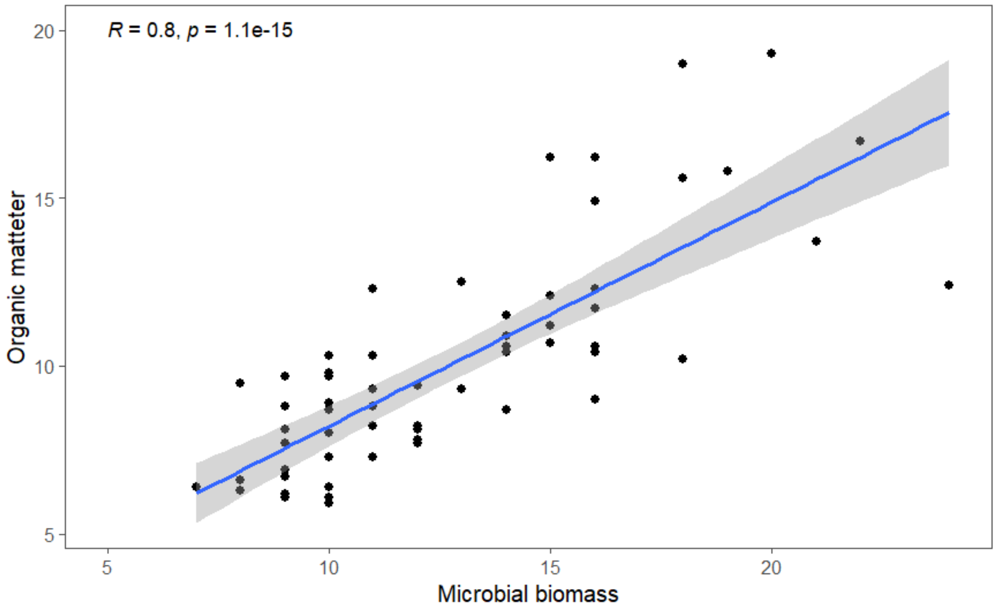


Figure 3-7 Correlation between microbial biomass and soil organic matter, measured in 2022 for four treatments and in all four fields.

3.5.5 Nematodes

3.5.5.1 Nematode community

At the time of sampling in 2013 the treatments had not yet been applied, but analysis was done for the determination of the initial situation. In 2013 there was no significant difference in numbers of plant feeders among the plots where the two treatments (Control and Combi-NT) were going to be applied (Table 3-25; Appendix 13). Results of the sampling in 2013 of the fields 70-3, 70-4 and 71-1 are given in Appendix 13.

Regarding the free-living nematodes, in 2013 the only difference between the two future treatments was found in the number of fungal and bacterial feeding nematodes, which were both higher in Combi-NT than in the Control (Table 3-25).

No sedentary endoparasitic nematodes (*Meloidogyne* spp.) were found in the soil. It should be noted that the extraction method was not targeted towards endoparasites, of which juveniles may hatch from the eggs after incubation of the soil. Therefore the results of the extraction of plant parasitic nematodes (section 3.4.5.2) should be valued more in this respect.

In 2020, the number of plant feeders and PP3-nematodes were significantly higher in the treatment Combi-NT than in the Control (Table 3-25). This mainly concerned a (non-significant) difference in the number of *Meloidogyne* sp., that showed a gradient in the field (significant Block effect; Appendix 13). The numbers were higher in plots with lower numbers (49, 56) and increased towards fields with higher numbers (86, 92). As the set-up of the experiment was such that the strips with treatment NT were assigned lower numbers and the strips with treatment T higher numbers, the difference between Comb-NT and the Control can be caused by spatial variation rather than treatment effects. As has been mentioned earlier, more value should be given to the results of the extraction targeted at plant parasitic nematodes.

Tagetes was grown in the treatment Combi-NT in 2013, but in 2020 there was no significant difference in the number of *Pratylenchus* sp. (migratory endoparasite) between the two treatments. Again, more value should be given to the numbers in the analysis of plant parasitic nematodes, that is aimed at extraction of endoparasites. In 2020 there was no significant difference between Combi-NT and the Control regarding the numbers of free-living nematodes: fungal and bacterial feeders, predators and omnivores. Neither was there a difference in the calculated indices.

In comparison with 2013, in 2020 in both treatments the number of fungal feeders was relatively high, of which a large part belonged to the genus *Aphelenchoides* (CP-2). Also, in both treatments the number of Neodiplogastridae was high (184-586 · 100 mL soil^{-1}).

The number of dauer larvae (a resting stage) were high in both treatments, which points towards ample food supply in the period previous to sampling.

Table 3-25 Results of the measurements of the nematode community in 2013 and 2020 in field 71-2. The numbers and biomass are expressed per 100 g of fresh soil and are medians (back transformed averages); therefore the numbers in the different groups do not add up to the total number. The indices and diversity (number of taxa) are averages (n=4). Different letters indicate differences within a year and variable.

	2013				2020			
Variable	Control		Combi-NT		Control		Combi-NT	
Dauer larvae	242	a	242	a	563	a	408	a
Total number	1910	a	2336	b	2841	a	2887	a
Plant feeders	954	a	1063	a	241	a	403	b
Fungal feeders	16	a	27	b	251	a	249	a
Bacterial feeders	824	a	1051	b	1779	a	1701	a
Predators	4	a	16	a	96	a	9	a
Omnivores[#]	91	a	140	a	381	a	456	a
Sedentary endoparasites	0	a	0	a	9	a	91	a
Migratory endoparasites	408	a	398	a	58	a	34	a
Semi-endoparasites	0	a	0	a	0	a	0	a
Ectoparasites	374	a	471	a	3	a	10	a
Roothair feeders	138	a	133	a	101	a	84	a
CP1-nematodes	199	a	292	a	1499	a	1232	a
CP2-nematodes	556	a	725	b	961	a	1187	a
CP3-nematodes	27	a	37	a	8	a	3	a
CP4-nematodes	61	a	91	a	34	a	12	a
CP5-nematodes	76	a	74	a	5	a	2	a
PP2-nematodes	138	a	133	a	115	a	84	a
PP3-nematodes	766	a	881	a	87	a	240	b
PP4-nematodes	15	a	16	a	0	a	1	a
PP5-nematodes	0	a	0	a	0	a	0	a
Maturity Index	2	a	2	a	1.47	a	1.54	a
Maturity Index 2-5	2.54	a	2.55	a	2.14	a	2.07	a
Plant Parasite Index	2.89	a	2.90	a	2.46	a	2.67	a
Channel Index	2.25	a	2.38	a	7.37	a	7.94	a
Basal Index	25.1	a	24.8	a	13.4	a	18.5	a
Enrichment Index	58.9	a	62.2	a	86.0	a	81.1	a
Structure Index	58.5	a	57.3	a	22.5	a	12.5	a
Biomass (mg)	1.88	a	2.54	a	8.34	a	9.03	a
Number of taxa	26.3	a	27.8	a	26.8	a	27.8	a

[#] Mainly Neodiplogastridae with a CP-value of 1. They are currently categorized in Ninja as bacterial feeders.

The food web analysis diagram shows that over time there has been a shift from the upper right to the upper left quadrat (Figure 3-8). The upper right quadrat indicates a more stable system that regulates pests and diseases (Figure 2-1). The upper left corner indicates a disturbed system that is conducive to pests and diseases. Both quadrats are characterized by a high N-content, a low C:N ratio and are dominated by bacteria. The different crops that were grown in the year preceding the sampling presumably had a larger effect on the nematodes than the treatments.

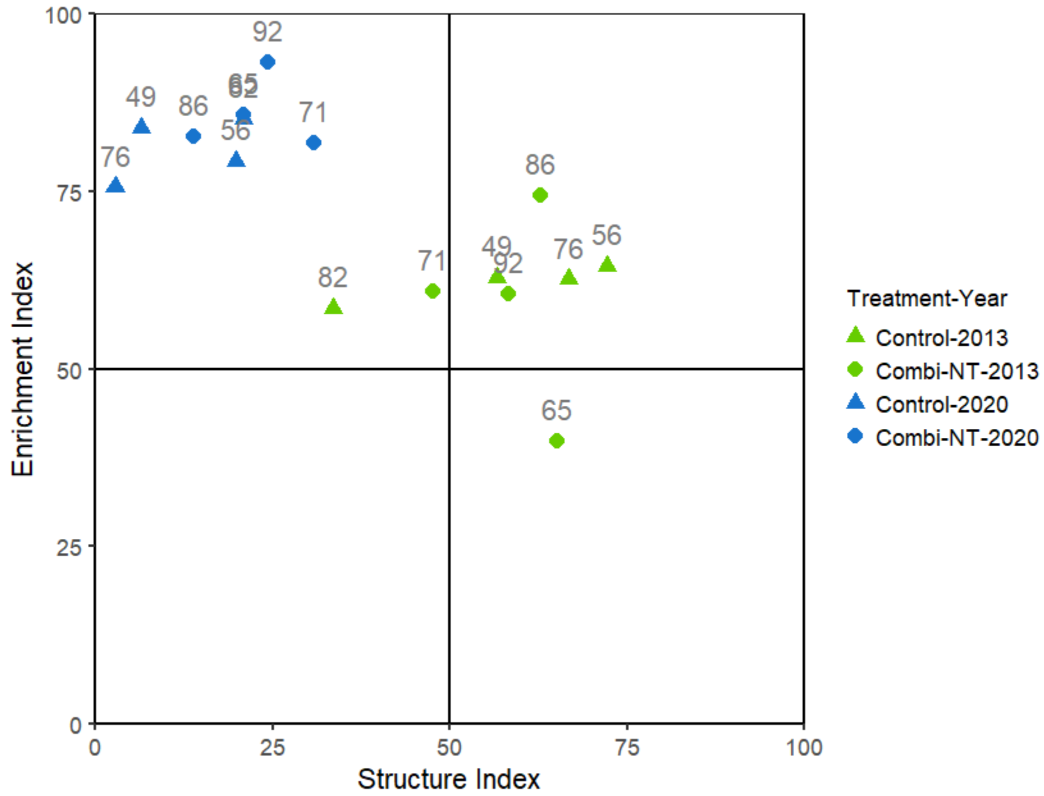


Figure 3-8 Food web analysis diagram with the Enrichment and Structure Index of the plots in two treatments (Control and Combi-NT) in field 71-2 in the experiment 'Bodemkwaliteit Veenkoloniën' in March 2013 and 2020. The measurements are marked with plot numbers.

3.5.5.2 Plant parasitic nematodes

The sampling that was performed in spring 2013 (at T0) showed that the Northern root lesion nematode *Pratylenchus penetrans* was present in all four fields. To a lesser extent, two other root lesion nematode species were present, *P. crenatus* (cereal root lesion nematode) and *P. neglectus* (sugar beet lesion nematode). Potato is rather sensitive to *P. penetrans*, whereas sugar beet and cereals are rather insensitive to this species. As far as known, *P. crenatus* and *P. neglectus* do not cause damage to potato and sugar beet. In all four fields, a very low infestation was found with trichodorids (Trichodoridae; stubby-root nematode) and root knot nematodes (*Meloidogyne* spp.). The densities of these nematode species were far below the damage threshold of potato, cereals and sugar beet. All four fields were infested with *Tylenchorhynchus* spp. (stunt nematode). This nematode genus is rather commonly found on sandy soils. Potato and sugar beet are not sensitive to this genus, whereas cereals are slightly sensitive.

3.5.5.2.1 Pratylenchus penetrans

At the start of the experiment in spring 2013, a rather heavy infestation with *P. penetrans* was found in the fields with the exception of field 70-4 (see Figure 3-9 – Figure 3-12). The average density in fields 70-3, 71-1 and 71-2 was about 500 *P. penetrans* · 100 mL soil^{-1}. Field 70-4 was infested with a mixture of the root lesion nematode species *P. penetrans* and *P. crenatus*, of which the latter was the dominant species in this field. As far as known, this species does not cause damage to potato and sugar beet. In March 2013 the density of *P. penetrans* in this field was just below 100 *P. penetrans* · 100 mL soil^{-1}, which was far below the density in the other three fields.

In 2013, spring barley was grown on field 71-2. Therefore, this was the first field where spring barley was replaced by marigold (*Tagetes patula*) in the two treatments Marigold and Combi. On the fields 70-4, 71-1 and 70-3, marigold was grown for the first time in the treatments Marigold and Combi in 2014, 2015 and 2016 respectively. In field 71-2 the density of *P. penetrans* declined after growing spring barley, a moderate host plant, followed by black oat, a non-host plant. The decline is in line with the expectation based on the host plant status of the crops. The pattern in field 70-4 was similar to field 71-2, but the level of infestation was lower. On the contrary, in fields 71-1 and 70-3 the density of *P. penetrans* increased after growing spring barley and black oat. The increase in density of *P. penetrans* may have been caused by volunteer barley and weeds, mainly chickweed (*Stellaria media*), in the black oat crop. Barley and many weeds, among which chickweed, are host plants to *P. penetrans*.

When marigold was grown instead of spring barley and black oat, the density of *P. penetrans* strongly declined, in most plots even below the level of detection. The year after growing either spring barley or marigold, Festien was grown, which is a good host plant to *P. penetrans*. In the control treatment in fields 71-2 and 71-1, where the preceding crop was barley, the density of *P. penetrans* increased to about 400 and 800 *P. penetrans* · 100 mL soil^{-1} respectively. In field 70-3 the density of *P. penetrans* was rather high after growing spring barley and black oat. After growing Festien, the density of *P. penetrans* in field 70-3 had declined to approximately 400 *P. penetrans* · 100 mL soil^{-1}. In field 70-4, after growing barley the density of *P. penetrans* was rather low and it remained low after growing Festien (fewer than 50 *P. penetrans* · 100 mL soil^{-1}). When marigold was grown as a preceding crop, the density of *P. penetrans* remained very low even when the good host plant Festien was grown.

Festien was followed by sugar beet, which is a poor to moderate host plant to *P. penetrans*. The maximum final population density that plant parasitic nematodes can reach depends on the crop and even on the cultivar. The maximum final population density that *P. penetrans* can reach on sugar beet is approximately 300 *P. penetrans* · 100 mL soil^{-1}. Depending on the initial density at the start of the cultivation of sugar beet, the nematode density may increase or decrease. In the control treatment of the three fields 71-1, 71-2 and 70-3 with *P. penetrans* being the only root lesion nematode species, the density of *P. penetrans* had decrease to about 300 *P. penetrans* · 100 mL soil^{-1} after the growth of sugar beet. In field 70-4, with a mixed population of *P. penetrans* and *P. crenatus*, in 2016 the population increased and in 2020 it decreased to approximately 150 *P. penetrans* · 100 mL soil^{-1}. In all the treatments where marigold had been grown, the density of *P. penetrans* remained low also after growing sugar beet.

After the cultivation of sugar beet, potato was grown for the second time in the rotation, but this time Seresta. In most years and in most fields, after the growth of Seresta the density of *P. penetrans* in the control treatments had increased to 400-500 *P. penetrans* · 100 mL soil^{-1}. After the second potato cultivation (Seresta) a full rotation cycle cereal – potato – sugar beet – potato had been completed. After the second potato cultivation, the density of *P. penetrans* in the control treatment was somewhat lower than before sowing spring barley at the start of the rotation. The density of *P. penetrans* was well above the damage threshold of potato and other sensitive crops such as sowed onions. In the rotation with marigold the density of *P. penetrans* remained very low, also after growing potato a second time: on average fewer than 50 *P. penetrans* · 100 mL soil^{-1}.

In the rotation where marigold was grown once in eight years, spring barley was grown five years after the cultivation of marigold. This resulted in a clear increase in the density of *P. penetrans*, although the density in fields 71-2 and 70-4 still was significantly lower than in the control. The densities were about 100 and 50 *P. penetrans* · 100 mL soil^{-1} in the Marigold(8) treatments as compared to 400 and 275 *P. penetrans* · 100 mL soil^{-1} in the control treatments of the two fields, respectively. However, in fields 71-1 and 70-3, five years after the cultivation of marigold, the density of *P. penetrans* had increased to a density that was comparable to the control treatment. After the third potato cultivation in the rotation, which was six years after growing marigold, in fields 71-2 and 70-4 the density of *P. penetrans* had increased to a level that did not significantly differ from the control treatment. In the rotation where marigold was grown every four years, treatment Marigold(4), after the second cultivation of marigold the density of *P. penetrans* had again strongly decreased to levels that often were below the level of detection.

Tillage did not significantly influence the density of *P. penetrans*: no significant difference was found between the conventional tillage (T) and the non-inversion tillage treatments (NT). Neither could a difference be demonstrated between the treatments Marigold and Combi, in which the cultivation of marigold is one of the measures. Therefore, the other measures in the Combi treatment do not seem to affect the density of root lesion nematodes.

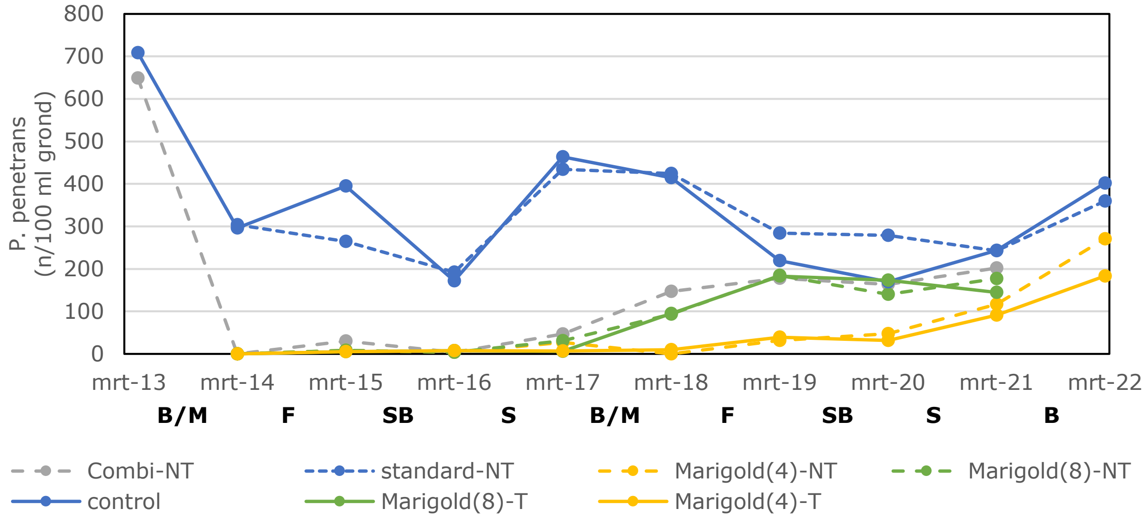


Figure 3-9 Development of the *Pratylenchus penetrans* population in field <u>71-2</u>. In 2013 in the control and standard-NT treatments barley was grown, whereas Marigold was grown in Combi-NT and all Marigold-treatments. In 2017, Marigold was only grown in the Marigold(4) treatment, whereas barley was grown in all other treatments.

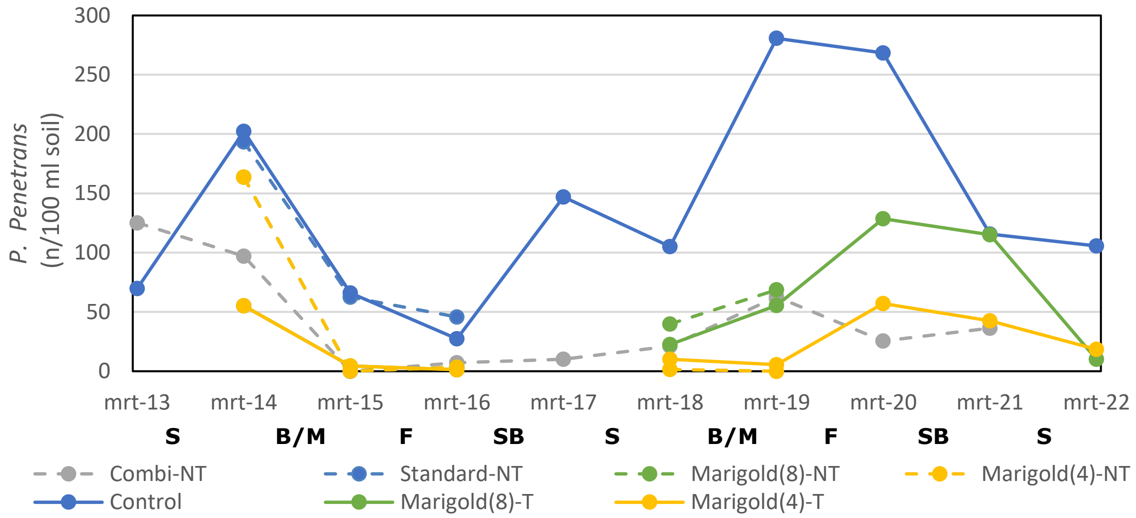


Figure 3-10 Development of the *Pratylenchus penetrans* population in field <u>70-4</u>. In 2014 in the control and standard-NT treatments barley was grown, whereas Marigold was grown in Combi-NT and all Marigold-treatments. In 2018, Marigold was only grown in the Marigold(4) treatment, whereas barley was grown in all other treatments.

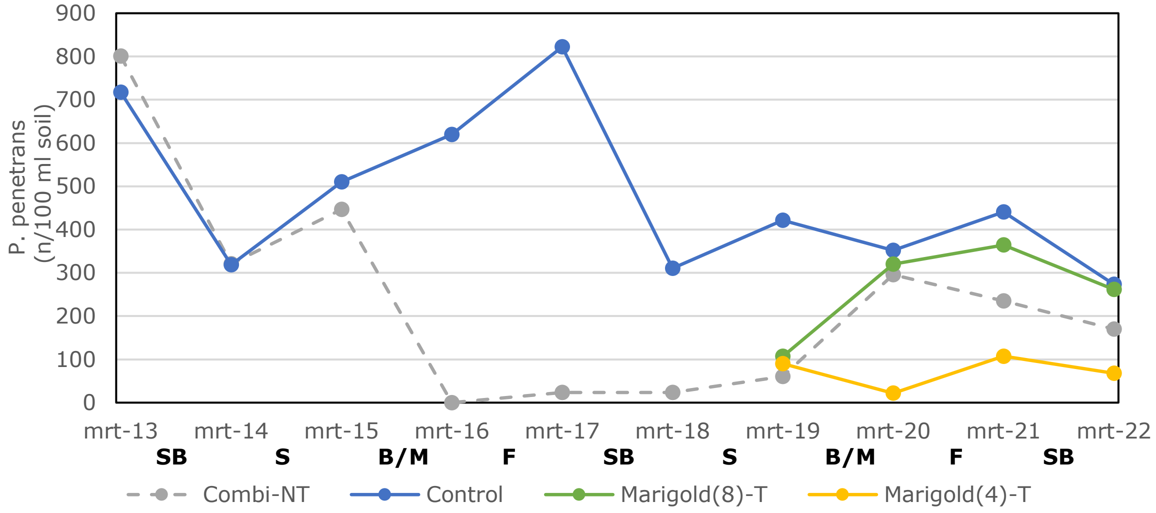


Figure 3-11 Development of the *Pratylenchus penetrans* population in field 71-1. In 2015, in the control treatment barley was grown, whereas Marigold was grown in Combi-NT and all Marigold-treatments. In 2019, Marigold was only grown in the Marigold(4) treatment, whereas barley was grown in all other treatments.

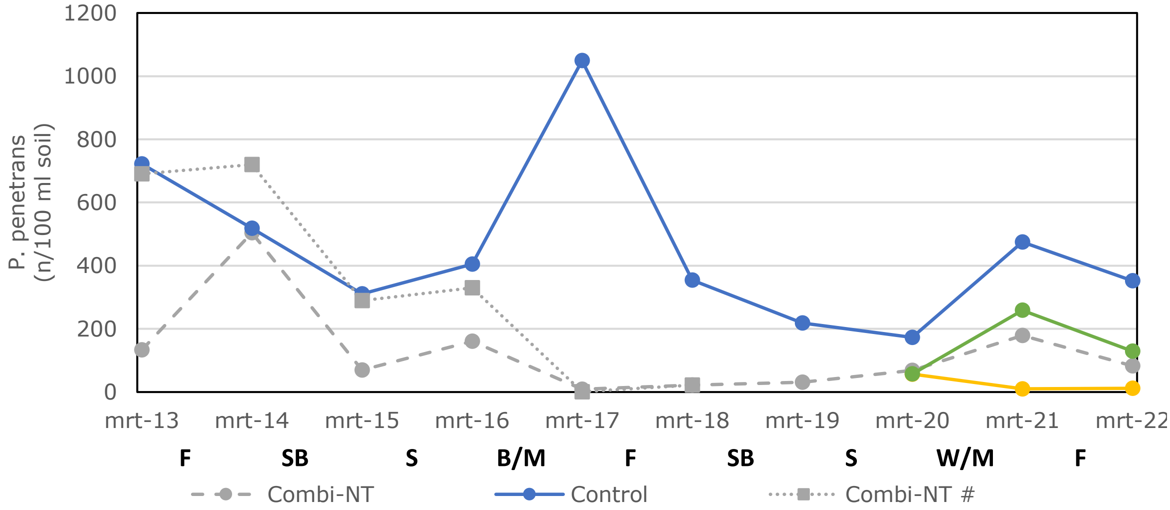


Figure 3-12 Development of the *Pratylenchus penetrans* population in field 70-3. In 2016, in the control treatment barley was grown, whereas Marigold was grown in Combi-NT and all Marigold-treatments. In 2020, Marigold was only grown in the Marigold(4) treatment, whereas wheat was grown in all other treatments.

3.5.5.2.2 Meloidogyne and Trichodoridae

Besides *P. penetrans*, the fields also contained a low density of root knot nematodes (*Meloidogyne chitwoodi* and *M. fallax*) and stubby root nematodes (Trichodoridae, mainly *Paratrichodorus pachydermus*). Both *M. chitwoodi* and *M. fallax* have a wide host range and are able to multiply moderately to strongly on spring barley, sugar beet and potato. Black oat is a very good host plant to *M. chitwoodi* as well as *M. fallax*. Marigold is a very poor host plant to both nematode species, which became clear in 2020 in field 70-3. After the cultivation of marigold, the density of *Meloidogyne* spp. had declined from 660 to 6 *M. chitwoodi* and *M. fallax* · 100 mL soil^{-1} (see Appendix 14).

Spring barley and sugar beet are rather insensitive to *M. chitwoodi* and *M. fallax*. In contrast, both species can cause considerable quality damage to potato by damaging the tubers on the outside and, when present in high densities, also yield loss. However, outside damage to the tubers does not lead to a lower classification of starch potatoes.

At the beginning of the experiment in 2013, the infestation with *Meloidogyne* spp. was very low and varied from 0 to 15 *M. chitwoodi* and *M. fallax* · 100 mL soil^{-1}, with an average of fewer than 5 *M. chitwoodi* and *M. fallax* · 100 mL soil^{-1}. The infestation in field 70-4 was lowest and it remained very low (see Appendix 14). In the other three fields, the density of *Meloidogyne* spp. had increased after the third cultivation of potato (the second cultivation of 'Festien'), followed by sugar beet. The increase can largely be contributed to the growth of black oat as a cover crop in the year preceding the cultivation of 'Festien'. Black oat is a very good host to both these *Meloidogyne* species, which led to on average higher densities prior to the cultivation of 'Festien'. Especially in field 70-3 the density had increased rather strongly but, as far as known, was still below the threshold damage for yield of starch potato.

Trichodorids are able to multiply on many different crops. Most trichodorid species multiply rather strongly on potato, sugar beet and spring barley, whereas the multiplication on black oat is unknown. It is difficult to predict the level of damage that trichodorids may cause, as the influence of the yearly conditions is often stronger than the level of infestation. The risk of yield loss is most severe in years with a wet and cold spring.

At the start of the experiment in 2013 the fields were very lightly infested with trichodorids. The density varied from 5 to 35 trichodorids · 100 mL soil^{-1}, which is below the damage threshold for potato and sugar beet. The population density fluctuated over the years (see Appendix 14) and increased to a maximum of 75 trichodorids · 100 mL soil^{-1} in field 71-1. This density is still rather low and presumably did not cause any damage. There are no relevant (and significant) effects of the treatments on the crops in the rotation on the level of infestation with trichodorids. The levels of infestation stayed low to very low. The host status of marigold to different trichodorid species is unknown. There are indications, but no reliable data, that *P. pachydermus* may multiply on marigold moderately to well. In this experiment we did not find an increase in the density of trichodorids after the cultivation of marigold, possibly because of the low initial densities (see Appendix 14).

3.5.6 Weed pressure

The weed pressure of Standard-T and Standard-NT are presented in Figure 3-13. No significant effect of the tillage type was found on the total number of weeds for both soil layers. The total number of weeds that germinated was significantly higher in the 0-10 cm layer compared to the 10-30 cm layer. In total 27 different weed species were observed in the greenhouse. The species that were most abundant are *Poa annua* (POAAN), *Stellaria media* (STEME), *Solanum nigrum* (SOLNI) and *Chenopodium album* (CHEAL).

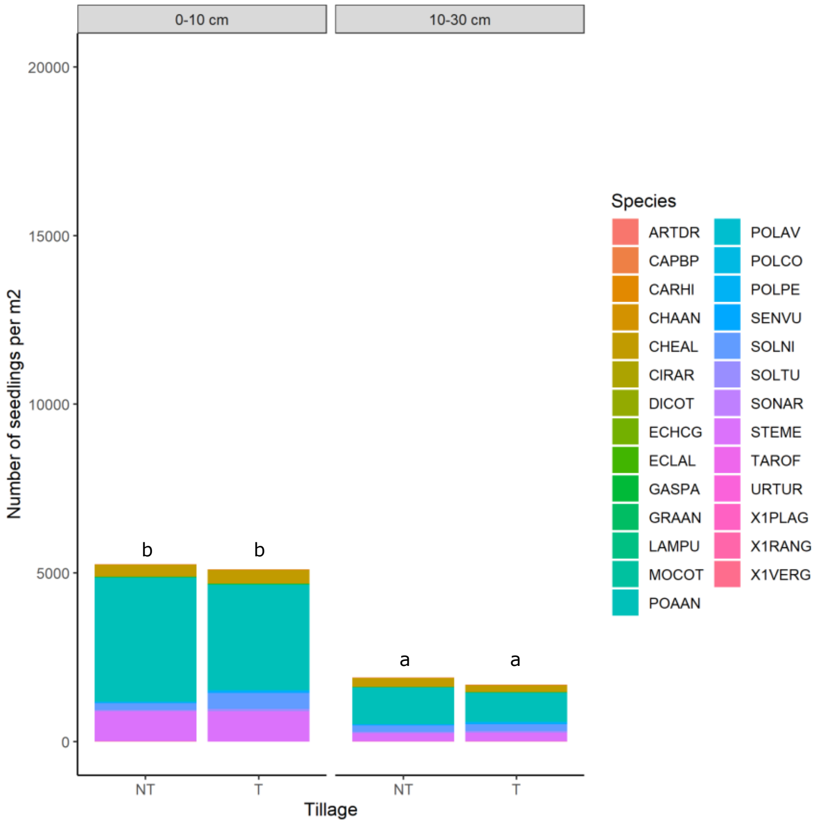


Figure 3-13 Effect of tillage type on the average number of weed seedlings per m^2 for different soil layers. Data is combined for the four fields. Four species were most abundant: *S. media* (STEME), *P. annua* (POAAN), *S. nigrum* (SOLNI) and *C. album* (CHEAL). Meaning of other species coding can be found in appendix 15.

The effect of tillage and soil depth on weed seedling density is different for the four separate fields within the trial (see Appendix 15). Weed densities on field 71-1, where spring barley was cultivated in 2021, were significantly higher in the 0-10 cm layer compared to 10-30 cm. No significant effect of tillage was found, although a trend towards higher weed densities with NT is visible. Weed densities in field 71-2, with sugar beet being cultivated in 2021, were not significantly different between both tillage type and soil depth.

For fields 70-3 and 70-4, both with potato cultivated in 2021, the observed weed seedling density was higher in the 0-10 cm layer. The tillage type did not result in significantly different weed seedling densities, although the data suggest that NT had resulted in higher weed densities in the top layer on field 70-4.

3.6 Practical applicability

The applicability of the treatments in this experiment has been reported by Selin Noren et al. (2022) in terms of required knowledge and experience, labour, the need for investments and the financial consequences.

3.6.1 Non-inversion tillage

NT requires some experience, especially regarding the timing and specific field conditions. Difficulties with incorporating (cover)crop residues did not occur in this experiment, but might be a point of attention in crop rotations with more crop residues and cover crops, especially in crop rotations with crops with small seeds. Another point of attention is the risk of harmful leaf- and soil fungi. When infected crop residues remain in the topsoil and decompose more slowly, fungi can survive on these crop residues and infect crops next growing season. The actual risk of NT remains unclear, and will be studied more in depth in the coming years. NT does not require additional labour in a conventional system, but might requires additional labour in organic systems with increased numbers of weeds (Selin Noren et al., 2022). Including non-inversion strategies within the farm system will be paired with investments when a cultivator needs to be purchased, but most farmers in the region already have the required equipment. The costs of a cultivator are however limited when compared to the equipment needed for rotary spading. Disc coulters might be needed when seeding after NT, which lead to additional investments. Experiences with NT in this experiment with the cultivation of potatoes and sugar beets are reported respectively by van Balen et al. (n.d.-a) and van Balen et al. (n.d.-b). With NT the soil is less loosened when compared to spading, but NT was still associated with the right conditions to prepare ridges for the cultivation of potatoes. For sugar beet the preparation of a good seed bed was more difficult. The soil structure in the topsoil should be loose enough to surround the seed with moist soil to provide optimal germination conditions, but not too loose considering the risk of erosion. Crop residues in the topsoil could hinder optimal contact between the seed and the soil particles. Creating the optimal conditions seemed more difficult with NT than with T. This is due to the specific circumstances of the soil at the start of the season. When the topsoil is dry, T will bring moist soil to the surface, which is ideal for germination. The soil of NT in this case will remain dry, posing a higher risk at the start of the season, especially when no sufficient precipitation is expected after sowing. Some might therefore say that the circumstances should determine the type of tillage that will be applied.

3.6.2 Marigold

The cultivation of marigold requires some knowledge and experience and the right equipment. Marigold should only be sown when the field is infected by *P. penetrans*. Soil sampling is advised to gain insight in the presence of plant parasitic nematodes and decide whether it is needed to cultivate marigold. Sowing marigold is difficult because of the shape of the seeds. It is therefore advised to outsource the sowing by contract workers with the right equipment and experience. Also, the timing of sowing is a point of attention. Marigold is susceptible to frost and should therefore be sown not to early nor too late, but requires sufficient time to develop an intense root system (~three months). When marigold replaces the cultivation of barley this should not be an issue. Timing can be an issue however when cultivated after (winter) barley, and should be sown before August. Another point of attention is weeds. Marigold develops relatively slowly in the first phase, giving space to weeds. Since some weeds are hosts to *P. penetrans*, the soil should be kept free of weeds for an optimal reduction of *P. penetrans*. Therefore, the cultivation requires more labour when compared to other cover crops, but not when compared to the cultivation of spring barley and black oats.

3.6.3 Compost

The application of compost is not a technically difficult treatment, the only challenge might be to find compost of sufficient quality for a good price. Incorporating compost in the farm strategy requires some changes in the fertiliser schemes and legislation regarding the use of (organic) fertilisers should be taken into account. Furthermore, the application of compost does generally not require investments in machinery when done by contract workers. Applying compost requires limited additional labour, especially when done by contract workers.

3.6.4 BCSR

The application of BCSR requires knowledge regarding nutrients and alterations in the fertilisation schemes are needed. Doses, effects on yield quality and interactions between nutrients should be considered and the nutrient status and CEC saturation should be monitored over time. Adjusting and monitoring the fertilisation scheme is somewhat complex, and it is therefore advised to seek collaboration with experts. In this experiment we collaborated with NovaCrop Control and followed their advice. The application of the nutrients itself is not complicated and does not require additional investments in machinery.

3.6.5 Rockdust

The application of rockdust is relatively simple and does not require much experience. The additional labour needed to apply rockdust is limited. Rockdust can be applied with a lime spreader, if not in possession by a farmer, the work can be done by contract workers.

3.7 Financial aspects

The financial aspects of this experiment were reported by Bijker et al. (2023). They took into account costs related to the treatments (both including annual costs and depreciation) and the effects on the returns (in terms of crop yield). For the latter they did not look at significance of the differences. They included only 2016-2020 in their analysis.

3.7.1 Non-inversion tillage

Over the period 2014-2016 Standard-NT was associated with an increased return of €47 for Festien and €53 for Seresta and a decreased return of €190 for sugar beet and €60 for spring barley when compared to the control, which is -€37 ha^{-1} yr^{-1} when averaged over the crop rotation. The costs were, however, also lower. This was due to lower investment costs for a rigid tine cultivator with subsoiler compared to a rotary spading machine. Also the maintenance costs are lower for NT than for T. Besides, NT requires less fuel than T (de Wolf et al., 2019). Altogether, the costs were €88 ha^{-1} yr^{-1} lower for NT than for T. Taking into account both the lower returns and costs, the net effect would be +€51 ha^{-1} yr^{-1}.

3.7.2 Marigold

The cultivation of Marigold increases the yield and return for Festien and Seresta respectively with €360 and €406 ha^{-1} yr^{-1}. However, the cultivation of Marigold replaces the cultivation of spring barley. The cultivation of spring barley would have been associated with a return of €1,110 ha^{-1} yr^{-1}. The effect on sugar beet was marginal, -€3 ha^{-1} yr^{-1}. Averaged over the crops, the net effect would be negative: -€87 ha^{-1} yr^{-1} (Bijker et al., 2023). The increased return on the potatoes does not outweigh the loss of the spring barley. However, replacing spring barely and black oats by marigold also affects the costs. The costs of the cultivation of Marigold is more expensive than black oats, especially the seed is more expensive, and Marigold requires more labour the black oats (de Wolf et al., 2019). The cultivation of spring barley is replaced and the cultivation costs of spring barley are therefore 0. The total cultivation costs of Marigold are €745 ha^{-1} yr^{-1}, compared to €1372 ha^{-1} yr^{-1} when spring barley and black oats would have been cultivated. All-in-all, this would result in a net positive effect of €540 ha^{-1} yr^{-1}. These calculations are based on financial data of 2018 (Bijker et al., 2023). The prices of barley and artificial fertiliser have been increasing over the past year, and the result might therefore be less positive. An update of the financial analysis for Marigold will be made in a follow-up study. Besides, the yield effect in this study is based on a crop rotation of Marigold – Festien – sugar beet – Seresta. Seresta is however a more susceptible variety to *P. penetrans* than Festien, switching Festien and Seresta in the crop rotation might therefore have an even more positive effect on the yield increase of the potatoes.

3.7.3 Compost

Applying compost resulted in a significant yield increase for sugar beet (+€134 ha^{-1} yr^{-1}), and a non-significant yield increase for Festien (+€121 ha^{-1} yr^{-1}) and Seresta (+€66 ha^{-1} yr^{-1}) and a decrease for spring barely (-€9 ha^{-1} yr^{-1}). When applying compost, the application of artificial fertiliser of P_2O_5 and K_2O could be reduced, which saves some costs. However, the reduction in costs for artificial fertiliser did not outweigh the costs of compost. The additional costs were €121 ha^{-1} yr^{-1}. This resulted in a negative net balance of -€43 ha^{-1} yr^{-1} (Bijker et al., 2023). When neglecting the non-significant yield increases, the result will be even more negative. However, quite expensive compost has been used. Using less expensive compost will lead to a less negative or even positive net balance.

3.7.4 BCSR

BCSR resulted in an averaged (non-significant) yield increase of €24 ha^{-1} yr^{-1} when compared to the control (Bijker et al., 2023). For the treatment, additional fertiliser was needed (Dologran, Kieseriet and Kali-60). The additional costs were €287 ha^{-1} yr^{-1} (de Wolf et al., 2023). This resulted in a net effect of -€263 ha^{-1} yr^{-1}. When neglecting the non-significant effects on yield, the net effect would be -€287 ha^{-1} yr^{-1}.

3.7.5 Rockdust

Rockdust resulted in an averaged (non-significant) yield increase of €24 ha^{-1} yr^{-1} (Bijker et al., 2023). Additional costs for this treatment included costs for biolit and zeolite, and the application itself. The additional costs were €193 ha^{-1} yr^{-1} when applied in two of the four years. Bijker et al. (2023) only took to applications into account since they analysed the period 2016-2020. This resulted in a net negative effect of -€174 ha^{-1} yr^{-1}. Biolit and zeolite were however applied in four of the eight years. Still, with the absence of significant yield effects, the treatment is associated with a net negative financial consequence when compared to the control.

3.7.6 Combi

The combination of all measures resulted in a yield increase for Festien (+€243 ha^{-1} yr^{-1}), Seresta (+€405 ha^{-1} yr^{-1}), sugar beet (+€112 ha^{-1} yr^{-1}) and spring barley (+€24 ha^{-1} yr^{-1}). The loss of the yield of spring barley was not considered here, as Marigold was grown 1:8 in the Combi treatment and Bijker et al. (2023) only considered the second crop rotation. A combination of all treatments is associated with large additional costs when compared to the control, especially for compost and artificial fertiliser, as the application of (artificial) fertiliser was not corrected for the application of compost. The additional costs were €660 ha^{-1} yr^{-1}. Averaged over the crop rotation, this would result in a net effect of -€464 ha^{-1} yr^{-1}.

4 Discussion

4.1 Yield effects

The main yield effects found include the effect of Marigold in potatoes, none of the other treatments were able to increase the potato yield. The yield of sugar beet was mainly affected by the application of compost. Also the yield of spring barley was negatively impacted by NT.

4.1.1 Non-inversion tillage

It is not likely that NT affected the crop yield of potato and sugar beet. NT did have a negative impact on the yield of spring barley (-1.8%). Although tillage systems are researched more often, a comparison between rotary spading and non-inversion tillage with subsoiling is not available. Reduced tillage was tested on a sandy soil in the South of the Netherlands and compared to conventional tillage (mouldboard plough) (Selin Norén et al., 2022). They found a yield increase for potatoes (+4%) and for spring barley (+7%), which is not in line with our findings, sugar beet was not part of their crop rotation. They found a negative effect on crops with small seeds, carrots in their case. They noticed that due to the more coarse soil structure in NT, small seeds had difficulties with germination resulting in a lower number of plants and they found that carrots grown in NT were shorter. The same could be true for sugar beets, which also has small seeds. The number of plants per square meter was noted for three years in our experiment. For only one year a significant lower number of plants was found for N compared to T, but this did not seem to be related to the crop yield. Also Paauw (2003) has looked into the effect of NT compared to rotary tillage on the number of plants in sugar beet. They did not find a lower number of plants under NT, and also did not find any significant differences in yield between T and NT (Paauw, 2003; 2006). Also for potatoes a significant effect of NT was not found (Paauw, 2003; 2006). For spring barley the number of plants was noted in our experiment for two years, but no significant differences were found between NT and T. Besides, both sugar beet and barley can compensate for fewer plants. A lower number of plants therefore does not correspond to a lower yield. It remains unclear why NT resulted in a negative yield effect for spring barley. All-in-all, it seems that there is no general effect of NT on the crop yields of sugar beet, potato or spring barley, but rather field and year specific.

4.1.2 Marigold

The cultivation of Marigold led to a yield increase of the potatoes, which was stronger when grown every four years compared to every eight years. No effect was found on the yield of sugar beet or spring barley. Korthals et al. (2014) and Visser et al. (2023) also assessed the effect of Marigold on arable crop production. Their research was located on a sandy soil in the South of the Netherlands, with a crop rotation existing of wheat, potato, lilly, carrot, peas and leek. They found a significant reduction in *P. penetrans* after growing Marigold. Marigold even seemed to be more effective in the reduction than the chemical control (Korthals et al., 2014). The population remained low for at least five years (Korthals et al., 2014), but was again on a similar level after eight years (Visser et al., 2022). Although the crop rotation was different from our experiment, similar results were found. After several years of growing host plants for *P. penetrans*, the population increases again. Cultivating Marigold affected the potato yield in the years directly following the cultivation of Marigold (Korthals et al., 2014). Marigold resulted in a higher potato yield when compared to the control (+14.6% and +28.2%), similar to the chemical control. After eight years, no effects were found for both the cultivation of Marigold and the chemical control (Visser et al., 2022). The same was true for our experiment, but the effect on potato yield lasted only four years (two potato cultivations). After five years (third cultivation of potatoes), the effect was neutral to negative.

4.1.3 Compost

Sugar beet benefitted from the application of compost, the other crops did not. It is unclear why the yield of sugar beet was affected. The effect of compost is studied in several (long term) experiments. Two experiments are even performed on the same soil type (reclaimed peat soils), in the period 2006-2009 (Wijnholds, 2010) and in 2010-2015 (van Balen et al., 2016). In the experiment of Wijnholds (2010), an amount of 25 ton compost ha^{-1} yr^{-1} was applied and compared to the control in which only synthetic fertilizer was applied. Wijnholds (2010) did not find any differences in crop yield for potato (year 1 and 3) and spring barley (year 2), but did find significant differences for sugar beet (year 4). Applying compost was associated with a yield increase of 0.6 ton sugar per hectare. This is in line with the findings of our experiment, in which applying compost did not affect the yields of potatoes nor spring barley, but did for sugar beet. The average yield increase was exact 0.6 ton ha^{-1} yr^{-1} as well. The yield increase in our experiment may be due to the additional nutrients applied (mainly K_2O and P_2O_5), whereas Wijnholds (2010) compensated for the nutrients in compost, and the yield effect might be a direct result of compost. Van Balen et al. (2016) even applied an amount of 63 ton compost ha^{-1} yr^{-1} annually, and corrected for the N application. They did not find a significant difference in yields between the application of compost and standard fertilization with slurry or with artificial fertilizer, nor for sugar beet, nor for the other crops. D'Hose et al. (2012) found a yield effect after four years of applying compost. In the intermediate years, additional mineral N fertilization was required to reach the optimum yield because the compost applied had a high C/N ratio (18), and it seems reasonable that the compost immobilized N. In our experiment the C/N ratio of the compost was lower (~11) and additional N was applied in the form of slurry and artificial fertilizer. The reason why D'Hose et al. (2012) did find a yield effect might be due to the low initial soil organic matter content in the experiment compared to ours. This effect was also found by de Haan et al. (2018). The PAN application for both compost and the control was similar, but larger amounts of total N, P_2O_5 and K_2O were applied with compost compared to the control. In their experiment compost led only to a yield increase when no exogenous organic matter was applied for a long period of time. De Haan et al. (2018) added compost to two fertilization schemes: one with a low organic matter supply (~952 kg EOS ha^{-1} yr^{-1}) and one with a standard organic matter supply (2333 kg EOS ha^{-1} yr^{-1}). Adding compost to a low organic matter supply resulted in a 5% yield increase for sugar beet, but had no effect on the yield of potato or spring barley. The yield effect of compost on sugar beet was lower for the standard organic matter supply. This is in line with our findings, applying compost additional to a low to standard organic fertilization scheme (1371 kg EOS ha^{-1} yr^{-1}) increased the yield of sugar beet. Also Wijnholds and Meuffels (2011) compared various fertilization schemes with compost. They did not find a yield effect in the first three years between a standard fertilization scheme and one with slurry combined with compost. Not even for sugar beet. Due to the relatively short experiment duration (three years), long term effects have not been established. More in general, the effect of applying organic material on crop yields has been studied more extensively. Hijbeek et al. (2017) performed a meta-analysis and concluded that the mean additional yield effect of organic inputs was not significant across all experiments. However, organic inputs did increase yields for root and tuber crops, spring sown cereals and for sandy soils. In our experiment this was solely the case for sugar beet. It needs to be mentioned, however, that Hijbeek et al. (2017) only assessed experiments in which the effects of macro nutrients were excluded and organic inputs (not just compost) were compared to a control in which no organic inputs were applied. In our experiment manure was applied (both with compost and in the control), and the application of synthetic fertilisers was only partly corrected for additional nutrients applied with compost.

4.1.3.1 Yield effects as a result of nutrients?

The reason why no yield effects were found for the potatoes and spring barley in our experiment might be that the nutrient supply (soil nutrient status and fertilisation) for these crops was no limiting factor. A reason for the yield effect in sugar beet might be that one of the nutrients was a limiting factor in the control and the shortage was compensated by the supply of compost. The initial K-status in the soil was relatively low, and therefore the advised K_2O fertilisation for sugar beet was 250 kg K_2O ha^{-1} yr^{-1}. Standard-T was fertilised with 180 kg K_2O ha^{-1} yr^{-1} and Compost-T with 284 kg K_2O ha^{-1} yr^{-1}. On top of that, straw was incorporated into the soil for Compost-T and not for Standard-T, which is a difference of 15 kg K_2O ha^{-1} yr^{-1} when averaged over the crop rotation. The K_2O fertilisation was thus more optimal for Compost-T than for the control, which might explain the yield effect for sugar beet. However, the K_2O fertilisation of sugar beet for BCSR and Rockdust was 234 and 271 kg K_2O ha^{-1} yr^{-1} respectively and a significant yield effect for these treatments was absent. For P_2O_5, the advised fertilisation for sugar beet was 47 kg P_2O_5 ha^{-1} yr^{-1}. Standard-T was fertilised with 58 and Compost-T with 162 kg P_2O_5 ha^{-1} yr^{-1}. As both applications were above the advised quantity, it is not likely that the yield effect in sugar beet was a result of P_2O_5. For N, the advised fertilisation for sugar beet was ≤150 kg N ha^{-1} yr^{-1}. Standard-T was fertilised with 162 kg N ha^{-1} yr^{-1} (140 kg PAN) and Compost-T with 357 kg ha^{-1} yr^{-1} (160 kg PAN). The difference in PAN might have led to the yield increase in sugar beet. The exact cause of the yield increase for sugar beet, however, remains unclear.

4.1.4 BCSR

In our experiment limited to no yield effects were found for BCSR, which is in line with was found in literature (e.g. Bussink et al., 2020). The BCSR method has been studied for more than over 100 years. Kopittke and Menzies (2007) conducted a literature review and concluded that data does not support the claims of BCSR and the use of BCSR will result in inefficient use of resources. Bussink et al. (2020) state that interactions between nutrients do occur but normally do not affect crop yields. In numerous studies it was found that plant yields were not affected by the Ca/Mg ratios studied, ranging from 0.25:1 to 31:1 (Kopittke & Menzies, 2007). In our study, the ratios ranged from 5:1 to 12:1, and indeed, the effect on crop yield was limited. Our results are therefore in line with the conclusion of Kopittke and Menzies (2007), stating that soils that contain adequate absolute quantities of Ca, Mg and K, the ratios of these cations generally do not influence plant yield within the ranges commonly found in agricultural soils. Additionally they stated that the addition of lime (using $CaCO_3$) to increase the Ca/Mg ratio simultaneously increase soil pH and thereby reduce any growth limitations imposed on the plant by soil acidity. In our study we did not analyse the effects of liming and Ca/Mg ratios separately. Kopittke and Menzies (2007) also noted that a purpose of reaching a high Ca saturation, as described by Bear and Toth (1948), is to minimize luxury K uptake, as K is a much more expensive element than the Ca which it replaces. The optimum K saturation described in literature was 2 to 5%. However, in our experiment additional K was provided (containing chloride) and the K saturation in our experiment ranged from 0.9 to 3.4%, which can be considered as low. However, in our experiment the application of K already led to overconsumption and had adverse effects on the quality of the potatoes. Increasing the K saturation therefore is not likely a solution to improve crop yield.

4.1.5 Rockdust

The application of Rockdust did not have an impact on the crop yields in our experiment. Van Balen et al. (2016) also analysed the effect of Rockdust on crop yields, on a field adjacent to our experiment. They did not find a significant effect on the yield for any of the crops. Russchen and de Haan (2017) reported the effects of rockdust in another experiment on the same soil type. Various types and doses of rockdust were applied at one moment, crop growth was monitored for one year. The set-up of the experiment was far from optimal (e.g. the control plot was located adjacent to a strip of trees), and therefore not statistically analysed. No consistent effects were found for the application of rockdust on the potato yield. The difference between in field yield between Biolit and the control ranged from -3.9 to 2.6 ton ha^{-1} yr^{-1}, and -0.6 and 0.4 ton starch ha^{-1} yr^{-1}. Biolit led to an increase in yield in sugar beet, which was 1.1 ton ha^{-1} yr^{-1} and 0.1 ton sugar ha^{-1} yr^{-1}. Because of the lack of statistical analysis, it is difficult to interpret whether Rockdust had an effect on yield in their experiment. When considering these three experiments altogether, it is not likely that Rockdust will increase crop yield.

4.2 Quality aspects

4.2.1 Potatoes

For potatoes, the effects of the treatments on the quality aspects were limited. Only BCSR (and Combi) have led to a lower starch content in Festien and Seresta, Compost to a lower content in Seresta and Marigold(4) in Festien. The effect in BCSR might be due to the application of K_2O in the form of Kali-60, which contains chloride and is known to have a negative impact on the starch content and the underwater weight (UWW). The effect was however absent in Rockdust, in which also Kali-60 was applied. Another reason for a lower starch content in might be a yield increase. The starch content is negatively correlated with yield (data not shown), the yield increase might have reduced the starch content for BCSR and to a lesser extent also for Compost in Seresta and for Marigold(4) in Festien. The lower starch content for BCSR might be a result of the combination of the yield increase and the application of Kali-60. The UWW of potatoes is another important quality aspect. The UWW is, amongst others, affected by the application of N and K. Higher N and K applications generally result in a lower UWW (Veerman, 2001). Increased quantities of N and K_2O were applied with compost, and large quantities of K_2O were applied with BSCR method and Rockdust. The BSCR method (and the combination of treatments) resulted in a significant lower UWW. The absence of an effect in UWW with the application of compost and might be because the additional N and K_2O in compost was not directly available, it is unclear why the effect was absent for Rockdust but it might be that K_2O in Rockdust did also not become directly available. Also van Balen et al. (2016) did not find an effect of Compost or Rockdust on the UWW. Russchen and de Haan (2017) did however find an effect of Rockdust on the K concentration and the starch content for Festien. The K concentration was higher when Rockdust was applied and the starch content lower. This was however not the case for all potato varieties.

4.2.2 Sugar beet

For sugar beet, applying compost, BSCR and the combination of all treatments were associated with a lower extractability compared to the control. The extractability of sugar from the sugar beet is influenced by the soil fertility, fertilization and weather conditions. A high N and K concentration in the soil and/or application results in low extractability, just like drought. It is likely that the low extractability for these treatments is a result of the K concentration rather than the N concentration. Although a similar amount of K2O was applied with BSCR and Rockdust, BSCR resulted in a higher K concentration and lower extractability while applying Rockdust did not. It remains unclear why the K2O application with Rockdust did not result in a lower extractability. More important is the sugar concentration. A sugar concentration of <16% is considered low, between 16-17% as tolerable and >17% as good. The sugar concentration varied between 16.0 and 20.5% in the period 2014-2021, so the sugar content was sufficiently high. The variation between the years is larger than between the treatments. The average sugar concentration over de period 2014-2021 did not show large differences between the treatments, only BSCR was associated with a significant higher sugar concentration, both for tillage and non-inversion tillage. The reason behind remains unclear. The concentration of sugar in the sugar beet is influenced by pests and diseases, the moment of harvesting and the N application (IRS). It is assumed that an additional application of 50kg N ha^{-1} causes a reduction in the sugar concentration of 0.29%. With compost, an additional amount of 150kg N ha^{-1} jr^{-1} was applied, but did not result in a significant different sugar concentration.

4.2.3 Spring barley

The effects of the treatments on the quality aspects of spring barley were limited. The percentage plump grains (kernels >2.5 mm) should be 90% at minimum. This was the case for all treatments. The percentage screenings (kernels <2.2 mm) should be 2% at maximum, and this was also the case for all treatments. Applying compost was associated with a lower percentage plump grains in the first few years but not in a significant higher percentage screenings (de Haan et al., 2020). In the subsequent years (2018, 2019, 2021) the percentage plump grains did not differ significantly between compost and the control, and neither did the percentage screenings (data not shown). In general the N application increases the protein content in spring barley and negatively impacts the quality when large amounts of N are applied. An increased amount of N was applied in Compost and Combi (only the first few years), and did significantly affect the protein content in the spring barley in these years (de Haan et al., 2020). This was not the case for the subsequent years (2018, 2019 and 2021). Why the protein content was not affected by compost remains unclear. The protein content was however affected by NT. This might be due a lower yield found for NT. Additionally, the moisture content was higher for NT, which might indicate a more slow process of ripening. The latter was not measured, and therefore not supported by data.

4.3 Nutrient management

Treatments varied in the amounts of nutrients supplied. This influenced the nutrient concentrations in the crop leaves of potatoes. BCSR led to higher K, Mg and S concentrations and to a lower Ca concentration. The latter was not significant for the young leaves of Festien. The distribution of Ca through the crop is hampered when crops experience stress. Lower Ca concentrations in old leaves, lower Ca concentrations in the young leaves and no consistent effect on the Ca concentrations in the potato (data not shown) might therefore indicate that the BCSR method caused stress and therefore reduced the Ca uptake and distribution through the crop, or that the Ca availability was lower for BCSR. BCSR generally led to higher concentrations of Mg in the leaves (although not all significant), but also to a lower concentration in the young leaves of Seresta. High K concentrations might hamper the uptake of Mg, which might explain the lower Mg concentration in the young leaves of BCSR in the Seresta. In all other cases, a higher K concentration did not lead to a lower Mg concentration. Magnesium deficiencies usually occur in old leaves, while the concentrations of Mg for BCSR and Combi were especially high for the old leaves. The application of compost led to higher concentrations of Cl. For S, higher concentrations were found in the old leaves but lower in the younger leaves. Besides, lower concentrations of Mn, Fe, N, Ca, Zn and B were found in the crop leaves. For Ca this could be explained by a lower application of CaO. No reason was found for the lower concentrations of N, since larger amounts of N and NAC were applied. Moreover, higher quantities of P_2O_5, K_2O and MgO were supplied with compost, but the application did not affect the concentrations in the crop leaves. It did however increase the total P_2O_5 and MgO uptake, this was not the case for K_2O.

With the treatments BCSR, Rockdust, Compost and Combi large amounts of nutrients were applied. The removal by crop yield did not increase accordingly, resulting in overconsumption but even larger nutrient surpluses. BCSR led to the overconsumption of MgO, K_2O and SO_3, Rockdust to the overconsumption of CaO and SO_3. Surpluses were especially found for K_2O, MgO and CaO for Rockdust and BCSR. For BCSR The latter is in line with the findings of Kopittke and Menzies (2007), who state that the BCSR results in an inefficient use of nutrients. Van Balen et al. (2016) found surpluses related to Rockdust, which resulted in increased soil concentrations of K-PAE, Mg-PAE and Na-PAE and a higher CEC. The nutrient concentrations in the crops were not measured. The application of MgO was expected to have an impact on sugar beet yields, especially when Mg levels in the soil are low (Bussink et al., 2020). The results of our experiment show however that a yield increase as a result of MgO application did not occur. Large quantities of Dologran (BCSR and Combi) and biolit and zeolite (Rockdust and Combi) were applied, containing CaO and therefore expected to increase both the amount of Ca and Ca availability in the soil, crop leaves and yield. In Combi the total Ca in the soil did increase, whereas the availability did not. The application did not result in higher Ca levels in the soil for BCSR and Rockdust. Also the concentrations in the crop yield do not seem to be affected. The application did, however, lead to lower concentrations in the crop leaves. Lower concentrations are remarkable since large amounts were applied. This might be due to nutrient interactions, which is further elaborated in section 4.3.1.

Russchen and de Haan (2017) assessed the nutrient concentrations as a result of the application of Rockdust. They concluded that the application of Rockdust did not affect the nutrient concentrations in the potatoes consistently.

For compost, large nutrient surpluses were found for N, P_2O_5, K_2O and MgO. Overconsumption did occur for P_2O_5 and MgO, but not for N and K_2O. Large nutrient surpluses, inefficient use of nutrients and overconsumption because of compost application was also found by Selin Noren et al. (2022). The application of compost in a 1:6 arable crop rotation on a sandy soil resulted in an efficiency decrease from 59 to 40% for N, 108 to 61% for P and 90 to 77% for K (Selin Noren et al., 2022). The decreases in efficiency were even larger in our experiment, which decreased from 85 to 47%, 102 to 52% and 115 to 83% respectively. The same was true for the surpluses. According to de Haan et al. (2020), the surpluses as a result of compost application will increase the soil nutrient status, rather than being lost to the atmosphere or ground- or surface water. As can be seen in Table 3-18, the soil nutrient status indeed increased for P and Mg, but did not for N and K. Nutrient losses were not measured in detail as part of this study. Timmermans et al. (2023), however, examined the nutrient balances and (potential) losses of this experiment in more detail. They found that only 16 kg of N ha^{-1} of the compost mineralised in the first four years. Wijnholds (2010) even found a lower nitrate concentration in the soil after the application of compost compared to the control. When only considering the mineral N and mineralised N, rather than the total N applied, Timmermans et al. (2023) found that the N-efficiency did not differ much between the application of compost and the control. In terms of losses they found that the application of compost was associated with an increase in denitrification, but a decrease in N-leaching. De Haan et al. (2018) however measured nitrate leaching on a sandy soil, and did not find any significant effects of compost on nitrate leaching. Likewise, D'Hose et al. (2012) measured nitrate levels after the application of compost as well, and did not find any consistent differences. It would then be plausible that a large part of the in compost is still in the soil, which was assumed by Timmermans et al. (2023). Also D'Hose et al. (2012) assume that the continuous application of compost will result in considerable accumulated amounts of residual organic N in the soil. This was however not supported by our data, a higher but not significant N status was found for Compost compared to the control. This might be due to the vast amounts of N in the soil, which is about 7500 kg ha^{-1}. An additional surplus of 154 kg ha^{-1} yr^{-1} is therefore relatively small, but still an effect could have become visible after eight years. It remains unclear what exactly happened with the N applied with compost. Likewise, K is also susceptible to leaching and no higher soil K status was measured resulting from the surplus associated with the application of compost. On the opposite, Mg might be even more susceptible to leaching than N and K (Gransee & Führ, 2012). A higher Mg soil status was measured, but the increase does not explain the total surpluses. In short, the application of compost led to nutrient surpluses but the effect on nutrient losses remains unclear since nutrient losses were not examined in detail here.

4.3.1 Nutrient interactions in the soil and plant

BCSR, Rockdust, Compost and Combi were associated with large supplies of K_2O. Large K_2O applications could reduce the uptake of Ca (Bussink et al., 2020). Large amounts of additional CaO were applied with BCSR, Rockdust and Combi, but not for Compost. The Ca concentrations in yield did not differ between the treatments, but did for the concentrations in the crop leaves. This suggests that K might have oppressed the uptake of Ca in BCSR, Rockdust and Compost, even when additional CaO was applied.

Ca and Mg are also known to suppress each other in case of high availability. Increasing the Ca concentration to a certain level may increase the uptake of Mg, because slightly increasing the Ca concentration restores the membrane functionality and enhances de uptake of other cations. Further increasing Ca leads to competition and suppressing the Mg uptake (Gransee & Führs, 2013). BCSR did lead to similar or even lower CaO concentrations in the crop and leaves, while the concentration of MgO were somewhat higher. This indicates that CaO did not suppress MgO.

Compost was associated with large supplies of N, K_2O, P_2O_5 and MgO. The combination of N and K2O is known to have a (weak) synergistic effect on the potato and sugar beet yield (Bussink et al., 2020). The results in Section 3.4 show that the N and K_2O in Compost did not led to a significant increase in potato yield but did in the sugar beet. For reclaimed peatland it is known that applying additional N reduces the K concentration in the sugar beet (IRS). However, in Table 3-11 it becomes apparent that this was not the case when compost (and therewith larger quantities of N) was applied. This might be because the amount of NAC applied did not differ greatly between the treatments. Additionally, it needs to be noted that there are more interaction effects with the application of compost than N and K_2O alone.

The additional supply of P_2O_5 with Combi-NT resulted in a higher P-Al compared to the control. However, the P-PAE was lower for Combi-NT compared to the control. This is contrary to the expectations, as more P_2O_5 was applied in Combi-NT, and the increase in pH for Combi-NT is expected to increase the availability of P_2O_5. However, large quantities of Ca were applied, which can bind P and decrease the availability for plant uptake. Also Fe was applied (in zeolite), which can bind P and decrease the availability.

4.4 Soil quality

4.4.1 Soil fertility

The application of compost has led to an increase in some soil nutrients, such as P-Al, Mg and Ca. The increase in P-Al and Mg is in line with the expectations, as large amounts were applied. As mentioned above, an effect of K_2O and N on the soil nutrient status was absent. Wijnholds (2010), who studied the effect of compost on reclaimed peatland, also found an increase in soil P, Ca and Mg, but did not find an increase in K. It remains unclear why the surplus of K was not found in the soil nutrient status. The soil contains an amount of around 350 kg K ha^{-1}, and an annual difference of 68 kg K ha^{-1} yr^{-1} between Compost-T and the control is therefore expected to become visible after eight years. For Ca Wijnholds (2010) found a high variability through the years, and did not find an explanation for these variations in time. In our experiment an increase in the soil Ca status was found. The application of compost led to a higher pH, CEC and CEC saturation in our experiment. An increase in CEC might be due to the application of organic matter and the increased CEC saturation might be a result of a higher pH. Compost generally has a higher pH than the soil (6-8 and around 5 respectively in this case), but it is unclear if this was the reason for the increase in pH after compost application.

For BCSR the Ca/Mg ratio related to the desired ratio were most of importance. the Ca/Mg ratio of BCSR moved towards the desired ratio and was reached in 2018-2021. The Mg saturation reached the optimum level, while the Ca saturation did not. The total CEC saturation was higher for BCSR when compared to the control which is both a result of an increasing pH as well as the application of MgO and K_2O. Also the K saturation increased for BCSR compared to the control (data not shown). It is known that K competes with Ca saturation at the CEC. However, K saturation for both BCSR and the control were relatively low. It is likely that Mg and possibly K have replaced H+ in BCSR (because of the liming effect), rather than Ca. Which is surprising, as the CEC prefers Ca. Mg is relatively mobile and therefore more likely to remain in solution and be subject to leaching (Gransee & Führ, 2012). Yet another reason why the Ca saturation has not reached the desired ratio might be the pH, which is still somewhat lower than the advised pH (5.8 vs 6.3). The pH of the soil is kept relatively low because it reduces the damage by plant parasitic nematodes. The total Ca status in the soil increased, while the Ca saturation and the plant uptake did not. Taking everything into account makes it likely that the either Ca saturation reached its maximum, which might be a result of the pH not being sufficiently high, or that competition with other cations at the CEC occurred.

For Combi a combined effect of compost and BCSR can be expected. Compared to the control, Combi-NT led to a higher pH, CEC satuaration, P-Al, total K, K-number, total Mg and total Ca. This increase in soil nutrient levels is in line with the expectations.

4.4.2 Soil organic matter

The effects of the treatments on the soil organic matter was done via a simple model approach. The results showed that the control was associated with a negative organic matter balance, resulting in a decline of 0.1 percentage point of the soil organic matter. Compost and Combi resulted in an increase of 0.7 percentage point. Given the uncertainties, differences in soil organic matter content should be >1.01% in soil organic matter to be able to measure any differences (de Haan et al., 2020). After eight years, the expected increase in soil organic matter based on the model approach does not exceed the 1.01 percentage point for any of the treatments. Therefore, differences in measured soil organic matter contents could not be expected. As can be seen in Appendix 10, a consistent difference in the soil organic matter percentage between Combi-NT and the control did not become visible. Only for field 70-3 and 71-2 the soil organic matter content of Combi-NT was >1.01 percentage point higher than the control, but is likely to be related to the measured initial soil organic matter content. Timmermans et al. (2023) used a more complex model, NDICEA, to model the effects on the soil organic matter content. They conclude, in line with our results, that the control was associated with a decline in the soil organic matter content, while the soil organic matter content of Compost and Combi are expected to increase. Selin Noren et al. (2022) however found a significant increase of the soil organic matter content due to the application of compost to a sandy soil based on measurements. Also Ruyschaert et al. (2014) found a significant increase in soil organic carbon after the annual application of (farm) compost to a sandy soil after a period of seven years. Measuring effects of treatments on the soil organic matter content on a reclaimed peatland is however more complicated, due to its high content and variability. It is therefore plausible that the application of compost in our experiment contributed to the soil carbon stock, but difficult to prove taking into account the difficulties concerning C measurements on reclaimed peatlands. The effect of the other treatments on the soil organic matter level were not investigated in detail as part of this study, as the effects were expected to be too small to measure. The effect of NT on the soil organic matter level has been studied more extensively in other experiments (e.g. De Haan et al., 2018; Hoogmoed et al., 2021; Koopmans et al., 2020). Hoogmoed et al. (2021) and Koopmans et al. (2020) found no significant difference in soil organic carbon content or stock for NT compared to T on a sandy soil, when corrected for the initial level. Experimental data on sandy soils in the Netherlands is however scarce. Cooper et al. (2016) conducted an international meta-analysis and concluded that NT does not increase the soil organic matter level through the soil profile (0-30 cm). On the contrary, in some other international studies a significant increase was found (e.g. van Groenigen et al., 2011). Van Groenigen et al. (2011) found a higher carbon stock in the upper 15cm, while no significant difference was found for the layer 15-60 cm. This is contrary to the common expectation that NT management leads to stratification with higher concentrations in the top layer but lower concentrations at deeper depths, resulting in in net difference in stocks (Cooper et al., 2016). The effect of NT on C sequestration is hotly debated in literature, due to a lack of reliable measurements in our experiment it is difficult to indicate whether NT had an impact on C sequestration.

4.4.3 Soil structure and water availability

4.4.3.1 Non-inversion tillage

During the experiment, it was observed that more crop residues remained at the surface for NT when compared to T (see Appendix 16). This seemed to affect the germination of sugar beets, but later in the season differences became less visible. Also the soil surface contained more coarse material for NT than for T. Other visual effects of NT on the soil structure were not observed. NT was associated with a lower PR, somewhat lower bulk density and root hindrance occurred at a greater depth compared to T. A compacter soil for T might be due to the cultipacker. Hoogmoed et al. (2021) compared non-inversion tillage with mouldboard ploughing and found opposite results. They found a higher PR and bulk density for NT compared to the control, and generally found a lower PR when compared to our experiment. Hoogmoed et al. (2021) state that the switch from conventional to inversion tillage can lead to a more compacted soil in the first few years, as the soil requires time to restore the soil structure. In our experiment, such a trend was not found. Hoogmoed et al. (2021) also note that an increased penetration resistance is not necessarily associated with a poor soil structure, as the water holding capacity improved. Since the values found for both NT and the control were in the target range as described in Hanegraaf et al. (2019) both for the bulk density as well as the PR, it can be concluded that NT did not necessarily improved the soil structure in this experiment. Besides, the target values for PR are questionable. The PR is insensitive to pore size distribution, a higher PR is therefore not directly associated with lower crop growth (Zwart et al., 2011). The MPa at which root hindrance occurs is crop specific, and determined for potatoes on sandy soils in the United Kingdom (Zwart et al., 2011). The MPa at which root hindrance occurs at reclaimed peatsoils might be different. A limited effect on the soil structure between T and NT might have several reasons. The soil disturbance of T and NT might not be very different. Usually conventional tillage is compared to no-till practices or at least reduced tillage. The practices tested in this experiment might not have been different enough. Moreover, switching to less soil disturbance is usually accompanied by a systematic change, in which no-till is combined other practices such as cover crops and direct seeding. In this experiment solely the effect of practices was studied. Besides, the soil disturbance in this experiment is relative high, as three out of four crops in the rotation are root vegetables. The difference in tillage practices might therefore not come to expression.

4.4.3.2 Compost

Compost did not have an effect on the PR or the depth at which root hindrance or inhibition occurred. The bulk density or aggregate stability was not measured. Ruysschaert et al. (2014) monitored the effect of annual compost application on the soil structure in more detail. They found a higher aggregate stability and a lower bulk density. In line with our results, no effect was found on the PR. They attribute the absence of an effect in PR to the high variability and wet circumstances when measuring. In Schepens et al. (2022) a comparison was made between compost and no organic fertilization, and they found a lower bulk density but no effect on the PR. van Balen et al. (2016) also analysed the effects of compost application on the soil structure. They did not find a significant difference in the water permeability, PR, aggregate stability and water holding capacity. All-in-all it is not likely that compost affected the PR, effects on other physical aspects might have occurred, but were not measured as part of this study.

4.4.3.3 BCSR

The results show that BCSR did not significantly affect the PR. It is however often assumed that the Ca/Mg/K ratios in the soil affect the soil structure. Ca and to a lesser extent Mg are able to adsorb to organic matter and thereby form micro-aggregates. Kopittke and Menzies (2007) describe a study in which the effect of Ca/Mg ratios on the soil structure was researched. They found that a reduction in the Mg saturation (from 18-28% to 11-21%) did not affect bulk density, moisture content and the infiltration rate. Also in our experiment we did not find any effects of a changing Mg saturation on the soil structure, measured as penetration resistance. The Ca saturation might be of more importance, but did not change much during the experiment. All-in-all, it is not likely that BCSR improved the soil quality, but no farfetched conclusions can be draws since only one physical soil parameter was measured.

4.4.3.4 Combi treatment

Combi-NT led to a lower PR and root hindrance at a greater depth. Based on the results of the measurement which was carried out simultaneously for standard-NT, Combi-NT and Compost-T (15-06-2021) it is likely that the results of Combi-NT are due to the combination of treatments, of which non-inversion tillage explains the largest part (data not shown). Whether additional effects as a result of the combination of treatments occurred is difficult to determine, because not all treatments have been measured. As stated in section 2.4.6.1, PR is influenced by many factors, such as the bulk density and soil organic matter. In our experiment the PR was significantly related to the crop type, field, the soil organic matter content and the treatment (data not shown). As discussed in section 3.5.1, no significant differences in soil organic matter were found between Combi-NT and the control. Therefore, it is likely that the treatment affected the PR. To conclude, Combi-NT resulted in a lower PR compared to the control, which was probably may be due to NT rather than compost or BCSR.

4.4.4 Water availability

Reduced tillage and both the soil organic matter and the application of organic matter influence the water availability in multiple ways. Organic matter has a lower volumetric mass density than soil particles, and might result in a lower bulk density and a higher water holding capacity. Inversion tillage might lift up moist soil to the dry surface, leading to a (temporary) higher soil moisture content at 15cm compared to non-inversion tillage. Crittenden (2015) hypothesized that soil water in reduced tillage systems moves through a denser soil matrix, and these movements will be slower. As a result, moisture might be longer retained in the soil before draining towards the subsoil. In turn, a lower bulk density is associated with a higher pore volume and can contain larger quantities of water. NT was associated with a slightly lower bulk density compared to the control, Combi-NT was associated with an even lower bulk density. All-in-all it is expected that organic matter will improve the water availability and that NT will have a limited effect.

As derived from the bulk density and the moisture content at FC, the soil treated with Combi-NT is able to retain more water when compared to the control, but the differences were small. The fact that Combi-NT at the high soil organic matter interval was associated with the largest capacity to contain water, did not lead to more plant available water.

Plant available water did not seem to be linked to the treatment, but seems to be interfered by the soil organic matter interval. Higher soil organic matter seems to be associated with higher plant available water. The difference between low and high organic matter intervals became clear for the control (with organic matter levels of 8,5 and 10,3% respectively). The plots of Combi-NT even had a larger difference in soil organic matter level (7,2 and 15,6%), but due to a high variation in plant available water at the low organic matter level, the difference in plant available water between a low and high soil organic matter level was not consistent.

Thus, the results show that there was no effect of the treatments on the plant available water, but the soil organic matter level did seem to have an effect. Additionally, the results showed that there was no or limited difference in water retention between the treatments (Combi-NT vs Control) or the organic matter level (high vs low). Lal (2020) performed a meta-analysis and found that soil organic matter could increase the soil water retention and plant available water capacity. They note, however, that the effect depends on soil texture and the initial soil organic matter content. For sandy soils with an organic matter content of 0.5-1.0%, an 1% increase would improve the plant available water by 3-4mm. For soils with an organic matter content of 1-3% this would be a 2-3mm increase and for soils with a soil organic matter content of >3% this would be 1mm (Wösten & Groenendijk, 2019). Although the soil organic matter content in our experiment was much higher, a link between the soil organic matter content and plant available water was found. Wösten and Groenendijk (2019) mention, however, that the effect in a dry summer on crop growth will be very limited.

However, it is still uncertain whether soil organic matter levels have led to more plant available water. Even if there would be a strong link between the soil organic matter level and plant available water, this could be due to the fact that plots with a high soil organic matter interval are usually situated lower (because of degrading peat), and therefore may contain more soil moisture.

An additional point of discussion is the fact that the soil moisture loggers were placed at a depth of 15cm, and therefore do not provide a clear picture of the soil structure throughout the soil profile or water logging as a result of subsoil compaction.

4.4.5 Soil biology

In our experiment it turned out that the soil organic matter strongly affected soil biology, but that soil treatments can still influence some parameters. Combi-NT led to a higher fungal number, more fungal biomass, a higher fungal/bacterial ratio, and more diversity. Compared to the control, applying compost increased the amount of protozoa and led to a higher fungal/bacterial ratio. Schepens et al. (2022) found a higher soil microbial biomass for compost compared to the control, both for bacteria as well as for fungi. Also Ruysschaert et al. (2014) found an increase in soil biology parameters when (farm)compost was applied. The soil microbial biomass increased by 50% and also the number of earth worms increased. Likewise, D'Hose et al. (2018) found a 30% increase in soil microbial biomass and a 65% increase in earth worms. It is therefore likely that the application of compost affects several aspects of the soil biology.

In our experiment NT did not significantly affect any of the soil biological indicators. Likewise, Hoogmoed et al. (2021) did not find any effects of NT on the soil microbes in a sandy soil. In other studies, a higher fungal and bacterial biomass were found with NT. This has been attributed to a decreased disturbance of fungal hyphae and an increased concentration of organic matter in the upper soil layer (Roger-Estrade et al., 2010). However, in the present study three of the crops were grubbed at harvest, which represents a disturbance of the soil, and therefore the impact of NT might be diminished.

4.4.6 Nematodes

4.4.6.1 Nematode community

In comparison with 2013, in 2020 in both treatments the number of fungal feeders was relatively high, of which a large part belonged to the genus *Aphelenchoides* (CP-2). Also, in both treatments the number of Neodiplogastridae was high (184-586 $\cdot$ 100 mL soil^{-1}) compared to soil from other experiments in Vredepeel, in the South of the Netherlands ('Bodemgezondheidsproef' and 'Bodemkwaliteit op Zand'). In the other systems the same function is probably performed by other bacterial feeding groups, like Rhabditidae. Nematodes in the family Neodiplogastidae feed on bacteria as well as protozoa and other nematodes (Georgieva *et al*., 2005) and were classified as omnivores in Ninja. In November 2022, after our analysis had been performed, this classification was changed to bacterial feeder. The CP-value of this family is 1, which means that they can quickly respond to changes in food availability. This nematode family also contributes to the calculation of the Enrichment Index (Ron de Goede, pers. comm.), in contrast to what is mentioned in the first definition of the index (Ferris *et al*., 2001). The same holds for the predator *Mononchoides* with CP-value 1. *Mononchoides* occurred in both treatments, but was not found in fields 49 and 56, which both were located in one of the strips Combi-NT. The results are in agreement with the higher biomass of bacteria and fungi in 2020 than in 2013. They may relate to the crop that was grown in the preceding year; sugar beet was grown in 2019, leaving behind more crop residues than the potato that was grown in 2012.

In general, only a limited effect can be expected of compost addition on bacterial and plant feeding nematodes (Thoden et al., 2011; D'Hose et al., 2018; Herren et al., 2020; Brinkman et al., 2022). Brinkman et al. (2022) assessed the effect of several soil treatments on the nematode community. They did not find an effect of compost application on the total abundance of nematodes, different groups or calculated indexes. By applying compost, organic matter is added to the soil in the form of decomposed material that contains a limited amount of food for the soil community (Brinkman et al., 2022). The compost itself contains nematodes that are added to the soil as well, but these nematodes disappear within a few months after application (Herren et al., 2020).

The amount of information on the effect of soil tillage on the nematode community is limited. Probably the effect on plant feeders mainly depends on the crop-nematode combination, whereas the effect on fungal- and bacterial-feeding nematodes depends on the crop rotation and the structure and distribution of organic matter in the soil (D'Hose et al., 2018). In a field experiment, the density of bacterial feeders, omnivores and predators was lower in no-till than in conventional tillage, but there was no difference in the Maturity Index (Treonis et al., 2018). Some other studies do not report numbers, but express the nematodes in the feeding groups as proportion of the total number. Bongiorno et al. (2019) analyzed effects of reduced tillage in multiple field experiments and found a smaller proportion of bacterial feeders, a reduction of the Enrichment Index (EI) and an increase of the Maturity Index (MI), Structure Index (SI) and Channel Index (CI) compared to conventional tillage. The shifts were relatively small and on average were in the order of magnitude of 6 points for EI, 7-8 points for SI, 2-4 points for CI (all on a scale of 0-100), and 0.20 points for MI (on a scale of 1-5). Thus, in general soil measures only caused a small shift of the points in the food web analysis diagram. Also Neher et al. (2019) mentioned a reduction in the proportion of bacterial feeders in no-till, but did not find an effect on other feeding groups. However, the effect of tillage can also be related to the addition of organic material and the sampling depth (Treonis et al., 2010). Tillage increased the total number of nematodes, but the effect only was significant in the layer 0-5 cm (and not in the layer 5-25 cm) when no organic amendment was applied to the soil (Treonis et al., 2010). In the top layer, the number of nematodes was higher than in the lower layer. Tillage reduced the proportion of fungal feeders and increased the proportion of bacterial feeders in the top soil layer, but only when no organic matter was applied. When combined with organic amendment, tillage increased fungal feeding nematodes. They conclude that when combined with organic amendments, tillage seems to stimulate soil life beyond the effect of amendment alone (Treonis et al., 2010). In the present set-up, the combination of the tillage and fertilization treatments, that is Control=Standard-T versus Combi-NT, makes it impossible to draw conclusions on their separate effects on the nematode community.

4.4.6.2 Plant parasitic nematodes

As expected, the cultivation of marigold strongly depressed the density of root lesion nematodes. The effect of growing marigold on the density of root lesion nematodes was so strong that after two cultivations of the good host plant potato the density had hardly increased. In contrast, in the rotation with spring barley and black oat the density of root lesion nematodes had already increased to a level above the damage threshold after one cultivation period of potato.

In the treatment Marigold(8), in two out of four fields even the third cultivation period of potato profited from the reduction in the density of *P. penetrans*. In these two fields the density of *P. penetrans* still was significantly lower than in the treatments without marigold even five years after the cultivation of marigold, after growing spring barley and black oat.

An increase in Trichodoridae was expcected but not found, probably due to a relatively long period of bare soil prior to the cultivation of Marigold. An increase of Meloidogyne as a result of the cultivation of Marigold was also absent.

4.4.7 Weed pressure

The weed seedbank analysis that is performed, should be regarded as a general survey that tries to investigate the overall changes in weed seedbank densities and composition after the trial period until spring 2022. As no initial seedbank data were available, we assume that the initial seedbank densities and composition were equal between fields. The results should be interpreted as such. As sampling was performed over all crops in the rotation, it gives a cross section of the state of the soil seedbank at system level at a given point in time.

Comparing the overall effect of NT versus T, we conclude that NT did not result in significant differences in the density and composition of the weed seed bank compared to the standard tillage practices (see Figure 3-13). It is assumed that the weed seedbank was homogenous at the start of the trial period in 2013. Between the four trial fields, slight differences in seedbank size and composition were observed with regard to the tillage type. These differences are more likely to be the result of the differences induced by recent crops in the crop sequence rather than tillage type. For example, more annual grasses were observed when the crop in 2021 was spring barley (see Appendix 15: field 71-1). As both spring barley and annual grass are monocotyledons, the reproduction of annual grass is more likely and relatively more grass seeds are found during the seedbank analysis. The same logic is true for instance for black nightshade in potato crops.

For NT it is known that the majority of seeds is found is the top layer of the soil (Swanton *et al*. 2000; Joseph *et al*. 1992). The vertical distribution of weed seeds in non-inversion tillage is found to decline rapidly with increasing depth and about 60% of the weed seeds are found in the top few centimeters (Yenish et al., 1992). Accordingly, our study showed that most germinating seeds were found in the 0-10 cm layer. Even under standard tillage, weed density was highest in the 0-10 cm layer. The standard tillage method in this experimant was rotary spading, a method that mixes the weed seeds through the soil profile in contrast to for instance moldboard ploughing where more seeds are buried deeper in the soil. Yenish et al. (1992) describe that with moldboard ploughing an uniform distribution of weed seeds may be expected.

Weed seedbanks commonly consist of many species, but often only a few species are dominant and account for over 70% of the total seedbank (Wilson, 1988). In this study, we found only four dominant species throughout all treatments. The tillage regimes in our trial favor these species. Especially grassy species, such as *Poa annua*, are favored by shallow and non-burying tillage operations (Froud-Williams et al., 1983). Species like lambsquarters and common chickweed are also known to have shallow emergence depths and can potentially become more dominant in tillage systems with shallow operation depths (Radosevich et al., 2007).

Additionally it needs to be mentioned that herbicides were used conventionally in both treatments. When the use of herbicides would have been reduced, differences in the seedbank between T and NT might have become visible.

5 Conclusion

5.1 Non inversion tillage

Effect on yield
When averaged over the crops, the effect of NT on marketable yield was minor. NT did not affect the crop yield of the starch potatoes or sugar beet. For spring barley, NT was associated with a lower yield when compared to T (-1.8%). The small seeded crops in this experiment (sugar beet and spring barley) did not experience difficulties with germination under NT, NT did not consistently affect the number of plants. The exact reason why spring barley was impacted negatively remains unclear, but the moisture content of the yield was higher for NT than for T. This might indicate a slower growth and later ripening. Apart from the spring barley, NT did not affect any quality aspects of the crops.

Effect on nutrient uptake
As a direct result of a lower yield for spring barley, the nutrient removal was somewhat lower. This resulted in an increased nutrient surpluses for N, P_2O_5 and K_2O of respectively of 23, 7 and 57 and kg ha^{-1} yr^{-1}. Seen over a crop rotation, the effect of NT on the nutrient balance was small. Therefore, the effect on the soil nutrient status is expected to be limited.

Effect on soil structure
NT affected the soil structure. Compared to T, NT was associated with more crop residues in the soil surface and a coarser soil structure. NT was also associated with a lower PR and a lower bulk density. This is surprising, as the soil under NT is less mechanically loosened. Root hindrance occurred at a greater depth, which could positively affect crop growth. This was directly related to the depth of which the soil is loosened, which was at a greater depth for NT than for T. However, the values found for both T and NT related to soil structure (PR and bulk density) were within the target range, and therefore NT did not necessarily improve the soil structure. NT did not improve the water holding capacity, as NT was not associated with a higher moisture content at FC than T.

Effect on soil biology
NT did not affect any of the soil biological indicators such as soil fungi and bacteria. It is unclear why NT did not affect the soil biology, since a lower soil disturbance is known to have a beneficial effect on soil biology, especially on soil fungi. The difference in soil disturbance between T and NT might not have been large enough for the soil fungi to benefit. Furthermore, it is known that a more compacted soil hinders the activity of the plant parasitic nematode *P. penetrans*. In our experiment NT did not have an effect on the population of *P. penetrans* in the soil or potato yield.

Effect on weed pressure
NT did not affect the presence of weed seeds in the soil, the distribution through the soil profile or the composition of weeds when compared to the control. It needs to be mentioned, however, that herbicides were used conventionally in both treatments.

Applicability
NT requires some experience, especially regarding the specific field conditions. Creating the optimal conditions for crop growth, especially for sugar beet, can be more difficult for NT than for T. The investments needed are limited, the maintenance needed for NT equipment is low relative to rotary spading. Moreover, NT requires less fuel, and the annual costs are therefore lower than for T. The lower costs outweigh the losses in yield for spring barley, having a positive net financial effect. With the changing prices for barley and fuel, the financial aspects should be evaluated for specific years and conditions.

All-in-all, NT could be financially attractive and is relatively easy to apply. However, NT did not improve soil functioning greatly. Switching from NT tot T could therefore be considered when it fits in the context of the current farm management, but large effects on the soil quality cannot be expected.

5.2 Marigold

Effect on yield
The cultivation of Marigold had a positive effect on crop yields. As a result lower concentrations of *P. penetrans* in the soil, the starch potatoes benefitted in the first two to three cultivations after Marigold was grown. Therefore, the yield effect on the susceptible crops, potato in this case, is larger when Marigold was grown every four years compared to once every eight years. Growing Marigold once every four years resulted in a yield increase of 8.3 and 13.7% respectively for Festien and Seresta, which was 5.3 and 9.9% when grown every eight years. The yield effects might be even larger when the crop sequence would have been changed to Marigold-Seresta-Festien-sugar beet. This is because Seresta is more susceptible to *P. penetrans* and could

therefore benefit more from a lower population of *P. penetrans* in the soil. The yield of sugar beet was not affected.

Effect on plant parasitic nematodes
The cultivation of Marigold successfully reduced the population of *P. Penetrans* in the soil. The population remained low for the five to six subsequent years. Therefore, the effect is still visible after one crop rotation. After two crop rotations, the population had increased again until the initial level. With the cultivation of Marigold every four years, it is therefore possible to keep the population low. Furthermore, Marigold is a poor host for Meloidogyne and Trichodoridae. Since Marigold replaced a rather good host for these nematodes, the densities decreased. The densities remained low for both the treatments as the control.

Applicability
The cultivation of Marigold is somewhat challenging, and requires knowledge, experience and the right equipment. Outsourcing the sowing of Marigold can be a solution. Timing and keeping the soil free of weeds are points of attention. The cultivation of Marigold therefore requires more labour than other cover crops. Besides, the cultivation of Marigold is more expensive than other cover crops. Based on the studied period, replacing spring barley + black oats by Marigold was financially attractive. However, costs of barley and artificial fertiliser have been increased, which has financial consequences. An update of the financial analysis for Marigold will be made in a follow-up study.

Summarised, the cultivation of Marigold successfully reduced harmful nematode populations and increased potato yields. Sowing Marigold is, however, only beneficial if the plant parasitic nematode *P. penetrans* is present at a certain level. Soil monitoring related to the presence of this nematode is therefore required. Effects on other soil functions were studied to a limited extent.

5.3 Compost

Effect on yield
The application of compost affected the yield. The marketable yield of sugar beet increased (+3.6%). The increase in yield might be an effect of the increased amounts of nutrients applied with the application of compost, but cannot be stated with certainty on the basis of this experiment. The marketable yield of potato and spring barley were not affected by the application of compost. The reason why sugar beet benefitted and the potatoes and spring barley did not remain unclear.

Effect on nutrient balance
Compost contains substantial amount of nutrients, which was (partly) compensated for in the artificial fertilisation of P_2O_5 and K_2O. Averaged over all crops, Compost led to the over consumption of P_2O_5 and MgO, but led to lower concentrations for some of the micronutrients in the crop leaves of the potato. Altogether, the application of Compost was associated with nutrient surplus for Ntot, P_2O_5, K_2O and MgO and reduced nutrient use efficiencies when compared to the control.

Effect on soil fertility
The nutrient surpluses associated with applying compost led to a higher soil nutrient concentration of P-Al, Mg and Ca in the soil. The latter was surprising, as less CaO was applied with compost. An increase of Ntot and K_2O was expected, but was not found. Nutrient losses were not studied as part of this experiment, and it therefore remains unclear what exactly happened to the K_2O and N in compost.

Effect on soil structure
No visual effects of the application of compost on the soil structure were observed. Furthermore, no effects on the PR were found. Solely one indicator regarding the soil structure was measured. The application of compost could possibly affect the aggregate stability or bulk density, but these parameters were not assessed. It can therefore not be stated with certainty that the application of compost did not affect the soil structure.

Effect on soil biology
Along with nutrients, the application of compost is accompanied with the supply of organic matter. Organic matter is the main source of food for soil life. The soil organic matter content correlated positively with the number of bacteria and fungi. The application of organic matter in the form of compost only increased the amount of protozoa and the fungi/bacteria ratio. Previous studies make it plausible that the application of compost increases soil life, but the effect of compost is dependent among other things on the type of compost and compost age.

Applicability
The application of compost is relatively easy, but is associated with additional costs. The yield increase for sugar beet did not outweigh the associated costs. Financially, the annual application of compost might be not attractive. However, the application of sufficient organic matter might be relevant on the long-term. In earlier studies we have seen that not applying sufficient organic matter might cost yield on the long-term. When not applying compost, the supply of sufficient organic matter should be a point of attention.

In short, the application of compost did improve some aspects of soil functioning, including yield and soil life. These effects were however limited. In addition, the yield increase did not outweigh the extra costs.

5.4 BCSR-method

Effect on yield
BCSR aims at optimum saturation levels for Ca, Mg and K in the soil. The altered soil nutrient levels did however not affect the marketable crop yield. BCSR only had a positive effect on the field yield of starch potatoes, but the chloride in Kali-60 reduced the starch content, resulting in marketable yields similar to the control. The yield of other crops was not affected by BCSR.

Effect on nutrient uptake
With BCSR, large amounts of K_2O, MgO, CaO and SO_3 were applied. Higher concentrations of K, S and Mg were found in Festien, higher concentrations of K and S in sugar beet and higher concentrations of Mg in Seresta. K and Mg are usually in competition, but the higher concentrations of K did not lead to lower concentrations of Mg in this case. During crop growth, no Mg deficiencies were observed. The concentrations of Ca did not differ between BCSR and the control, and deficiencies were not observed.

Effect on nutrient balance
The BCSR treatment led to overconsumption of K_2O, MgO and SO_3, which means that the crop production did not increase proportionally with the nutrient uptake. Even though the nutrient uptake increase, BCSR resulted in large nutrient surpluses of K_2O, MgO, CaO and SO_3, which can be seen as inefficient nutrient use.

Effect on soil fertility
With the applications and associated surpluses, the optimum Mg saturation and Ca/Mg ratio was reached after 4-7 years. The Ca saturation level did not reach the level which is considered as optimal, but the Ca status in the soil did increase. It is likely that Mg and possibly K have replaced H+ at the CEC, rather than Ca. Another reason might be that the pH was not sufficiently high.

Effect on soil structure
Altered nutrient ratios and saturation at the CEC in the soil can have an influence on the soil structure. No visual effects of BCSR on the soil structure was observed and no effect was measured on the PR. Solely one parameter of the soil structure was measured and it can therefore not be stated with certainty that BCSR did not affect the soil structure.

Applicability
Knowledge and soil monitoring is required to make alterations in the fertilisation schemes and reach the Ca, Mg and K levels that are considered to be optimal. Although no investments are needed, annual costs for artificial fertiliser will increase. As the yield did not increase accordingly, BCSR is not a financial attractive measure.

To conclude, BCSR altered the soil nutrient status towards levels that are considered as optimal. This did however not increase crop yields, did not alter the soil structure and led to lower nutrient use efficiencies. As BCSR is associated with additional costs and did not improve the soil functioning, the treatment will not be advised to arable farmers in the region.

5.5 Rockdust

Effect on yield
The annual application of Rockdust did not affect crop yields nor the quality aspects. The application was therefore discontinued in 2017.

Effect on nutrient uptake
Large amounts of K_2O, MgO and CaO were applied. Higher concentrations in the crops were measured. Crop yields did not increase accordingly. Rockdust therefore led to the overconsumption of CaO and SO_3.

Effect on nutrient balance
Since and the crop yields were unaltered, Rockdust resulted in large nutrient surpluses. This can be considered as inefficient nutrient use. The effects of the surpluses on the soil nutrient status or losses was however not measured.

Applicability
The application of Rockdust is relatively easy, and no additional investments are required. The treatment did not result in a yield increase but was associated with higher costs, the treatment is therefore not financially attractive.

All-in-all, it is not likely that the application of Rockdust improved the soil functioning, but rather led to inefficient nutrient use and an unnecessary increase in costs. Farmers in the region are therefore not advised to adopt this measure.

5.6 Combination

Effect on crop yield
In the Combi-NT treatment, all treatments are combined. The idea behind it was to maximize the possible effects. The combination resulted in a yield increase, but the increase was lower than for the sum of the separate treatments. Marigold (both 1:4 and 1:8) increased the yield of Festien and Seresta more than Combi-NT did. This is probably due to similar effects on the population of *P. penetrans*, but the negative effect of Kali-60 on the starch content. For sugar beet, the yield increase of Combi was equal to compost. The cultivation of spring barley was replaced every eight years, for the other years an effect on the yield of spring barley was not observed. It is not plausible that synergistic effects between any of the treatments on the crop yield occurred for any of the crops.

Effect on nutrient uptake
The combination of fertiliser strategies as part of Combi-NT led to increased nutrient concentrations for N, P, K and to some extent for Mg and S. Even though Combi-NT was associated with a higher yield when compared to the control, Combi-NT led to the overconsumption of P_2O_5, K_2O, MgO and SO_3.

Effect on nutrient balance
Compost, Rockdust and BCSR resulted in large nutrient surpluses. A combination of these treatments resulted in even larger surpluses. Main surpluses were found for N, P_2O_5, K_2O, MgO, CaO and SO_3.
Effect on soil fertility
As a result of the high surpluses, higher soil nutrient levels were found for P-Al, K-number, total K, Mg, Ca and the CEC saturation. For P-Al, the K-number and Mg this effect is desirable, for the other elements a proper target value is not available. It remains unclear why the surplus of N was not found in the soil.

Effect on soil biology
The application of compost as part of Combi-NT led to an increased supply of organic matter. In combination with NT, a positive effect on the soil life was expected. Combi-NT increased the number of fungi, the fungal biomass and the fungi/bacteria ratio. This might be an effect of the combination of compost with NT, or caused by any of the other treatments. These effects are difficult to disentangle, because not all of the treatments were analysed separately. Regarding the soil nematodes, Combi-NT did not affect the communities. Only the plant parasitic nematode *P. penetrans* was affected. The effect was similar to Marigold(8).

Effect on soil structure
For the soil structure, it is likely that the effect of Combi-NT was a result of NT. Combi-NT resulted, like NT, in a lower PR and a greater depth at which root hindrance occurred, while this was not the case for Compost-T nor BCSR-T. However, Combi-NT did not seem to be associated with higher water availability. The water availability seemed to be linked to the soil organic matter level, but could not be ascertained with data.

Synergistic effects of the treatments
Synergistic effects of combining all treatments did not occur for crop yield, the yield increase associated with Combi-NT was lower than adding the yield increase of all separate measures. For all other aspects (e.g. soil biology, soil structure, water availability), it is difficult to determine whether synergistic effects occurred, as those were not measured for all treatments separately and combined.

All-in-all, a combination of treatments increased the soil nutrient level but was associated with a lower nutrient use efficiency, increased some aspects of the soil fungi and reduced *P. penetrans* but did not affect other aspects of the soil biology, altered the soil structure but did not improve the water availability, and most of all, was not associated with higher yields than some of the treatments. Together with the associated costs, Combi-NT is not a realistic strategy to improve soil functioning.

5.7 Overall conclusion

Several treatments were investigated on their effects on crop yields and soil quality aspects. The cultivation of Marigold instead of spring barley and black oat turned out to be the most feasible treatment to improve crop yields, by reducing the plant parasitic nematode *P. penetrans*. Since the start of this experiment, the cultivation of Marigold is applied increasingly within the region. Another interesting treatment includes the application of compost. Compost showed to increase the yield of sugar beet. The application of compost was also associated with large nutrient surpluses, which should be paid attention to in case of long-term annual application in terms of mineralization and potential nutrient leaching. Compost is associated with an increase in costs, it should therefore be considered whether compost is the best choice to apply organic matter to the soil. Apart from Marigold and compost, none of the treatments increased the yields substantially. NT altered the soil structure, but none of the crops strongly benefited from this change in soil structure, only spring barley was affected negatively. NT, compared to conventional tillage, could reduce costs and could therefore still be interesting. The effect of NT is largely related to specific field conditions, which have to be kept in mind. BCSR and Rockdust mainly resulted in inefficient nutrient use, without improving crop yield, and are therefore not interesting treatments.

Although Marigold affected the nematode population, Compost and BCSR affected the soil nutrient status, and NT affected the soil structure, large improvements in the integral soil quality were not observed. The applied treatments ranged from experimental to more common ones, but were all unable to improve the integral soil quality substantially. It can therefore be concluded that improving the integral soil quality within the current crop rotation is not easy.

5.7.1 Follow-up

The soil measures were applied already in 2013-2014. The effects have been monitored for two crop rotations, and the final results are presented in this report. All treatments have been evaluated and it was debated whether (additional) effects can be expected on a longer period of time. We also kept in mind that farmers will need to experience a positive result in the first two crop rotations to continue a soil treatment. Due to a lack of a positive prospect, we decided to discontinue the experiment. Marigold is an exception here. Because of the crop rotation, it takes several years before Marigold has been grown on all fields. The second crop rotation is therefore not yet complete for all fields. Therefore, one field will be maintained and monitored for one more year (2022) and one field will be maintained and monitored for two more years (2022 + 2023). In a follow-up study, the effects of Marigold(4) and Marigold(8) will be studied in more detail when all data is complete.

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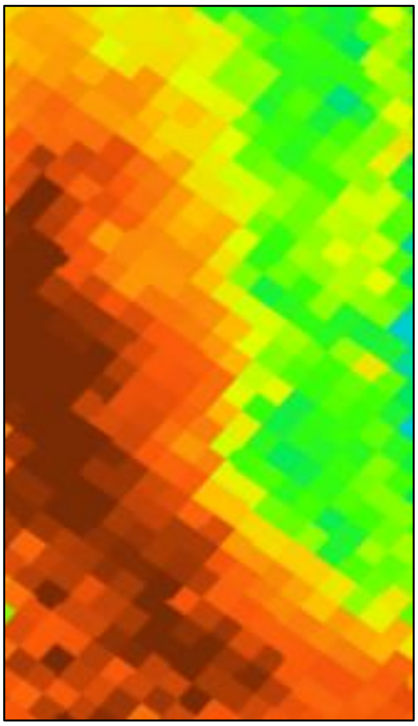
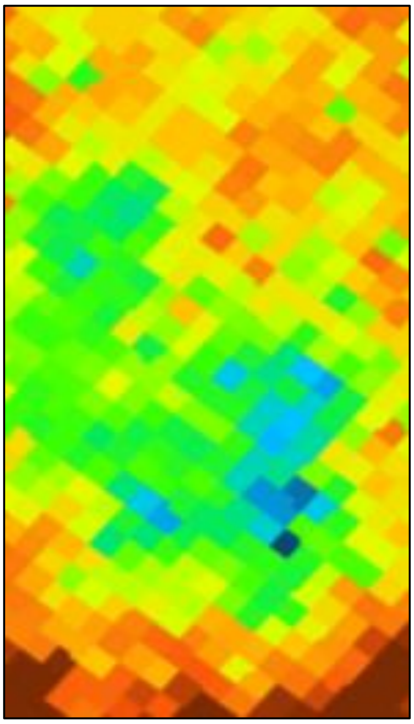
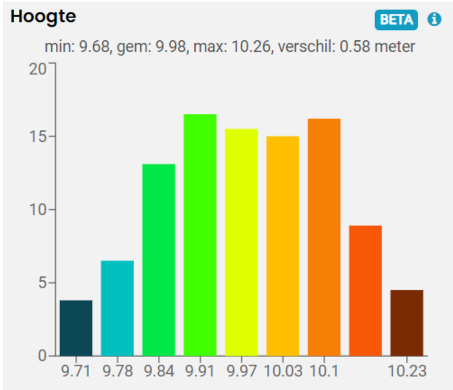
Appendix 1 Soil elevation map



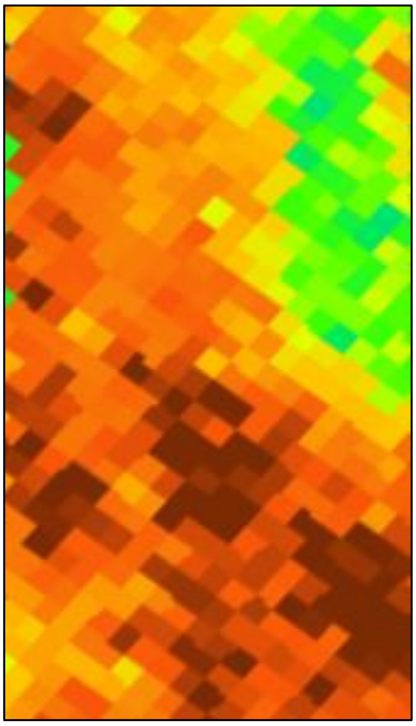
Field 71.2



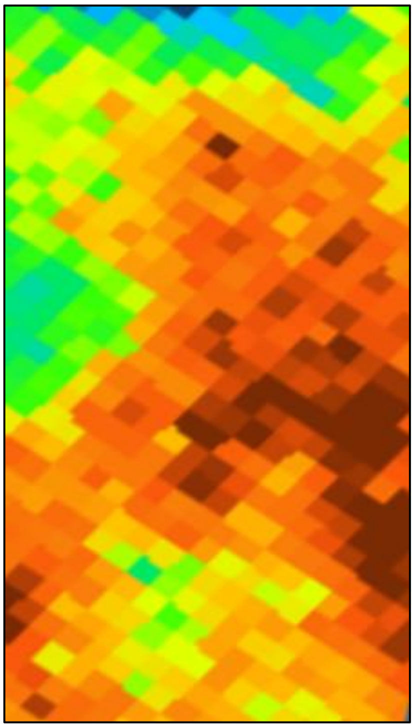
Field 70.4



Legend, from 9.68m till 10.26m (Boer en Bunder, 2019).



Field 71.1



Field

Appendix 2 Map of the experimental field

Field 71-2

60	Compost	72	Compost	84	BCSR	96	BCSR
59	Standard	71	Standard	83	Compost	95	Compost
58	Rockdust	70	Rockdust	82	Combi	94	Combi
57	Mar4 Mar8	69	Mar8 Mar4	81	Mar4 Mar8	93	Mar8 Mar4
56	Combi	68	Combi	80	Standard	92	Standard
55	BCSR	67	BCSR	79	Rockdust	91	Rockdust
54	Compost	66	Compost	78	Compost	90	Compost
53	Standard	65	Standard	77	Rockdust	89	Rockdust
52	Mar4 Mar8	64	Mar8 Mar4	76	Combi	88	Combi
51	BCSR	63	BCSR	75	BCSR	87	BCSR
50	Rockdust	62	Rockdust	74	Standard	86	Standard
49	Combi	61	Combi	73	Mar4 Mar8	85	Mar8 Mar4
	NT		T		NT		T

Field 70-4

156	BCSR	168	BCSR	180	Mar4 180b	192	192a Mar4
155	Rockdust	167	Rockdust	179	Combi	191	Combi
154	Compost	166	Compost	178	Rockdust	190	Rockdust
153	Standard	165	Standard	177	BCSR	189	BCSR
152	Combi	164	Combi	176	Standard	188	Standard
151	Mar4 151b	163	163a Mar4	175	Compost	187	Compost
150	Standard	162	Standard	174	Combi	186	Combi
149	Mar4 149b	161	161a Mar4	173	BCSR	185	BCSR
148	Compost	160	Compost	172	Rockdust	184	Rockdust
147	Combi	159	Combi	171	Compost	183	Compost
146	BCSR	158	BCSR	170	Mar4 170b	182	182a Mar4
145	Rockdust	157	Rockdust	169	Standard	181	Standard
	T		NT		T		NT

Field 71-1

12	Rockdust	24	Rockdust	36	Mar4 Mar8	48	Mar8 Mar4
11	Combi	23	Combi	35	Rockdust	47	Rockdust
10	Compost	22	Compost	34	Compost	46	Compost
9	Mar4 Mar8	21	Mar8 Mar4	33	Combi	45	Combi
8	BCSR	20	BCSR	32	Standard	44	Standard
7	Standard	19	Standard	31	BCSR	43	BCSR
6	Combi	18	Combi	30	Standard	42	Standard
5	BCSR	17	BCSR	29	Compost	41	Compost
4	Compost	16	Compost	28	Rockdust	40	Rockdust
3	Mar4 Mar8	15	Mar8 Mar4	27	Combi	39	Combi
2	Standard	14	Standard	26	Mar4 Mar8	38	Mar8 Mar4
1	Rockdust	13	Rockdust	25	BCSR	37	BCSR
	NT		T		T		NT

Field 70-3

108	Standard	120	Standard	132	BCSR	144	BCSR
107	Rockdust	119	Rockdust	131	Compost	143	Compost
106	Combi	118	Combi	130	Mar4 Mar8	142	Mar8 Mar4
105	BCSR	117	BCSR	129	Standard	141	Standard
104	Compost	116	Compost	128	Combi	140	Combi
103	Mar4 Mar8	115	Mar8 Mar4	127	Rockdust	139	Rockdust
102	Mar4 Mar8	114	Mar8 Mar4	126	BCSR	138	BCSR
101	Standard	113	Standard	125	Compost	137	Compost
100	BCSR	112	BCSR	124	Rockdust	136	Rockdust
99	Combi	111	Combi	123	Standard	135	Standard
98	Rockdust	110	Rockdust	122	Mar4 Mar8	134	Mar8 Mar4
97	Compost	109	Compost	121	Combi	133	Combi
	NT		T		T		NT

Appendix 3 Nutrient measurements

Table 1 Nutrient measurements by Eurofins (grey) and Nova Crop Control (black).

Year	Treatment		Festien			Seresta			Sugarbeet			Spring barley			Black oats	Marigold
			Eurofins	NCC		Eurofins	NCC		Eurofins	NCC		Eurofins	NCC			
			Product	Product	Leaf	Product	Product	Leaf	Product	Product	Leaf	Product	Product	Leaf		
2014	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2015	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2016	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															

	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2017	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2018	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2019	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2020	Standard	T														
	Tagetes-4															

	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
2021	Standard	T														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															
	Standard	NT														
	Tagetes-4															
	Tagetes-8															
	Compost															
	BCSR															
	Rock dust															
	Combi															

Appendix 4 crop development and field yield

In Table 26 – Table 29, the crop development and N-uptake is presented of both potato crops.

Table 26 NVDI of Festien in the period 2014-2020.

		2014				2015				2016				2017				2018				2019				2020			
		16-jul		12-sep		11-aug		18-sep		26-jul		31-aug		4-jul		4-sep		17-aug		17-sep		30-jul		20-sep		20-jul		16-sep	
Standard	T	0.85	a	0.80	a	0.92	a	0.85	a	0.91	a	0.89	ab	0.91	abc	0.90	a	0.85	a	0.76	a	0.84	a	0.70	ab	0.80	a	0.81	b
Marigold(4)	T	0.86	a	0.81	a	0.92	a	0.88	a	0.91	a	0.90	ab	0.91	ab	0.90	a	0.86	a	0.82	a	0.86	a	0.73	ab	0.82	a	0.82	b
Marigold(8)	T																			0.79	a	0.84	a	0.75	ab	0.83	a	0.82	ab
Compost	T	0.86	a	0.82	a	0.92	a	0.87	a	0.91	a	0.90	ab	0.91	ab	0.91	a	0.86	a	0.76	a	0.83	a	0.72	ab	0.81	a	0.82	b
BCSR	T	0.87	a	0.84	a	0.92	a	0.88	a	0.91	a	0.90	ab	0.91	abc	0.90	a	0.86	a	0.80	a	0.86	a	0.73	ab	0.82	a	0.82	ab
Rockdust	T	0.86	a	0.81	a	0.92	a	0.86	a	0.91	a	0.89	a	0.91	abc	0.89	a	0.84	a	0.76	a	0.83	a	0.66	ab	0.79	a	0.80	b
Combi	T	0.89	a	0.87	a	0.92	a	0.88	a	0.91	a	0.91	b	0.91	c	0.92	a	0.87	a	0.78	a	0.84	a	0.80	ab	0.85	a	0.84	ab
Standard	NT	0.85	a	0.80	a	0.92	a	0.86	a	0.91	a	0.90	ab	0.90	abc	0.90	a	0.84	a	0.77	a	0.84	a	0.66	a	0.79	a	0.80	ab
Marigold(4)	NT	0.87	a	0.84	a	0.92	a	0.89	a	0.91	a	0.90	ab	0.91	abc	0.90	a	0.87	a	0.83	a	0.87	a	0.72	ab	0.83	a	0.83	b
Marigold(8)	NT																			0.81	a	0.86	a	0.71	ab	0.81	a	0.81	ab
Compost	NT	0.86	a	0.81	a	0.91	a	0.87	a	0.91	a	0.90	ab	0.91	abc	0.91	a	0.85	a	0.79	a	0.85	a	0.68	ab	0.80	a	0.80	ab
BCSR	NT	0.85	a	0.78	a	0.92	a	0.88	a	0.91	a	0.90	ab	0.90	ab	0.90	a	0.85	a	0.76	a	0.83	a	0.76	ab	0.83	a	0.81	a
Rockdust	NT	0.85	a	0.79	a	0.91	a	0.86	a	0.91	a	0.90	ab	0.90	a	0.89	a	0.86	a	0.77	a	0.84	a	0.70	ab	0.81	a	0.81	ab
Combi	NT	0.89	a	0.87	a	0.92	a	0.89	a	0.91	a	0.91	ab	0.91	abc	0.91	a	0.87	a	0.79	a	0.85	a	0.81	b	0.86	a	0.84	ab

Table 27 N uptake (kg ha^{-1}) of Festien in the period 2014-2020.

		2014				2015				2016				2017				2018				2019				2020			
		16-jul		12-sep		11-aug		18-sep		26-jul		31-aug		4-jul		4-sep		17-aug		17-sep		30-jul		20-sep		20-jul		16-sep	
Standard	T	176	a	62	a	214	a	83	a	192	a	82	a	99	a	91	ab	119	a	50	a	84	ab	28	ab	108	a	92	a
Marigold(4)	T	189	a	88	ab	223	a	143	ab	190	a	82	a	111	a	99	ab	153	a	66	a	85	ab	31	ab	105	a	90	a
Marigold(8)	T																			57	a	81	ab	35	ab	98	a	84	a
Compost	T	182	a	86	ab	237	a	122	ab	186	a	98	a	105	a	146	b	133	a	50	a	88	b	29	ab	108	a	96	a
BCSR	T	192	a	90	ab	213	a	147	abc	186	a	92	a	99	a	82	ab	145	a	60	a	95	ab	31	ab	105	a	88	a
Rockdust	T	178	a	63	a	210	a	97	ab	187	a	74	a	102	a	98	ab	107	a	51	a	76	ab	23	a	98	a	85	a
Combi	T	213	a	115	b	215	a	158	abc	192	a	122	a	116	a	134	ab	159	a	56	a	86	ab	43	b	115	a	95	a
Standard	NT	185	a	60	a	206	a	110	ab	188	a	94	a	90	a	94	ab	102	a	51	a	73	ab	23	a	90	a	80	a
Marigold(4)	NT	186	a	62	ab	210	a	227	cd	193	a	95	a	106	a	109	ab	146	a	65	a	78	ab	28	ab	88	a	80	a
Marigold(8)	NT																			56	a	77	ab	29	ab	90	a	76	a
Compost	NT	184	a	62	ab	176	a	152	abc	198	a	111	a	97	a	127	ab	117	a	52	a	69	a	27	ab	92	a	81	a
BCSR	NT	183	a	56	a	196	a	185	bcd	191	a	105	a	94	a	102	ab	91	a	48	a	70	ab	33	ab	81	a	70	a
Rockdust	NT	194	a	56	a	202	a	124	ab	204	a	86	a	88	a	78	a	132	a	48	a	71	ab	26	ab	91	a	80	a
Combi	NT	212	a	90	ab	191	a	261	d	201	a	135	a	103	a	106	ab	125	a	51	a	80	ab	44	b	94	a	80	a

Table 28 NVDI of Seresta in the period 2014-2020**.**

		2014		2015				2016				2017				2018		2019		2020	
		26-aug		12-aug		18-sep		26-jul		31-aug		28-aug		4-sep		17-aug		30-jul		15-jul	
Standard	T	0.78	a	0.91	a	0.74	a	0.92	a	0.79	abc	0.84	a	0.69	a	0.43	ab	0.90	ab	0.90	bd
Marigold(4)	T	0.77	a	0.91	a	0.77	ab	0.92	a	0.87	abc	0.86	a	0.78	a	0.73	cd	0.90	ab	0.90	bd
Marigold(8)	T																			0.89	ac
Compost	T	0.73	a	0.91	a	0.81	ab	0.92	a	0.80	abc	0.84	a	0.73	a	0.45	ab	0.90	ab	0.90	bd
BCSR	T	0.84	a	0.91	a	0.82	b	0.92	a	0.80	abc	0.86	a	0.78	a	0.52	abcd	0.90	ab	0.90	bd
Rockdust	T	0.71	a	0.91	a	0.76	ab	0.92	a	0.80	abc	0.86	a	0.73	a	0.42	ab	0.90	ab	0.90	bd
Combi	T	0.83	a	0.91	a	0.84	b	0.93	a	0.88	bc	0.88	a	0.84	a	0.75	cd	0.91	b	0.90	bd
Standard	NT	0.81	a	0.91	a	0.82	ab	0.91	a	0.66	a	0.84	a	0.73	a	0.57	abcd	0.89	a	0.90	cd
Marigold(4)	NT	0.80	a	0.91	a	0.84	ab	0.92	a	0.85	bc	0.86	a	0.81	a	0.76	bd	0.90	ab	0.90	cd
Marigold(8)	NT																			0.88	ab
Compost	NT	0.82	a	0.91	a	0.82	ab	0.91	a	0.70	ab	0.85	a	0.79	a	0.45	ac	0.89	a	0.90	cd
BCSR	NT	0.83	a	0.90	a	0.86	ab	0.91	a	0.74	abc	0.87	a	0.81	a	0.52	abcd	0.90	ab	0.90	cd
Rockdust	NT	0.80	a	0.91	a	0.80	ab	0.91	a	0.74	abc	0.86	a	0.82	a	0.57	abcd	0.89	ab	0.90	cd
Combi	NT	0.78	a	0.91	a	0.84	ab	0.92	a	0.87	c	0.88	a	0.88	a	0.61	abcd	0.90	ab	0.90	cd

Table 29 N uptake (kg ha^{-1}) of Seresta in the period 2014-2020.

		2014		2015				2016				2017				2018		2019		2020	
		26-aug		12-aug		18-sep		26-jul		31-aug		28-aug		4-sep		17-aug		30-jul		15-jul	
Standard	T	64.43	a	242.31	a	44.00	a	186.02	a	51.83	ab	63.63	a	26.93	ab	19	a	86	a	157	a
Marigold(4)	T	62.99	a	246.89	a	51.51	a	188.18	a	90.29	b	70.02	a	37.89	ab	58	a	91	a	143	a
Marigold(8)	T																			152	a
Compost	T	53.54	a	248.64	a	64.05	a	191.77	a	55.31	ab	63.72	a	32.65	ab	21	a	92	a	155	a
BCSR	T	93.79	a	247.01	a	67.94	a	175.27	a	55.73	ab	68.79	a	41.96	ab	27	a	89	a	142	a
Rockdust	T	52.86	a	244.76	a	51.90	a	181.50	a	58.94	ab	72.36	a	31.90	ab	17	a	85	a	158	a
Combi	T	89.30	a	267.07	a	79.37	a	197.30	a	90.63	b	76.58	a	48.60	ab	58	a	100	a	154	a
Standard	NT	89.94	a	260.23	a	83.96	a	143.25	a	31.59	a	57.33	a	36.98	a	37	a	76	a	134	a
Marigold(4)	NT	67.52	a	267.33	a	79.69	a	158.16	a	59.26	ab	67.30	a	49.05	ab	62	a	88	a	129	a
Marigold(8)	NT																			144	a
Compost	NT	72.42	a	248.50	a	72.50	a	147.85	a	34.68	a	63.41	a	50.02	ab	22	a	83	a	134	a
BCSR	NT	89.97	a	233.43	a	95.90	a	143.16	a	41.12	a	68.77	a	47.49	ab	29	a	81	a	128	a
Rockdust	NT	70.84	a	250.78	a	62.14	a	141.35	a	38.36	a	65.66	a	54.23	ab	46	a	78	a	135	a
Combi	NT	81.90	a	277.77	a	86.59	a	177.25	a	64.67	ab	74.32	a	75.51	b	37	a	88	a	127	a

Field yield over the period 2014-2021

The net yield of starch potatoes, sugar beet and spring barley corresponding to the treatments Compost, BCSR, Rockdust, Combi and the control are presented in Table 30. The field yield of the treatment with Marigold is presented separately in paragraph 0, since the crop rotation determines the start of the treatment, which is different from the other treatments. To make a fair comparison between NT and T, it is preferred to look at the averages over all treatments (because straw was exported for Standard-T but incorporated into the soil for all the other treatments). Therefore, the effect of NT and T on the yields is presented separately in Table 31.

Each of the treatments resulted in similar to higher yields compared to the control (up to 13.5%), only NT resulted in lower yields for sugar beet (-2.2%). NT resulted in higher yield for Festien (+1.6%), and did not affect the yields of Seresta and spring barley. The yield of spring barley was not affected by any of the treatments. Combi (both T and NT) resulted in the highest increase in yield, especially in the starch potatoes (+11.1 and +13.5%). This is for a large extend due to the effect of Marigold, which is further elaborated on in paragraph 0. The application of compost only led to an increased yield of the sugar beet under conventional tillage (+4%). Applying compost in combination with NT did not lead to increased yields compared to the control. NT led to lower yields in the sugar beet, but this effect was diminished in combination with applying compost. BCSR increased the yield for both starch potato varieties, both in combination with conventional T as with NT (+4.7 till 8.2%). The application of rockdust did not affect the crop yields in the period 2014-2017 and was therefore no longer applied in the subsequent years (de Haan et al., 2020). It becomes visible that no positive effect occurred in the subsequent years. Therefore, the application of rockdust did not result in increased yields over the full period (2014-2021). Only in combination with NT the application of rockdust resulted in higher yields for Festien (+3.7%). For Festien NT already resulted in increased yields. Hence, the effect of Rockdust-NT found in Festien can be attributed to NT.

Table 30 Average field yield in relative numbers over the years 2014-2021.

	Seresta		Festien		Sugar beet		Spring barley		Average
Standard T	100	a	100	a	100.0	ab	100	a	100.0
Standard NT	100.4	a	102.6	abc	97.6	a	97.2	a	99.5
Compost T	102.1	ab	102.7	abc	104.0	d	98.9	a	101.9
Compost NT	102.2	ab	103.4	abc	101.1	bc	98.6	a	101.3
BCSR T	104.7	bc	105.7	cd	100.8	abc	98.8	a	102.5
BCSR NT	105.4	cd	108.2	de	99.4	ab	97.1	a	102.5
Rockdust T	101.2	a	101.6	ab	100.6	abc	98.9	a	100.6
Rockdust NT	100.9	a	103.7	bc	97.8	a	97.4	a	99.9
Combi T*	111.1	f	113.5	f	105.5	d			110.0
Combi NT*	110.0	ef	112.7	f	103.8	cd			108.8
100% (ton/ha)	49.9		49.2		86.0		7.1		

*Combi includes Marigold(8).

Table 31 Average field yield tillage and average field yield non- inversion tillage in relative numbers over the years 2014-2021*

	Seresta		Festien		Sugar beet		Spring barley		Average
Average T	104.5	a	105.9	a	102.0	b	99.1	a	102.9
Average NT	104.7	a	107.4	b	99.8	a	97.6	a	102.4
Effect NT (%)	0.3		1.6		-2.2		-1.5		-0.5

*This table includes Marigold (1:4).

Field yield Marigold 1:4 and Marigold 1:8

The effect of replacing spring barley and black oats by the cultivation of Marigold on the field yield is presented in Table 32. Seresta and Festien both benefitted from the cultivation of Marigold. The effect of Marigold was relatively large compared to the other treatments. The effect of Marigold(4) and Marigold(8) on the yield are equal for the first three years after the cultivation of Marigold. The difference between 1:4 and 1:8 will show in the subsequent years. As expected, the effects of 1:4 and 1:8 diverged in the subsequent years. For both potato varieties, the yield of Marigold(8) was significantly lower than for Marigold(4) for the period 2018-2021 (Festien) and 2020-2021 (Seresta). Averaged over 8 years (Festien) and 6 years (Seresta), the effect of Marigold(8) was still positive compared to the control. Hence, the positive effect of the cultivation of Marigold was larger when cultivated once every four years than every eight years. The magnitude of the effect depends on the initial P. penetrans infection, and whether the cultivation of Marigold was successful. These processes in relation to yield are described in more detail in paragraph #. Combining Marigold with NT did not have an additional effect on the yield of the potatoes. The yield of sugar beet was not affected by the cultivation of Marigold. Likewise, the yield of spring barley was not affected by the cultivation of Marigold(8).

Table 32 Average field yield of Marigold (1:4) and Marigold (1:8) in relative numbers over the years 2014-2021*

	Seresta		Festien		Sugar beet		Average
Standard T	100.0	a	100.0	a	100.0	abc	100.0
Standard NT	100.2	a	102.7	a	96.5	a	99.8
Marigold(1:4) T	114.1	b	112.0	b	100.9	bcd	109.0
Marigold(1:4) NT	114.8	b	114.0	b	98.2	ab	109.0
Marigold(1:8) T	110.4		108.6		101.0		106.7
Marigold(1:8) NT	112.1		109.9		98.7		106.9
100% (ton/ha)	47.5		49.2		86.0		

*Seresta average is over the years 2016-2021 and sugar beet average is over the years 2015-2021.

Annual field yield and trends

Annual field yield and trends are shown in Table 33 - Figure 0-8. The years 2018, 2019 and 2020 are considered as dry years. A lack of precipitation causes stress to some degree, as irrigation within this experiment is postponed compared to common agricultural practice. Against the expectations, none of the treatments led to a consistent higher field yield in these dry years. However, most treatments showed year-to-year variability. Compost-T did not result in significant higher yields in the individual years for the individual crops, but averaged over 2014-2021 the yield of sugar beet was significant higher compared to the control. No significant lower yields were found for Compost (T and NT) for any of the years or crops. Compared to the control, Combi and BCSR (both T and NT) resulted in equal to higher yields than the control for all individual years and crops. In none of the years and for none of the crops significant lower yields were found. Rockdust-T resulted in equal yields compared to the control for all individual years and crops, no significant higher or lower yields were found for any of the years or crops. Rockdust-NT resulted in a larger variation, both significant lower and higher yields were found for some years and crops. None of the treatments resulted in consistently lower yields compared to the control. BCSR, Compost and Combi did not result in significant lower yields in any of the years or crops.

The annual effects of Marigold 1:4 and 1:8 are presented in Table 37- Table 39. Compared to the control, Marigold(4) led to a significant increase in yield in 6 of the 8 years for Festien, and in 2 of the 6 years for Seresta, and in none of the years to a significant lower yield. The yield of Festien was significantly increased by Marigold(4) in most years, except for 2014 (71-2) and 2021 (70-3). This is not just a field effect, as Marigold(4) did increase the yield of Festien in 2017 (70-3) and 2018 (71-2). The cultivation of Marigold(4) had a significant positive effect on the yield of Seresta in 2016 (71-2) and 2018 (71-1). However, Marigold(4) did not increase the yield on field 71-2 each time. On field 70-4 (2017 and 2021) Marigold(4) never increased the yield of Seresta. Compared to the control, Marigold(8) led to a significant increase in yield in 4 of the 8 years for Festien, and in 2 of the 6 years for Seresta. In 1 of the 6 years, Marigold(8) led to a significant lower yield. The cultivation of Marigold(8) did not lead to a significant higher yield of Festien in 2019-2021 (70-4, 71-1 and 70-3), which is not a field effect, but a direct effect of the treatment. The cultivation of Marigold(8) even resulted in a lower yield for Seresta on field 70-4 (2021). The variation in effect is due to field conditions (P. penetrans infection and drought), and whether the prior cultivation of Marigold was successful or not.

Table 33 Relative field yield of Festien in the period 2014-2021.

Year	Standard	Compost	BCSR	Rockdust	Combi	Marigold 1:4
Tillage						
2014	100.0	100.2	108.2	104.5	116.0	107.4
2015	100.0	101.5	106.8	102.5	116.7	112.1
2016	100.0	101.2	112.7	101.1	131.2	122.1
2017	100.0	108.5	113.8	100.9	128.9	116.6
2018	100.0	109.9	107.3	105.6	112.5	112.9
2019	100.0	101.2	103.0	101.3	116.1	112.3
2020	100.0	102.5	95.3	99.4	95.1	109.2
2021	100.0	98.5	100.1	98.4	96.0	102.9
Non-inversion tillage						
2014	107.5	107.5	112.2	107.5	115.6	112.8
2015	103.6	107.2	111.2	106.4	120.3	113.4
2016	100.4	96.6	108.0	94.5	126.1	120.2
2017	107.3	107.5	117.3	107.1	131.2	119.4
2018	106.2	108.8	104.9	118.0	114.8	125.5
2019	100.3	104.8	105.8	106.7	110.1	108.7
2020	96.7	97.9	92.8	93.6	91.9	110.5
2021	99.5	97.9	111.6	97.9	95.1	104.2

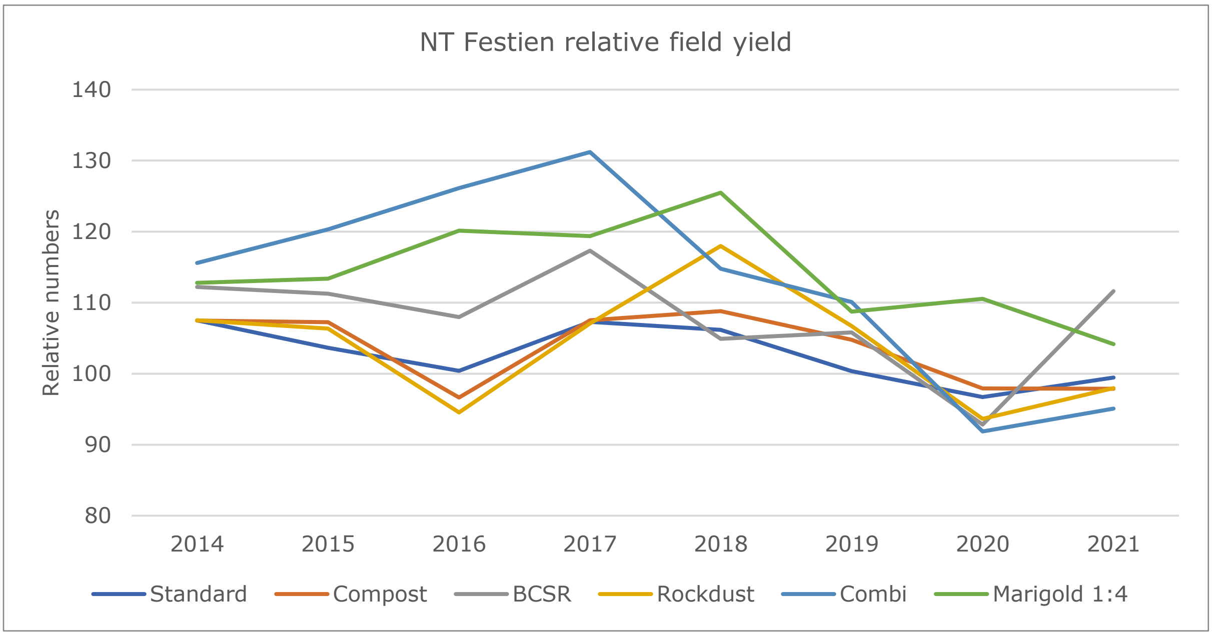


Figure 6-1 Relative field yield of Festien in the period 2014-2021, NT only.

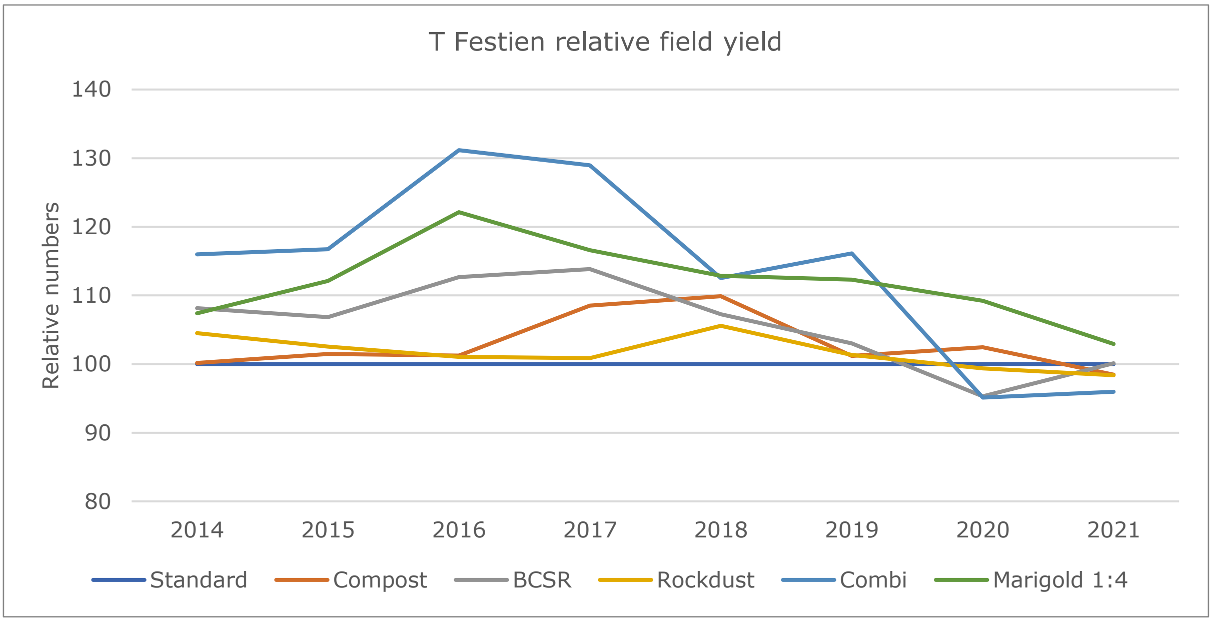


Figure 6-2 Relative field yield of Festien in the period 2014-2021, T only.

Table 40 Relative field yield of Seresta in the period 2014-2021.

Year	Standard	Compost	BCSR	Rockdust	Combi	Marigold 1:4
Tillage						
2014	100.0	96.2	106.4	96.0	103.3	96.8
2015	100.0	104.0	106.6	99.1	104.1	99.1
2016	100.0	106.6	101.7	100.0	119.7	115.8
2017	100.0	102.7	106.5	102.6	113.4	107.2
2018	100.0	97.8	108.5	100.4	136.8	141.9
2019	100.0	104.6	103.6	103.2	127.3	109.6
2020	100.0	104.1	100.5	105.6	98.2	106.9
2021	100.0	100.4	104.0	103.7	99.6	102.9
Non-inversion tillage						
2014	100.0	96.3	104.2	95.7	100.8	101.3
2015	101.5	102.4	109.7	101.0	104.6	100.9
2016	98.2	103.5	100.9	101.0	117.3	117.5
2017	103.5	105.3	109.5	110.8	115.3	111.4
2018	98.5	100.5	104.2	84.6	123.1	135.6
2019	104.8	108.3	115.1	106.3	122.2	120.3
2020	98.2	102.5	99.6	101.7	103.6	105.3
2021	97.7	99.5	100.2	99.3	101.1	98.8

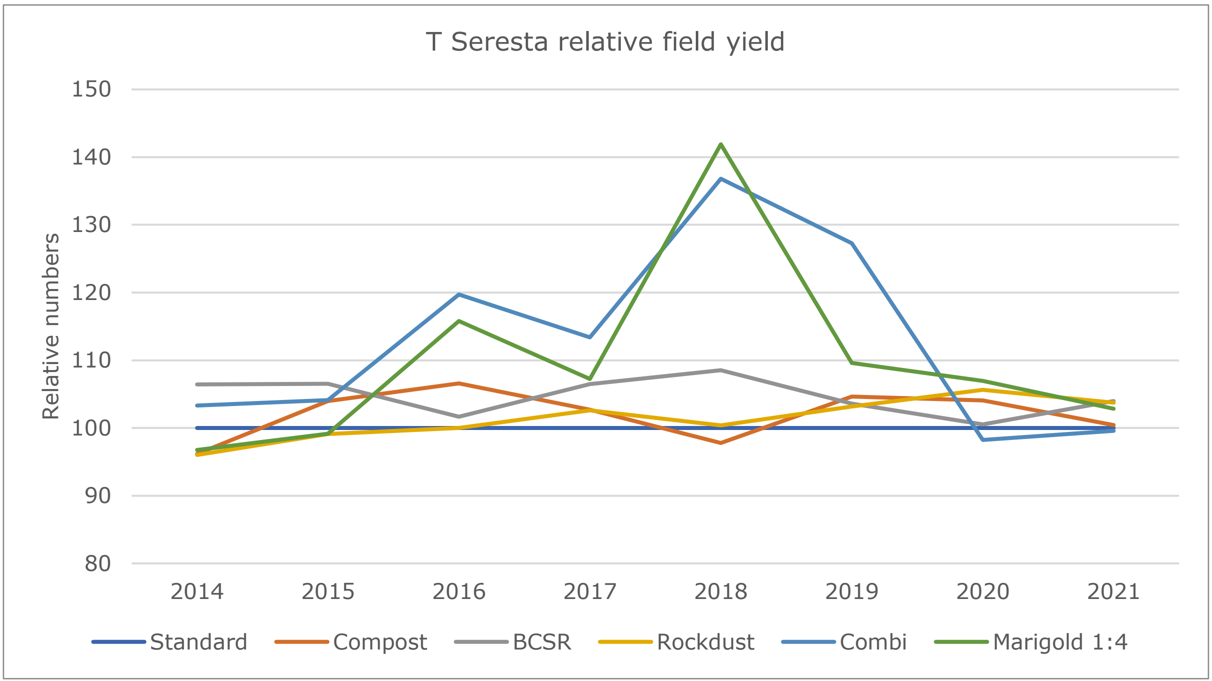


Figure 6-4 Relative field yield of Seresta in the period 2014-2021, T only.

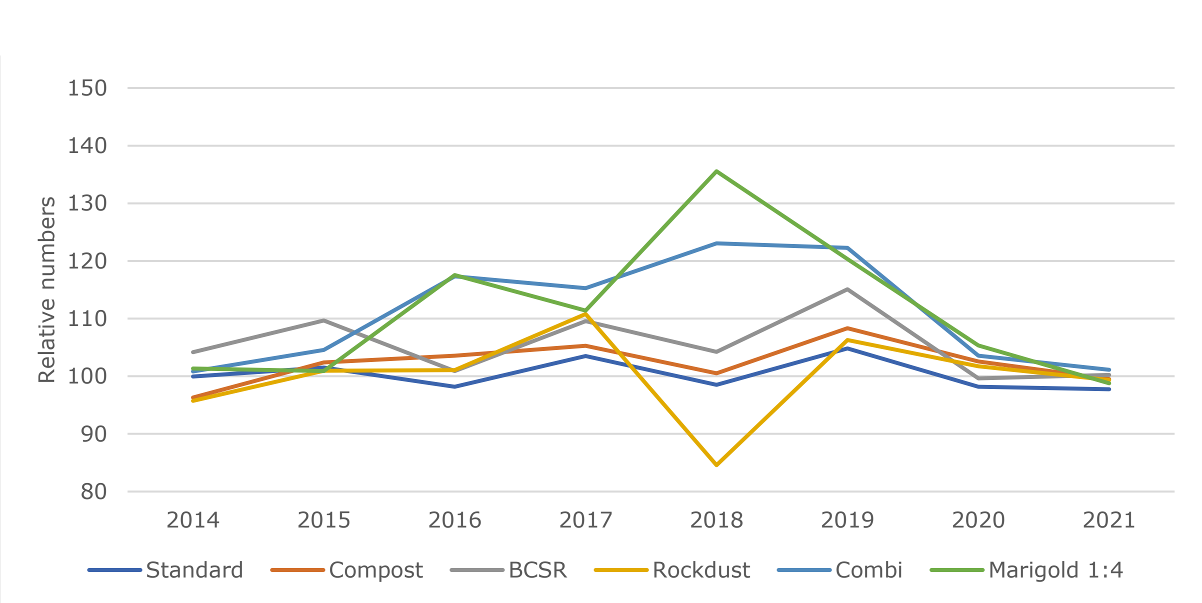


Figure 6-3 Relative field yield of Seresta in the period 2014-2021, NT only.

Table 41 Relative field yield of sugar beet in the period 2014-2021.

Year	Standard	Compost	BCSR	Rockdust	Combi	Marigold 1:4
Tillage						
2014	100.0	103.0	103.9	103.0	100.0	101.9
2015	100.0	104.7	99.5	101.6	105.3	101.2
2016	100.0	102.6	99.2	98.1	104.6	99.0
2017	100.0	101.9	102.4	97.4	105.4	102.2
2018	100.0	99.1	87.4	105.5	108.6	103.0
2019	100.0	106.9	106.7	110.4	110.5	99.5
2020	100.0	108.8	100.9	95.1	108.5	99.8
2021	100.0	104.0	102.3	97.3	103.2	101.5
Non-inversion tillage						
2014	101.7	104.3	107.5	102.8	106.2	104.2
2015	99.9	97.7	97.8	101.9	106.3	100.2
2016	95.7	99.6	99.9	95.4	102.5	101.4
2017	95.8	99.1	99.7	96.1	103.3	97.5
2018	88.3	103.0	91.6	86.9	95.4	96.2
2019	93.7	102.0	95.0	105.0	104.4	95.0
2020	101.0	102.5	98.0	97.2	108.2	101.4
2021	101.5	101.9	101.9	94.2	101.6	95.4

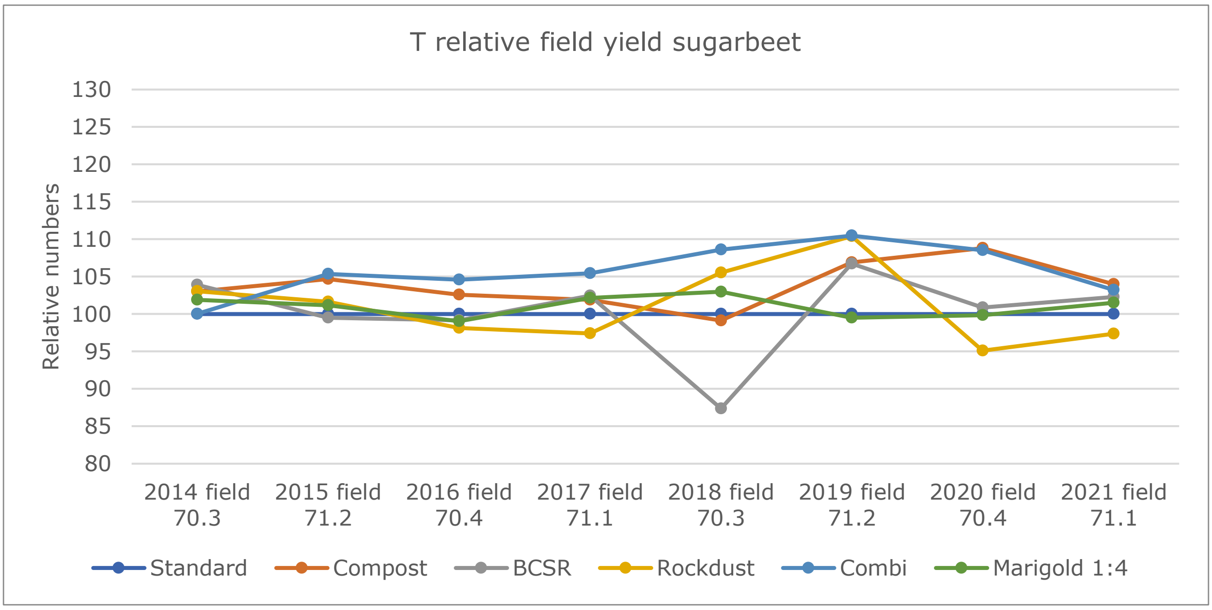


Figure 6-5 Relative field yield of sugar beet in the period 2014-2021, T only.

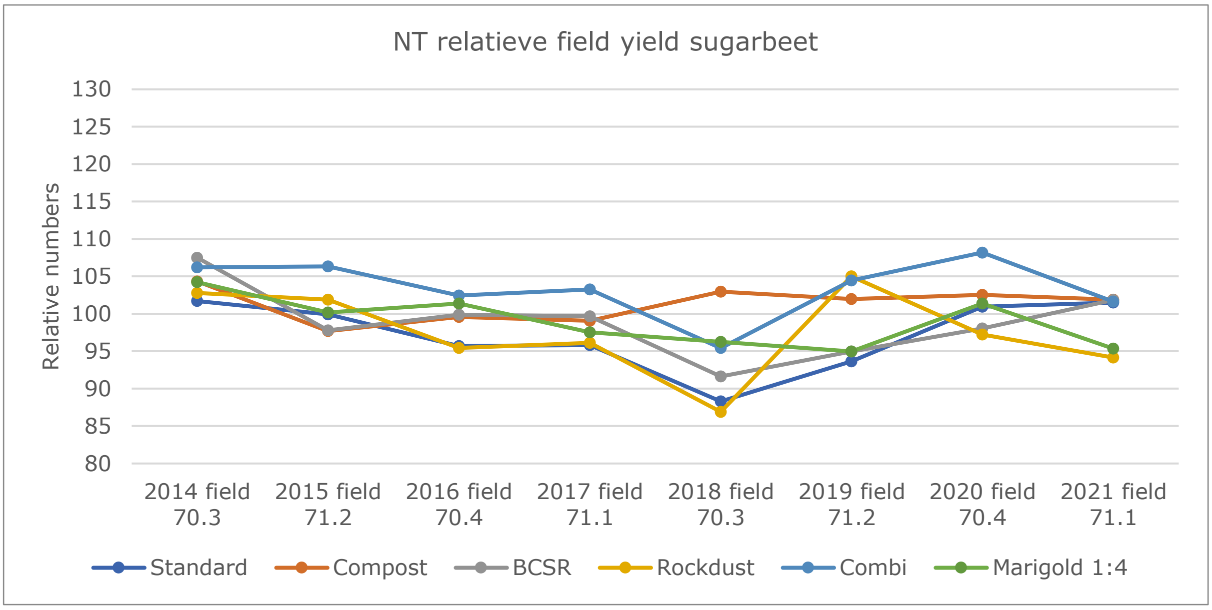


Figure 6-6 Relative field yield of sugar beet in the period 2014-2021, NT only.

Table 42 Relative field yield of spring barley in the period 2014-2021*.

Year	Standard	Compost	BCSR	Rockdust
Tillage				
2014	100.0	90.2	101.0	98.5
2015	100.0	98.9	102.4	94.7
2016	100.0	95.3	96.8	98.3
2017	100.0	104.2	100.9	104.2
2018	100.0	104.1	96.3	99.2
2019	100.0	92.8	100.4	92.2
2020	100.0	95.5	89.2	96.9
2021	100.0	105.3	100.9	105.2
Non-inversion tillage				
2014	105.1	95.1	102.3	99.7
2015	100.5	97.8	101.3	96.4
2016	103.4	93.5	97.9	99.5
2017	97.6	98.2	91.6	105.5
2018	103.5	106.9	99.6	101.9
2019	89.0	102.1	91.1	79.9
2020	80.0	86.9	85.4	87.4
2021	96.9	104.5	98.3	102.5

**The moisture content differed between the years, but did not show large differences between the treatments.*

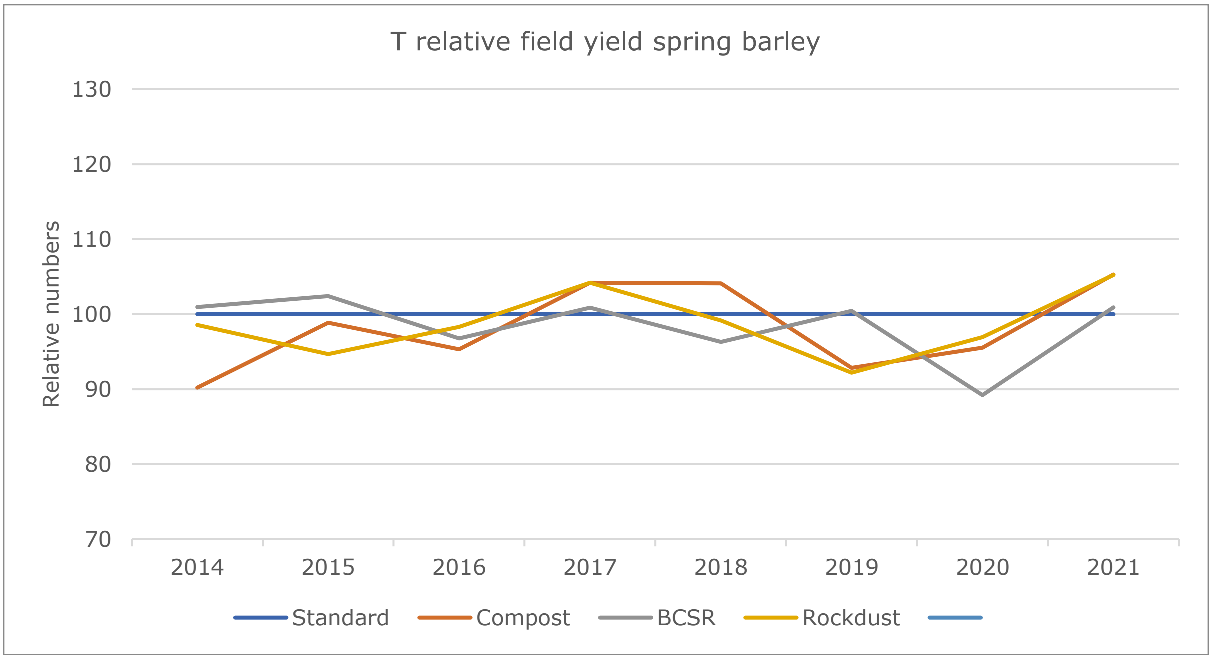


Figure 6-8 Relative field yield of spring barley in the period 2014-2021, T only.

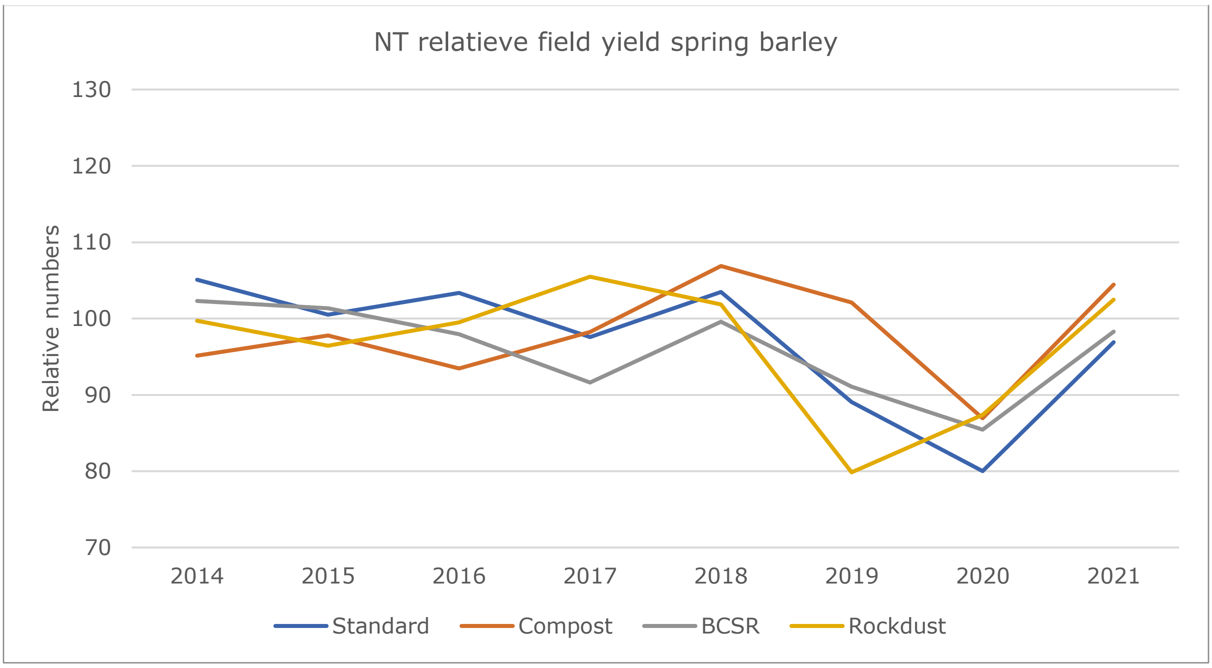


Figure 6-7 Relative field yield of spring barley in the period 2014-2021, T only.

Field	71-2		70-4		71-1		70-3		71-2		70-4	
Year	**2016**		**2017**		**2018**		**2019**		**2020**		**2021**	
Standard T	100.0	fghi	100.0	jkl	100.0	a	100.0	bcd	100.0	a	100.0	cd
Standard NT	98.2	efgh	103.5	lm	98.5	a	104.8	cde	98.2	a	97.7	bcd
Marigold(1:4) T	115.8	kl	107.2	lm	141.9	bc	109.6	defg	106.9	abcd	102.9	d
Marigold(1:4) NT	117.5	lm	111.4	m	135.6	b	120.3	hi	105.3	abc	98.8	bcd
Marigold(1:8) T	115.8	kl	107.2	lm	141.9	bc	109.6	defg	98.2	a	89.5	ab
Marigold(1:8) NT	117.5	lm	111.4	m	135.6	b	120.3	hi	96.7	a	90.9	abc

Table 37 Relative field yield for Seresta of Marigold(4) and Marigold(8), in relative numbers over the years 2016-2021.

Table 44 Relative field yield for Festien of Marigold(4) and Marigold(8), in relative numbers over the years 2014-2021.

Field	71-2		70-4		71-1		70-3		71-2		70-4		71-1		70-3	
Year	**2014**		**2015**		**2016**		**2017**		**2018**		**2019**		**2020**		**2021**	
Standard T	100,0	c	100,0	a	100,0	ab	100,0	cde	100,0	a	100,0	abc	100,0	de	100,0	hi
Standard NT	107,5	abc	103,6	ab	100,4	ab	107,3	efgh	106,2	ab	100,3	abc	96,7	bcde	99,5	ghi
Marigold(1:4) T	107,4	abc	112,1	bc	122,1	fghi	116,6	ijk	112,9	bcde	112,3	ef	109,2	fgh	102,9	i
Marigold(1:4) NT	112,8	b	113,4	c	118,0	efghi	119,4	jk	125,5	fg	108,7	cde	110,5	gh	104,2	i
Marigold(1:8) T	107,4	abc	112,1	bc	122,1	fghi	116,6	ijk	110,9	bcd	101,3	abcd	99,1	cde	99,3	ghi
Marigold(1:8) NT	112,8	b	113,4	c	121,5	efghi	119,4	jk	111,3	bcde	107,7	cde	96,1	bcde	97,4	ghi

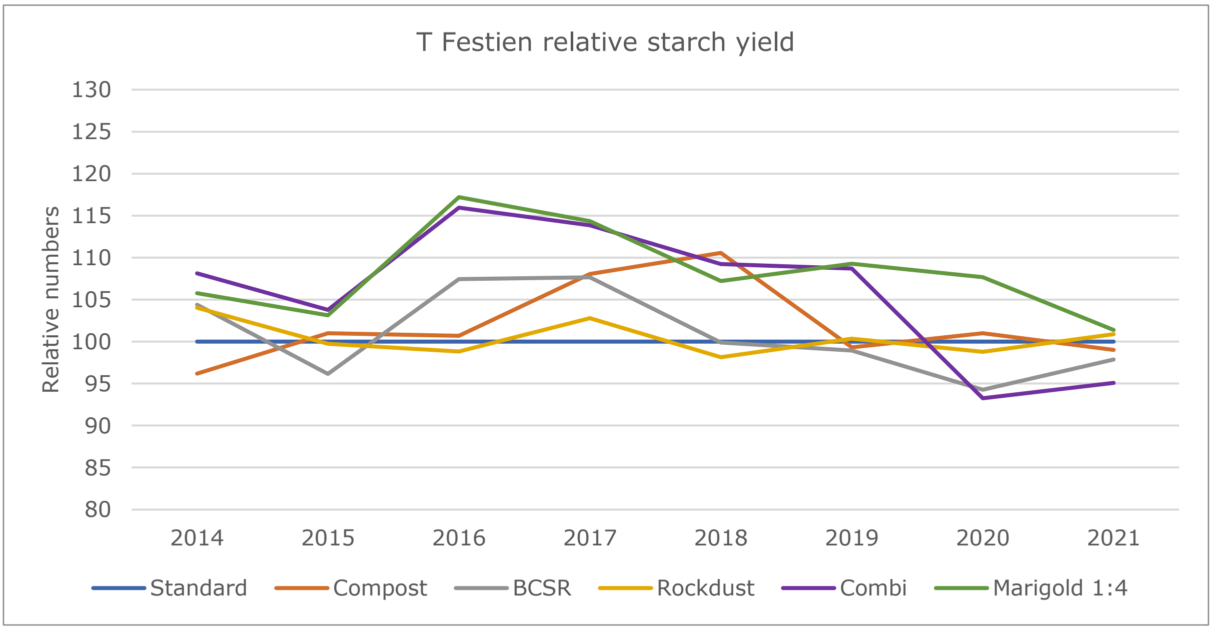
Table 39 Relative field yield for sugar beet of Marigold(4) and Marigold(8), in relative numbers over the years 2015-2021.

	2015		2016		2017		2018		2019		2020		2021	
Standard T	100.0	def	100.0	def	100.0	g	100.0	a	100.0	abcd	100.0	a	100.0	cd
Standard NT	99.9	def	95.7	cd	95.8	efg	88.3	a	93.7	a	101.0	a	101.5	d
Marigold(1:4) T	101.2	def	99.0	de	102.2	g	103.0	a	99.5	abc	99.8	a	101.5	d
Marigold(1:4) NT	100.2	def	101.4	def	97.5	fg	96.2	a	95.0	ab	101.6	a	95.4	abcd
Marigold(1:8) T	101.2	def	99.0	de	102.2	g	103.0	a	103.2	abcde	100.6	a	97.7	bcd
Marigold(1:8) NT	100.2	def	101.4	def	97.5	fg	96.2	a	99.7	abcd	101.6	a	94.5	abcd

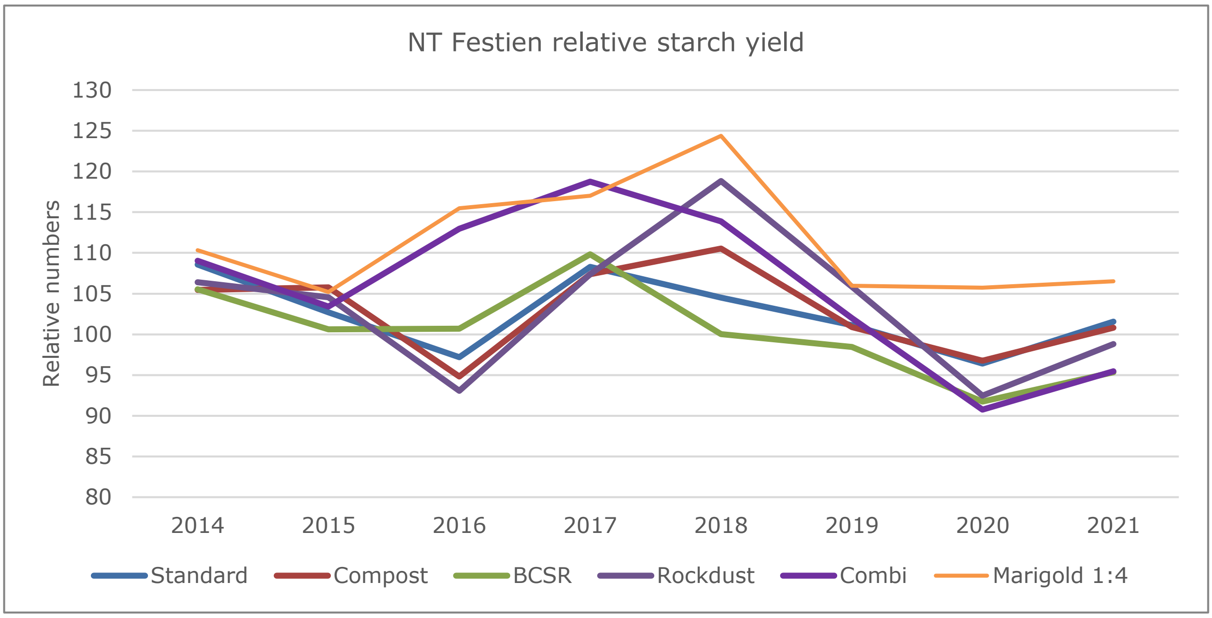
Appendix 5 Annual marketable yield

Table 46 Relative marketable yield of Festien, in the period 2014-2021.

Year	Standard	Compost	BCSR	Rockdust	Combi	Marigold 1:4
Non-inversion tillage						
2014	100	96.2	104.4	104.0	108.1	105.8
2015	100	101.0	96.1	99.7	103.8	103.1
2016	100	100.7	107.5	98.8	116.0	117.2
2017	100	108.1	107.7	102.8	113.8	114.4
2018	100	110.6	99.9	98.1	109.2	107.2
2019	100	99.3	99.0	100.3	108.7	109.3
2020	100	101.0	94.3	98.8	93.3	107.7
2021	100	99.0	97.9	100.9	95.1	101.4
Tillage						
2014	108.6	105.4	105.5	106.4	109.0	110.3
2015	102.7	105.8	100.6	104.5	103.4	105.2
2016	97.2	94.8	100.7	93.1	113.0	115.5
2017	108.3	107.4	109.8	107.4	118.8	117.0
2018	104.5	110.5	100.0	118.8	113.9	124.4
2019	101.1	100.9	98.5	105.9	102.0	106.0
2020	96.4	96.8	91.7	92.5	90.8	105.7
2021	101.6	100.8	95.4	98.8	95.5	106.5



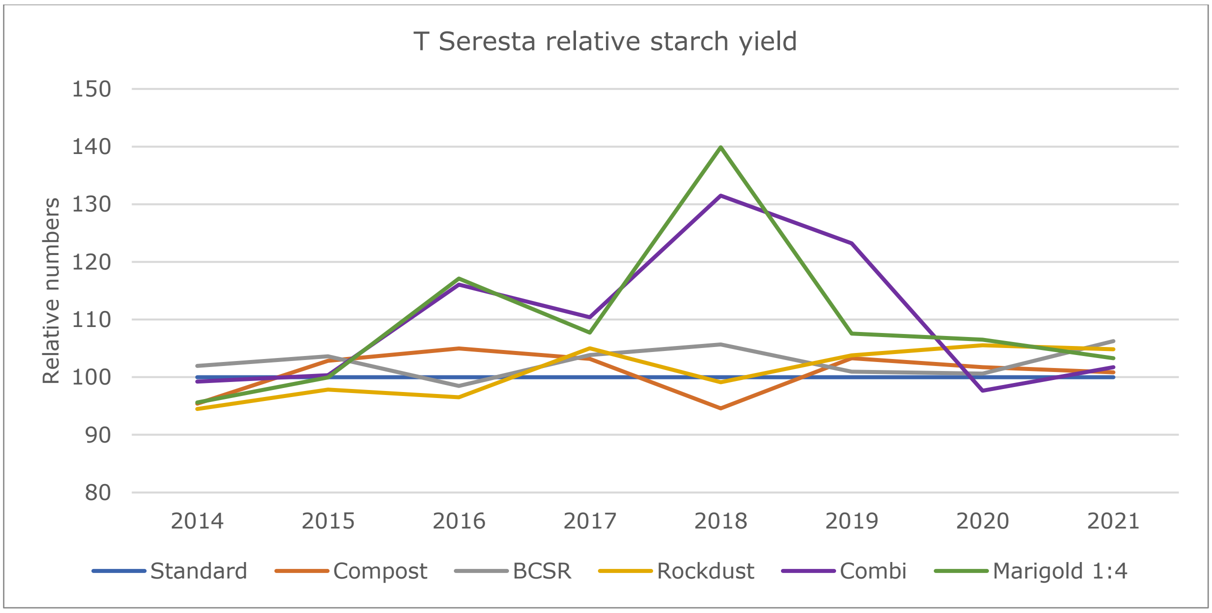
Relative marketable yield of Festien, in the period 2014-2021, T only.



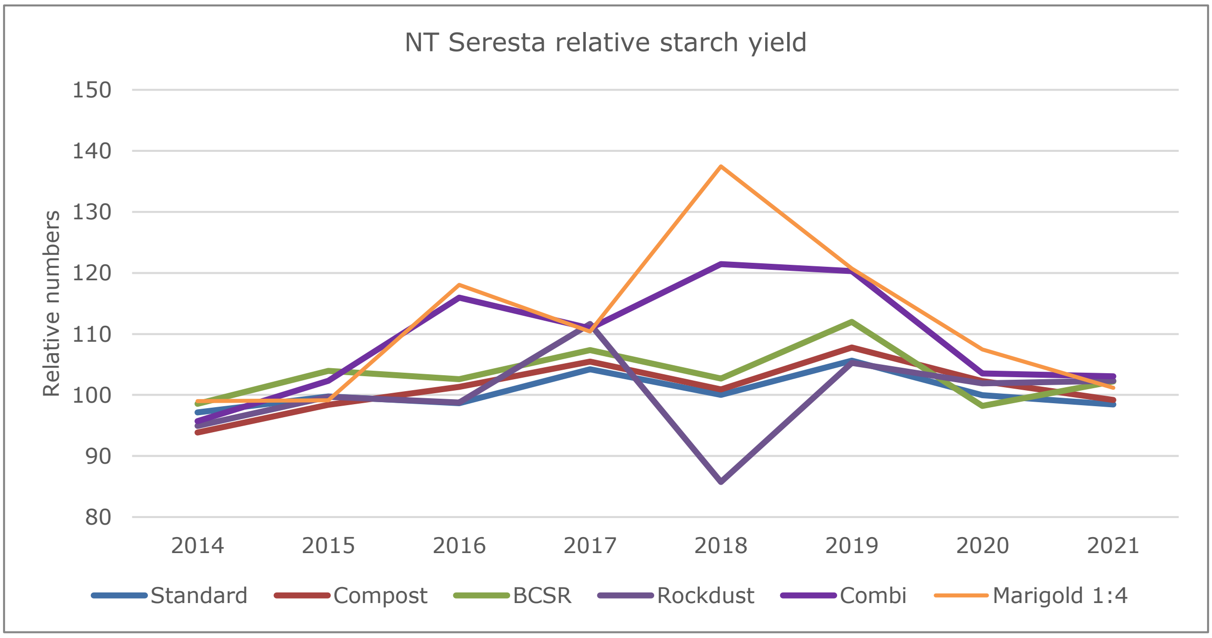
Relative marketable yield of Festien, in the period 2014-2021, NT only.

Table 47 Relative marketable yield of Seresta, in the period 2014-2021.

Year	Standard	Compost	BCSR	Rockdust	Combi	Marigold 1:4
Tillage						
2014	100.0	95.4	102.0	94.5	99.2	95.6
2015	100.0	102.9	103.6	97.9	100.3	99.9
2016	100.0	105.0	98.5	96.5	116.1	117.1
2017	100.0	103.2	103.9	105.0	110.4	107.7
2018	100.0	94.6	105.7	99.1	131.5	139.9
2019	100.0	103.3	101.0	103.8	123.2	107.5
2020	100.0	101.7	100.6	105.5	97.7	106.5
2021	100.0	100.9	106.3	104.8	101.7	103.3
Non-inversion tillage						
2014	97.1	93.9	98.5	94.9	95.7	99.0
2015	99.8	98.4	103.9	99.7	102.3	99.1
2016	98.6	101.3	102.6	98.8	115.9	118.1
2017	104.2	105.5	107.3	111.6	110.9	110.4
2018	100.0	100.9	102.7	85.7	121.4	137.5
2019	105.6	107.8	112.0	105.3	120.3	120.7
2020	100.0	102.3	98.2	101.9	103.5	107.5
2021	98.4	99.2	102.2	102.3	103.1	101.2



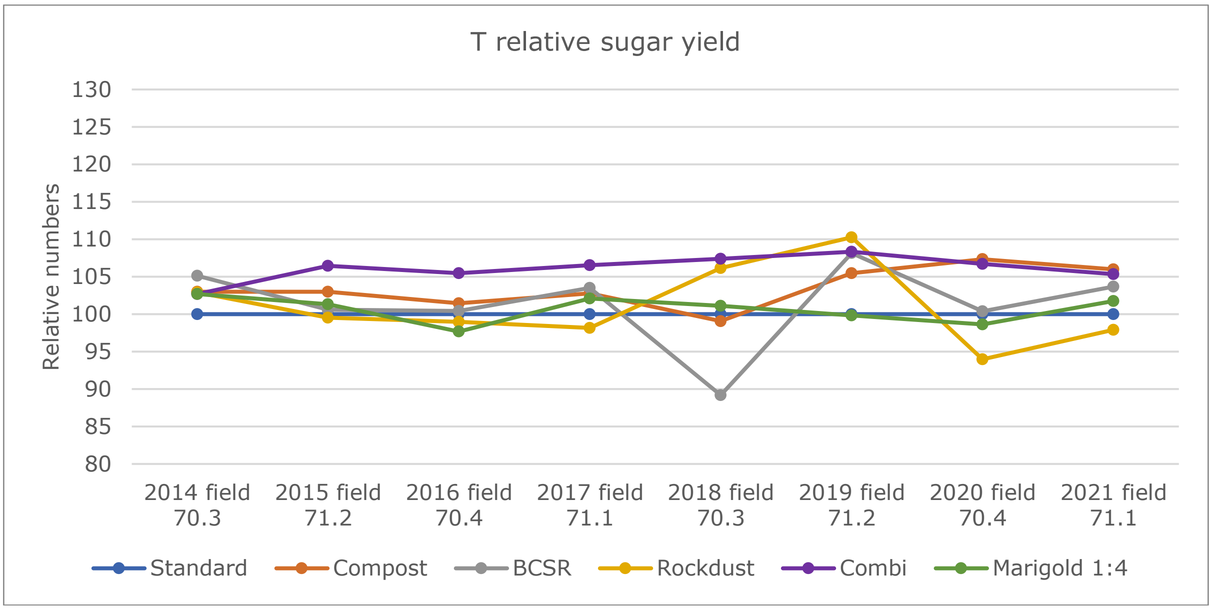
Relative marketable yield of Seresta, in the period 2014-2021, T only.



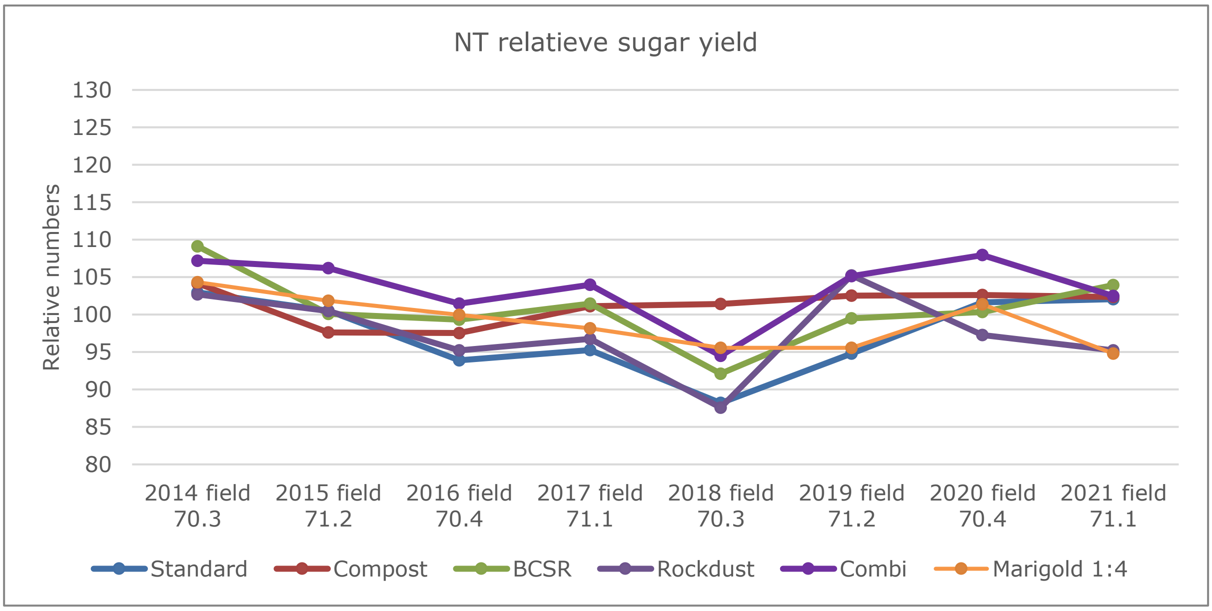
Relative marketable yield of Seresta, in the period 2014-2021, NT only.

Table 48 Relative marketable yield of sugar beet, in the period 2014-2021.

Non-inversion Tillage sugarbeet, relative sugar yield						
Year	**Standard**	**Compost**	**BCSR**	**Rockdust**	**Combi**	**Marigold 1:4**
Tillage						
2014	100.0	103.0	105.1	102.9	102.7	102.7
2015	100.0	103.0	100.6	99.5	106.5	101.3
2016	100.0	101.5	100.4	99.0	105.5	97.7
2017	100.0	102.8	103.5	98.2	106.5	102.1
2018	100.0	99.1	89.2	106.2	107.4	101.1
2019	100.0	105.5	108.1	110.3	108.3	99.8
2020	100.0	107.3	100.4	94.0	106.7	98.6
2021	100.0	106.0	103.7	97.9	105.3	101.8
Non-inversion tillage						
2014	103.0	104.2	109.1	102.7	107.2	104.3
2015	100.5	97.6	100.1	100.5	106.2	101.9
2016	93.9	97.5	99.3	95.2	101.5	100.0
2017	95.3	101.1	101.4	96.7	104.0	98.2
2018	88.2	101.4	92.1	87.6	94.5	95.5
2019	94.8	102.5	99.5	105.2	105.2	95.6
2020	101.6	102.6	100.4	97.3	107.9	101.4
2021	102.1	102.3	103.9	95.2	102.5	94.8



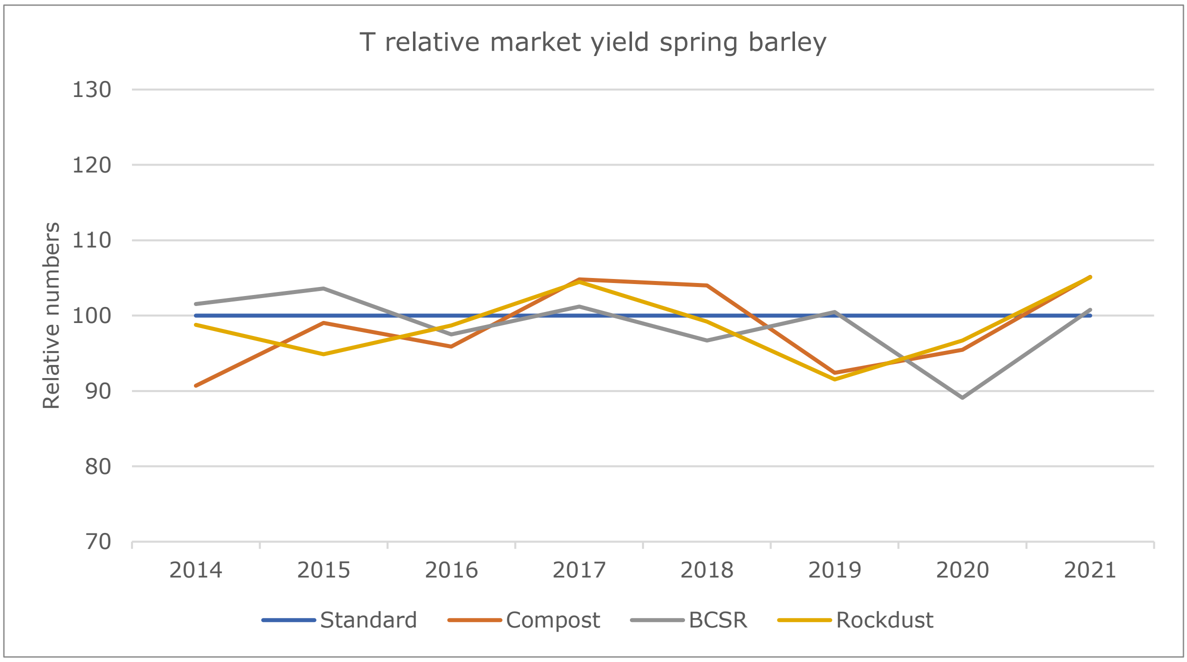
Relative marketable yield of sugar beet, in the period 2014-2021, T only.



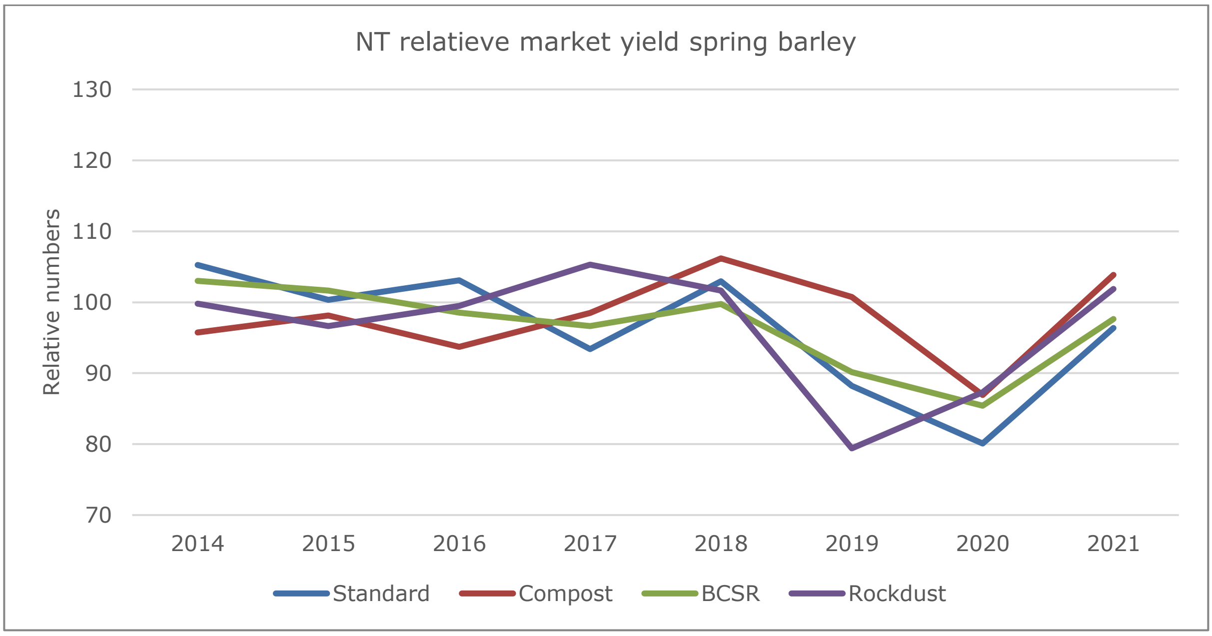
Relative marketable yield of sugar beet, in the period 2014-2021, NT only.

Table 49 Relative marketable yield of spring barley, in the period 2014-2021

Year	Standard	Compost	BCSR	Rockdust
Tillage				
2014	100.0	90.7	101.5	98.8
2015	100.0	99.1	103.6	94.9
2016	100.0	95.9	97.5	98.7
2017	100.0	104.8	101.2	104.5
2018	100.0	104.0	96.7	99.2
2019	100.0	92.4	100.5	91.5
2020	100.0	95.5	89.1	96.7
2021	100.0	105.1	100.8	105.1
Non-inversion tillage				
2014	105.3	95.7	103.0	99.8
2015	100.3	98.1	101.6	96.6
2016	103.1	93.7	98.5	99.5
2017	93.4	98.5	96.6	105.3
2018	103.0	106.2	99.7	101.6
2019	88.2	100.7	90.2	79.4
2020	80.1	86.9	85.4	87.3
2021	96.4	103.9	97.6	101.9



Relative marketable yield of spring barley, in the period 2014-2021, T only.



Relative marketable yield of spring barley, in the period 2014-2021, NT only.

Appendix 6 Additional quality aspects

Table 50 Quality aspects of potatoes averaged over 2014-2021, statistical significant differences compared to the control are in bold.

		Potatoes					
		Growth disorder (%)		Scabbies (%)		Corky ringspot (%)	
		Festien	Seresta	Festien	Seresta	Festien	Seresta
Standard	T	0.10	0.00	2.47	0.89	0.00	3.44
Marigold-4		0.09	0.01	2.24	1.44	0.38	4.25
Marigold-8		0.18	0.01	2.79	1.34	0.13	7.00
Compost		0.14	0.07	3.67	2.35	0.00	3.25
BSCR		0.21	0.11	3.36	2.31	0.00	3.63
Rockdust		0.21	0.12	2.75	2.13	0.13	6.00
Combi		0.24	0.00	**5.01**	**4.86**	0.13	4.69
Standard	NT	0.15	0.05	3.03	2.04	0.50	4.13
Marigold-4		0.25	0.00	2.00	1.49	0.00	5.53
Marigold-8		0.18	0.00	2.63	1.39	0.00	4.94
Compost		0.09	0.05	**4.63**	**3.04**	0.00	3.84
BSCR		0.14	0.03	**6.60**	**3.63**	0.13	4.09
Rockdust		0.08	0.05	**4.38**	**3.26**	0.25	5.59
Combi		0.16	0.00	**9.58**	**6.60**	0.00	4.56

Table 51 Quality aspects of spring barley (2014, 2016, 2017, 2018, 2019, 2021 for HL and 2014-2019 for screenings), statistical significant differences compared to the control are in bold.

		HL (kg.HL)	Screenings (%)
Standard	T	63.21	1.00
Compost		63.11	1.15
BSCR		63.17	**1.28**
Rockdust		63.58	1.09
Standard	NT	62.86	0.93
Compost		63.25	1.15
BSCR		63.21	**1.32**
Rockdust		63.21	1.08

Appendix 7 Additional quality aspects

Table 52 Nutrient supply in kg ha^{-1} jr^{-1} per source, averaged over 2014-2021.

		N (total)		N (wz)			P2O5				K2O				MgO				CaO			SO3			Na2O		
		Slurry	Compost	Slurry	Compost	Artificial	Slurry	Compost	biolit & zeolite	Artificial	Slurry	Compost	biolit & zeolite	Artificial	Slurry	Compost	biolit & zeolite	Artificial	Slurry	biolit & zeolite	Artificial	Slurry	biolit & zeolite	Artificial	Slurry	biolit & zeolite	Artificial
Festien	Standard	109	0	87	0	80	55	0	0	33	100	0	0	87	30	0	0	0	51	0	0	0	0	0	26	0	0
	Marigold	109	0	87	0	80	55	0	0	33	100	0	0	87	30	0	0	0	51	0	0	0	0	0	26	0	0
	Compost	109	195	87	20	80	55	104	0	3	100	179	0	5	30	83	0	0	51	0	0	0	0	0	26	0	0
	BCSR	109	0	87	0	79	55	0	0	33	100	0	0	169	30	0	0	297	51	0	466	0	0	288	26	0	0
	Rockdust	109	0	87	0	80	55	0	6	33	100	0	89	81	30	0	75	0	51	93	0	0	1	0	26	55	0
	Combi	109	195	87	20	80	55	104	6	3	100	179	89	67	30	83	75	226	51	93	406	0	1	162	26	55	0
Sugarbeet	Standard	109	0	87	0	53	55	0	0	3	100	0	0	89	30	0	0	34	51	0	0	0	0	59	26	0	205
	Marigold	109	0	87	0	53	55	0	0	3	100	0	0	89	30	0	0	34	51	0	0	0	0	59	26	0	205
	Compost	109	195	87	20	53	55	104	0	3	100	179	0	5	30	83	0	0	51	0	0	0	0	0	26	0	207
	BCSR	109	0	87	0	53	55	0	0	13	100	0	0	134	30	0	0	247	51	0	341	0	0	360	26	0	204
	Rockdust	109	0	87	0	53	55	0	6	3	100	0	89	82	30	0	75	31	51	93	0	0	1	53	26	55	205
	Combi	109	195	87	20	53	55	104	6	3	100	179	89	46	30	83	75	184	51	93	324	0	1	243	26	55	181
Seresta	Standard	109	0	87	0	119	55	0	0	33	100	0	0	87	30	0	0	0	51	0	0	0	0	0	26	0	0
	Marigold	109	0	87	0	119	55	0	0	33	100	0	0	87	30	0	0	0	51	0	0	0	0	0	26	0	0
	Compost	109	195	87	20	119	55	104	0	3	100	179	0	5	30	83	0	0	51	0	0	0	0	0	26	0	0
	BCSR	109	0	87	0	119	55	0	0	26	100	11	0	156	30	0	0	226	51	0	355	0	0	304	26	0	0
	Rockdust	109	0	87	0	119	55	0	6	33	100	0	89	81	30	0	75	0	51	93	0	0	1	0	26	55	0
	Combi	109	195	87	20	119	55	104	6	3	100	179	89	47	30	83	75	184	51	93	344	0	1	222	26	55	0
Spring barley & black oats	Standard	19	0	15	0	105	9	0	0	0	17	0	0	147	5	0	0	8	22	0	0	0	0	53	5	0	0
	Marigold	19	0	15	0	90	9	0	0	0	17	0	0	147	5	0	0	5	22	0	0	0	0	33	5	0	0
	Compost	19	47	15	5	105	9	26	0	0	17	42	0	107	5	20	0	8	22	0	0	0	0	53	5	0	0
	BCSR	19	0	15	0	105	9	0	0	0	17	0	0	270	5	0	0	257	22	0	380	0	0	301	5	0	0
	Rockdust	19	0	15	0	105	9	0	6	0	17	0	89	141	5	0	75	8	22	93	0	0	1	53	5	55	0
	Combi	19	47	15	5	113	9	26	6	0	17	42	89	156	5	20	75	206	22	93	297	0	1	215	5	55	0

Appendix 8 Nutrients in crop leaves: compost and rockdust

Table 53 Nutrient concentration (ppm) crop leaves of Festien, 2014 only. Significant differences compared to the control are indicated in bold.

Treatment		K	Ca	Mg	Na	N	Cl	S	P	Si	Fe	Mn	Zn	B	Cu	Mo	Al
Young leaves																	
Standard	T	4515	2157	803	7,8	899	1082	298	175	21	5	15	1,2	4,5	0,7	0,1	0,6
Rockdust	NT	**4873**	**1932**	**821**	10,1	**819**	1164	609	169	21	4	15	1,3	4,2	0,6	**0,1**	0,8
Combi	NT	4515	1841	**890**	7,6	825	1207	545	195	20	4	15	1,5	3,4	0,8	**0,1**	0,8
Old leaves																	
Standard	T	3882	2281	620	5,3	910	771	206	113	15	3,7	15	1,5	3,3	0,3	0,1	1,1
Rockdust	NT	3952	**2333**	**746**	6,6	**854**	840	439	102	15	3,7	19	**1,6**	3,2	0,3	**0,1**	1,1
Combi	NT	3557	2484	**854**	5,2	896	916	430	114	13	2,9	**19**	1,8	2,7	0,4	**0,1**	0,9

Table 54 Nutrient concentration (ppm) crop leaves of Seresta, average over 2015-2016-2017. Significant differences compared to the control are indicated in bold.

Treatment		K	Ca	Mg	Na	N	Cl	S	P	Si	Fe	Mn	Zn	B	Cu	Mo	Al
Young leaves																	
Standard		3652	1092	698	5,8	1094	1198	152	205	15	3,6	11,1	1,6	2,4	0,8	0,1	0,5
Compost		3703	**1021**	653	6,6	**1071**	**1299**	**137**	209	**15**	**2,8**	**8,9**	**1,5**	**2,3**	0,8	0,1	**0,5**
BCSR	NT	**4533**	**786**	**564**	5,6	1057	1223	**189**	179	14	3,0	**8,2**	1,4	2,2	0,7	0,1	0,6
Rockdust		3704	**1009**	662	6,4	1072	**1283**	**152**	199	16	3,4	**9,5**	**1,5**	**2,3**	0,9	0,1	0,5
Combi		**4210**	**800**	645	5,4	**1047**	1464	169	206	14	3,1	**7,1**	1,4	2,0	0,8	0,1	0,5
Old leaves																	
Standard		3123	1455	670	6,8	1164	800	106	74	14	3,8	14,5	1,6	1,7	0,3	0,1	2,8
BCSR		3162	**1463**	673	6,8	1174	**913**	101	76	14	3,1	**12,5**	1,5	1,7	0,3	0,1	2,3
Compost	NT	4045	**992**	553	6,3	1076	**898**	**128**	72	13	**3,4**	**11,3**	**1,6**	**1,6**	0,3	0,0	2,5
Rockdust		3177	**1443**	679	6,8	1173	**860**	**105**	75	14	**3,3**	**13,5**	**1,6**	**1,6**	0,3	**0,1**	2,2
Combi		**3582**	**1180**	**649**	6,1	1149	**1071**	116	76	13	3,0	**10,3**	1,5	1,6	0,3	0,1	1,9

Appendix 9 Soil nutrient balances

Table 55 Soil nutrient balance (kg ha^{-1} yr^{-1}) in the period 2014-2021 of the cultivation of starch potatoes (Festien).

Treatment			N-tot	Nwz	P2O5	K2O	MgO	CaO	SO3	NaO
Standard	T	Supply	189	167	88	187	30	51	0	27
		Removal	189		65	300	18	5	43	2
		Balance	0		22	-113	12	46	-43	25
Marigold-4	T	Supply	189	167	88	187	30	51	0	27
		Removal	219		90	351	24	6	55	2
		Balance	-31		-2	-164	6	45	-55	24
Marigold-8	T	Supply	189	167	88	187	30	51	0	27
		Removal	213		87	340	23	6	53	2
		Balance	-24		1	-154	7	45	-53	24
Compost	T	Supply	384	186	161	283	113	51	0	27
		Removal	202		75	321	21	5	47	2
		Balance	182		86	-38	92	46	-47	25
BCSR	T	Supply	188	166	88	269	328	517	288	27
		Removal	206		73	347	23	5	53	2
		Balance	-18		15	-78	304	512	235	24
Rockdust	T	Supply	189	167	94	270	105	144	1	82
		Removal	201		70	309	20	5	49	2
		Balance	-12		23	-38	85	139	-48	80
Combi	T	Supply	384	186	167	435	413	551	163	82
		Removal	210		91	388	26	6	58	2
		Balance	175		76	47	388	544	106	80
Standard	NT	Supply	189	167	88	187	30	51	0	27
		Removal	204		70	298	19	5	44	2
		Balance	-15		18	-112	12	46	-44	24
Marigold-4	NT	Supply	189	167	88	187	30	51	0	27
		Removal	221		90	354	23	6	55	2
		Balance	-32		-2	-167	7	45	-55	24
Marigold-8	NT	Supply	189	167	88	187	30	51	0	27
		Removal	212		87	340	22	5	53	2
		Balance	-23		1	-153	8	46	-53	24
Compost	NT	Supply	384	186	161	283	113	51	0	27
		Removal	201		72	322	21	5	47	2
		Balance	183		90	-39	92	46	-47	24
BCSR	NT	Supply	188	166	88	269	328	517	288	27
		Removal	208		72	369	25	5	55	2
		Balance	-20		15	-100	302	512	232	24
Rockdust	NT	Supply	189	167	94	270	105	144	1	82
		Removal	207		72	312	20	5	47	2
		Balance	-19		21	-42	85	139	-46	80
Combi	NT	Supply	384	186	167	435	413	551	163	82
		Removal	216		77	359	25	6	54	2
		Balance	168		90	76	388	545	109	80

Table 56 Soil nutrient balance (kg ha^{-1} yr^{-1}) in the period 2014-2021 of the cultivation of sugar beet.

Treatment			N-tot	Nwz	P2O5	K2O	MgO	CaO	SO3	NaO
Standard	T	Supply	162	140	57	189	64	51	59	231
		Removal	105		56	152	39	23	17	7
		Balance	57		2	37	25	28	41	224
Marigold-4	T	Supply	162	140	57	189	64	51	59	231
		Removal	98		66	156	41	26	19	8
		Balance	64		-8	33	23	25	40	223
Marigold-8	T	Supply	162	140	57	189	64	51	59	231
		Removal	98		66	155	41	26	19	8
		Balance	64		-8	33	23	25	40	223
Compost	T	Supply	330	138	147	261	105	26	0	226

		Removal	110		66	171	42	25	19	8
		Balance	221		81	90	64	1	-19	218
BCSR	T	Supply	162	140	57	244	278	392	360	230
		Removal	103		60	172	41	22	19	7
		Balance	59		-3	72	237	370	341	223
Rockdust	T	Supply	162	140	63	271	136	144	54	287
		Removal	99		65	155	40	26	19	9
		Balance	63		-2	116	96	119	35	279
Combi	T	Supply	330	138	153	391	364	443	245	255
		Removal	108		69	189	46	25	21	8
		Balance	223		83	202	318	418	224	248
Standard	NT	Supply	162	140	57	189	64	51	59	231
		Removal	95		65	147	39	22	17	6
		Balance	67		-7	42	26	29	42	225
Marigold-4	NT	Supply	162	140	57	189	64	51	59	231
		Removal	97		62	157	46	25	19	7
		Balance	65		-5	32	18	26	40	224
Marigold-8	NT	Supply	162	140	57	189	64	51	59	231
		Removal	97		63	157	46	25	19	7
		Balance	65		-5	32	18	26	40	224
Compost	NT	Supply	330	138	147	261	105	26	0	226
		Removal	99		69	157	46	29	21	8
		Balance	231		78	104	59	-3	-21	217
BCSR	NT	Supply	162	140	57	244	278	392	360	230
		Removal	95		64	169	42	24	19	6
		Balance	67		-6	75	236	368	341	224
Rockdust	NT	Supply	162	140	63	271	136	144	54	287
		Removal	92		63	152	43	23	19	8
		Balance	70		0	119	92	122	35	279
Combi	NT	Supply	330	138	153	391	364	443	245	255
		Removal	115		64	185	40	22	19	7
		Balance	216		89	206	323	421	226	248

Table 57 Soil nutrient balance (kg ha^{-1} yr^{-1}) in the period 2014-2021 of the cultivation of starch potatoes (Seresta).

Treatment			N-tot	Nwz	P2O5	K2O	MgO	CaO	SO3	NaO
Standard	T	Supply	228	206	88	187	30	51	0	26
		Removal	204		60	286	20	4	49	3
		Balance	23		28	-99	10	47	-49	24
Marigold-4	T	Supply	228	206	88	187	30	51	0	26
		Removal	215		72	308	21	5	49	2
		Balance	13		15	-121	9	46	-49	24
Marigold-8	T	Supply	228	206	88	187	30	51	0	26
		Removal	209		70	300	21	5	48	2
		Balance	19		17	-113	10	46	-48	24
Compost	T	Supply	423	225	161	283	113	51	0	26
		Removal	208		70	297	20	4	45	3
		Balance	215		91	-14	93	47	-45	24
BCSR	T	Supply	228	206	88	256	257	406	316	26
		Removal	205		65	320	24	4	53	2
		Balance	23		23	-64	233	402	263	24
Rockdust	T	Supply	228	206	94	270	105	144	1	82
		Removal	210		67	285	20	5	48	3
		Balance	17		26	-15	85	140	-47	79
Combi	T	Supply	423	225	167	415	372	488	234	82
		Removal	219		73	344	23	5	54	2
		Balance	204		94	71	348	483	180	79
Standard	NT	Supply	228	206	88	187	30	51	0	26
		Removal	199		69	290	20	4	45	2
		Balance	28		19	-103	11	47	-45	24
Marigold-4	NT	Supply	228	206	88	187	30	51	0	26
		Removal	228		81	306	21	5	48	3
		Balance	-1		7	-119	10	46	-48	24
Marigold-8	NT	Supply	228	206	88	187	30	51	0	26
		Removal	224		79	300	20	5	47	3

		Balance	3		8	-114	10	46	-47	24
Compost	NT	Supply	423	225	161	283	113	51	0	26
		Removal	200		69	272	17	4	37	2
		Balance	223		93	12	96	47	-37	24
BCSR	NT	Supply	228	206	88	256	257	406	316	26
		Removal	201		63	305	22	4	51	2
		Balance	26		25	-49	235	402	265	24
Rockdust	NT	Supply	228	206	94	270	105	144	1	82
		Removal	200		66	266	17	4	40	2
		Balance	27		28	5	88	140	-39	80
Combi	NT	Supply	423	225	167	415	372	488	234	82
		Removal	222		67	313	22	4	49	3
		Balance	201		100	101	350	483	185	79

Table 58 Soil nutrient balance (kg ha^{-1} yr^{-1}) in the period 2014-2021 of the cultivation of spring barley.

Treatment			N-tot	Nwz	P2O5	K2O	MgO	CaO	SO3	NaO
Standard	T	Supply	168	164	9	164	13	22	53	
		Removal	135		61	96	12	4	19	
		Balance	33		-52	68	1	18	34	
Marigold-4	T	Supply	113	116	9	164	10	22	33	
		Removal	0		0	0	0	0	0	
		Balance	113		9	164	10	22	33	
Marigold-8	T	Supply	169	172	9	164	13	22	53	
		Removal	61		29	26	7	2	11	
		Balance	108		-20	139	6	19	42	
Compost	T	Supply	208	162	35	166	33	22	53	
		Removal	108		56	39	11	4	18	
		Balance	100		-21	126	22	18	35	
BCSR	T	Supply	168	164	9	286	262	402	301	
		Removal	108		55	39	12	4	17	
		Balance	59		-46	247	250	398	283	
Rockdust	T	Supply	168	164	15	247	88	115	55	
		Removal	106		54	39	11	5	17	
		Balance	62		-39	207	77	111	37	
Combi	T	Supply	215	169	41	304	306	412	216	
		Removal	71		33	26	0	0	0	
		Balance	145		8	278	306	412	216	
Standard	NT	Supply	168	164	9	164	13	22	53	
		Removal	108		54	39	12	4	18	
		Balance	60		-45	125	2	18	35	
Marigold-4	NT	Supply	113	116	9	164	10	22	33	
		Removal	0		0	0	0	0	0	
		Balance	113		9	164	10	22	33	
Marigold-8	NT	Supply	169	172	9	164	13	22	53	
		Removal	66		32	24	7	2	11	
		Balance	102		-23	140	6	20	42	
Compost	NT	Supply	208	162	35	166	33	22	53	
		Removal	108		56	39	11	4	19	
		Balance	100		-21	127	22	18	35	
BCSR	NT	Supply	168	164	9	286	262	402	301	
		Removal	108		53	39	12	4	17	
		Balance	59		-44	248	250	398	284	
Rockdust	NT	Supply	168	164	15	247	88	115	55	
		Removal	106		54	39	12	4	18	0
		Balance	62		-39	208	76	111	37	60
Combi	NT	Supply	215	169	41	304	306	412	216	60
		Removal	71		32	26	8	2	12	0
		Balance	144		8	278	298	410	204	60

Appendix 10 Soil fertility

Table 59 Soil fertility of Combi-NT and the control averaged over 2014-2022, expressed per field, significant differences with the control are indicated in bold.

		70-3				70-4				71-1				71-2			
		Control		Combi-NT		Control		Combi-NT		Control		Combi-NT		Control		Combi-NT	
C:N ratio	-	23,5	a	24,1	a	22,0	a	21,4	a	23,2	a	23,1	a	22,8	a	23,2	a
pH	-	5,1	a	5,2	a	4,9	a	**5,3**	b	4,7	a	**5,2**	b	5,0	a	5,2	a
Soil organic matter	%	9,3	a	11,3	a	13,8	a	13,4	a	9,8	a	8,9	a	9,4	a	11,1	a
Lutum	%	1,7	a	1,7	a	1,7	a	1,7	a	1,7	a	1,8	a	1,9	a	2,1	a
CEC	mmol kg^{-1}	137	a	**166**	b	184	a	197	a	126	a	123	a	133	a	165	a
CEC saturation	%	89	a	93	a	86	a	**94**	b	84	a	**91**	b	88	a	92	a
C:S ratio	-	111	a	117	a	116	a	106	a	116	a	111	a	109	a	104	a
Total N	mg N kg^{-1}	2323	a	**2760**	b	3726	a	3732	a	2523	a	2288	a	2453	a	2886	a
P-PAE	mg P kg^{-1}	5,6	a	5,6	a	3,5	a	3,2	a	4,6	b	3,4	a	3,9	a	3,6	a
P-Al	mg P2O5 100g^{-1}	26	a	26	a	27	a	**32**	b	20	a	**25**	b	25	a	27	a
Total K	mmol kg^{-1}	2,9	a	3,2	a	3,2	a	**3,6**	b	2,4	a	2,6	a	2,6	a	3,1	a
K-number	-	7,9	a	**11,1**	b	7,1	a	**12,2**	b	8,6	a	**11,8**	b	8,4	a	9,2	a
Total S	mg S kg^{-1}	495	a	576	a	700	a	753	a	506	a	478	a	517	a	648	a
Total Mg*	mg Mg kg^{-1}	9,2	a	**13,2**	b	13,1	a	23,6	a	9,7	a	12,3	a	10,4	a	13,9	a
Total Na*	kg Na ha^{-1}	1,0	a	1,1	a	1,2	a	1,3	a	1,1	a	1,0	a	1,0	a	1,2	a
Total Ca	kg Ca ha^{-1}	6168	a	**7418**	b	6940	a	8225	a	5163	a	5599	a	5814	a	7138	a
Available Ca	kg Ca ha^{-1}	133	a	124	a	110	a	118	a	111	a	101	a	89	a	85	a

** Only measured in 2019-2022.*

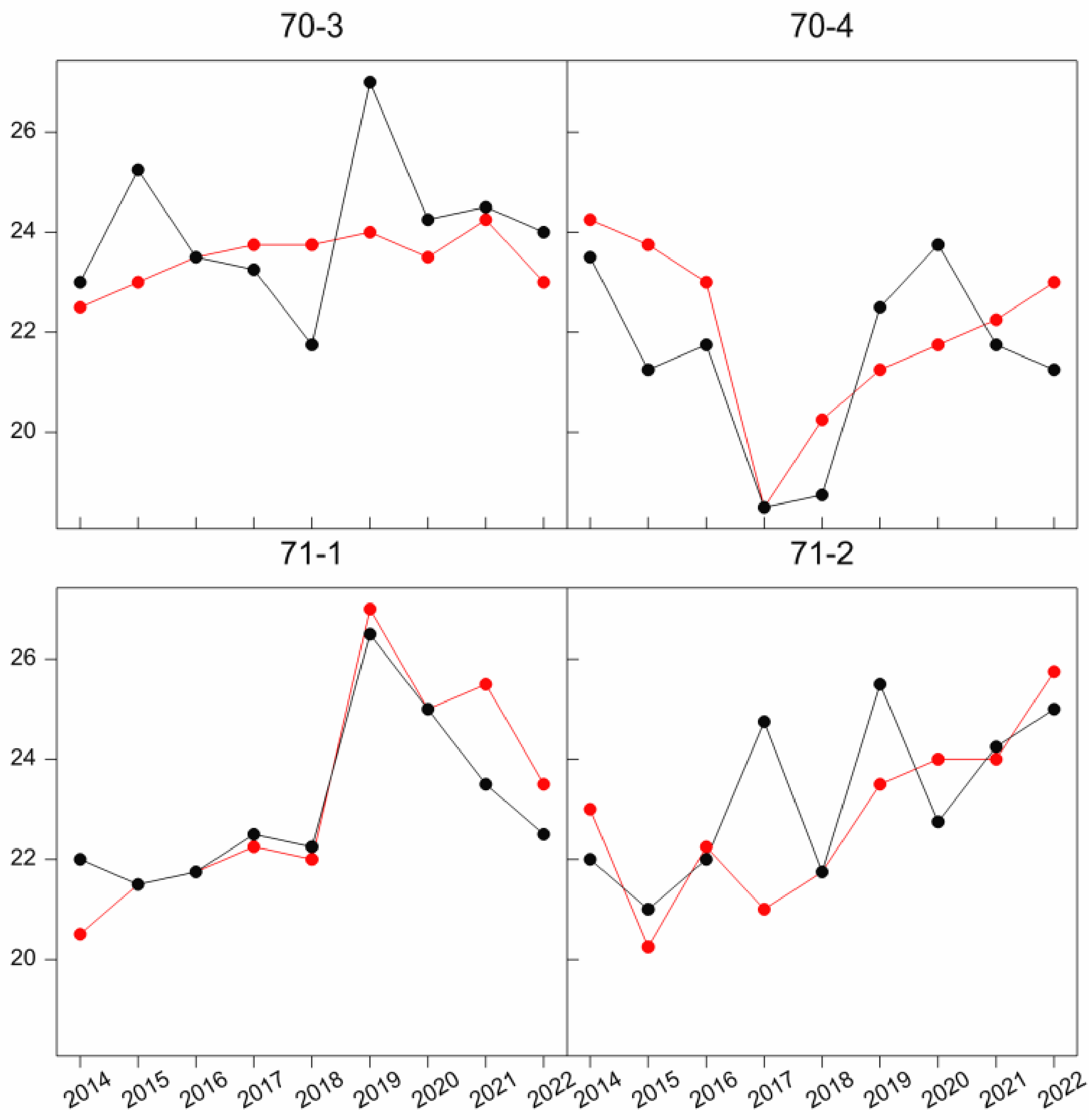
Table 60 Soil fertility of Compost-T and the control averaged over 2021-2022, expressed per field, significant differences with the control are indicated in bold.

		70-3				70-4				71-1				71-2			
		Control		Compost-T		Control		Compost-T		Control		Compost-T		Control		Compost-T	
C:N ratio	-	23,6	a	23,8	a	22,6	a	23,8	a	24,5	b	**22,6**	a	24,9	a	24,5	a
pH	-	5,0	a	5,2	a	4,9	a	5,1	a	4,7	a	**4,9**	b	4,9	a	5,0	a
Soil organic matter	%	9,0	a	9,1	a	13,8	a	15,6	a	9,4	a	8,8	a	9,5	a	12,1	a
Lutum	%	1,8	a	2,0	a	1,9	a	2,3	a	2,1	a	2,1	a	2,1	a	2,1	a
CEC	mmol.kg	127	a	136	a	187	a	219	a	119	a	119	a	130	a	**164**	b
CEC saturation	%	89	a	94	a	84	a	90	a	84	a	90	a	89	a	89	a
C:S ratio	-	101	a	107	a	106	a	131	a	108	a	122	a	106	a	100	a
Total N	mg N.kg	2138	a	2203	a	3638	a	4088	a	2246	a	2391	a	2159	a	2993	a
P-PAE	mg P.kg	5,6	a	5,5	a	3,5	a	3,5	a	4,1	a	**4,7**	b	4,0	a	4,5	a
P-Al	mg P2O5.100g	24,9	a	**26,6**	b	26,1	a	30,1	a	19,3	a	**22,4**	b	25,5	a	29,8	a
Total K	mmol.kg	3,3	a	3,5	a	3,6	a	3,7	a	2,8	a	2,6	a	3,0	a	3,4	a
K-number	-	10,0	a	9,8	a	6,5	a	7,0	a	8,4	a	8,8	a	10,0	a	10,4	a
Total S	mg S.kg	506	a	487	a	746	a	743	a	513	a	453	a	514	a	689	a
Total Mg	mg Mg.kg	7,8	a	**10,2**	b	11,9	a	16,4	a	7,8	a	8,5	a	9,7	a	10,5	a
Total Na	kg Na.ha	1,0	a	1,1	a	1,2	a	1,2	a	1,1	a	1,0	a	1,1	a	1,1	a
Total Ca	kg Ca.ha	6157	a	6977	a	7472	a	**9138**	b	5404	a	5867	a	6143	a	**7320**	b
Available Ca	kg Ca.ha	101	a	116	a	139	a	116	a	72	a	79	a	79	a	86	a

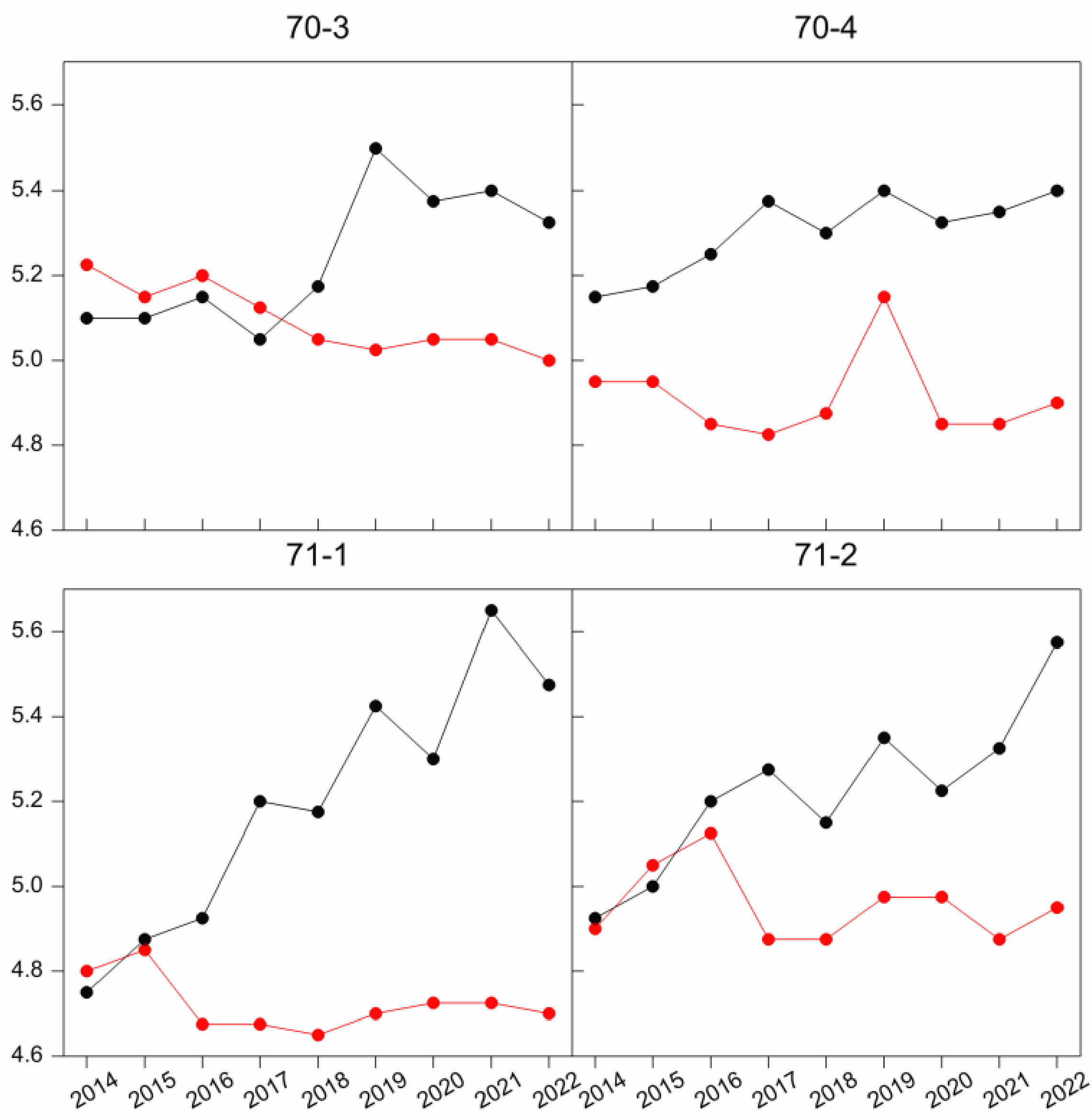
Soil fertility aspects of Combi-NT and the control

In the following figures, results are expressed per field. The control is presented in red, and Combi-NT in black.

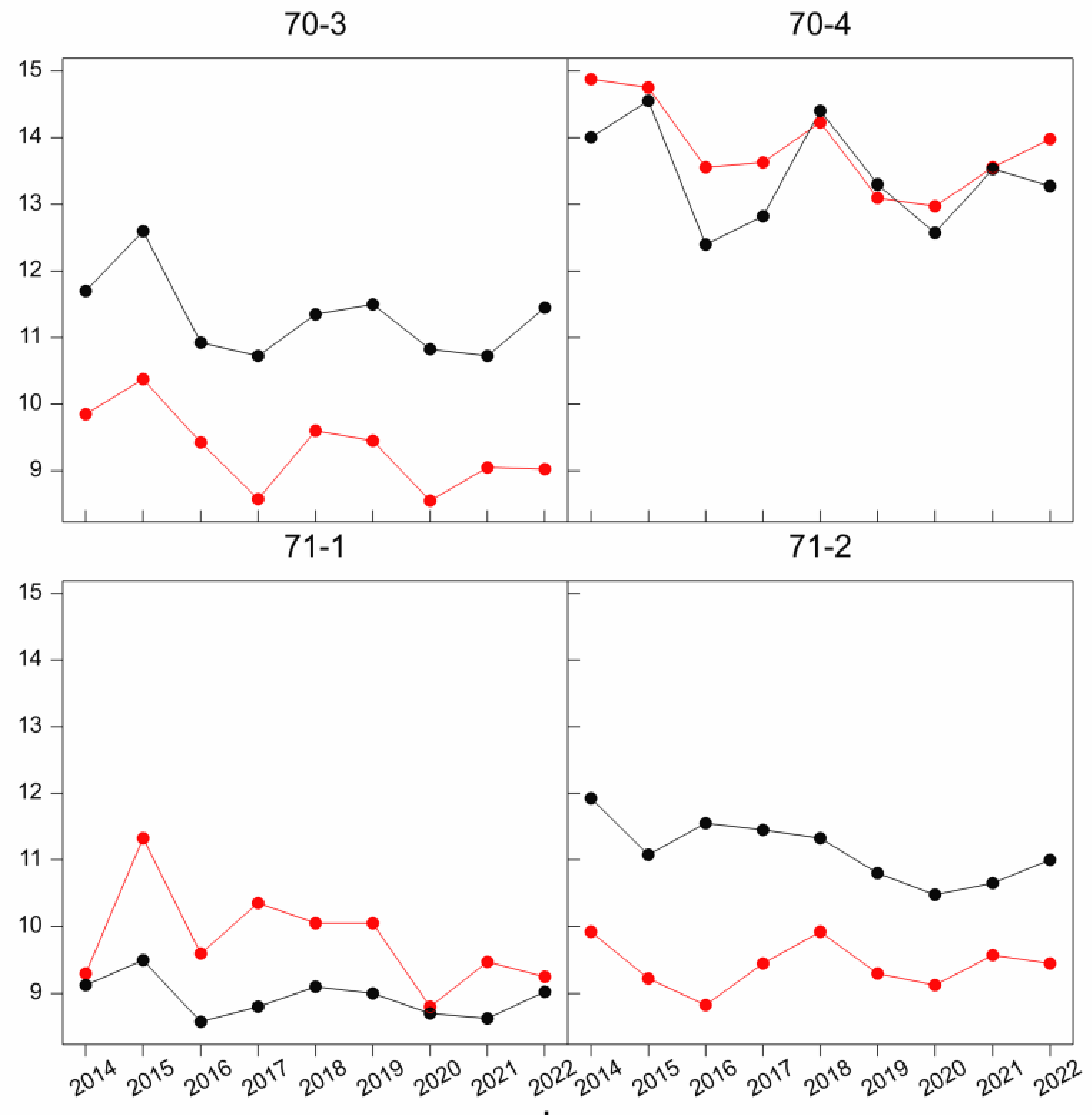
C:N ratio (-)



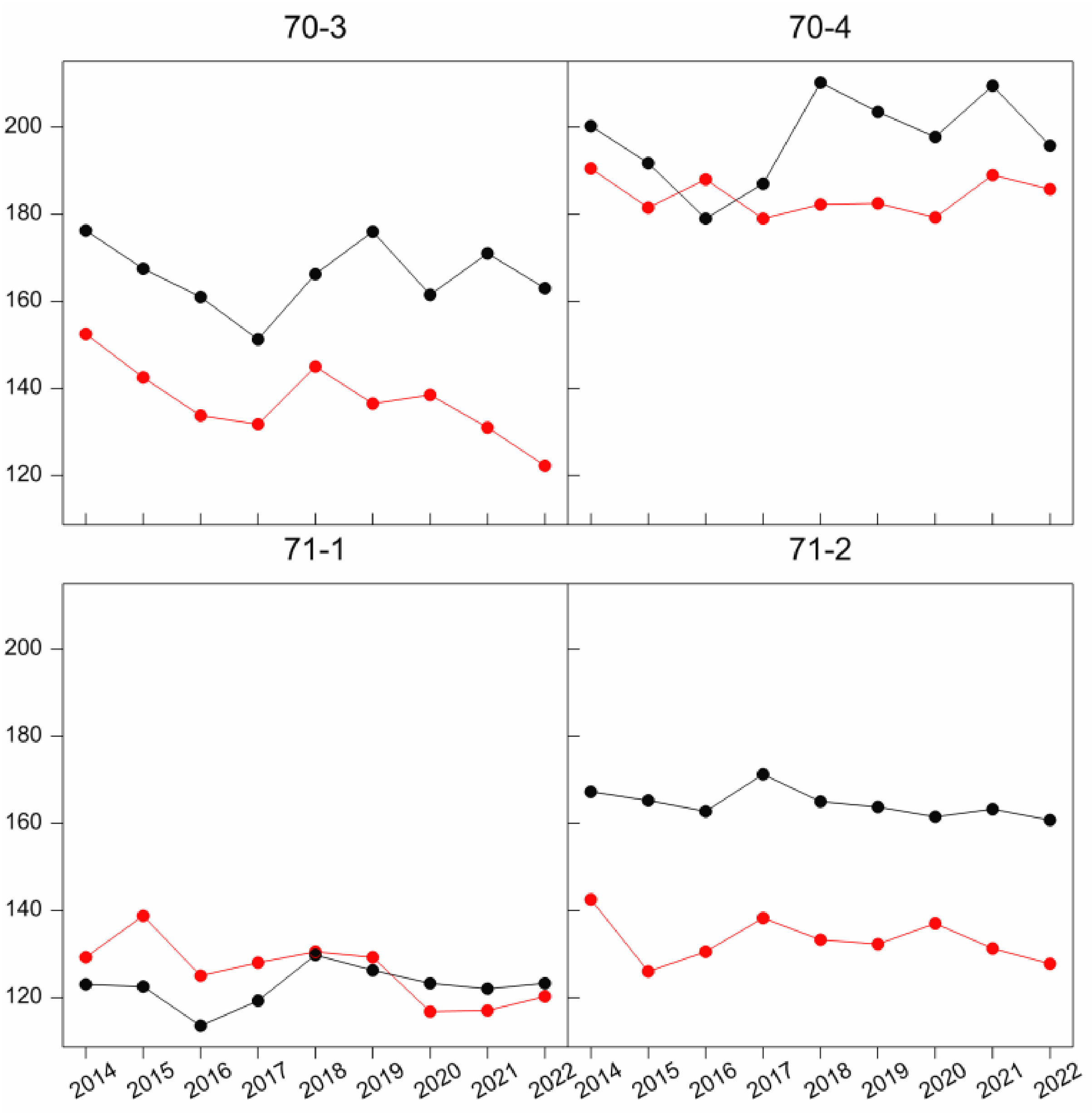
pH (-)


70-3
70-4
71-1
71-2
5.6
5.4
5.2
5.0
4.8
4.6
2014
2015
2016
2017
2018
2019
2020
2021
2022

Soil organic matter (%)

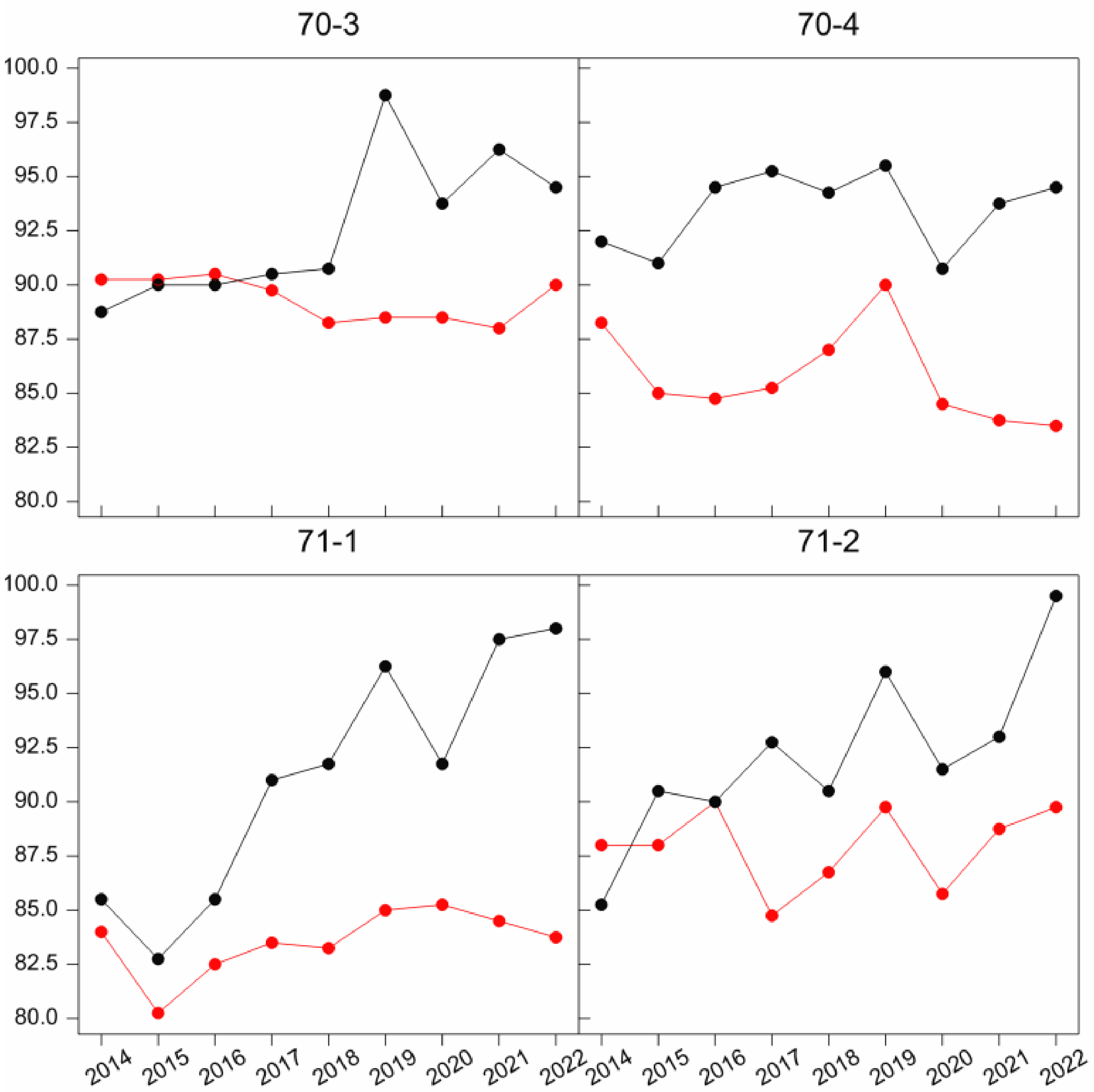


CEC (mmol kg^{-1})

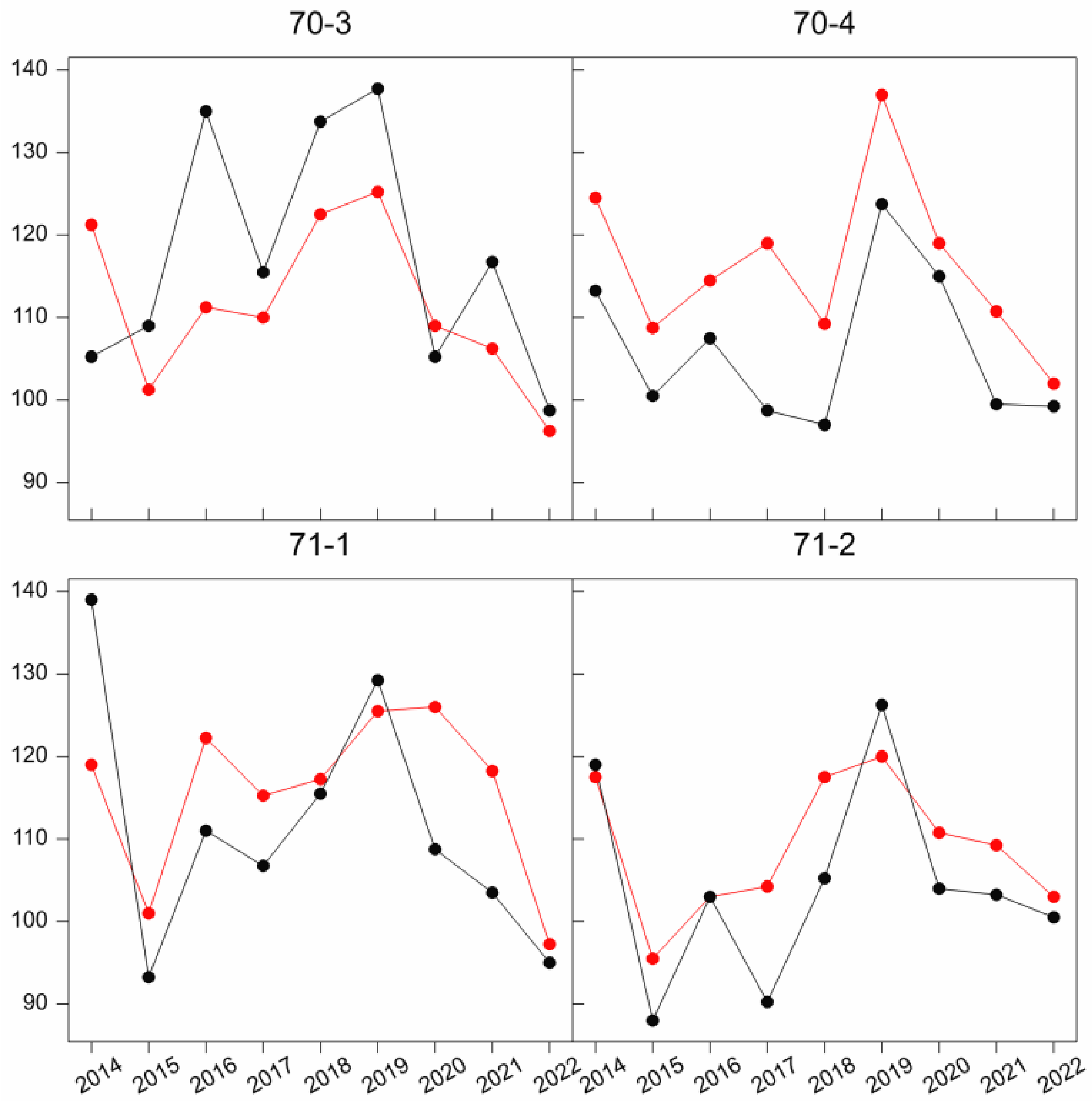


70-3
70-4
71-1
71-2
200
180
160
140
120
2014
2015
2016
2017
2018
2019
2020
2021
2022

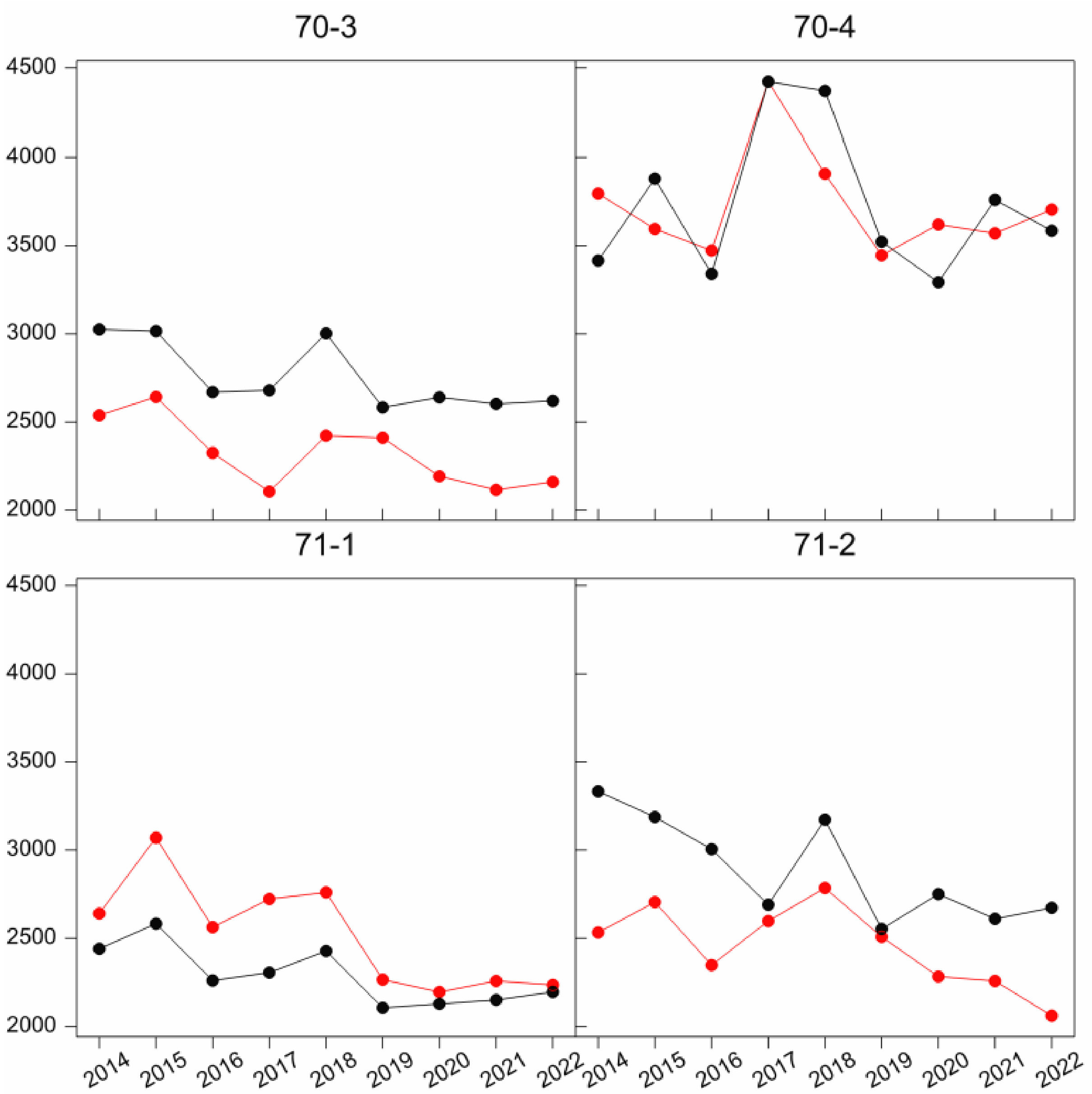
CEC saturation (%)



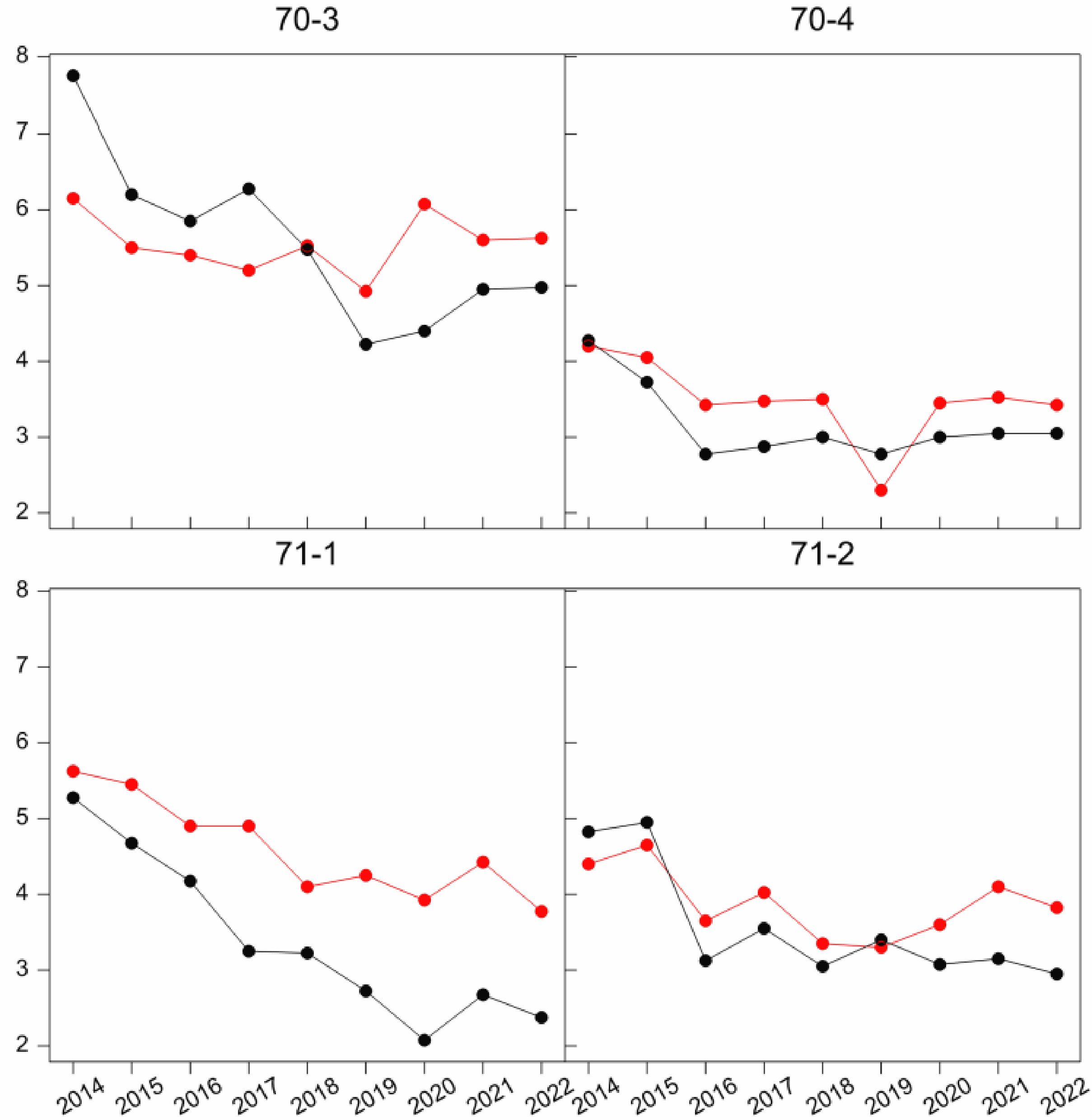
C:S ratio (-)


70-3
70-4
71-1
71-2
140
130
120
110
100
90
2014
2015
2016
2017
2018
2019
2020
2021
2022

Total N (mg N kg^{-1})

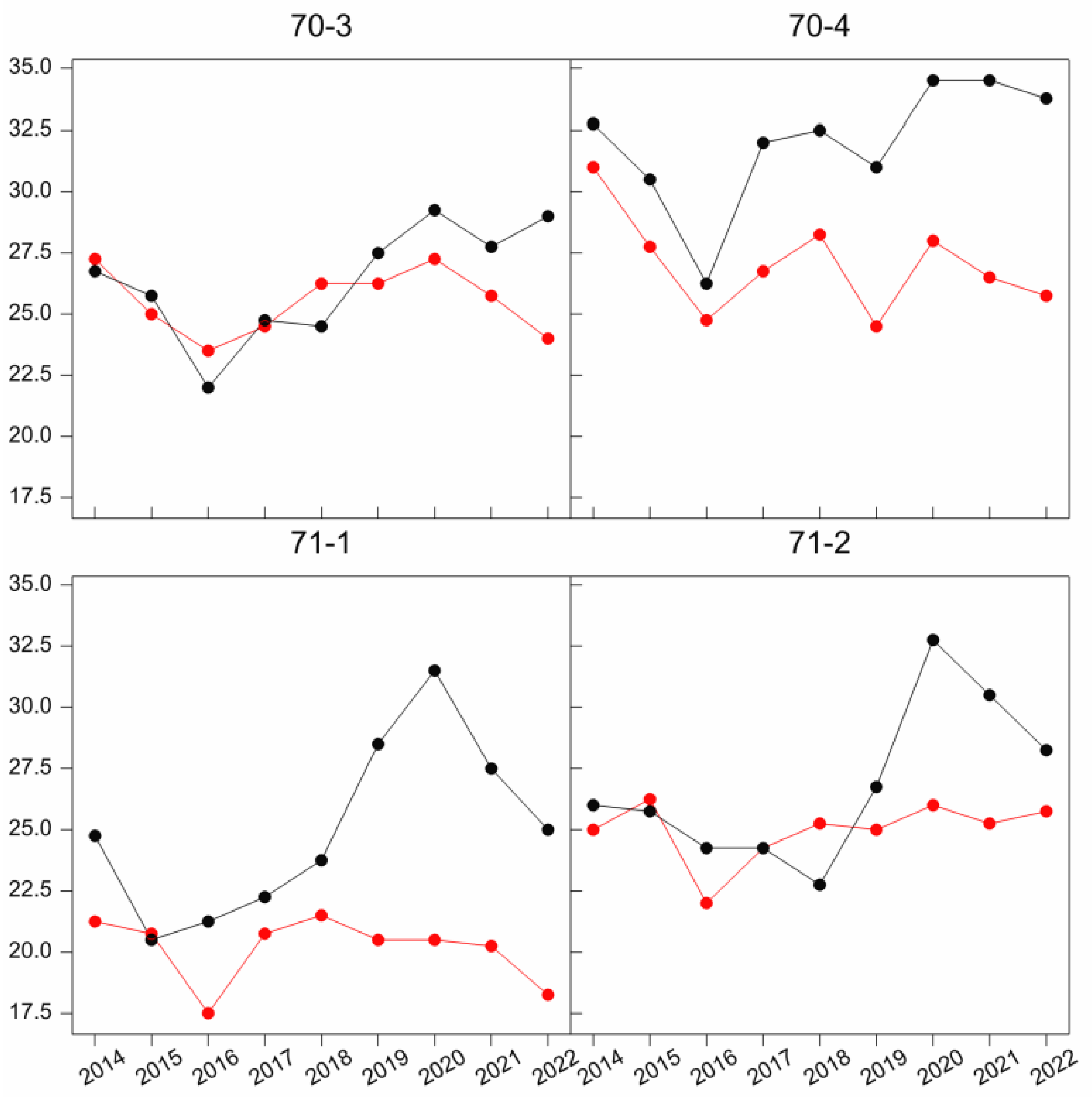


P-PAE (mg P kg^{-1})

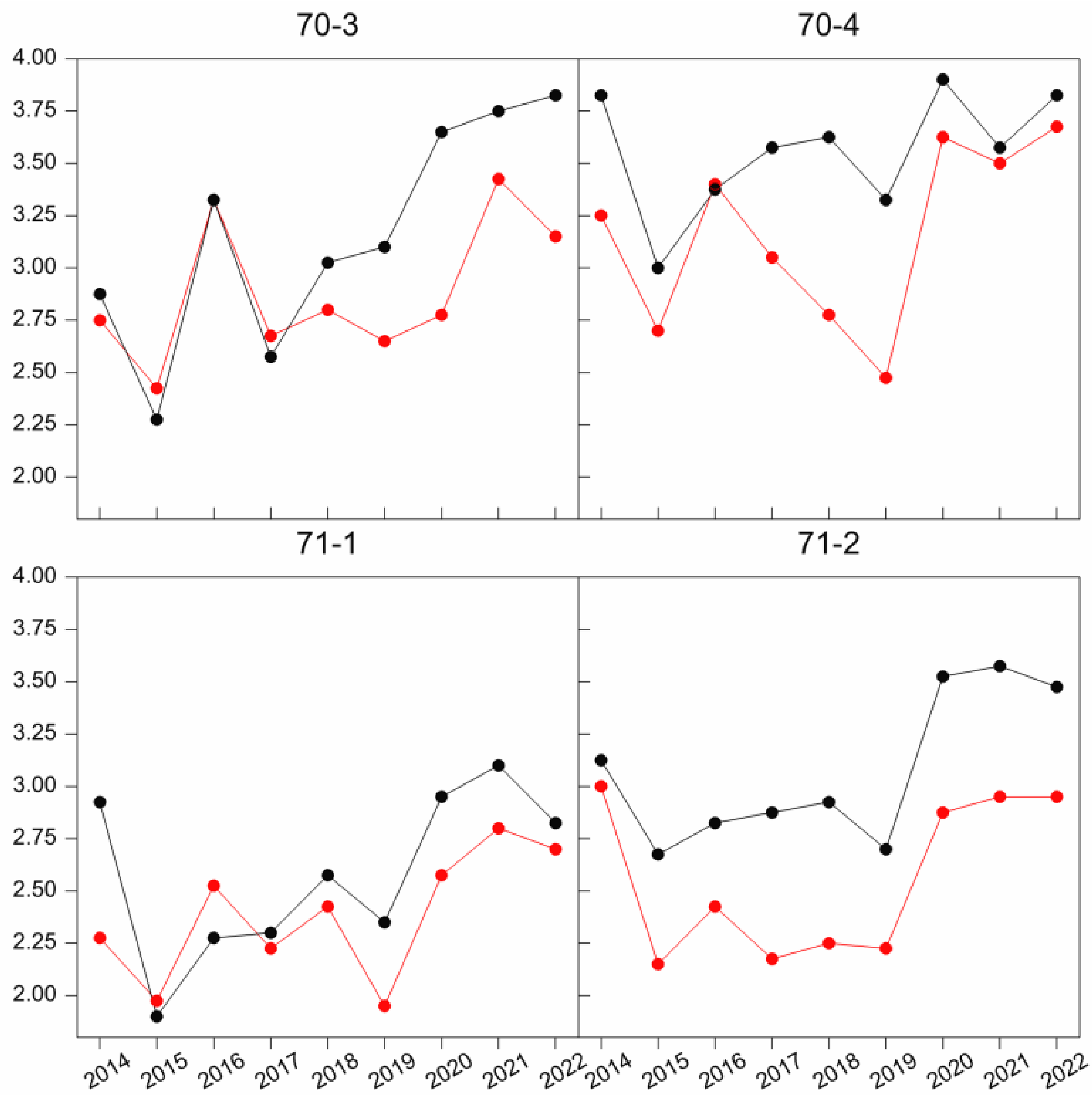


70-3
70-4
71-1
71-2
8
7
6
5
4
3
2
2014
2015
2016
2017
2018
2019
2020
2021
2022

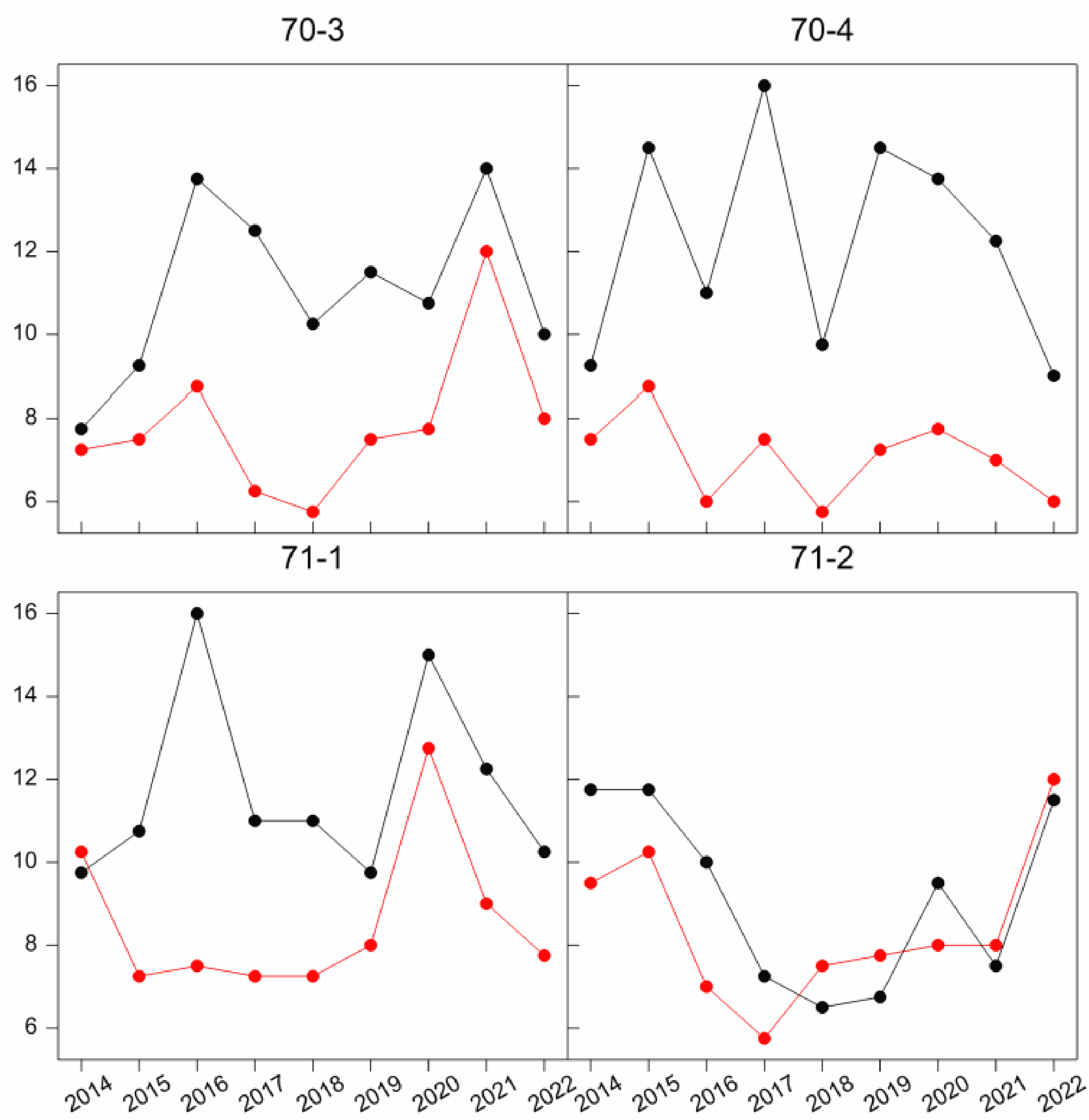
P-AL (mg P2O5 $100g^{-1}$)



K status (mmol kg^{-1})

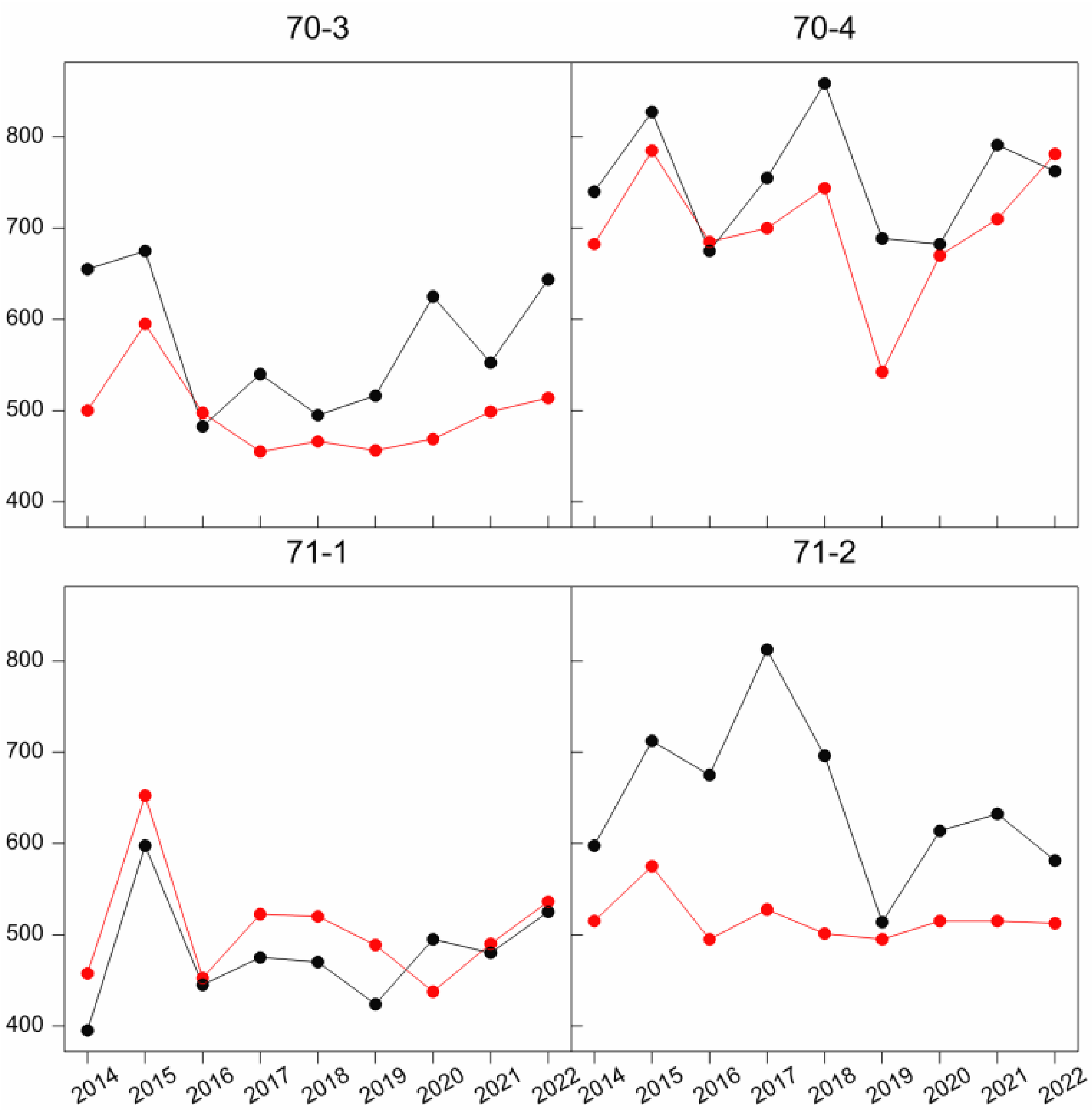


K-number (-)

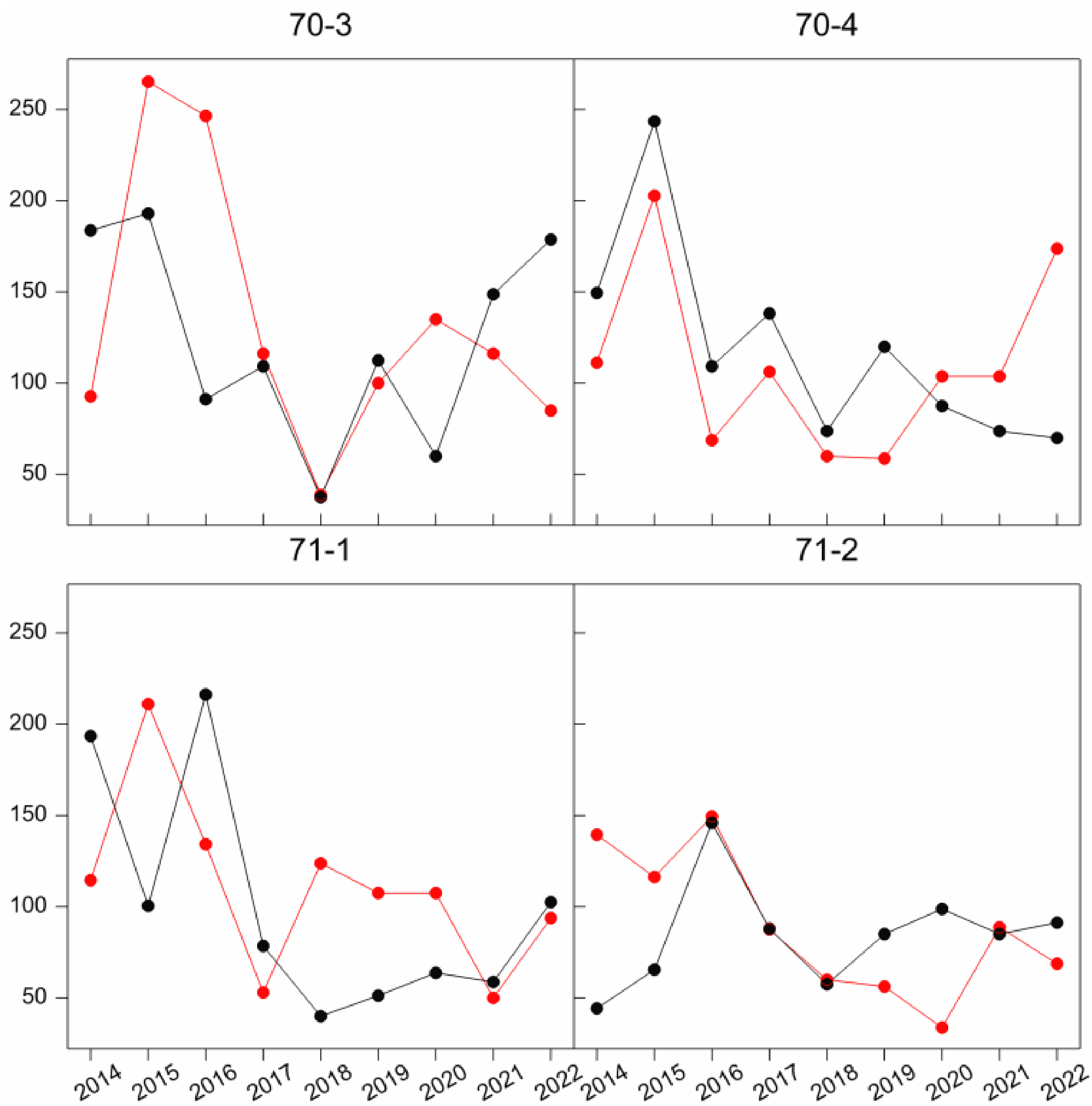


70-3
70-4
71-1
71-2
16
14
12
10
8
6
2014
2015
2016
2017
2018
2019
2020
2021
2022

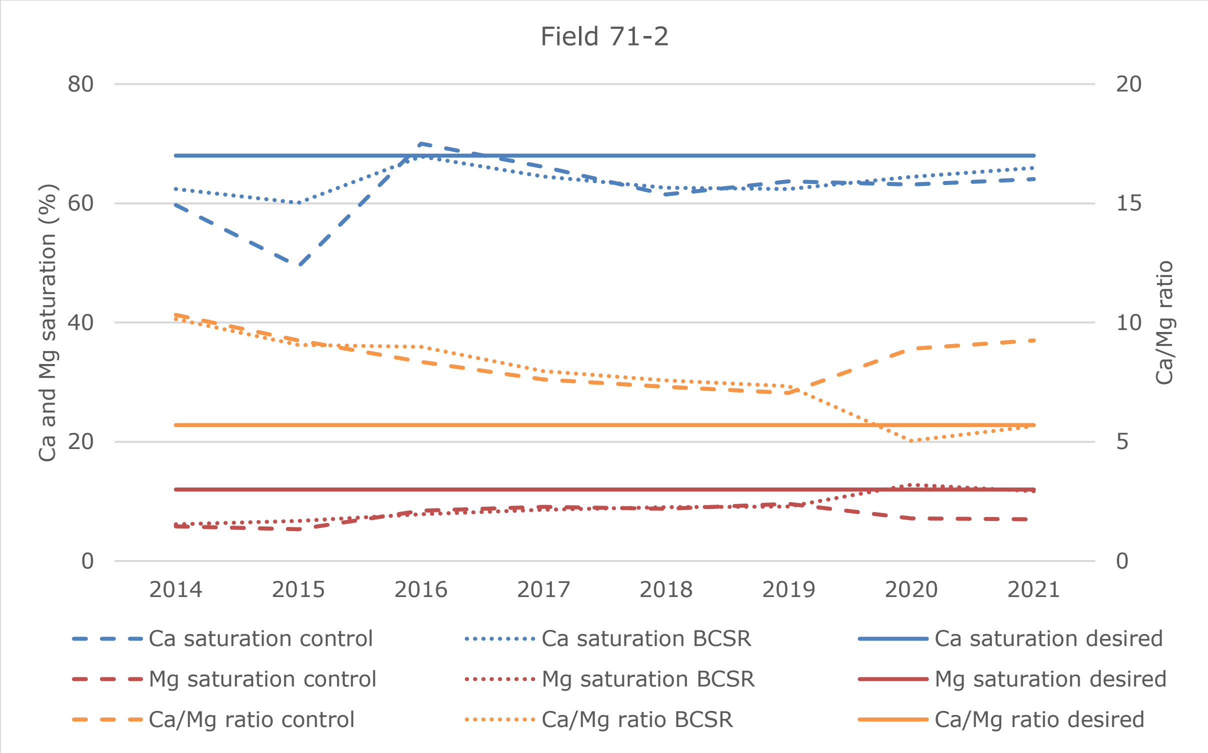
Total S (mg S kg^{-1})

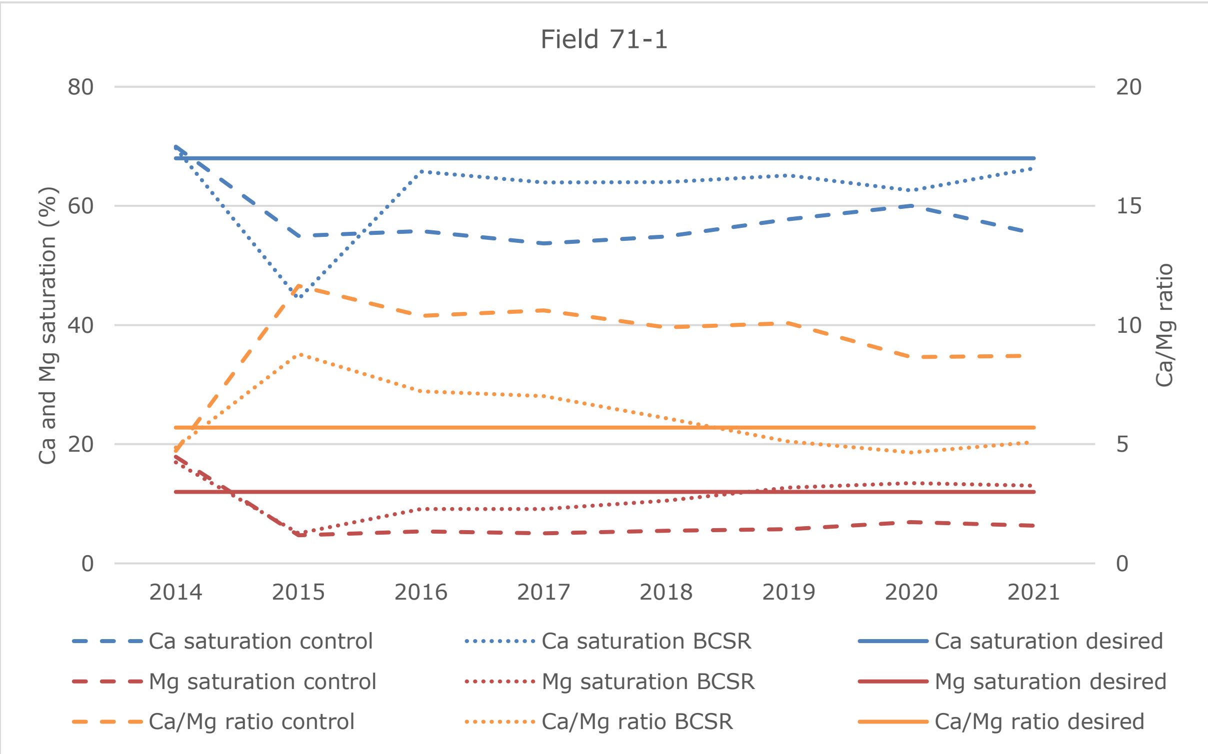


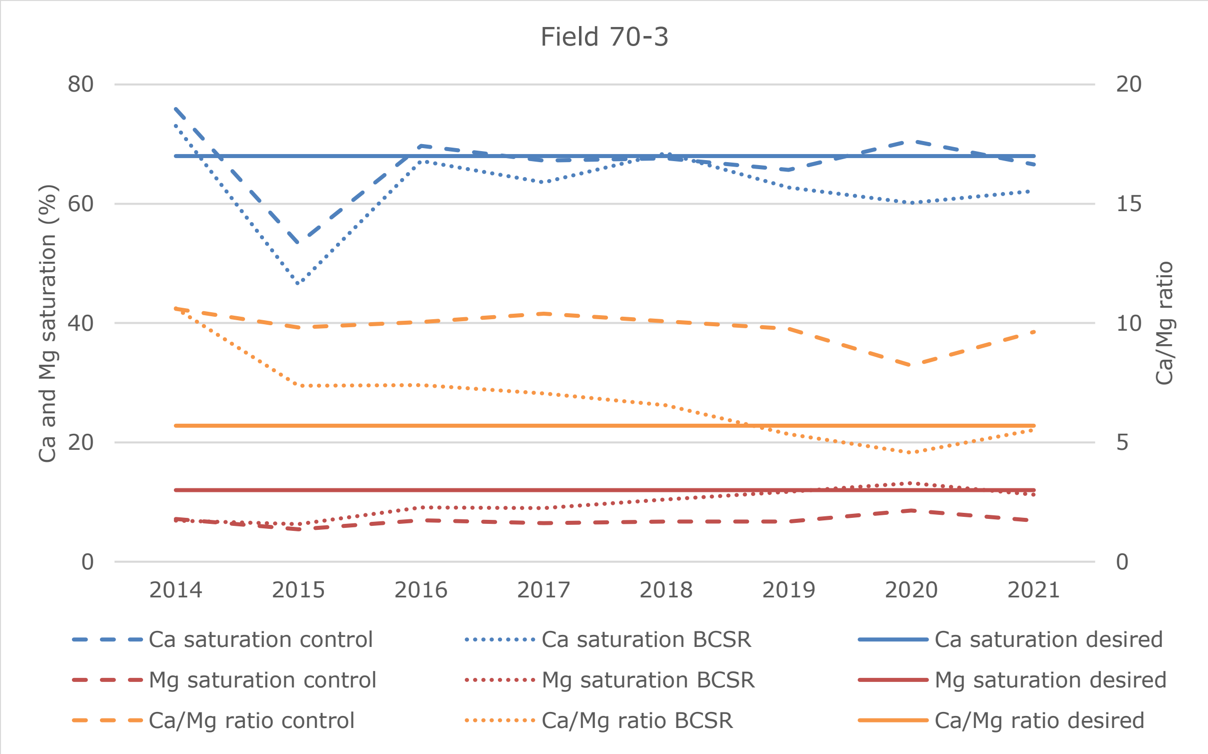
Ca availability (kg Ca ha^{-1})

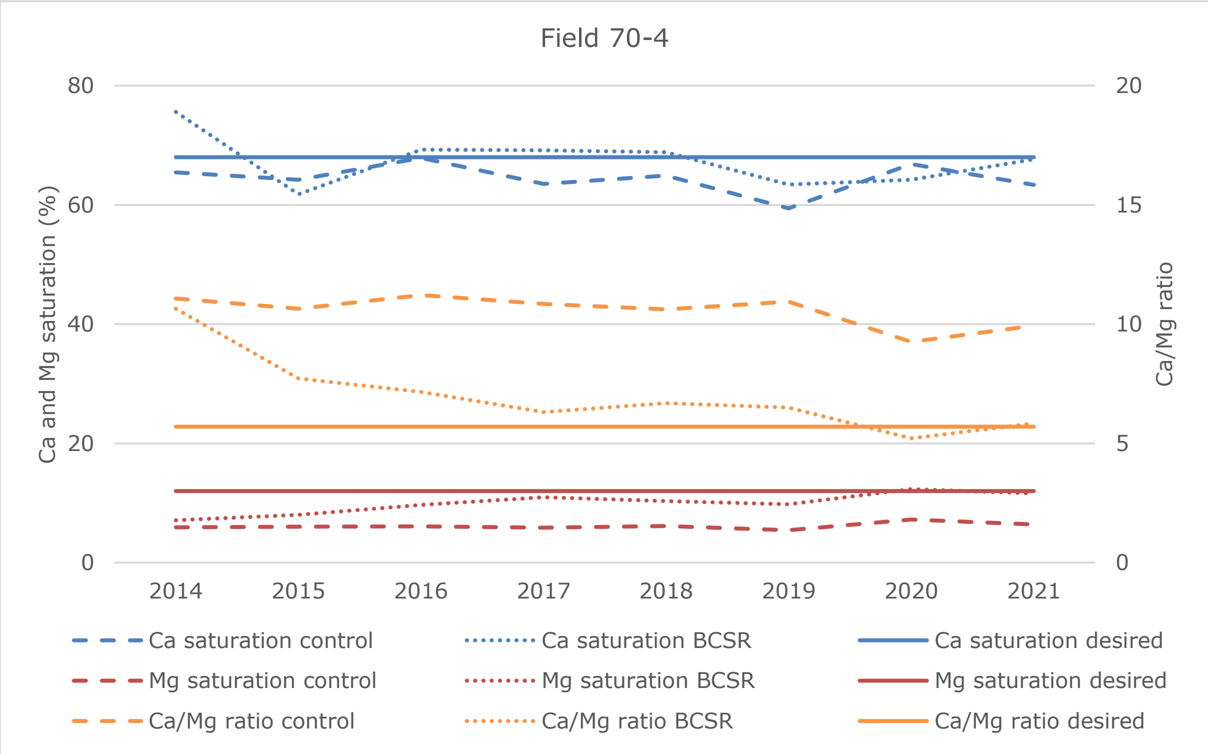


Ca and Mg saturation of the BCSR method



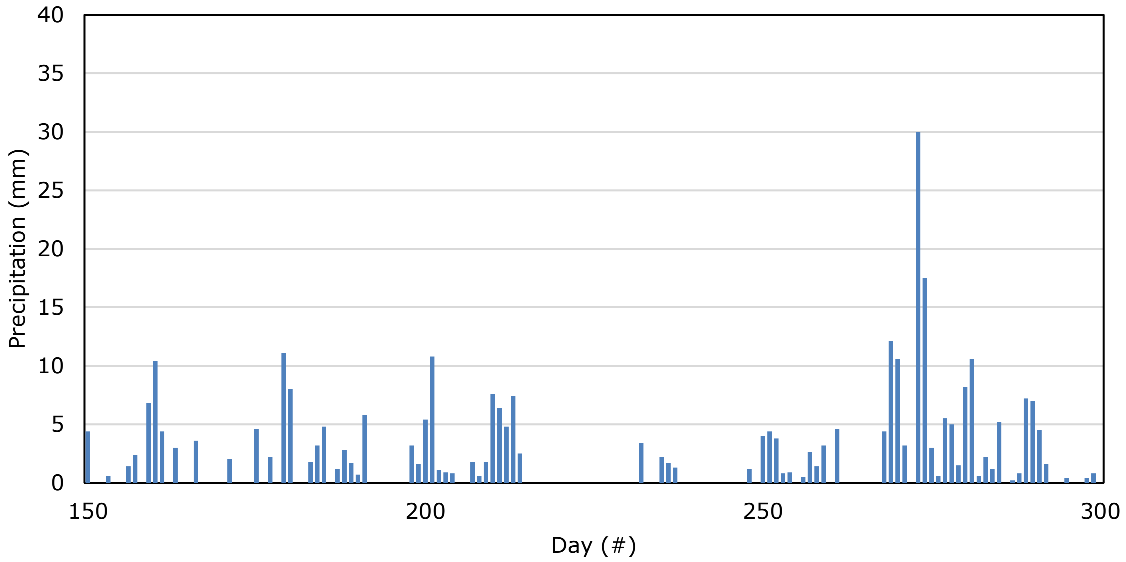


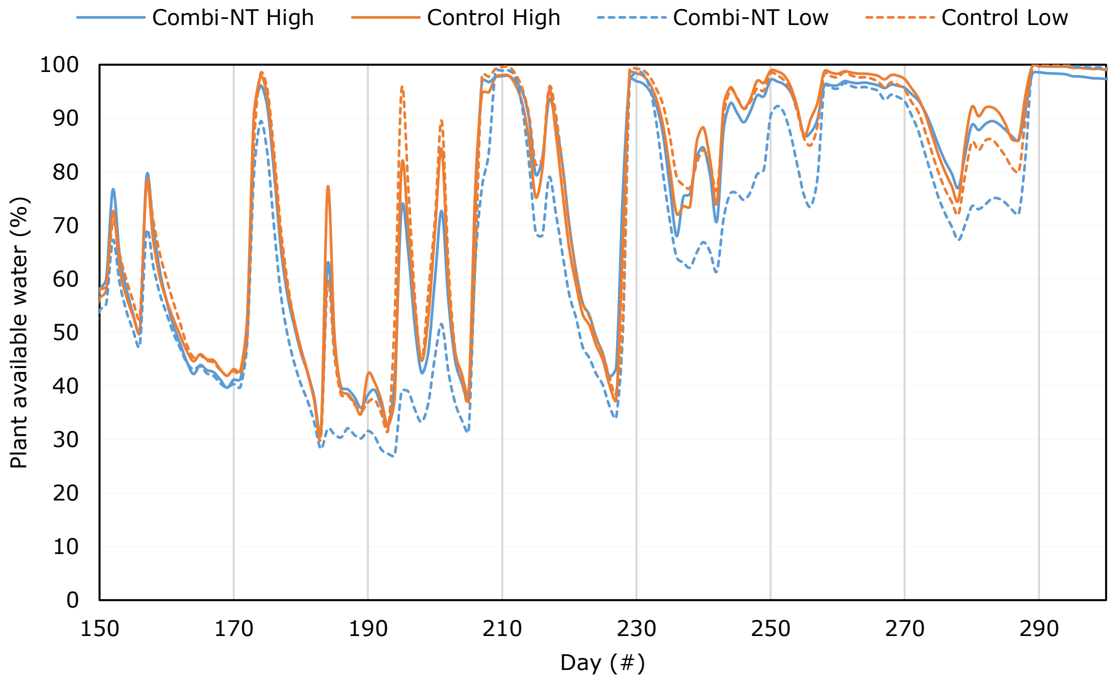

Field 70-3
Ca and Mg saturation (%)
Ca/Mg ratio
80
60
40
20
0
20
15
10
5
0
2014
2015
2016
2017
2018
2019
2020
2021
Ca saturation control
Ca saturation BCSR
Ca saturation desired
Mg saturation control
Mg saturation BCSR
Mg saturation desired
Ca/Mg ratio control
Ca/Mg ratio BCSR
Ca/Mg ratio desired


Field 70-4
Ca and Mg saturation (%)
Ca/Mg ratio
80
60
40
20
0
20
15
10
5
0
2014
2015
2016
2017
2018
2019
2020
2021
Ca saturation control
Ca saturation BCSR
Ca saturation desired
Mg saturation control
Mg saturation BCSR
Mg saturation desired
Ca/Mg ratio control
Ca/Mg ratio BCSR
Ca/Mg ratio desired

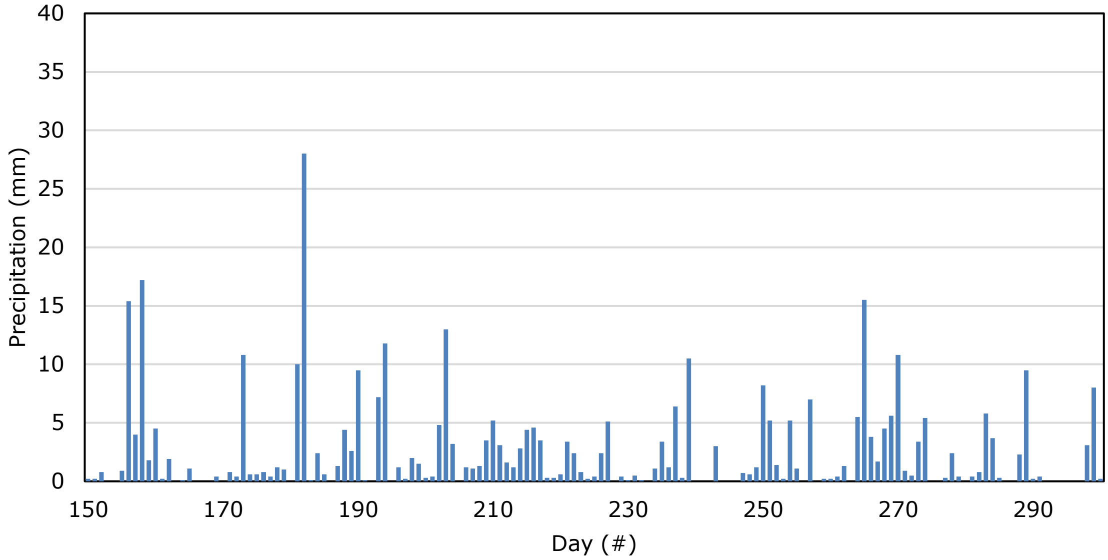
Appendix 11 Soil moisture content and precipitation

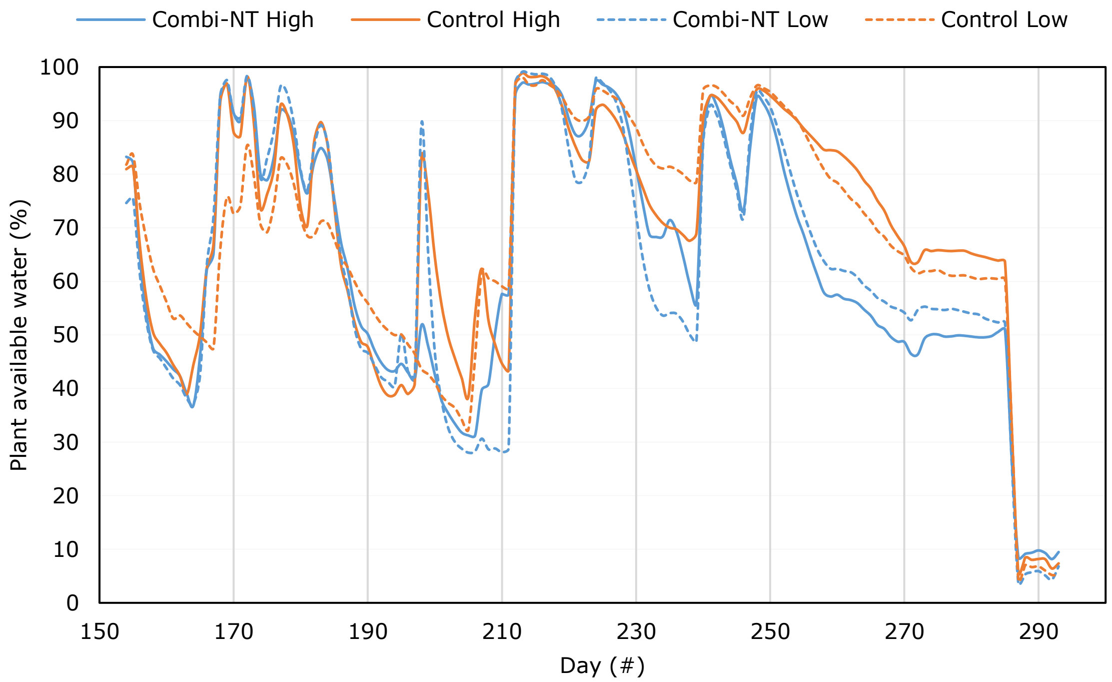
2015 Sugar beet



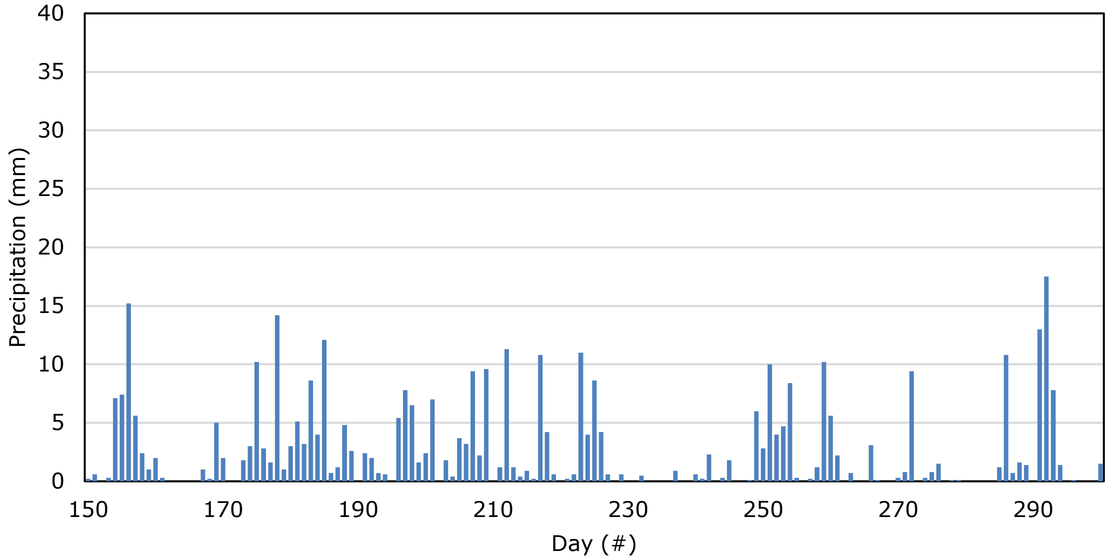


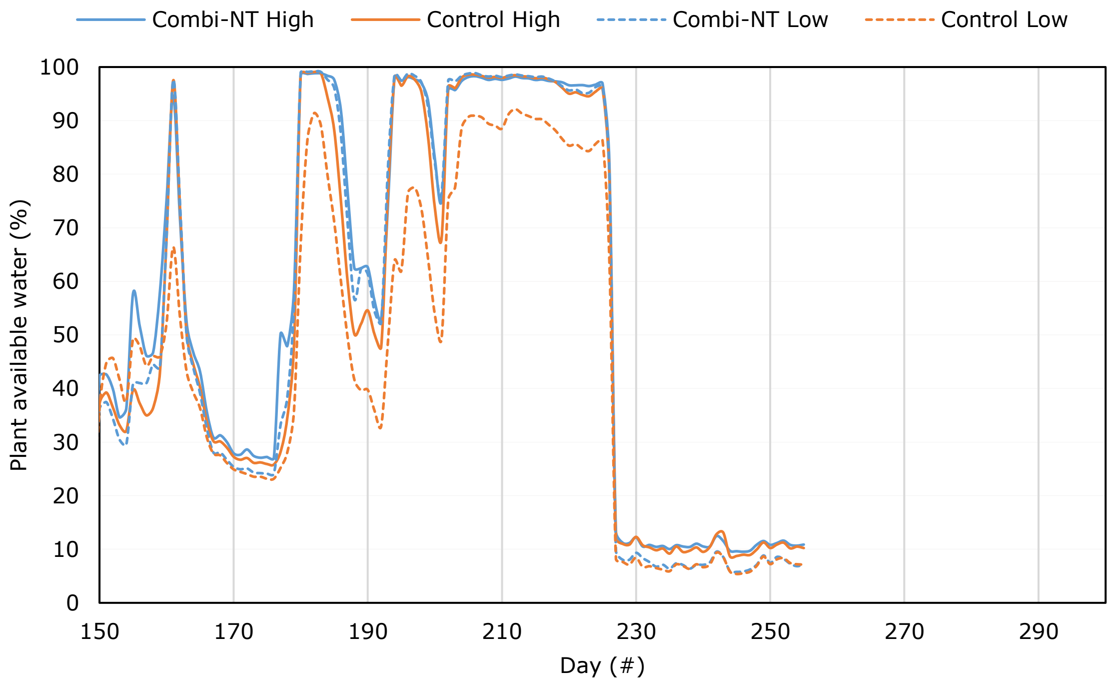
2016 Seresta



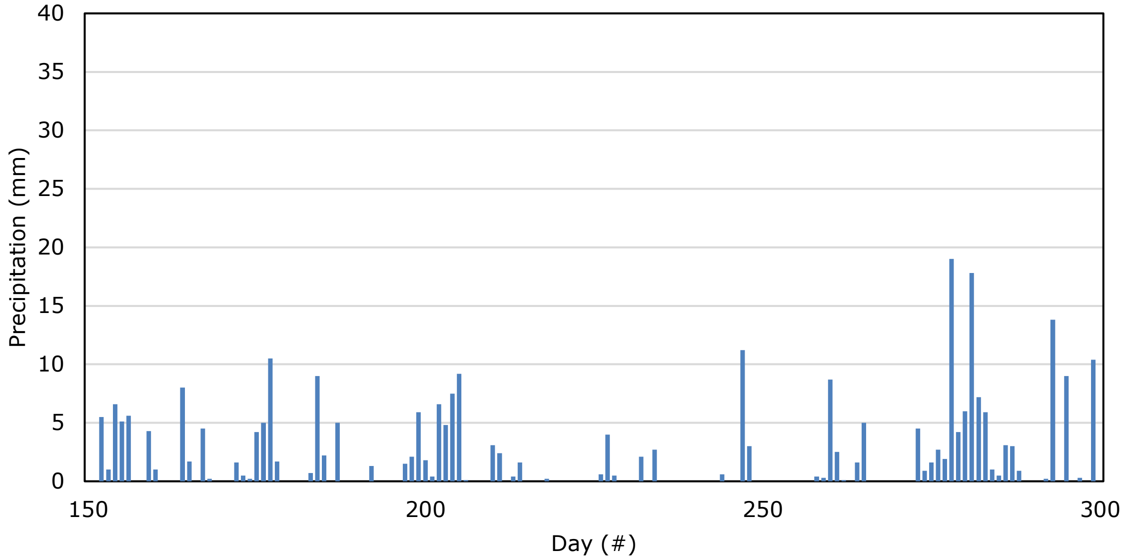


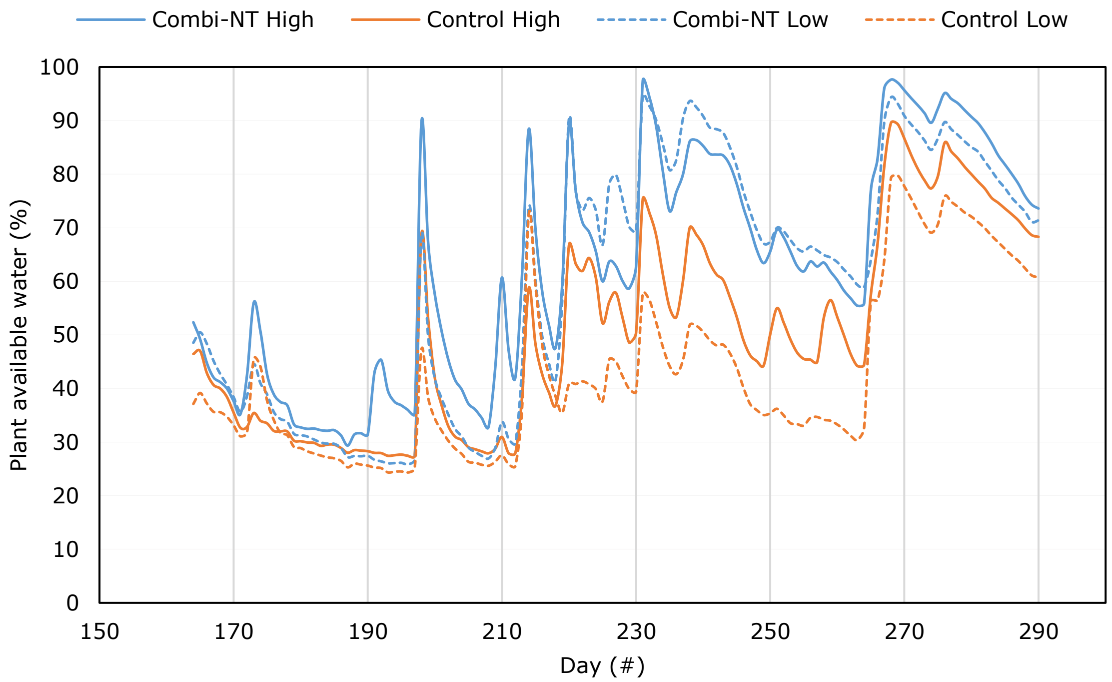
2017 Spring barley



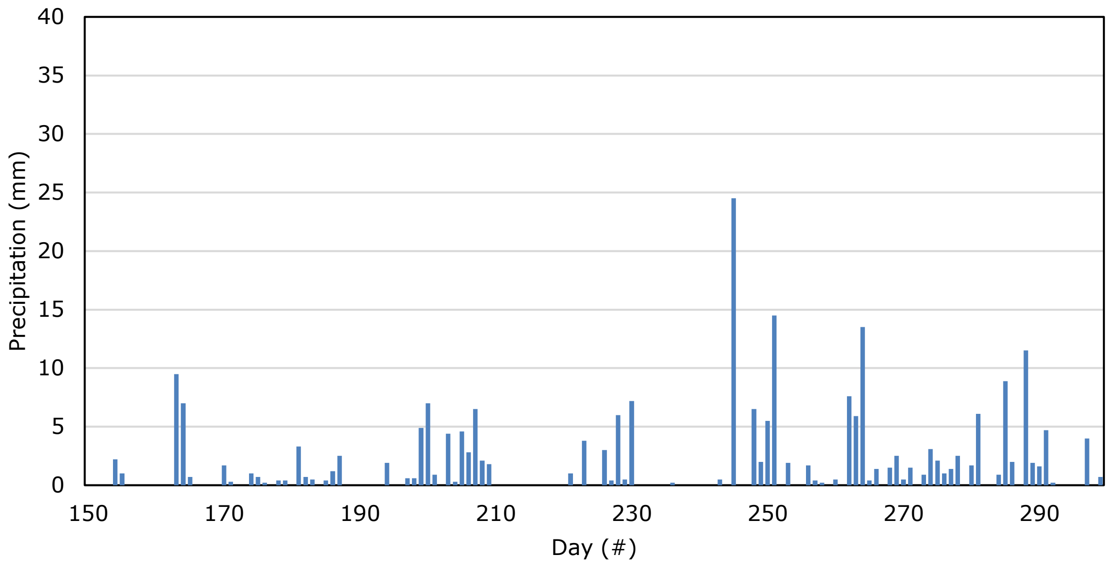


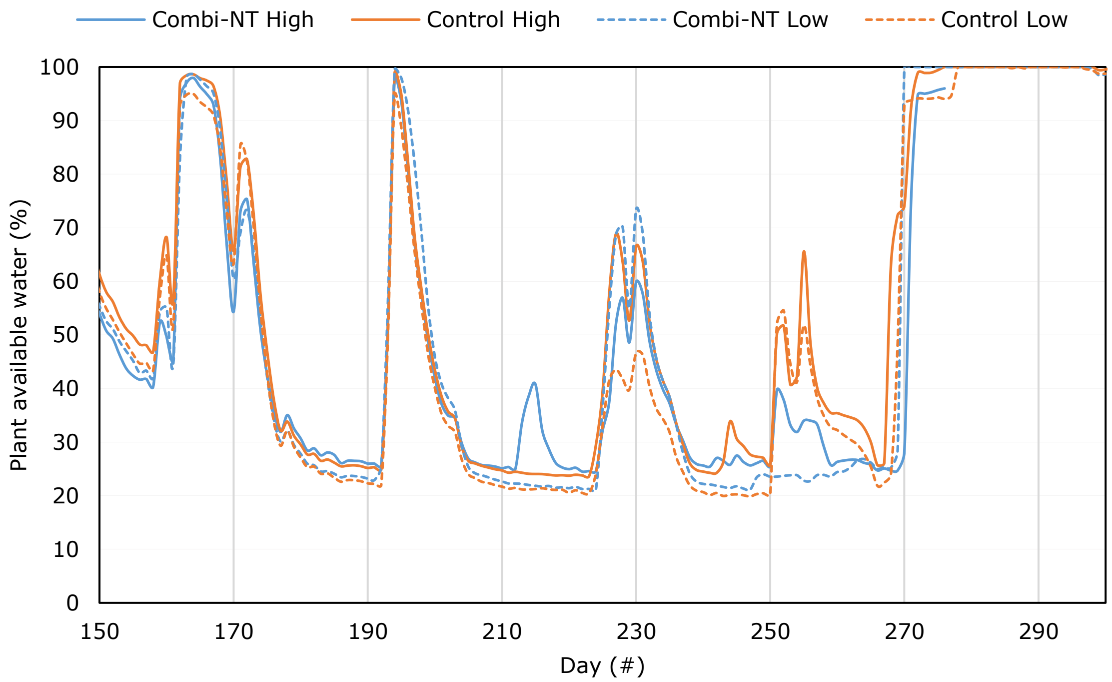
2018 Festien



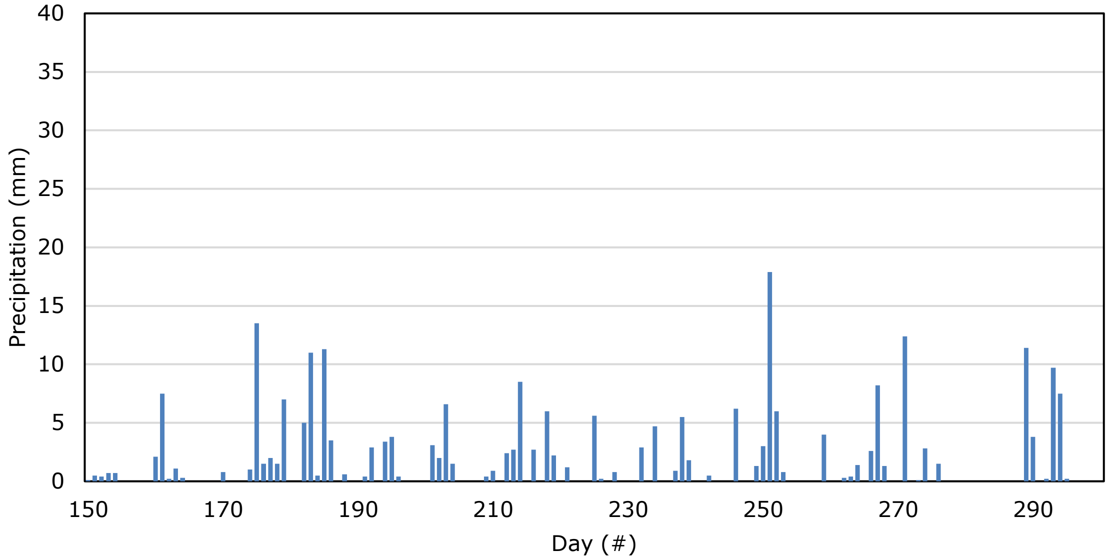


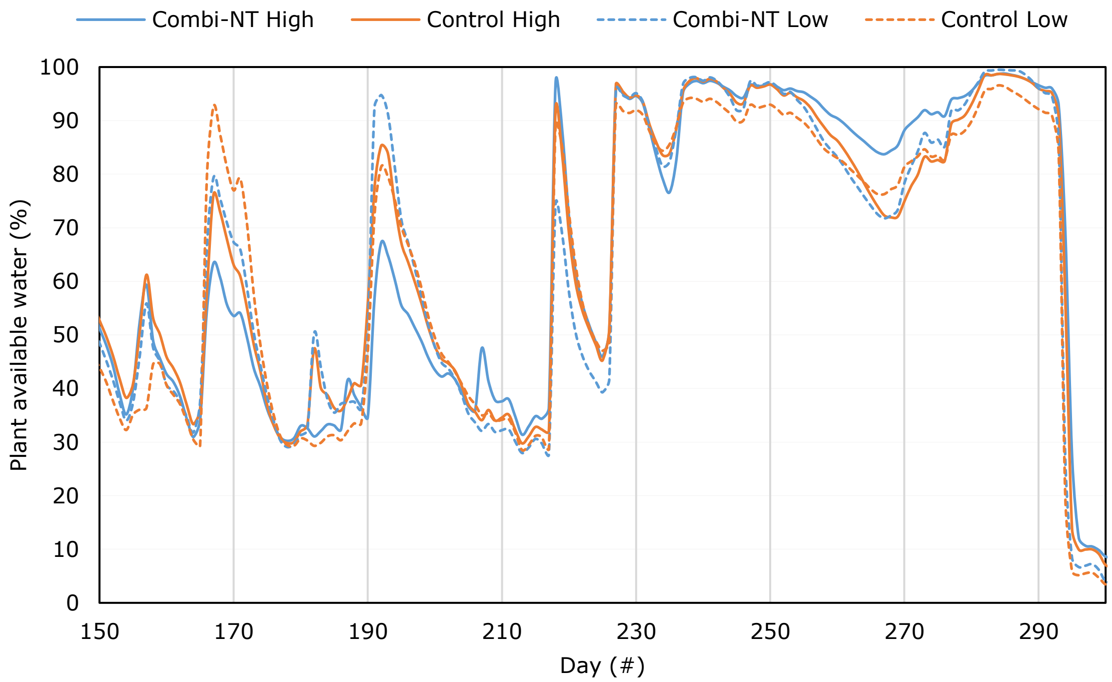
2019 Sugarbeets



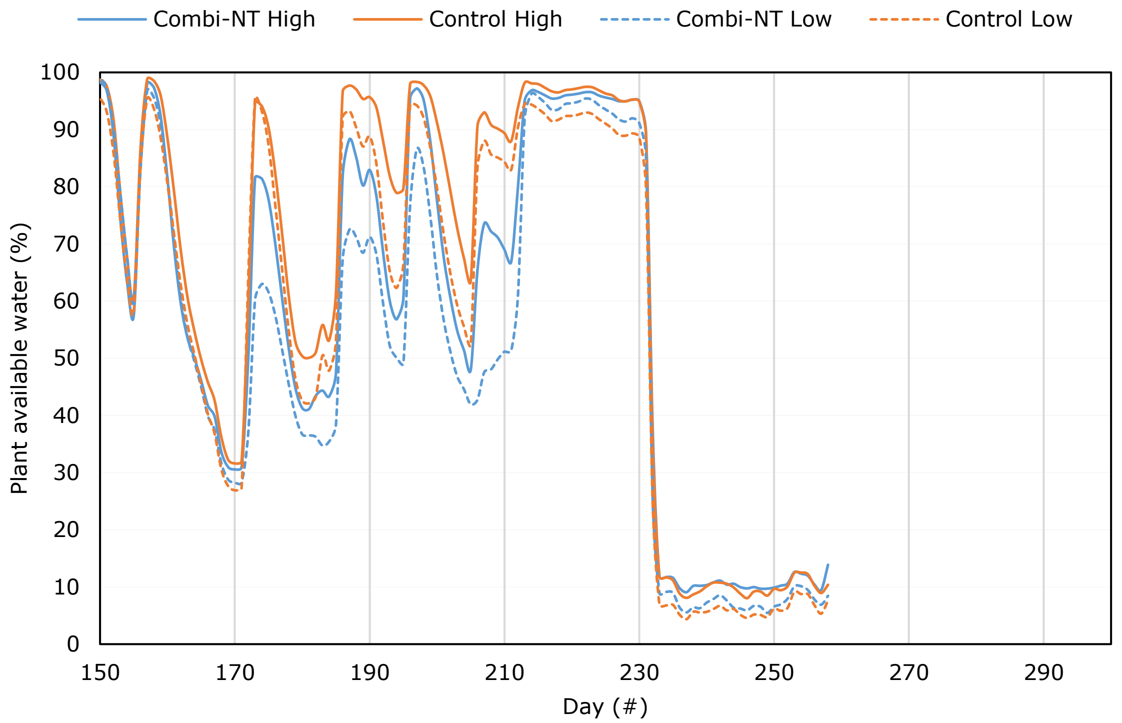


2020 Seresta

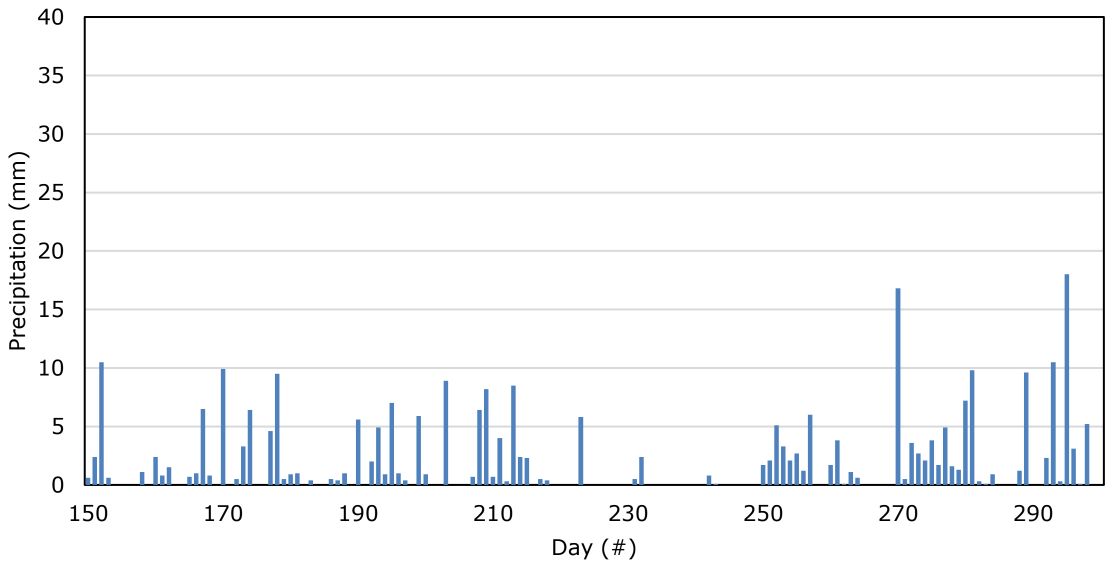




2021 Spring barley



Combi-NT High
Control High
Combi-NT Low
Control Low
Plant available water (%)
100
90
80
70
60
50
40
30
20
10
0
150
170
190
210
230
250
270
290
Day (#)



Precipitation (mm)
40
35
30
25
20
15
10
5
0
150
170
190
210
230
250
270
290
Day (#)

Appendix 12 Soil biology

Table 61 Averages of the parameters measured by the Soil Biology Lab in 2013 on field 71-2 in the plots of the intended treatments Combi-NT and Standard-T and the results of the linear model.

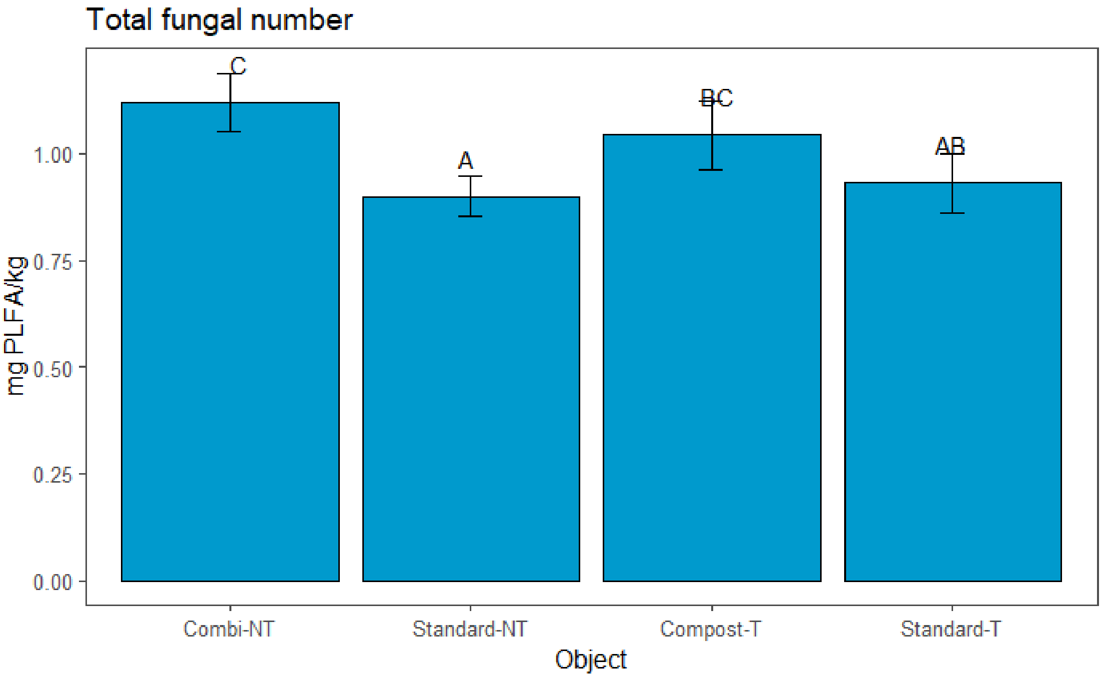
Parameter	Treatment	Average	F	P
Dry matter (%)	Combi-NT	79.55	2.48	0.21
Dry matter (%)	Standard-T	74.98		
Fungal biomass (µg C/g dry soil)	Combi-NT	11.88	2.48	0.21
Fungal biomass (µg C/g dry soil)	Standard-T	11.00		
Active fungi (% hyphal length)	Combi-NT	0	1.00	0.39
Active fungi (% hyphal length)	Standard-T	2.14		
Bacterial biomass (µg C/g dry soil)	Combi-NT	20.05	0.39	0.58
Bacterial biomass (µg C/g dry soil)	Standard-T	24.01		
PNM (mg/kg)	Combi-NT	3.11	0.59	0.50
PNM (mg/kg)	Standard-T	3.43		
PMN (mg/kg)	Combi-NT	41.35	0.00	0.96
PMN (mg/kg)	Standard-T	41.61		
PCM (mg/kg)	Combi-NT	34.00	0.01	0.92
PCM (mg/kg)	Standard-T	33.44		0
HWC (µg C/g)	Combi-NT	1594.55	0.19	0.69
HWC (µg C/g)	Standard-T	1511.57		
N mineralisation	Combi-NT	771.20	0.50	0.53
N mineralisation	Standard-T	813.72		
C mineralisation (bacC+funC) (qCO2)	Combi-NT	1.21	0.58	0.50
C mineralisation (bacC+funC) (qCO2)	Standard-T	1.54		
C mineralisation/bacC (qCO2)	Combi-NT	2.11	0.93	0.41
C mineralisation/bacC (qCO2)	Standard-T	1.54		
Bacterial number (1^e9/g)	Combi-NT	28.54	2.56	0.21
Bacterial number (1^e9/g)	Standard-T	34.69		
Cell volume (µm^3/cell)	Combi-NT	20.38	0.09	0.79
Cell volume (µm^3/cell)	Standard-T	21.56		
Unstained fungi (%)	Combi-NT	95.37	2.93	0.19
Unstained fungi (%)	Standard-T	83.95		
Fungi/bacteria	Combi-NT	76.25	0.66	0.48
Fungi/bacteria	Standard-T	56.74		0
Potential C mineralization (mg C/kg.wk)	Combi-NT	82.40	1.71	0.28
Potential C mineralisation (mg C/kg.wk)	Standard-T	74.44		

Table 62 Average values of parameters measured in 2013 on field 71-2 by Eurofins in the plots of the intended treatments Combi-NT and Standard-T and the results of a linear model.

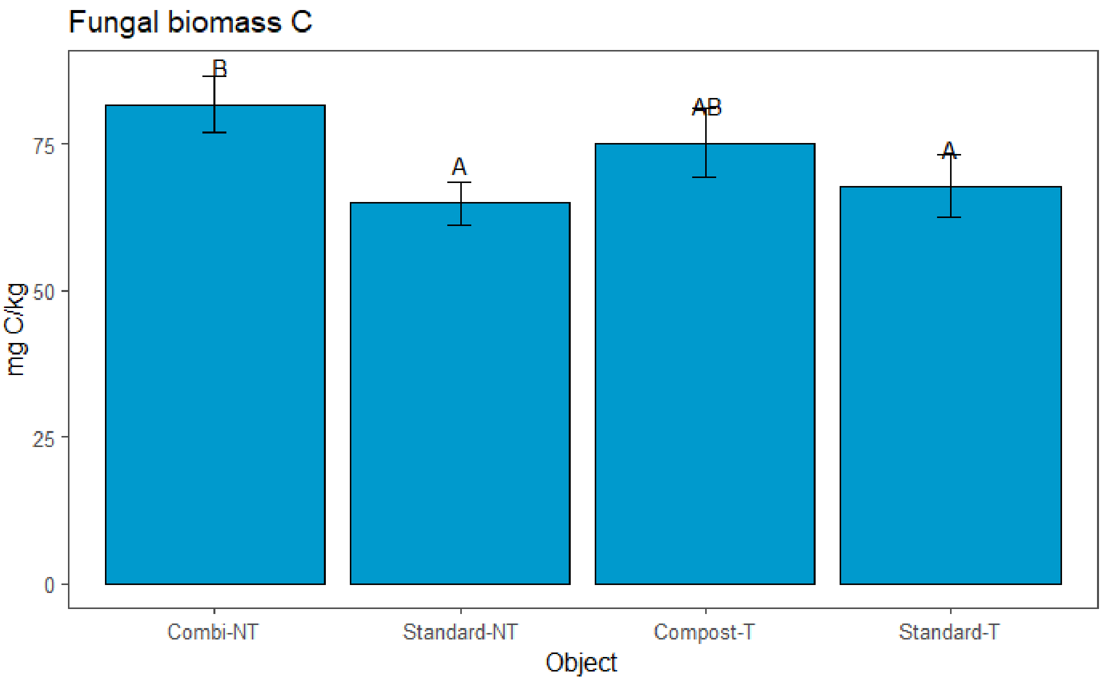
Parameter	Treatment	Average	F	P
OS (NIRS)	Combi-NT	11.30	0.14	0.74
OS (NIRS)	Standard-T	10.50		
pH	Combi-NT	5.05	0.33	0.61
pH	Standard-T	4.98		

Table 63 Average values of parameters measured in 2013 for each field, measured by the Soil Biology Lab.

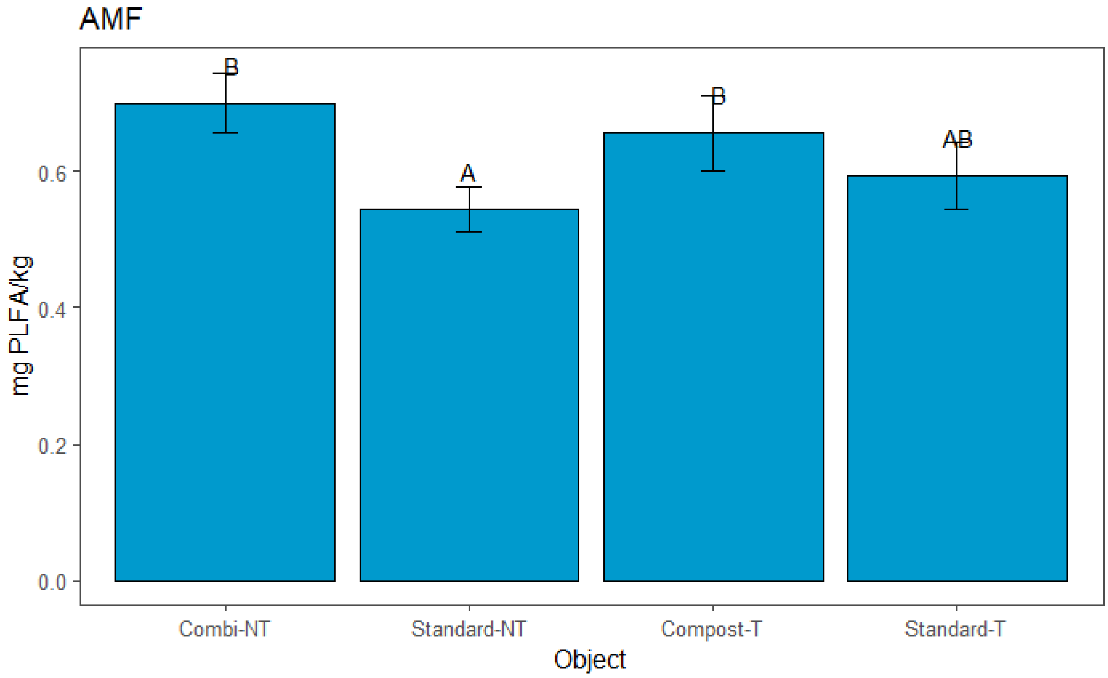
Parameter	70-3	70-4	71-1	71-2
Dry matter (%)	80.6	72.2	79.9	77.2625
Fungal biomass (µg C/g dry soil)	11	11.5	12.6	11.4375
Active fungi (% hyphal length)	0	0	21.9	1.075
Bacterial biomass (µg C/g dry soil)	14.1	22.8	17.7	22.0375
PNM (mg/kg)	2.66	4.68	3.42	3.2675
PMN (mg/kg)	35.9	60.8	42	41.4875
PCM (mg/kg)	19.8	36.6	14.5	33.7125
HWC (µg C/g)	1413	2257	1592	1553
N mineralisation	0.074	0.077	0.081	0.079375
C mineralisation (bacC+funC) (qCO2)	0.79	1.06	0.48	1.08875
C mineralisation/bacC (qCO2)	1.41	1.6	0.82	1.82875
Bacterial number (1^e9/g)	0.2	0.33	0.36	0.315
Cellvolume (µm^3/cell)	0.22	0.22	0.15	0.21
Bacterial number (1^e9/g)	86.1	91.2	73.2	89.6625
Fungi/bacteria	0.8	0.5	0.7	0.65
Potential C mineralisation (mg C/kg.wk)	54.03	67.68	49	78.42



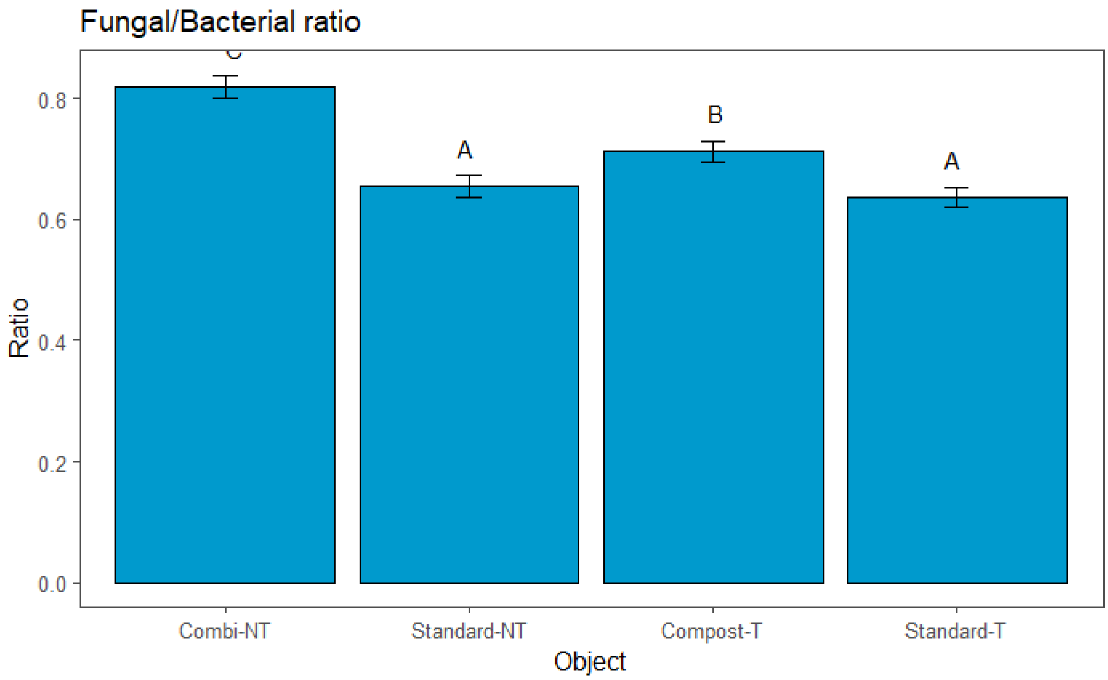
Total fungal numbers measured in 2022 in all four fields.



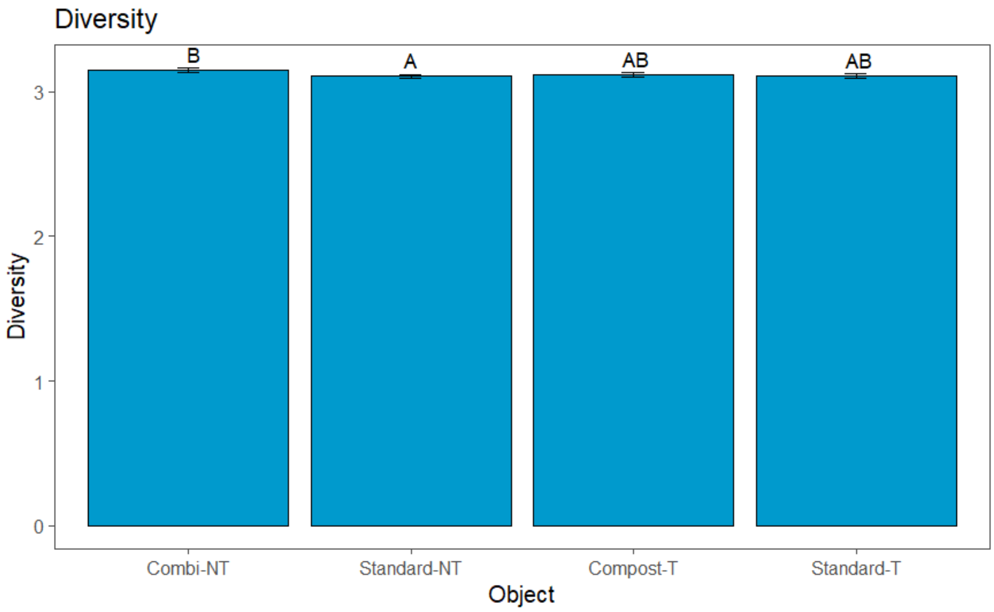
Fungal biomass measured in 2022 in all four fields.



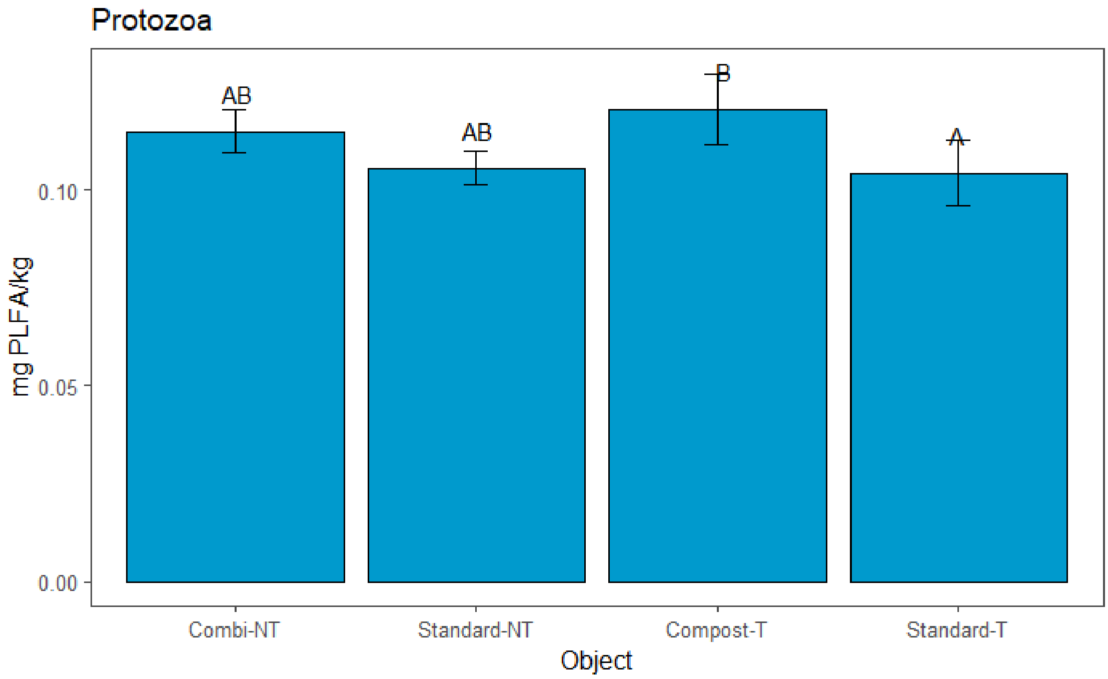
AMF measured in 2022 in all four fields.



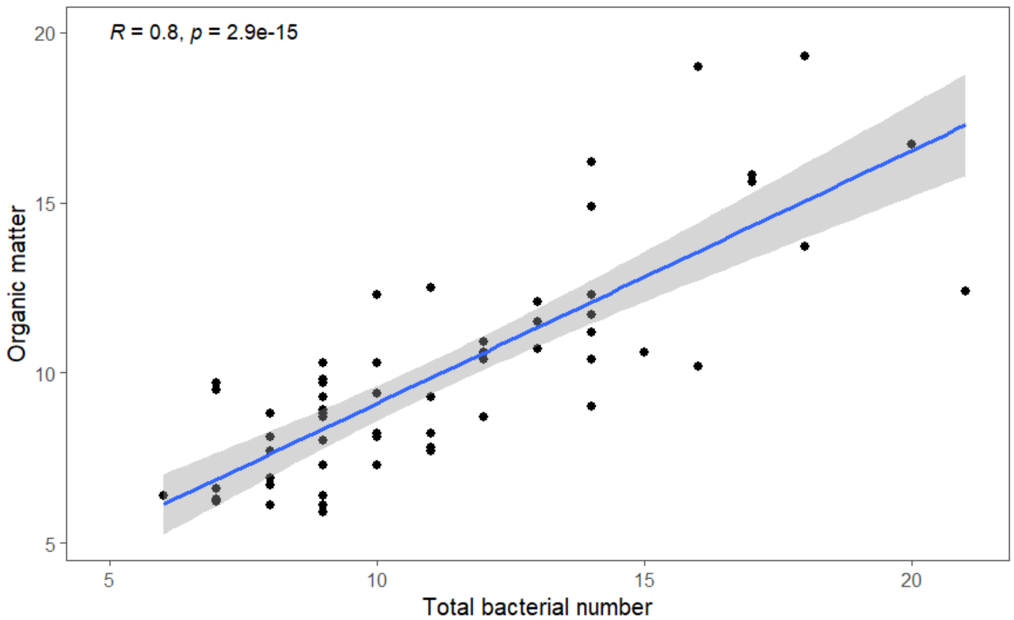
Fungi/bacteria ratio measured in 2022 in all four fields.



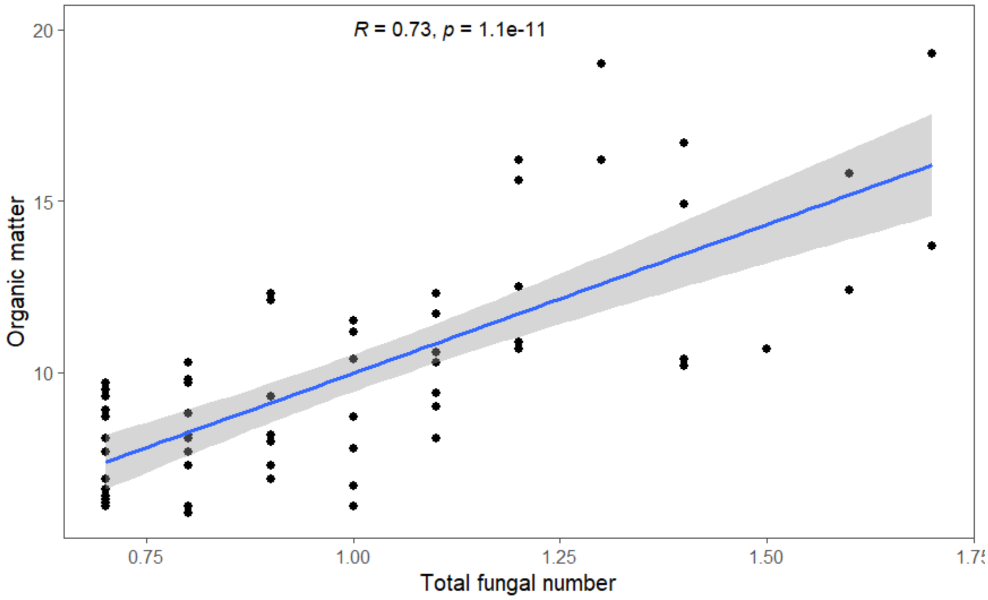
Diversity measured in 2022 in all four fields.



The biomass of protozoa measured in 2022 in all four fields.



Correlation found between the amount of organic matter with the number of bacteria, measured in 2022 on all four fields and four treatments.



Correlation found between the amount of organic matter with the number of fungi, measured in 2022 on all four fields and four treatments.

Appendix 13 Nematode community

Table 64 Results of the statistical analysis of the effect of two treatments (Control and Combi-NT) on parameters of the nematode community in 2013 and 2020 in field 71-2 in Valthermond. Df = number of degrees of freedom, F-value (Df numerator = 3) and p-value, n=4.

			2013		2020	
Variable	Factor	Df	F-value	p-value	F-value	p-value
Dauer larvae	Treatment	1	0.00	0.99	0.81	0.41
Dauer larvae	Block	3	5.79	0.09	0.12	0.75
Total nematodes (excl. dauer larvae)	Treatment	1	9.06	0.06	0.02	0.91
Total nematodes (excl. dauer larvae)	Block	3	2.15	0.27	0.19	0.68
Plant feeders	Treatment	1	0.42	0.56	14.94	<0.05
Plant feeders	Block	3	0.35	0.79	3.81	0.11
Fungal feeders	Treatment	1	11.42	<0.05	0.00	0.98
Fungal feeders	Block	3	3.66	0.16	2.32	0.19
Bacterial feeders	Treatment	1	13.02	<0.05	0.09	0.77
Bacterial feeders	Block	3	1.27	0.42	1.33	0.30
Predators	Treatment	1	1.93	0.26	4.10	0.10
Predators	Block	3	3.82	0.15	3.89	0.11
Omnivores	Treatment	1	1.97	0.25	0.29	0.61
Omnivores	Block	3	0.87	0.55	0.03	0.88
Sedentary endoparasites	Treatment	-	-	-	4.79	0.08
Sedentary endoparasites	Block	-	-	-	9.81	<0.05
Migratory endoparasites	Treatment	1	0.02	0.89	0.15	0.72
Migratory endoparasites	Block	3	1.35	0.40	0.00	0.97
Ectoparasites	Treatment	1	0.30	0.62	2.39	0.18
Ectoparasites	Block	3	0.38	0.78	19.93	<0.01
Roothair feeders	Treatment	1	0.01	0.93	0.43	0.54
Roothair feeders	Block	3	0.19	0.90	27.15	<0.01
CP1-nematodes	Treatment	1	2.62	0.20	0.72	0.43
CP1-nematodes	Block	3	1.47	0.38	0.70	0.44
CP2-nematodes	Treatment	1	5.11	0.11	2.88	0.15
CP2-nematodes	Block	3	0.21	0.89	0.99	0.37
CP3-nematodes	Treatment	1	1.59	0.30	0.37	0.57
CP3-nematodes	Block	3	1.14	0.46	0.07	0.80
CP4-nematodes	Treatment	1	0.61	0.49	0.98	0.37
CP4-nematodes	Block	3	0.31	0.82	0.08	0.79
CP5-nematodes	Treatment	1	0.00	0.97	0.31	0.60
CP5-nematodes	Block	3	1.15	0.45	0.02	0.91
PP2-nematodes	Treatment	1	0.01	0.93	0.95	0.37
PP2-nematodes	Block	3	0.19	0.90	17.05	<0.01
PP3-nematodes	Treatment	1	0.54	0.52	8.30	0.03
PP3-nematodes	Block	3	0.24	0.86	14.69	0.01
PP4-nematodes	Treatment	1	0.00	0.98	1.19	0.32
PP4-nematodes	Block	3	0.71	0.61	2.14	0.20
Taxa	Treatment	1	0.82	0.43	0.42	0.55
Taxa	Block	3	0.55	0.68	0.33	0.59
Maturity Index	Treatment	1	0.00	0.98	0.74	0.43
Maturity Index	Block	3	0.35	0.80	0.82	0.41

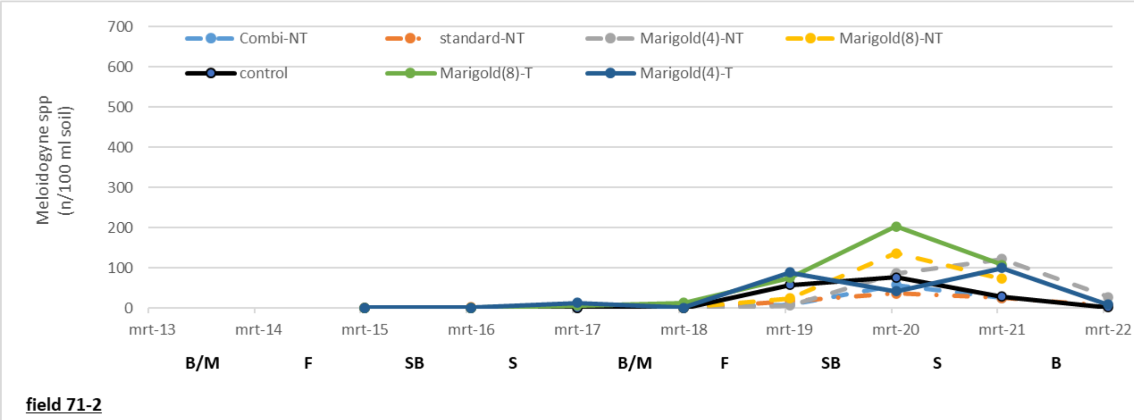
Maturity Index 2-5	Treatment	1	0.01	0.93	2.57	0.17
Maturity Index 2-5	Block	3	0.53	0.69	0.12	0.74
Plant Parasite Index	Treatment	1	0.01	0.93	5.97	0.06
Plant Parasite Index	Block	3	0.14	0.93	35.67	<0.01
Channel Index	Treatment	1	0.05	0.84	0.03	0.86
Channel Index	Block	3	1.46	0.38	1.26	0.31
Basal Index	Treatment	1	0.01	0.94	2.15	0.20
Basal Index	Block	3	1.11	0.47	0.52	0.50
Enrichment Index	Treatment	1	0.20	0.69	1.92	0.22
Enrichment Index	Block	3	0.95	0.52	0.54	0.50
Structure Index	Treatment	1	0.01	0.91	2.51	0.17
Structure Index	Block	3	0.64	0.64	0.12	0.75
Biomass	Treatment	1	7.05	0.08	0.05	0.84
Biomass	Block	3	3.16	0.18	0.57	0.48

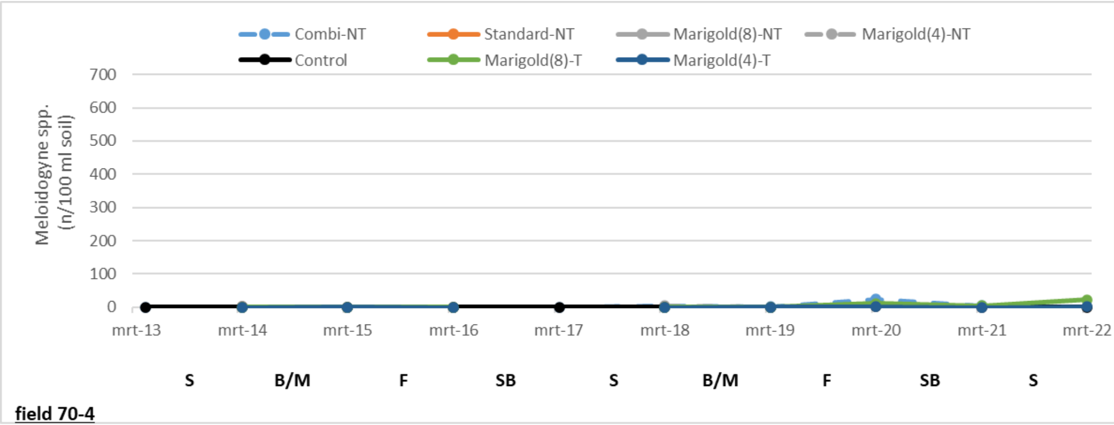
Table 65 Results of the measurements of the nematode community in 2013 in samples of fields 70-3, 70-4 and 71-1. The nematode numbers and biomass are expressed per 100 g of fresh soil. The indices and diversity (number of taxa) are numbers (n=1).

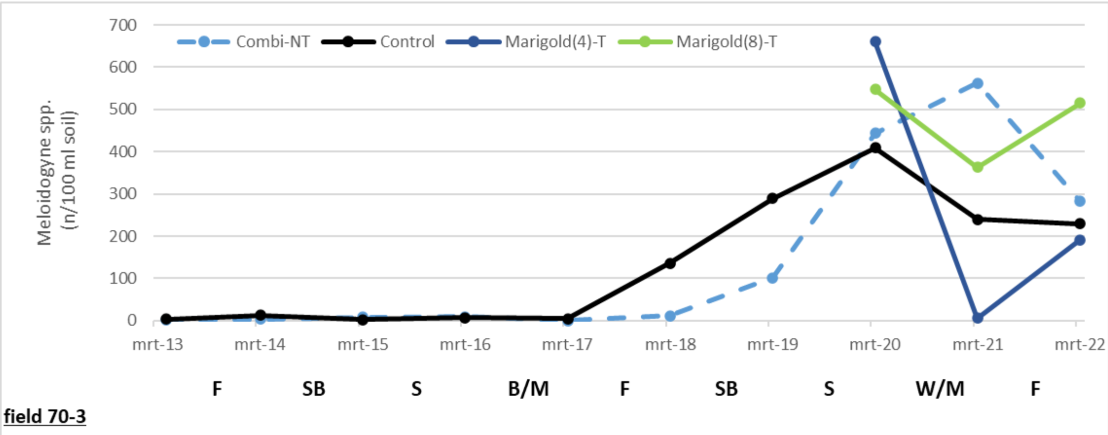
	Field		
Variable	70-3	70-4	71-1
Dauer larvae	266	402	270
Total number	3623	2386	2232
Plant feeders	1369	1016	1016
Fungal feeders	80	50	33
Bacterial feeders	1956	1133	1067
Predators	159	17	18
Omnivores[#]	54	169	100
Sedentary endoparasites	27	0	0
Migratory endoparasites	242	389	250
Semi-endoparasites	0	51	0
Ectoparasites	778	339	633
Roothair feeders	322	237	133
CP1-nematodes	651	203	283
CP2-nematodes	1248	794	715
CP3-nematodes	0	51	0
CP4-nematodes	327	152	134
CP5-nematodes	27	168	84
PP2-nematodes	322	237	133
PP3-nematodes	1020	694	849
PP4-nematodes	27	85	34
PP5-nematodes	0	0	0
Maturity Index	2.04	2.48	2.19
Maturity Index 2-5	2.46	2.74	2.56
Plant Parasite Index	2.78	2.85	2.9
Channel Index	3.1	5.9	2.8
Basal Index	23.1	23.1	24.3
Enrichment Index	68.3	52.1	61.9
Structure Index	54.1	69.1	59.7
Biomass (mg)	5.15	2.8	2.76
Number of taxa	25	24	33

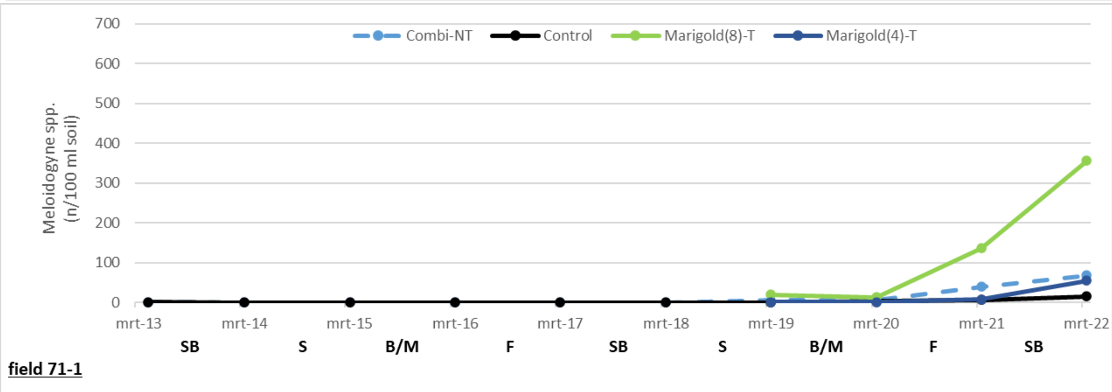
[#] Mainly Neodiplogastridae with a CP-value of 1. They are currently categorized in Ninja as bacterial feeders.

Appendix 14 Plant parasitic nematodes; Meloidogynea and Trichodoridae

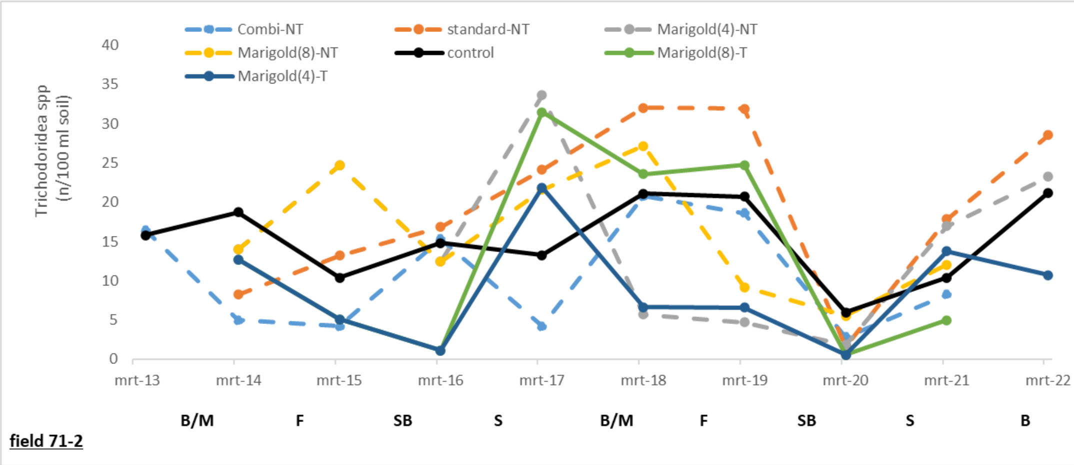


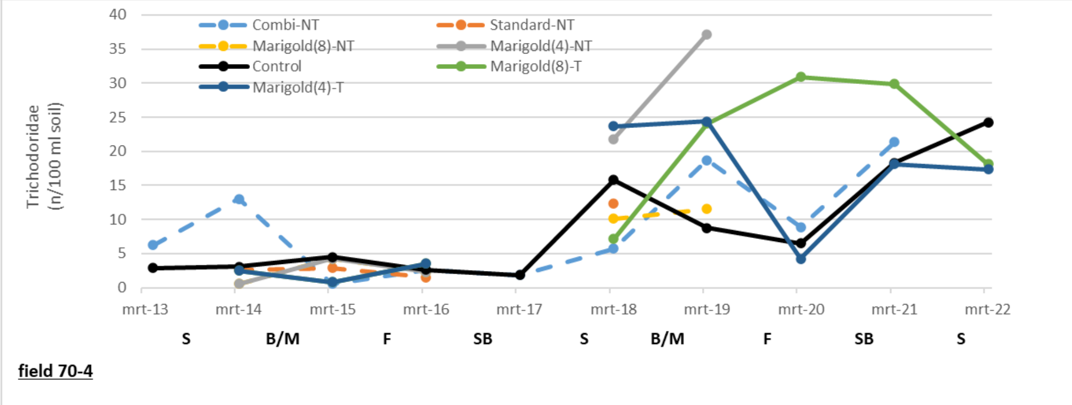


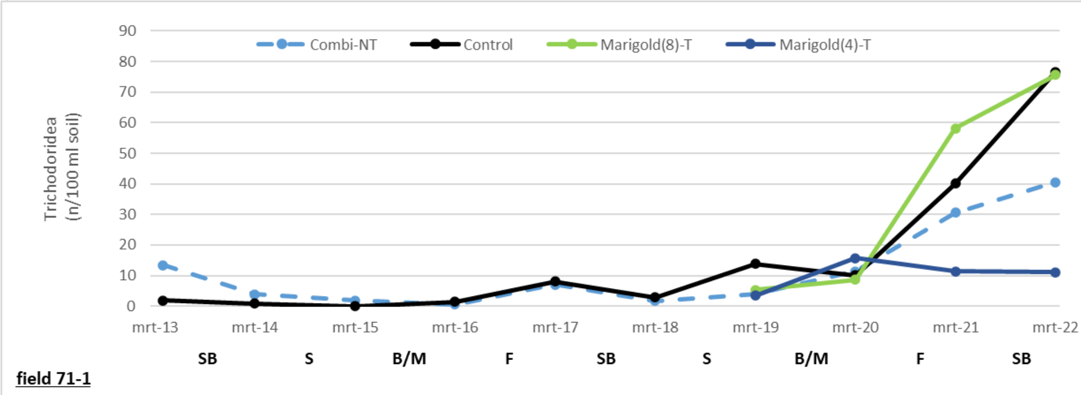


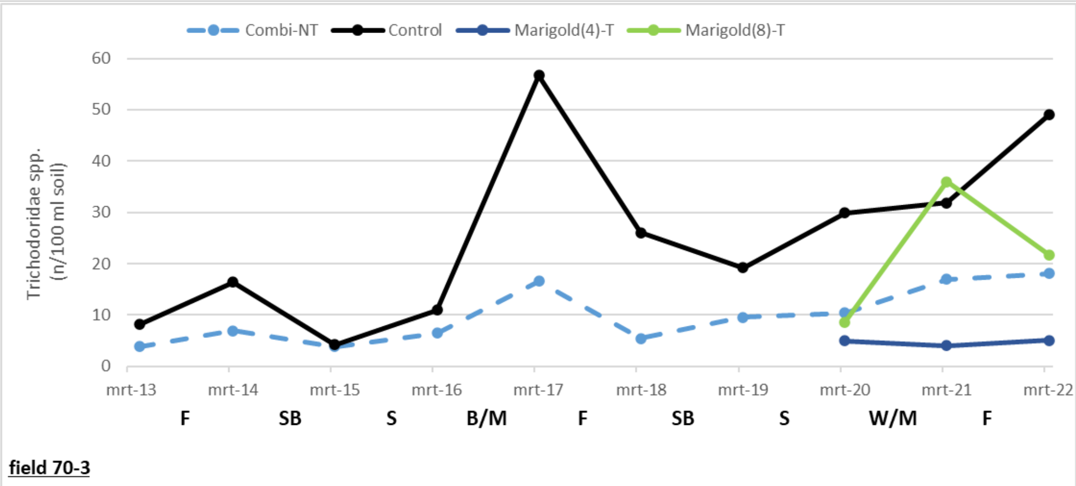


Development of the population of root knot nematodes (Meloigogyne spp)



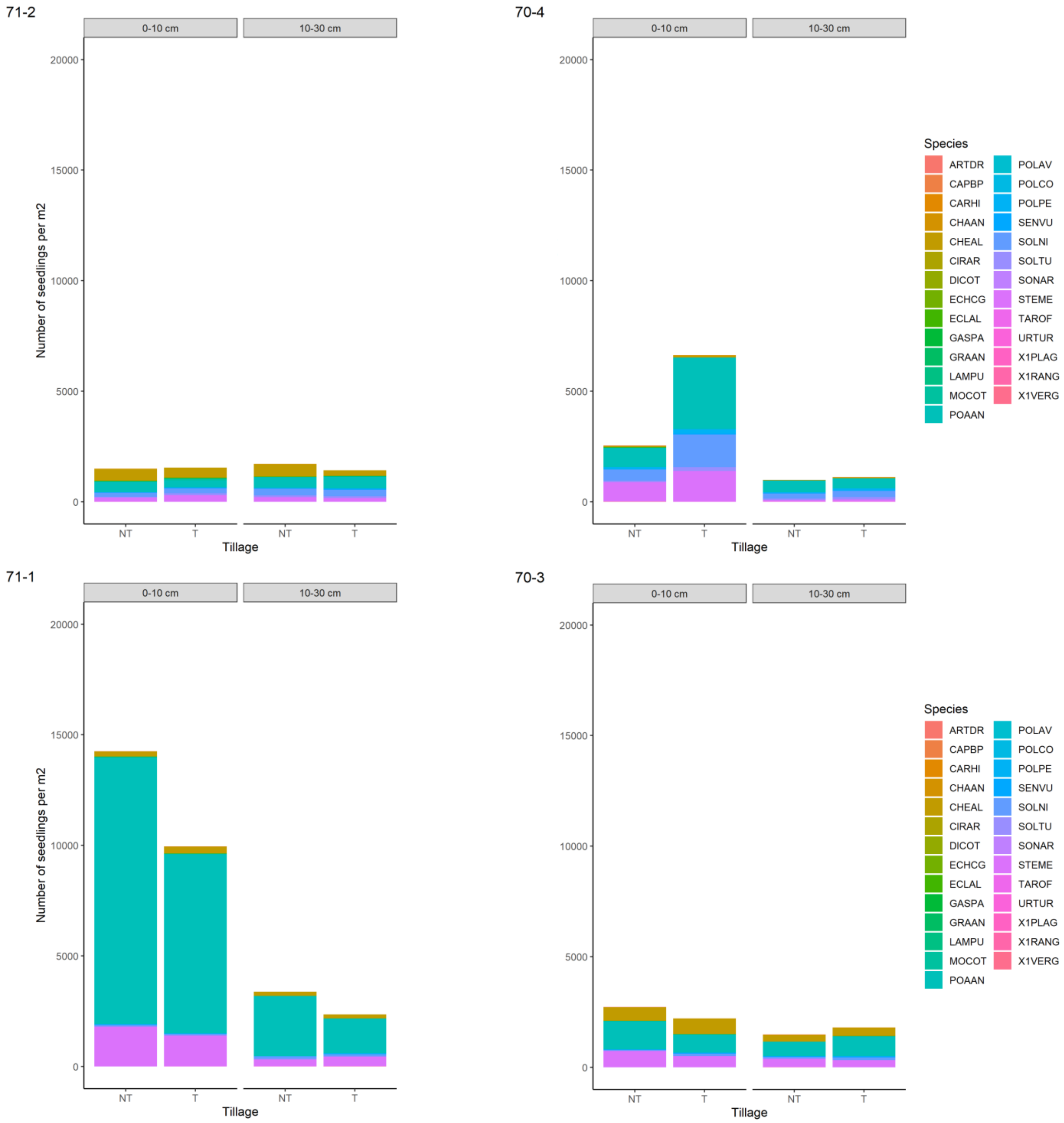






Development of the population of Trichodoridae spp.

Appendix 15 Soil weed bank



Effect of tillage type on the average number of weed seedlings per m^2 for different soil layers. The number of seedlings is presented for each of the four fields separately.

EPPO coding and corresponding scientific and English naming of weed species observed during seed bank germination.

EPPO	SCIENTIFIC NAME	ENGLISH
ARTDR	Artemisia dracunculus	Estragon
CAPBP	Capsella bursa-pastoris	Shepherd's purse
CARHI	Cardamine hirsute	Bristly bittercress
CHAAN	Chamerion angustifolium	Rosebay
CHEAL	Chenopodium album	Goosefoot
CIRAR	Cirsium arvense	Californian thistle
DICOT	Dicots	Dicots
ECHCG	Echinochloa crus-galli	Barnyard grass
ECLAL	Eclipta prostrata	White eclipta
GASPA	Galinsoga parviflora	Kew weed
LAMPU	Lamium purpureum	Purple archangel
MOCOT	Monocots	Monocots
POAAN	Poa annua	Pathgrass
POLAV	Polygonum aviculare	Common knotgrass
POLCO	Fallopia convolvulus	Bearbind
POLPE	Persicaria maculosa	Red-leg
SENVU	Senecio vulgaris	Birdseed
SONAR	Sonchus arvensis	Corn sowthistle
STEME	Stellaria media	Chickweed
TAROF	Taraxacum officinale	Blowball
URTUG	Urtica urens	Burning nettle
X1PLAG	Plantago	Plantago
X1RANG	Ranunculus	Ranunculus
X1VERG	Veronica	Veronica

Appendix 16 Visual effects of NT

Rotary spading (T) on the left and NT on the right. Picture taken in the sugar beet field in 2017.

Rotary spading (T) on the left and NT on the right. Picture taken in the Festien in 2018.

NT on the left and rotary spading (T) on the right. Picture taken in Seresta in 2018.

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