Effects of non-inversion tillage on ecosystem services on a sandy soil

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Wageningen University & Research

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Soil quality and thus sustainable soil management has become increasingly important in modern agricultural systems. Since 2011 the experiment Soil quality on sandy soil (Bodemkwaliteit op Zand) combines non-inversion tillage with conventional ploughing to research the effects on ecosystem services. The effect of non-inversion tillage on the crop yields and quality and soil quality are small. Weed densities increase under non-inversion tillage, while nitrogen losses decrease. Overall, non-inversion tillage is well applicable in an arable system on a sandy soil, when weeds can be controlled.

Keywords: arable farming, non-inversion tillage, sandy soil, crop yield, soil quality, nitrogen losses.

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Preface

Soil management in agriculture has been a topic of interest and research for a very long time. Already in 1989, the experiment Soil quality on sandy soil ("Bodemkwaliteit op Zand") was established in Vredepeel to measure effects of soil management practices on ecosystem services. In 2011 the comparison of two forms of tillage was added to this experiment: ploughing versus non-inversion tillage. This comparison was carried out for more than 10 years and results are described in the report.

The experiment and its outcomes were used for many purposes by all kinds of people. The experiment was visited by farmers, advisors, students and researchers and several discussions with the involved researchers about the results took place. Researchers from all over the country and across Europe took samples from our experiment for their own research.

We could never have written this report without Marc Kroonen, farm manager of the experimental farm in Vredepeel, and his hard-working staff. They made sure that the experiment was carried out and all the data could be gathered. Next to that we want to thank the *Begeleidingscommissie*, the committee of farmers and sector representatives. They came to visit the experiment several times and discussed outcomes and possible changes of the experiment with us. This experiment would not have been possible without financing, so therefor we want to thank all the partners of the PPS Beter Bodembeheer and the previous programs.

As it looks right now, the experiment appears to be coming to an end. Over the years we have learned a lot from this experiment, but on the other hand we have the feeling that we are not done yet. Considering the challenges that farmers are facing, environmental goals that have to be met in the near future, we feel that this experiment could play a part in that, but until now we have found no funding to continue the experiment.

On behalf of the authors,
Marie Wesselink
September 2023

Summary

Soil quality and thus sustainable soil management has become increasingly important in modern agricultural systems. Non-inversion tillage is often mentioned as a sustainable soil measure. By enhancing soil structure, non-inversion tillage has the potential to mitigate the negative impacts of agriculture on the environment. However, non-inversion tillage also imposes some challenges. Controlling weed populations is one of the largest constraints for farmers to implement non-inversion tillage systems. Numerous studies have examined the impact of non-inversion tillage practices on factors such as crop yield, crop quality, and organic matter content, with varying results. Nevertheless, it remains challenging to determine the effects of changing management practices on soil quality and ecosystem services like production, recycling of nutrients and water purification. Long-term experiments are an instrument to research these effects.

In 2011, a tillage comparison was setup in the experiment Soil Quality on sandy soil in Vredepeel, non-inversion tillage versus ploughing. This was done in the three farming systems of the experiment, two conventional systems and an organic system. The experiment has a six-year crop rotation with a combination of arable crops, field vegetables and fodder crops.

This report describes the results of this tillage comparison of the experiment over the period 2011-2021 to answer the research question: What is the effect of non-inversion tillage on crop yield and quality, soil quality, weed seedbank and nitrogen losses?

Every year, the crop yield and quality of every crop was measured. Chemical soil quality samples were analysed yearly, while physical and biological soil quality were only incidentally assessed. With information on fertilisation and yields and measurements on mineral nitrogen soil stocks and nitrate concentrations in groundwater, the nitrogen dynamics of the two tillage systems were analysed. The weed seedbank was determined 11 years after the implementation of the non-inversion tillage versus ploughing.

Over the complete crop rotation there is no difference in crop yield between ploughing and non-inversion tillage. For the individual crops there were minor differences, for example potato and spring barley showed a somewhat higher yield under non-inversion tillage, while carrots showed a little lower yield. None of the differences were significant. Crop quality was not influenced by the tillage treatments, only the carrots had a higher tare percentage.

No clear improvement or decline in soil quality appeared due to the tillage strategies. The organic matter content in the soil was less variable under non-inversion tillage compared to ploughing, and the nitrogen content in the soil was higher under non-inversion tillage. Other chemical soil parameters showed no consistent effect of tillage. There was no clear effect of tillage on soil physical parameters, but only very few measurements were done. Soil biological parameters were influenced by factors such as fertilisation and the preceding crop, but not so much by tillage.

Weed abundance was clearly influenced by the tillage treatments. Non-inversion tillage led to higher weed densities compared to ploughing, especially in the top ten centimetres of the soil. Weed densities were about twice as high in the top layer under non-inversion tillage than in ploughing.

The nitrogen balance (input – output) is approximately the same for non-inversion tillage and ploughing. Despite this, both the mineral nitrogen content in the soil and the nitrate concentration in the groundwaterare lower in the non-inversion tillage system. The hypothesis is that non-inversion tillage effects the mineralisation of the soil; when less oxygen is available more denitrification will occur, meaning that nitrogen is lost to the air instead of being mineralized.

Overall, it can be said that non-inversion tillage is a viable alternative for ploughing on the sandy soils in the southeast of the Netherlands. Many of the investigated parameters show only minor or no differences, while

there is a positive effect on nitrogen losses. A negative effect on weed abundance is however present. Yet, when sufficient (chemical) treatment opportunities are available, this is not a large problem.

Samenvatting

Bodemkwaliteit en daarmee duurzaam bodembeheer zijn steeds belangrijker geworden in moderne landbouwsystemen. Niet-kerende grondbewerking wordt vaak genoemd als een duurzame bodemmaatregel. Door de bodemstructuur te verbeteren, heeft niet-kerende grondbewerking potentie om de negatieve impact van landbouw op het milieu te verminderen. Toch brengt niet-kerende grondbewerking ook enkele uitdagingen met zich mee. Het beheersen van onkruidpopulaties is een van de grootste belemmeringen voor boeren om niet-kerende grondbewerkingssystemen toe te passen. Vele studies hebben het effect van niet-kerende grondbewerking op factoren zoals gewasopbrengst, gewaskwaliteit en organische stofgehalte onderzocht, met wisselende resultaten. Desondanks blijft het moeilijk om de effecten van teeltmaatregelen op bodemkwaliteit en ecosysteemdiensten zoals productie, recycling van voedingsstoffen en waterzuivering voor de Nederlandse situatie op het zuidoostelijk zand, vast te stellen. Langetermijnexperimenten zijn een instrument om deze effecten te onderzoeken.

In 2011 werd in het experiment Bodemkwaliteit op zandgrond in Vredepeel een vergelijking van grondbewerkingssystemen aangelegd, waarbij niet-kerende grondbewerking werd vergeleken met ploegen. Dit werd gedaan in de drie landbouwsystemen van het experiment, twee gangbare systemen en een biologisch systeem. Het experiment heeft een zesjarige gewasrotatie met een combinatie van akkerbouwgewassen, vollegrondsgroente en voedergewassen.

Dit rapport beschrijft de resultaten van deze vergelijking van grondbewerking in het experiment over de periode 2011-2021 om de onderzoeksvraag te beantwoorden: Wat is het effect van niet-kerende grondbewerking op gewasopbrengst en -kwaliteit, bodemkwaliteit, onkruidzaadbank en stikstofverliezen?

Elk jaar werd de gewasopbrengst en -kwaliteit van elk gewas gemeten. Chemische bodemmonsters werden jaarlijks geanalyseerd, terwijl fysieke en biologische bodemkwaliteit slechts incidenteel werden beoordeeld. Met informatie over bemesting en opbrengsten en metingen van minerale stikstofvoorraden in de bodem en nitraatconcentraties in het grondwater werden de stikstofdynamiek van de twee grondbewerkingssystemen geanalyseerd. De onkruidzaadbank werd 11 jaar na de invoering van niet-kerende grondbewerking versus ploegen bepaald.

Gedurende de gehele gewasrotatie was er geen verschil in gewasopbrengst tussen ploegen en niet-kerende grondbewerking. Voor de afzonderlijke gewassen waren er kleine verschillen, bijvoorbeeld aardappelen en zomergerst vertoonden een iets hogere opbrengst onder niet-kerende grondbewerking, terwijl wortels een iets lagere opbrengst vertoonden. Geen van de verschillen was significant. Gewaskwaliteit werd niet beïnvloed door de grondbewerkingstechnieken, alleen de wortels hadden een hoger tarrapercentage.

Er bleek geen duidelijke verbetering of verslechtering van de bodemkwaliteit te zijn als gevolg van de grondbewerkingstechnieken. Het organische stofgehalte in de bodem was minder variabel onder niet-kerende grondbewerking in vergelijking met ploegen, en het stikstofgehalte in de bodem was hoger onder niet-kerende grondbewerking. Andere chemische bodemparameters vertoonden geen consistente invloed van grondbewerking. Er was geen duidelijk effect van grondbewerking op fysieke bodemparameters, maar er werden slechts zeer weinig metingen gedaan. Bodembiologische parameters werden beïnvloed door factoren zoals bemesting en het voorgaande gewas, maar niet zozeer door grondbewerking.

De hoeveelheid onkruid werd duidelijk beïnvloed door de grondbewerkingstechnieken. Niet-kerende grondbewerking leidde tot hogere onkruiddichtheden vergeleken met ploegen, vooral in de bovenste tien centimeter van de bodem. De onkruiddichtheden waren ongeveer twee keer zo hoog in de bovenste laag onder niet-kerende grondbewerking dan bij ploegen.

De stikstofbalans (input - output) is ongeveer hetzelfde voor niet-kerende grondbewerking en ploegen. Desondankws zijn zowel het minerale stikstofgehalte in de bodem als de nitraatconcentratie in het

grondwater lager in het niet-kerende grondbewerkingssysteem. De hypothese is dat niet-kerende grondbewerking de mineralisatie van de bodem beïnvloedt; wanneer er minder zuurstof beschikbaar is, zal er meer denitrificatie optreden, wat betekent dat stikstof verloren gaat in de lucht in plaats van gemineraliseerd te worden.

Over het algemeen kan worden gezegd dat niet-kerende grondbewerking een uitvoerbaar alternatief is voor ploegen op de zandgronden in het zuidoosten van Nederland. Veel van de onderzochte parameters vertonen slechts kleine of geen verschillen, terwijl er een positief effect is op stikstofverliezen. Een negatief effect op de onkruiddruk is echter aanwezig. Dit hoeft geen onoverkomelijk probleem te zijn wanneer er voldoende aandacht voor is en er bestrijdingsmogelijkheden zijn.

1 Introduction

1.1 Soil quality and tillage

Soil quality and thus sustainable soil management has become increasingly important in modern agricultural systems. Especially with the effects of climate change becoming increasingly evident, the resilience of both soils and crops to extreme weather events is crucial. Therefore, the Dutch ministry of Agriculture, Nature and Food Quality has expressed the goal that all Dutch agricultural soils should be managed sustainably by 2030 (LNV, 2018). Sustainable soil management is seen as an important asset in combatting soil threats like erosion, soil compaction and a decrease in the organic matter content of soils.

Non-inversion tillage is often mentioned as a sustainable soil measure (Cooper et al., 2016). By enhancing soil structure, non-inversion tillage has the potential to mitigate the negative impacts of agriculture on the environment. Conventional tillage practices can break down soil aggregates, leaving organic matter unprotected and resulting in a faster degradation of the particles. In contrast, non-inversion tillage may preserve the soil aggregate structure, resulting in carbon sequestration in soil organic matter. Moreover, maintaining soil aggregates can prevent soil compaction by creating micropores between the aggregates. Morris et al. (2009) suggests that less disturbed soils usually have a higher soil strength and are therefore less likely to be compacted. Additionally, non-inversion tillage could potentially reduce labour and energy costs by reducing the time required for soil management.

However, non-inversion tillage also imposes some challenges. Controlling weed populations is one of the largest constraints for farmers to implement non-inversion tillage systems. Reduced tillage frequency can result in fewer uprooted weeds, increasing the dependency on chemical or mechanical weed control (Melander et al., 2013). Furthermore, non-inversion tillage may elevate pest and disease pressure within arable fields. When crop residues are not incorporated in the soil, they can provide a habitat for pests and pathogens, allowing them to persist until the next host plant cycle. Additionally, farmers are hesitant to implement non-inversion tillage systems as it results in a slower soil warm-up, potentially limiting the spring planting window.

Numerous studies have examined the impact of non-inversion tillage practices on factors such as crop yield, crop quality, and organic matter content, with varying results (Cooper et al., 2016; Arvidsson, Etana, Rydberg, 2014; Peralta, Alvarez, Taboada, 2021). Similarly, the relation between non-inversion tillage and nitrate leaching has been studied. For instance, Hansen en Djurhuus (1997) observed that the amount of nitrate leached out of sandy soils amongst others depends on soil cultivation practices. This is especially relevant for the Netherlands, where less than 10% of water bodies meet chemical quality standards (*Waterkwaliteit KRW, 2022 | Compendium voor de leefomgeving*, n.d.).

Nevertheless, it remains challenging to determine the effects of changing management practices on soil quality and ecosystem services like production, recycling of nutrients and water purification. Not in the least because changes in soil quality take time, so a long-term comparison is needed to test the effects. Besides, the effects of soil management practices vary largely per soil type. While sandy soils are usually less vulnerable to compaction, clay soils tend to be compressed when managed under wet circumstances. Sandy soils, however, are usually more vulnerable to nutrient leaching. This complexity results in knowledge gaps in the optimal soil management practice for various farming types. These knowledge gaps need to be filled to allow farmers to optimize their soil management, while minimizing their impact on the environment. This report contributes to the understanding of non-inversion tillage by presenting the results of a long-term experiment on a Dutch sandy soil.

1.2 Southeastern sandy soil area

The southeastern sandy soil area covers large parts of the Dutch provinces of Noord-Brabant and Limburg. For the Netherlands it is a relatively high area which is predominantly flat. Surface water is present in smaller rivers. As the name insinuates the main soil texture class is sand. Intensive agriculture in the area started after the second world war, with the introduction of chemical fertilisers.

In total 232.000 ha in the area is used for agriculture. Table 1 gives an overview of the types of crops grown. This shows that the majority of the crops grown are animal feed.

Table 1. *Overview of crops grown in the southeastern sandy soil area. (CBS 2019-2021)*

Crop	Hectares	% of total*
Grass	93.000	40%
Silage maize	45.000	19%
Cereals	21.500	9%
Potato	19.000	8%
Vegetables	21.500	10%
Sugar beet	9.000	4%

The current land use in the southern sandy area consists of 40% grass, 25% fodder crops, mainly corn silage, 25% arable farming, and 10% horticulture, predominantly open-field vegetables. The arable farming area is divided into 30% potatoes, 30% grains, 15% sugar beets, 15% arable-style vegetables, and 10% other crops (statline.cbs.nl). This results in approximately 40% of crops that are susceptible to leaching.

The region hosts a significant intensive livestock sector, accounting for about 60% of Dutch pigs and 40% of Dutch chickens. Around 7.9 million tons of liquid cattle manure and 6.7 million tons of liquid pig manure are produced in the region, contributing to over 90% of the total manure production in the area. As a result, the manure production exceeds the available space for manure placement as dictated by the manure policy. In 2014, the region produced 49 million kg of phosphate (P2O5), while there is only space for the placement of 15 million kg of phosphate (statline.cbs.nl). The excess must be disposed of outside the region, incurring high costs ranging from 15 to 25 euros per ton depending on the type of manure (Koeijer, de et al., 2016). The share of organic agriculture in the southern sandy area is small. Only 1.6% of the acreage is managed organically, with a greater share in dairy farming than in arable and horticultural activities (statline.cbs.nl).

1.3 Farming Systems Research at the Vredepeel Experimental Site

In 2011, the project "Bodemkwaliteit op zand” (”Soil Quality on Sandy Soils", from now on referred to as BKZ) was initiated at the WUR (Wageningen University & Research) Vredepeel location, situated in the southern sandy area. The project constitutes a farming systems research (Vereijken, 1999; Haan, de & Garcia Diaz, 2002). The aim of farming systems research is to design, test, and improve a system with a combination of strategies and measures on a semi-practical scale, to meet desired objectives. These objectives encompass societal aspects, such as emissions reduction, as well as economic goals with the aim of achieving economically sustainable operations. The approach is dynamic, with strategies and measures being evaluated and adjusted annually as needed.

Farming systems research at Vredepeel started in 1989. The "Bodemkwaliteit op zand" project has been ongoing since 2011 and represents a continuation, in modified form, of previous projects conducted on the same experimental fields of the Vredepeel research farm. These earlier projects include “Effect van organische stofbeheer op opbrengst, bodemkwaliteit en stikstofverliezen op een zuidelijke zandgrond”, "Nutriënten Waterproof" (NWP) from 2005 to 2008 (Haan, de et al., 2010) and "Telen met Toekomst" (TmT) from 2001 to 2003 (Smit et al., 2005). Prior to this, between 1989 and 2000, farming systems research primarily centered around integrated crop protection in arable farming (Wijnands & Kroonen, 2002a; Wijnands & Kroonen, 2002b), with a lesser emphasis on nitrogen leaching and improving nutrient efficiency. Results of the two conventional systems with a different organic matter strategy have been described in de Haan et al., 2018a. The results of the organic system over the period 2000-2016 have been described in de Haan et al., 2018b.

1.4 Aim and research questions

The objective of the "Bodemkwaliteit op zand" project is to develop practical and applicable strategies and measures that contribute to sustainable soil management on sandy soil, while also providing sufficient economic viability to arable farming and open-field vegetable cultivation in the southern sandy area.
The development of measures is intended for both organic and conventional farms and focuses on organic matter management and soil cultivation.

This report will specifically study the effects of non-inversion tillage, and will compare this to conventional ploughing. The comparison will be made for both the conventional and organic farms. Because of differences in soil quality and groundwater levels, it is not possible to compare the organic and conventional system with one another.

The main research question during this report will be:

What is the effect of non-inversion tillage, compared to conventional ploughing, in an arable system on a sandy soil in the Netherlands?

To make a viable comparison between the cultivation systems, the research question is subdivided into four sub questions, which are:

1. *What is the effect of non-inversion tillage on crop yield and quality?*
2. *What is the effect of non-inversion tillage on soil quality?*
3. *What is the effect of non-inversion tillage on the weed seed bank?*
4. *What is the effect of non-inversion tillage on nitrogen losses?*

Each of these sub questions will be answered separately in the different chapters.

2 Material and methods

2.1 Field experiment set-up

2.1.1 Location Vredepeel

The experimental farm of Vredepeel is situated on reclaimed peat soils of the Peel, located in the southeast of the Netherlands, about 8 kilometers west of Venray. This area experiences the most significant levels of nitrate leaching in the Netherlands. The soil is classified as "veldpodzol", with a cultivated layer of 30-40 cm, an irregular transition layer below of 10-15 cm and underneath the original cover sand (de Vos, et al., 2001). The soils on the farm are characterized as sensitive to leaching (average highest groundwater level ≥ 70 cm and average lowest groundwater level ≥ 120 cm) in the fertilizer legislation and are representative for sandy soils in the East of Brabant and the north of Limburg. The texture of the topsoil is moderately fine sand for 93%, loam for 4.5% and clay for 2.2%. The organic matter content of the soil varies between 3-4% roughly. Underneath the 'construction furrow' the texture of the soil is dominated by moderately fine sand. The sand layer is 2-12 m thick and contains lenses of loam and peat. The layer underneath exists of coarse sand, gravel, and lenses of clay and loam (Table 2 and Groenendijk et al., 2017). The plots of the different systems in this research contain no lenses of clay or loam in the 2 meters below the surface level. The subsoil is compacted according to Van den Akker en De Groot (2008) with bulk densities about 1700 kg m^{-3}. The plots on the farm are drained well, drains are on a distance of 6 meters from each other and at a depth of 60-80 cm. According to De Vos et al. (2006) about 60% of the water is discharged by drains. The 'Peelkanaal' west of the Vredepeel farm influences the drainage and groundwater levels of the farm, especially the plots bordering the channel. Groundwater level in winter is on average between 80 and 120 cm.

Table 2. *Description of soil profile in the surroundings of Vredepeel (van Beek et al., 2005 based on Rijks Geologische Dienst 1975). The peat layer at a depth of 2,7 m below the soil surface has a bad hydraulic conductivity and therefore constitutes a physical barrier for vertical water flow. It has an estimated resistance of 100 days.*

Layer (m below soil surface)	Description
0 – 0,6 m	Sand, moderately fine, humus, fawn, some embedded recent root residues
0.6 – 1.5 m	Sand, fine, pale yellow
1.5 -2.0 m	Sand, fine, light gray
2.0 – 2.7 m	Sand, moderately fine, lightly loamy, lightly humus, brown
2.7 – 3.2 m	Peat
3.2 – 5.5 m	Sand, moderately fine, humus, dark brown
5.5 – 7.8 m	Sand, very coarse, browngray, with few predominantly white quartz sand
7.8 m	Soil, fine and coarse

2.1.2 Farming systems

The research in BKZ encompasses two conventional farming systems and one organic system. Figure 1 shows where the systems are situated. The organic system contains arable, vegetable and fodder crops. It is SKAL-certified since 2003. SKAL is the Dutch agency that monitors and supervises organic agriculture in the Netherlands. In the organic system, no plant protection agents or artificial fertilizers are used. Because of requirements of the SKAL-certification, the system is situated as one block on the current location.

The conventional farming systems are called 'standard' and 'low'. Both systems have the same crop rotation. The organic matter supply in the standard system is intended to follow common practice in the area. Crops are fertilized with cow slurry and chemical fertilizer within the prevailing nitrate and phosphate standards. In the low system, a low input of organic matter is pursued by supplying (almost) no organic matter by means of animal manure. The only fertilizers used are chemical fertilizers, mineral concentrate of pig manure and precipitation of air washing systems in stables and all are used within the prevailing nitrate and phosphate standards. The concentrate of pig manure is the only fertilizer which still contains some organic matter. An equal supply of nutrients is pursued for both systems. Both systems have supply from organic matter coming from crop residues and cover crops.

All three systems encompass six fields, because of a six-year crop rotation. The organic system lies together as one block. The conventional farming systems alternate each other (which means the fields lie in an order of standard, low, standard etc.). Half of each of the parcels is ploughed and since 2011 the other half is cultivated with non-inversion tillage machinery.

On two fields of every system (34.1 & 34.2 for organic, 18.1 & 27.1 for standard and 18.2 & 27.2 for low) 4 plots are present where additional organic matter in the form of compost is applied. The amount was on average 15 tons/ha/year, which corresponds to approximately 3000 EOM/ha/year. Figure 2 and Figure 3 show the situation of the individual parcels and the compostplots. The fields where the compost plots are situated are also called the measurement fields. All irregular measurements are tried to be executed at least on these fields. From now on, field 18, 27 and 34.1 will be referred to as measurement fields.

There are no repetitions of the systems, and the individual fields are not randomized. Therefore it is not possible to do a statistical analysis of the obtained data within one year. The years can be seen as repetitions. For further details see paragraph 2.3.

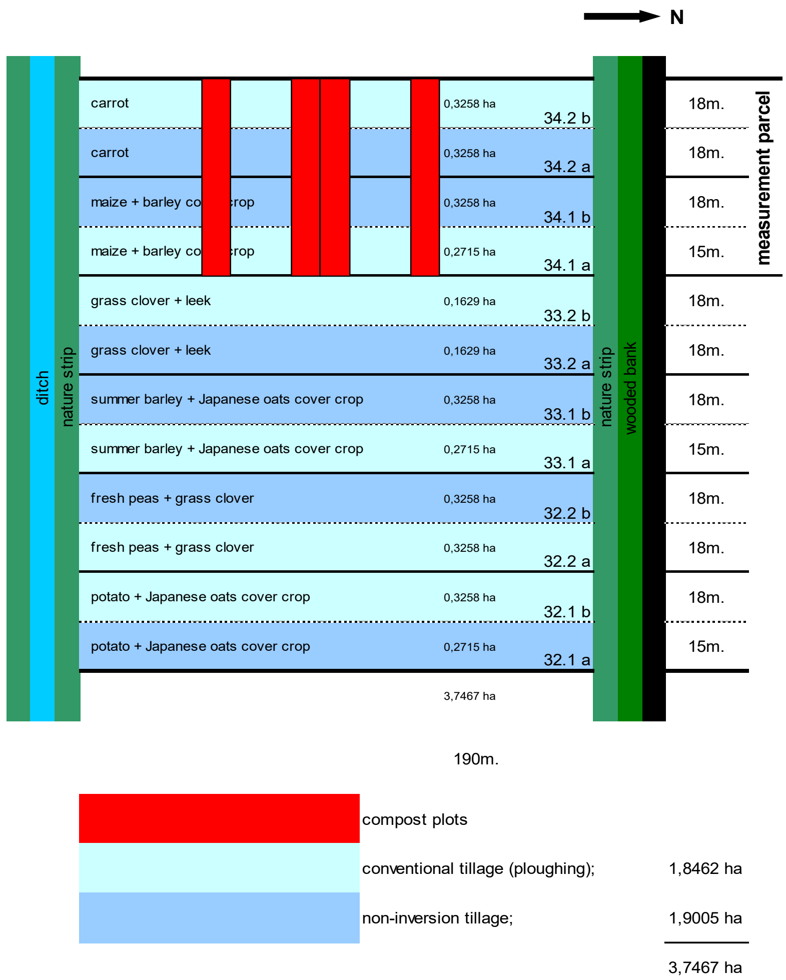

Figure 1. *Organic farming system; names of the plots, location of compost plots, tillage.*

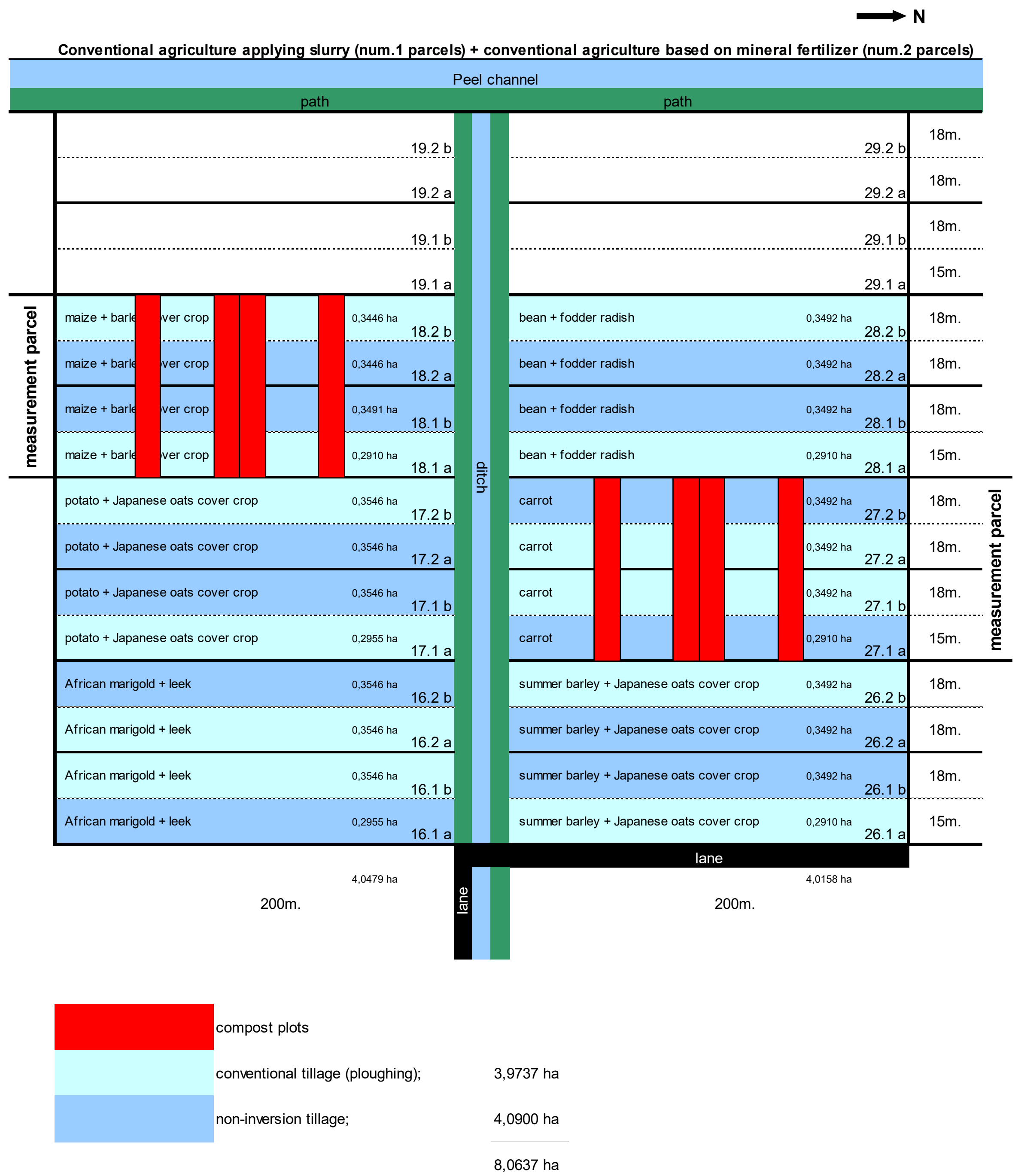

Figure 2. *Location of conventional farming systems (low and standard); with names of the plots, location of compost plots, tillage treatment and rotation of 2021.*

2.1.3 Crop rotation

All three systems have a similar crop rotation:

1. Potato – 2. Peas – 3. Leek (autumn) – 4. Spring barley – 5. Carrot* – 6. Silage maize

* up to and including 2015 sugar beets, instead of carrots, were grown in the two conventional systems.

In 2016, it was decided to level out the difference between the organic system and the conventional farming systems in terms of crop rotation. Therefore, sugar beet has been replaced by carrot, and the potato varieties in both systems were equalized. Straw (byproduct of spring barley) and crop residues of leek have been removed. The other crop residues stayed on the field.

In 2021, no peas were grown in the conventional systems, because of the plant parasitic nematode situation. Green beans were grown instead.

To minimize the leaching of nitrogen and get nitrogen available after the winter season a catch crop is grown after potato, pea, barley and maize. No catch crops are grown after leek, sugar beet and carrot, because of the late harvesting date. The chosen catch crops are:

- Perennial ryegrass + white clover after peas (from 2011 - 2014 only English ryegrass (without clover) was grown in the conventional farming systems). In 2019 and 2020 Tagetes was grown instead of grass clover, because of the nematode situation.
- After the green beans in 2021 fodder radish was grown.
- Black oat was grown after spring barley, except for 2011 and 2012, then fodder radish was grown.
- Black oat was also grown after potato.
- Winter barley was grown after silage maize, except for 2019 and 2020, then perennial ryegrass was under sown in the conventional systems.

From 2015 onwards the cover crops were not fertilized nor harvested. Until 2014 the perennial ryegrass in the conventional system was fertilized and harvested. The fodder radish in 2011 and 2012 was also fertilized.

The mentioned deviations from the crop rotation and cover crop choice were always applied in the ploughed as well as the non-inversion tillage plots.

2.1.4 Field operations

Since 2011 two forms of tillage are compared in BKZ: ploughing versus non-inversion tillage.

Table 3 illustrates the primary tillage procedures per crop carried out during spring. First, the incorporation of the cover crop was necessary. In the case of leek cultivation, the ryegrass grown before leek required several tillage operations involving a power tiller, cultivator, and power harrow to ensure complete incorporation. The application of manure was performed through the utilization of an arable slurry injector known as Evers Garanno. Tillage was performed after application of slurry, except for the cases where slurry was injected in rows 75 cm apart, then tillage was performed before slurry application. When this would have been done the other way around it would not be possible to plant exactly near the fertilization rows, because it would have been moved by tillage.

Ploughing was executed utilizing a plough equipped with subsoilers and a furrow press (see Figure 4). In Non-Inversion tillage, the main tillage operation consisted of a combination of subsoiling and cultivation (see Figure 5). Ploughing and non-inversion tillage were always performed in the spring, approximately at the same time. Apart from the main tillage operation, field operations were similar for the ploughing and non-inversion treatment.

Certain crops such as corn and potatoes did not require additional seedbed preparation. However, for other crops, a power harrow or cultivator was used. Fresh peas and spring barley were directly seeded using a pneumatic double discs seeder during the preparation of the seedbed (Jolink, 2018).

Table 3 *Main field operations*

	Incorporating Cover crop	Manure application	Seedbed preparation	Seeder/planter
Potatoes	Disc cultivator	In row (Garanno)		Grimme VL20KL
Peas	Disc cultivator	Slurry injector	Power harrow + seeder	Amazone AD-P
Leek	Flail mower + power tiller and cultivator	Slurry injector	Power harrow	
Spring barley	Disc cultivator	Slurry injector	Power harrow + seeder	Amazone AD-P
Sugar beets	Cultivator	Slurry injctor		
Corn	Disc cultivator	In row (Garanno)		Double disc corn planter
Carrots	Cultivator	Slurry injector	Power harrow	

Figure 3. *Machine combination used for ploughing.*

Figure 4. *Machine combination used for non-inversion tillage.*

2.1.5 Fertilisation

Each of the two conventional systems and the organic system have its own fertilisation strategy. The conventional low system uses chemical fertiliser exclusively, the conventional standard system combines slurry and chemical fertiliser, and the organic system relies on manure and slurry for the fertilization. The quantities added remain consistent for both tillage treatments within each system. A more detailed description of the fertilisation strategies is presented in Annex 2.

2.2 Measurements and analyses

Although the different tillage treatments started in 2011, some of the measurements of the non-inversion tillage plots only started later in the experiment. This delay was deliberately included, as it accounted for the fact that the effects of the new tillage method would not be immediately observable; rather, the soil needed time to adapt to the new tillage approach. For the individual measurements described below it will be mentioned when measurements started in the non-inversion tillage plots.

2.2.1 Yield

Since 2011, an annual assessment of all crop yields has been made in both tillage systems on gross fresh weight and marketable weight. To assess the marketable weight, a correction is added to some of the crops to incorporate losses during the harvest and storage. Those corrections are necessary to enable a comparison between the experiment's yields and those of actual farmers.

The marketable yield is the gross harvest corrected for the harvest and storage losses minus tarra. Spring barley has been recalculated to 15% moisture content; peas are corrected for a TM-number of 120. The yield of sugar beet is expressed in kg sugar per ha, and the yield of silage maize is expressed in kg dry matter per ha.

Variation in the field is addressed for by harvesting four plots per crop of 2–9 m^2 by hand in every field, except for spring barley. Instead, a strip of 1.5 m over the entire spring barley field is harvested by machine. The target values for the crop yields in the conventional and organic system are presented in Table 4 and Table 5. The target values for the crop yield and quality are based on KWIN numbers. The KWIN is a Dutch reference book used by farmers in the Netherlands to assess the costs and returns associated with various agricultural activities. (KWIN-AGV, 2018).

Table 4. *Target values for crop production and crop quality in conventional systems*

Crop	Target value production	Target value quality	
		Parameter	Target value
Potato (late till 2015)	50 ton/ha	Underwater weight	>425
Potato (early, since 2016)	40 ton/ha	Underwater weight	>360
Peas	4 ton/ha	TM-number	100-150
Leek	40 ton marketable/ha	none	
Spring barley	7 ton/ha	Hectolitre weight	>60
		Percentage moisture	<16%
Sugar beet	16 ton sugar/ha	Percentage sugar	>16,5%
		Extractability	>90%
Carrot	85 ton marketable/ha	Percentage tarra	<20%
Silage maize	16 ton dry matter/ha	Percentage moisture	>31% d.s.

Table 5. *Target values for crop production and crop quality in the organic system*

Crop	Target value production	Target value quality	
		Parameter	Target value
Potato	35 ton/ha	Underwater weight	>360
Peas	4 ton/ha	TM-number	100-150
Leek	35 ton marketable/ha	None	
Spring barley	5 ton/ha	Hectolitre weight	>60 kg/hl
		Percentage moisture	<16%
Carrot	80 ton marketable/ha	Percentage tarra	<20%
Silage maize	16 ton dry matter/ha	Dry matter percentage	>31% d.s.

2.2.2 Crop quality

To indicate crop quality, several parameters have been determined (Table 4 for the conventional system; table 5 for the organic system). The underwater weight is an indicator for potato quality, as it provides insights into the density and texture of the potato. Potatoes with a higher underwater weight tend to have a higher density, which is often preferred by processors. For peas, the quality is assessed by the hardness or TM number, with a target value of 120. TM stands for Tenderometer, which is the instrument to determine the hardness of the peas.

Spring barley is evaluated based on the moisture percentage and hectolitre weight. It is important for spring barley to have an adequate moisture percentage at the time of harvesting to avoid drying expenses. Ideally, the humidity level should be below 16%. The hectolitre weight is a measure of grain size, with a target value of at least 60 kilogram per hectoliter. For sugar beets, quality is based on the sugar percentage, with a target value set at 16.5%. Additionally, the target value for extractability is set at 90%. Silage maize quality is defined by the percentage of dry matter, which is ideally above 31% at the time of harvest. The quality of carrots is determined by the tarra percentage, with a target value set at less than 20%.

Leek does not have specific quality requirements, but the marketable value is determined by the size of the products. Products that fail to meet the standards for size, shape, or are damaged are not considered part of the marketable yield.

2.2.3 Soil quality

2.2.3.1 Organic matter

The organic matter content of the soil was analysed every year since 2011 in all the ploughing plots. The way it was analysed differed over the years. In 2011 and 2012 it was determined using Near Infrared Spectroscopy (NIRS). Since 2013 soil organic matter content was determined using NIRS as well as the loss-on-ignition method. It turned out the NIRS deviated from the loss-on-ignition method, and since loss-on-ignition is the classic well-known method, these data were preferred over the NIRS measurements.

2.2.3.2 Chemical soil quality

Annual soil fertility analyses were carried out by the laboratory of Eurofins Agro. After the harvest, 30 soil cores were taken per plot from the 0-30 cm layer in November. The samples were mixed, and a subsample was sent to Eurofins Agro for analysis where they were analysed for total N, C/N ratio, K soil stock, total S, and CEC (not in 2011 and 2012), P-CaCl2, K-CaCl2, Na-CaCl2, Mg-CaCl2, pH-KCl, Pw, K number, and P-Al. These were all measured or derived using NIRS. For some parameters, target ranges are available from the fertilization recommendations (www.handboekbodemenbemesting.nl): the target range for Pw is 30-45 mg P2O5/l soil, for the K number 11-17, for MgO 75-109 mg/kg soil, and for the pH-KCl 5.5-5.8.

2.2.3.3 Mineral nitrogen content in the soil

The mineral nitrogen content of the soil was measured multiple times a year. For the ploughed field this was done in spring, just after harvest and in November. For the NIT fields measurements were done less frequently; in spring only in 2019-2021, always after harvest and in autumn only in the measurement fields for 2011-2018, from 2019 onwards in all fields. Samples were taken with an auger in the layer 0-30 cm in spring, 0-30 and 30-60 after harvest, and 0-30, 30-60 and 60-90 in autumn.

2.2.3.4 Physical soil quality

Measurements to determine the soil structure were incidentally done. In 2020 a big measurement campaign was done in the experiment. Soil bulk density, soil moisture at field capacity and penetration resistance were determined.

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. 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. The moisture content at field capacity was determined by the weight at pF 2.0 minus the dry weight. Only in the organic system both ploughing and non-inversion tillage were sampled. Four out of the six fields were sampled, eight samples were collected per plot, four at a depth of 10-15 cm and four at a depth of 30-35 cm. Samples of one ploughed field got lost. Results were averaged per plot, and thereafter per tillage treatment.

Penetration resistance

Soil compaction can be characterized by the penetration resistance (PR) of the soil which is measured with a handheld 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 per 10 centimeters up until a depth of 50 cm. Measurements in the organic system were done at the same time and in the same field as for the bulk density measurements. Besides, the penetration resistance was measured in 2016 for the conventional system.

2.2.3.5 Biological soil quality

Soil Microbiology

Several microbiological parameters can be determined as important indicators for the status of soil health, such as microbial biomass, and fungal and bacterial biomass. A higher microbial biomass and activity are indicative of a faster decomposition and consequentially a higher availability of nutrients for plants. At the same time, a more active soil life can contribute to pathogen suppressiveness. A higher microbial biomass is expected when more organic matter is added to the soil.

Soil bacteria are generally more responsible for the decomposition of simple compounds, while soil fungi can degrade more complex compounds. The presence of recalcitrant material therefore promotes the amount of soil fungi. Bacterial and fungal biomass can be analysed by both PLFA and classical microscopical methods. In addition, PLFA analysis can distinguish different groups within soil bacteria. Gram-negative bacteria are associated with faster growth when easily degradable nutrients are available. In contrast, most of the Gram-positive bacteria are slow-growing and able to degrade recalcitrant material. An increase in the Gram-positive/Gram-negative bacterial ratio therefore indicates a decrease in available carbon. Also, the amount of Actinobacteria can be assessed by PLFA analysis. Several species within this group are known for their antagonistic activity against pathogens. Desulfobacteria are sulphate-reducing bacteria that are often found in sulphate rich marine environments, but also in polluted soil. Rhizobia, however, are important nitrogen-fixers and symbionts for plants.

Within the fungi, mycorrhiza (i.e., AMF) can be distinguished from saprophytic fungi. Mycorrhizae are important symbionts for many plants. On the other hand, the number of saprophytic fungi is often positively correlated with the C/N ratio and these fungi are responsible for the degradation of more complex substrates.

In addition, PLFA analyses can give an indication of the number of protozoa. Protozoa are a diverse group of unicellular eukaryotes, such as ciliates, flagellates, and amoebae. Protozoa have an important role as predators of bacteria. Some species are also known for selectively grating on bacteria with e.g., a specific cell volume.

Besides containing specific markers for groups of microorganisms, PLFA can also provide additional information about the status of the microbiome. Mono-unsaturated PLFAs are usually present in fast-growing Gram-negative bacteria, which are usually more abundant under high-nutrient conditions. Poly-unsaturated PLFAs, on the other hand, are mostly found in eukaryotes, such as fungi, which are slower-growing. Therefore, a lower ratio of mono- and poly-unsaturated PLFAs is an indicator for nutrient-limited soil life. Moreover, a higher ratio of cylcopropyl and cyclopropyl percursor PLFAs (Cy/precy) is an indicator for nutrient limitation and slower bacterial growth.
The ratio between trans- and cis isomers of PLFAs (t/c) is an indicator for stress in the microbiome. The higher this ratio, the higher the stress, caused for example by toxic compounds. Also, other ratios, such as between saturated and unsaturated PLFAs and between iso- and anteiso PLFAs (i/ai) are used as stress-indicators.

Classical microscopical measurements that make use of dyes can also be used to determine the amount of soil bacteria and fungi. The use of dyes can also distinguish active fungi (stained) and dead fungal hyphae (unstained).

Both HWC (hot water extractable carbon) and PMN (potential mineralizable nitrogen) are indicators for C and N in the microbial biomass, respectively, which are easily degradable and then available for plant uptake. HWC is also considered a sensitive indicator for the increase of organic matter in a soil. PCM (potential carbon mineralization) and PNM (potential nitrogen mineralization) are indicators for short-term changes in soil organic C and N.

The soil microbiology was measured in 2011, 2020 and 2021 using different methods. An overview of the different measurements is presented in Annex 4. The measurements done in the compost plots are not taken into account in this report.

Plant parasitic nematodes
Except for 2011, soil samples for analysis of plant parasitic nematodes were taken annually in January or February. Using a 13 mm soil auger, 35 cores (to a depth of approximately 25 cm) were taken and combined to obtain about 1.5 liters of soil per plot. From these soil samples, a 100 ml sub-sample was taken and analyzed for the composition of non-cyst forming nematode infestation in the laboratory WUR Field Crops in Lelystad. The 100 ml soil sample was sieved through a 180 µm sieve, and the nematodes in the collected suspension (<180 µm) were isolated using an Oosterbrink funnel (wash fraction). The soil and organic material remaining on the sieve (>180 µm) were incubated at 20°C for four weeks to allow any present eggs to mature and the nematodes to emerge from the roots (incubation fraction). The number of nematodes in each fraction was determined by counting in 2 x 10 ml of suspension. Species determination was carried out for each sample for the families Meloidogynidae, Pratylenchidae, and Trichodoridae.

Table 6 shows, as far as known, the damage thresholds for the most important nematode species. The "damage threshold" is the nematode density at which the first damage (yield loss) occurs in the crop. Next to that, the estimated maximum yield loss (damage percentage) is given. However, the level of damage that may occur is not only dependent on the density of the nematode infestation. Factors such as moisture, pH, organic matter content, presence of other pathogens, and also crop variety have an influence on the ultimate damage that occurs. Exact damage thresholds per nematode species and crop therefore cannot be given.

Table 6. *Damage threshold (1 (indicative, n/100 ml soil) for the most important plant-parasitic nematodes and the maximum yield losses (2(damage percentages)) which may occur when exceeding the damage threshold.*

crop	*Globodera pallida/ rostochiensis*	*Heterodera betae*	*Meloidogyne hapla*	*Meloidogyne chitwoodi/ fallax*	*Pratylenchus penetrans*	*Paratrichodorus pachydermus*	*Trichodorus similis*
Potato	200[1] (70)[2]	Not harmful	100 (30-50%)	10 (75-100%)	200 (30-50%)	10 (20)	10 (20%)
Peas	Not harmful	75 (>50%)	100 (30-50%)	10 (30-50%)	100 (15-30%)	10 (15-35%)	10 (15-35%)
Leek (autumn)	Not harmful	Not harmful	Not harmful	Not harmful	>1000 (10%)	10 (15-35%)	10 (15-35%)
Barley (spring)	Not harmful	Not harmful	Not harmful	? (<15%)	Not harmful	? (<15%)	? (<15%)
Sugar beet	Not harmful	75 (>50%)	100 (30-50%)	500 (10%)	Not harmful	150 (20%)	10 (10%)
Carrot	Not harmful	Not harmful	10 (100%)	10 (100%)	10 (20-40%)	50 (100%)	50 (100%)
Silage maize	Not harmful	Not harmful	Not harmful	? (0-15%)	? (15-35%)	? (15-35%)	1 (20%)

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, with the exception of 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 a large number of 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 fysical 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 and 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 6; Ferris et al., 2001). Observations from arable fields are often 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.

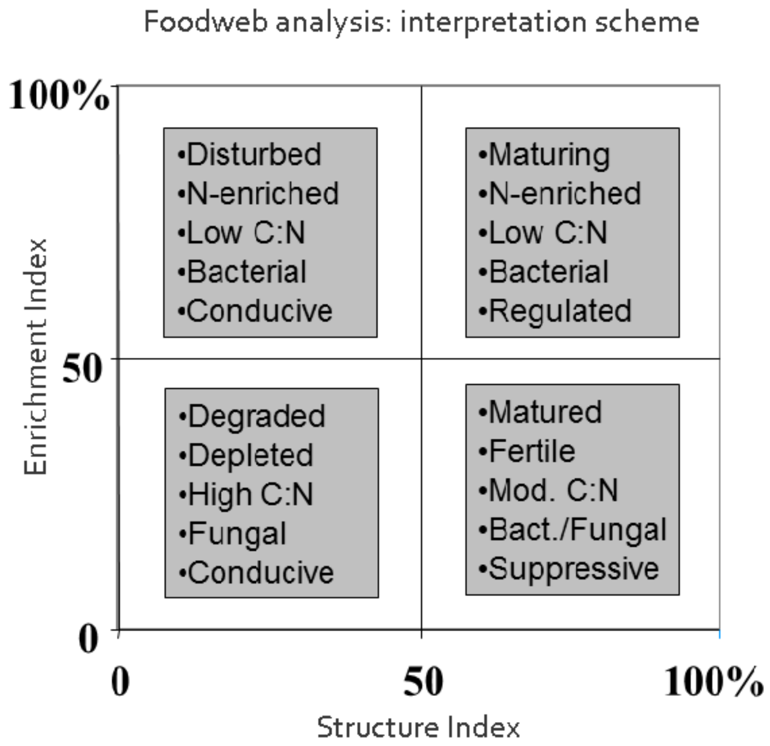

Figure 5. *Interpretation of the quadrats in the food web analysis diagram (from Ferris et al., 2001).*

Samples for determination of the nematode community were collected until a depth of 20 cm in March 2020. Two samples were taken in each treatment plot and they were analyzed separately. The sampled treatments are listed in Table 7.

Table 7. *Treatments that were sampled for determination of the nematode community in March 2020.*

Field	System	Tillage	Compost	Preceding crop in 2019
34.1b	Organic	Non-inversion tillage	No	Spring barley-Black oat
34.1b	Organic	Non-inversion tillage	Yes	Spring barley-Black oat
34.1a	Organic	Ploughing	No	Spring barley-Black oat
34.1a	Organic	Ploughing	Yes	Spring barley-Black oat
34.2a	Organic	Non-inversion tillage	No	Leek
34.2a	Organic	Non-inversion tillage	Yes	Leek
34.2b	Organic	Ploughing	No	Leek
34.2b	Organic	Ploughing	Yes	Leek
18.1	Conventional-standard	Ploughing	No	Spring barley-Black oat
18.2	Conventional-low	Ploughing	No	Spring barley-Black oat
27.1	Conventional-standard	Ploughing	No	Leek
27.2	Conventional-low	Ploughing	No	Leek

For measurement of soil moisture, a subsample of about 100 mL was weighed, dried at 105°C for 40-48 hours, then weighed again. The moisture content of the soil was calculated as ((moist soil weight)-(dry soil weight))/(dry soil weight). For determination of the soil nematode community, a subsample of about 100 mL soil was weighed. The soil was washed 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. Analysis of the data was performed in R version 4.2.1 (R Core Team, 2022) and RStudio® version 2022.07.0 (RStudio Team, 2022). Nematode biomass and numbers were transformed prior to analysis: biomass with log10(x)-transformation and nematode numbers with log10(x+1)-transformation. The results of the two samples per plot were averaged and then back transformed to the original scale.

2.2.4 Nitrate concentration in groundwater

Nitrate concentrations in the upper (phreatic) groundwater were measured at a depth of approximately 2 meters below the surface using the procedures followed in Hack-ten Broeke et al. (1993) and Smit et al. (2004). A tube is placed into the soil which allows samples to be taken of the groundwater at a fixed depth. The drawback of this method is that this fixed depth does not always represent the upper groundwater level due to interseasonal groundwater level fluctuations. In the national manure measuring network by the RIVM (LMM; landelijk meetnet mestbeleid) this is not the case.

In each plot, three monitoring well tubes with a length of 2.5 meters, a diameter of 4 cm, and a perforated zone of 50 cm have been installed. The groundwater tubes have been placed every autumn after harvest in November and removed before the start of the next growing season after the last measurement in February. Each tube was sampled monthly during the period from mid-November to mid-February (which adds up to 4 measurements per year).

The three tubes are diagonally placed over the plot in all plots, annually in roughly the same location. Each tube is emptied before sampling and 24 hours later, when the tube is refilled with groundwater, a sample is taken. The sample is cooled to 5°C and analyzed for nitrate concentration levels at the Chemical Biological Soil Laboratory (CBLB) in Wageningen. The results are compared to the maximum target value of 50 mg nitrate/l as described in the national nitrate directive. Drainage pipes were not sampled. It is unknown which part of the outflow has gone through the drains.

2.2.5 Weed seed bank

At the start of the 2022 season, 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 non-inversion tillage with ploughing after a trial period of eleven years.

To estimate the soil weed seedbank, soil samples were collected from the conventional standard system and the organic system. Samples were collected in the field from two different soil layers: 0-10 and 10-30 centimetres depth. In each field, 120 soil cores were collected following a fixed sampling scheme using a 25 mm width auger. Fields were subdivided into three strips and cores were taken every five metres. The cores were combined into one soil sample for each layer per field. This resulted in a total of 48 soil samples (2 cropping systems × 2 tillage systems × 2 soil layers × 6 fields). Soil sampling was done on 23 and 24 February, shortly before the first tillage operations in 2022.

The soil samples were taken to a greenhouse in Lelystad on 28 February and assessed using the seedling emergence method. During the period between March and September, the weed seeds were germinated in the greenhouse and weed seedlings were determined on species level. After each germination flush, the soil was air dried, mixed again and rewatered to stimulate a new germination flush and let the remaining seeds germinate. In total, five 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.

2.2.6 Nitrogen balance

The nitrogen balance is determined to be able to explain possible difference in nitrate concentrations in the groundwater. This is done by calculating the inputs and subtracting the outputs. Inputs are calculated based on the fertilisation plan, and are the same for the ploughing and non-inversion tillage treatment. Outputs are calculated by multiplying the yield with the N content of that yield. Here differences can occur for the tillage treatments. A detailed description of the nitrogen balance can be found in Annex 3.

2.3 Statistical analyses

When possible a statistical analysis was executed over the data. All statistical analyses were performed in R version 4.2.0 (R Core Team, 2022) and RStudio® version 2023.03.1 (RStudio Team, 2023). An analysis of variance (ANOVA) was done using linear (both fixed and mixed) models and a student T test for pairwise comparisons of the treatments using lme4 and base R’s linear model function. The fixed factor was soil treatment through the entire analysis, and random factors included were the factors year and wholeplot. A Shapiro-Wilk normality test was use to check for normality. A confidence interval of 95% was used, meaning that $p<0.05$ is considered significant.

Biological soil parameters were only incidentally measured, not in repetition and with a slightly different methodology for the different years, so no statistical analysis could be performed on this data.
The weed seed bank was only determined once, in two repetitions per treatment, so no statistical analysis could be performed on this data.

3 Results

3.1 Yield and quality

3.1.1 Yield

3.1.1.1 Conventional

Table 8 shows the variation in marketable yield for the crops cultivated within the conventional cropping system comparing Non-Inversion Tillage and Ploughing averaged over the time span of 2011 to 2021. None of the results presented are significant. Some of the crops (potato, spring barley) have attained slightly higher marketable yields in Non-Inversion Tillage systems compared to the ploughing system, while others (carrot, silage maize and sugar beets) attained a slightly lower marketable yield. However, this difference can also be explained by natural variation. The table also shows the target value as determined in chapter 2.2.1. For all the crops the target value was either being met, or close to being met.

Table 8 *Average marketable yield per crop for the soil management practices of Non-Inversion Tillage (NIT) and Ploughing (the years 2011 to 2021 in ton/ha per treatment in a conventional farming system). Peas are corrected to TM120, spring barley is corrected to 15% moisture, sugar beet is displayed in tonnes sugar/ha, and silage maize is expressed as ton dry matter/ha.*

Crop	NIT (ton/ha)	PL (ton/ha)	NIT relative to PL	P value	Target value (ton/ha)
Potato	50.2	48.8	103%	0.66	50
Peas	4.6	4.5	102%	0.88	4
Spring Barley	6.9	6.5	106%	0.27	7
Carrot	112.4	117.8	95%	0.28	85
Leek	35.8	35.6	100%	0.91	40
Silage Maize	16.7	17.4	96%	0.31	16
Sugar beets	16.1	16.4	98%	0.55	16

Figure 6 shows the marketable product in tons per ha for each crops over time in the conventional farming system. A large variation is visible between the years when looking at the marketable profit. None of the years show a significant difference between ploughing and non-inversion tillage. No clear trends over the years of the yield was seen. Significance for individual crops per year cannot be calculated since the experimental set-up has no repetitions.

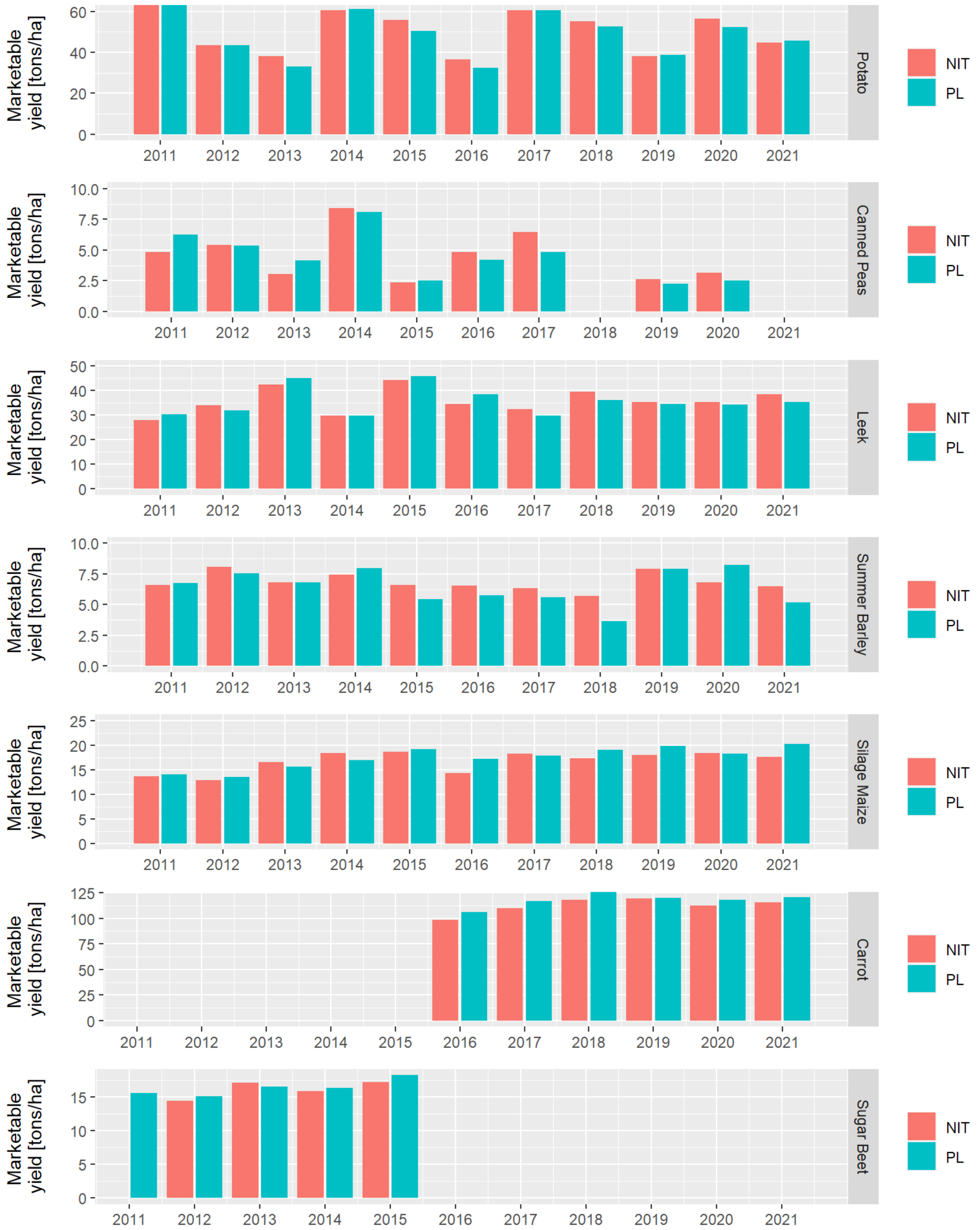

Figure 6. *Marketable product yield (tons/ha) per crop per year for Non-Inversion Tillage and ploughing in conventional farming system. Note that sugar beet was switched out with carrot from 2016 onwards in the crop rotation. In 2018, the pea harvest failed.*

3.1.1.2 Organic

Table 9 shows the variation in marketable yield for the crops cultivated organically comparing Non-Inversion Tillage and ploughing averaged over the time span of 2011 to 2021. Although some differences can be observed in the averages of the marketable yields, again none of the differences are significant. Just as for the conventional system, the target values are met or close to being met.

Table 9 *Average marketable yield per crop over the years 2011 to 2021 in ton/ha per treatment in the organic cropping system, comparing the soil management practices of Non-Inversion Tillage (NIT) and ploughing (PL). Conserved peas are corrected to TM120, spring barley is corrected to 15% moisture, and silage maize is expressed as ton dry matter/ha*

Crop	NIT (ton/ha)	PL (ton/ha)	NIT relative to PL	P-value	Target value (ton/ha)
Potato	36.0	33.5	108%	0.48	35
Peas	4.0	4.5	89%	0.45	4
Spring barley	4.4	3.8	115%	0.25	5
Carrot	70.3	71.7	98%	0.85	80
Leek	31.8	31.7	101%	0.993	35
Silage maize	17.6	18.5	95%	0.51	16

Figure 7 shows the marketable product in tons per ha for each crops over time. A large variation between the years can be seen when looking at the marketable profit. There are no statistically significantly differences between the tillage systems per year. In 2016 crop yield under both soil treatments were affected because of waterlogging due to large amounts of precipitation in June that year.

Figure 7. *Marketable product yield (tons/ha) per crop per year for Non-Inversion Tillage and ploughing in the organic farming system.*

3.1.2 Crop quality

3.1.2.1 Conventional

Table 10 shows the crop quality of the conventional crops based on the parameters as described in chapter 2.2.2. Except for the moisture content of the spring barley, the table does not show any noteworthy differences, indicating that tillage does not affect crop quality. The differences in moisture content in spring barley can also be explained by differences in harvesting moment, both in days (shortly after a rainfall event) or during the day (moisture contents generally decrease in the afternoon). All of the crop quality values meet the target values.

Table 10 *Crop quality per crop over the years 2011 to 2021 for its relevant parameter per treatment in the conventional cropping system, comparing the soil management practices of Non-Inversion Tillage (NIT) and ploughing (PL).*

Crop	parameter	NIT	PL	Target value
Potato	Underwater weight	376	380	>360
Peas	TM-number	137	142	100-150
Leek				
Spring barley	Percentage moisture	13.9	15.1	<16%
	Hectolitre weight	65.7	65.4	>60
Silage maize	Percentage d.m.	37.0	36.2	>31%
Sugar beet	Percentage sugar	17.8	17.8	>16.5%
	Extractability	92.1	92.0	>90%
Carrot	Percentage tarra	3.62	3.67	<20%

3.1.2.2 Organic

Table 11 shows the crop quality of the organically grown crops. For carrots, the percentage tarra in the non-inversion tillage system was 5 percent points higher than in the ploughing system. For the other crops, no noteworthy difference between the different cultivation systems was realized. Just as for the conventional system, all the target values were met.

Table 11 *Crop quality per crop over the years 2011 to 2021 for its relevant parameter per treatment in the organic cropping system, comparing the soil management practices of Non-Inversion Tillage (NIT) and ploughing (PL).*

Crop	parameter	NIT	PL	Target value
Potato	Underwater weight	364	361	>360
Peas	TM-number	116	122	100-150
Spring barley	Percentage moisture	15.0	15.3	<16%
	Hectolitre weight	61.0	61.9	>60
Silage maize	Percentage d.m.	32.8	32.3	>31%
Carrot	Percentage tarra	11.5	6.46	<20%

3.2 Soil quality

3.2.1 Organic matter content

3.2.1.1 Conventional

Annex 4 shows the organic matter content in the soil of the period before 2011. Firstly, the organic matter content in the conventional farming system with low organic matter input is discussed. Figure 8 illustrates an upwards trend in the organic matter content for both Non-Inversion Tillage and ploughing. The graph shows a difference in organic matter development between the two practices. Non-Inversion Tillage shows a faster accumulation of organic matter in the top soil and a higher potential of holding a larger amount of organic matter in the soil compared to when ploughing is performed. The difference between non-inversion tillage and ploughing is significant ($p<0.01$).

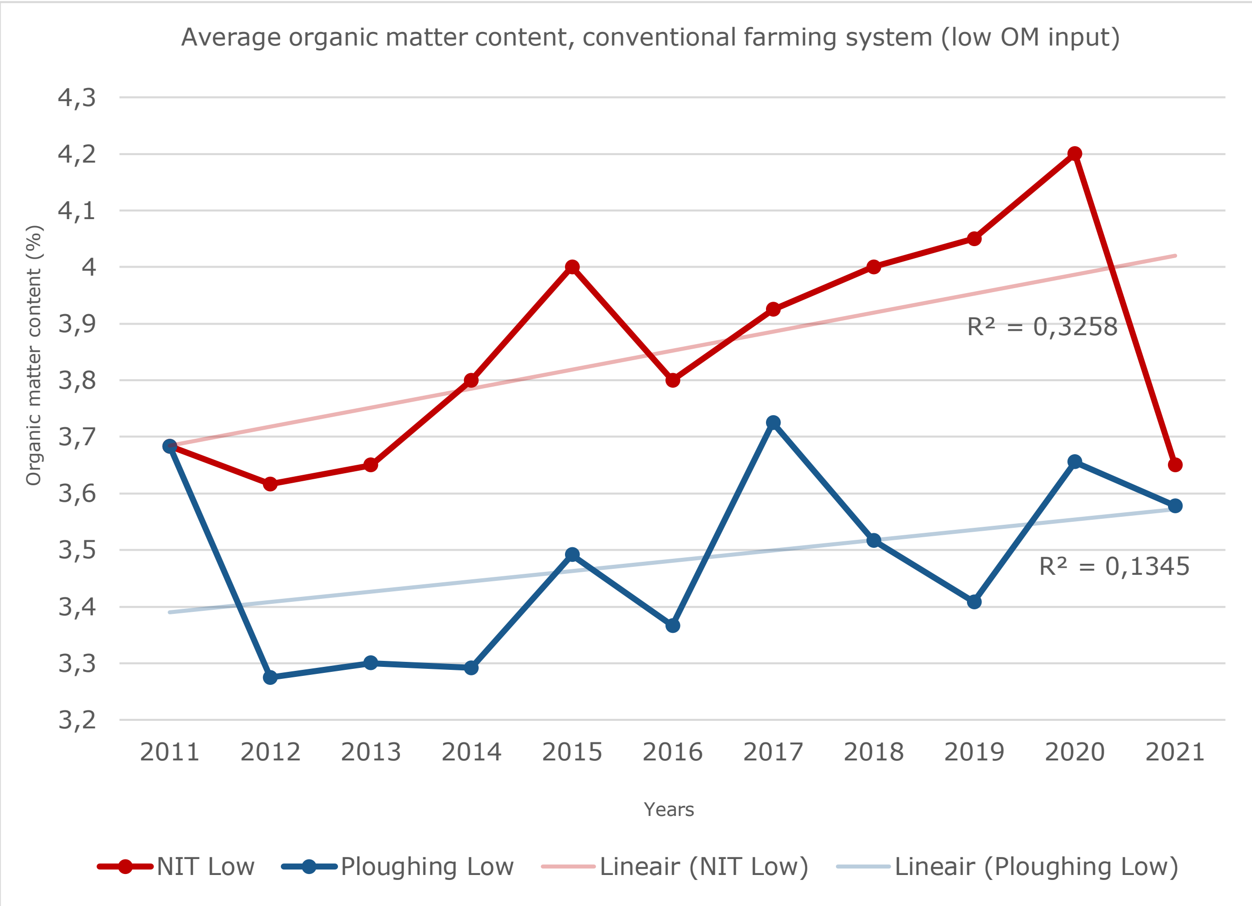

Figure 8 *Average organic matter content, expressed in percent, with a low amount of organic matter input in a conventional farming system since 2011 up and until 2021. A linear trendline is added for both practices.*

When looking at the data for the organic matter in the soil when conventional farming is applied with standard organic matter input it is visible that there is no significant difference between the two practices ($p=0.90$). The data shows that when using either of both practices there is an increase in the organic matter in the soil (R^2, Figure 9). A large fluctuation between the average organic matter content over the years is observed in both treatments.

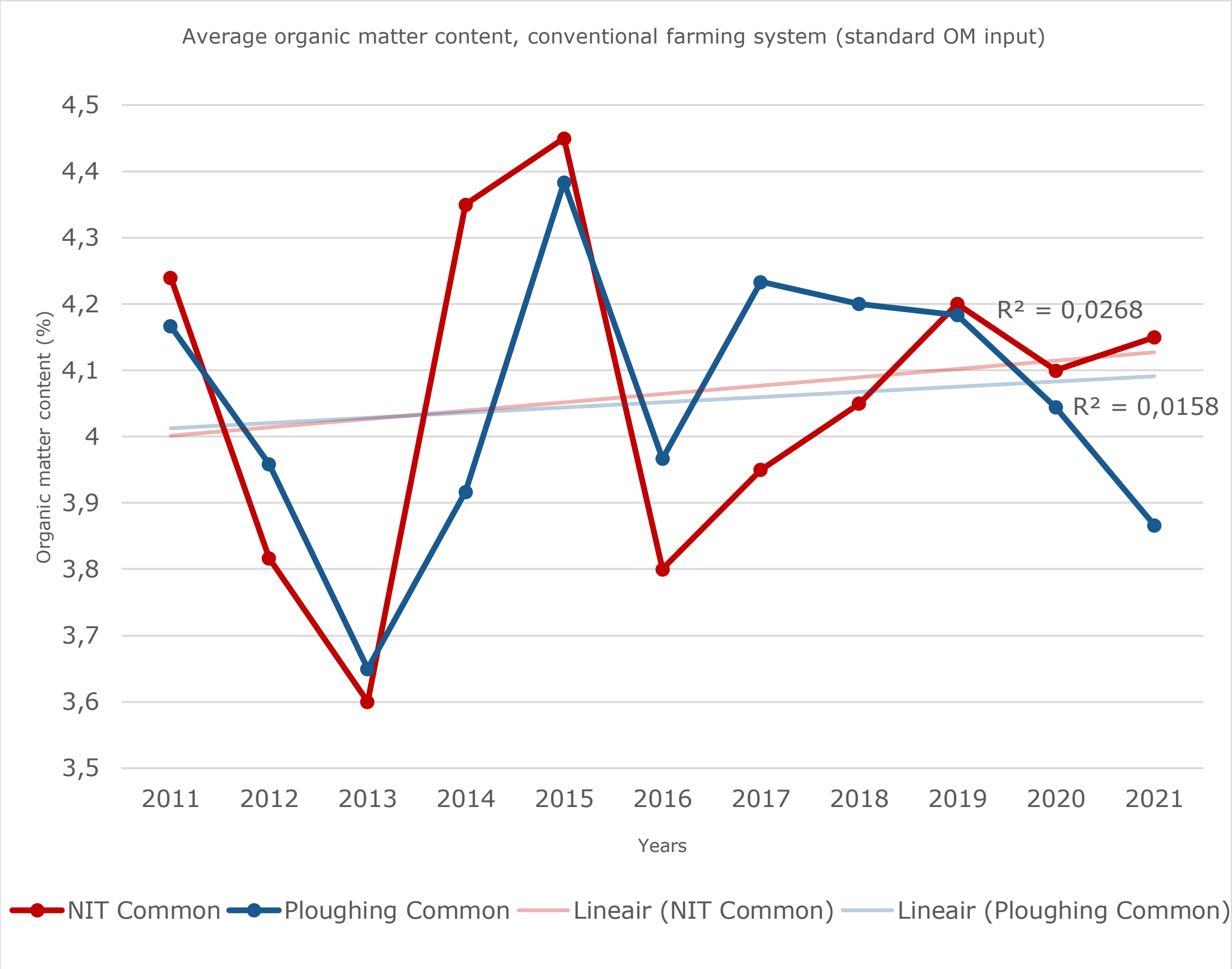

Figure 9 *Average organic matter content, expressed in percent, with a common amount of organic matter input in a conventional farming system since 2011 up and until 2021. A linear trendline is added for both practices.*

When looking at both graphs (Figure 8 & Figure 9) it could be argued that the effect on Non-inversion Tillage or ploughing on the organic matter content in the soil is only visible when low organic matter is added. Hence, the organic matter content is only improved by Non-Inversion Tillage when the organic matter content in the soil is low.

3.2.1.2 Organic

Figure 10 shows the difference in organic matter between the Non-Inversion tilled and ploughed fields. It is shown that when Non-inversion Tillage was applied the organic matter content is the soil was higher than when ploughing was applied. When looking at the linear line of both graphs the R^2 value shows that with 0.4773 for Non-inversion Tillage is higher than the R^2 value of ploughing with a value of 0.3498. Over the whole period (2011-2021) the difference in organic matter content between the two tillage treatments is significant (p=0.05).

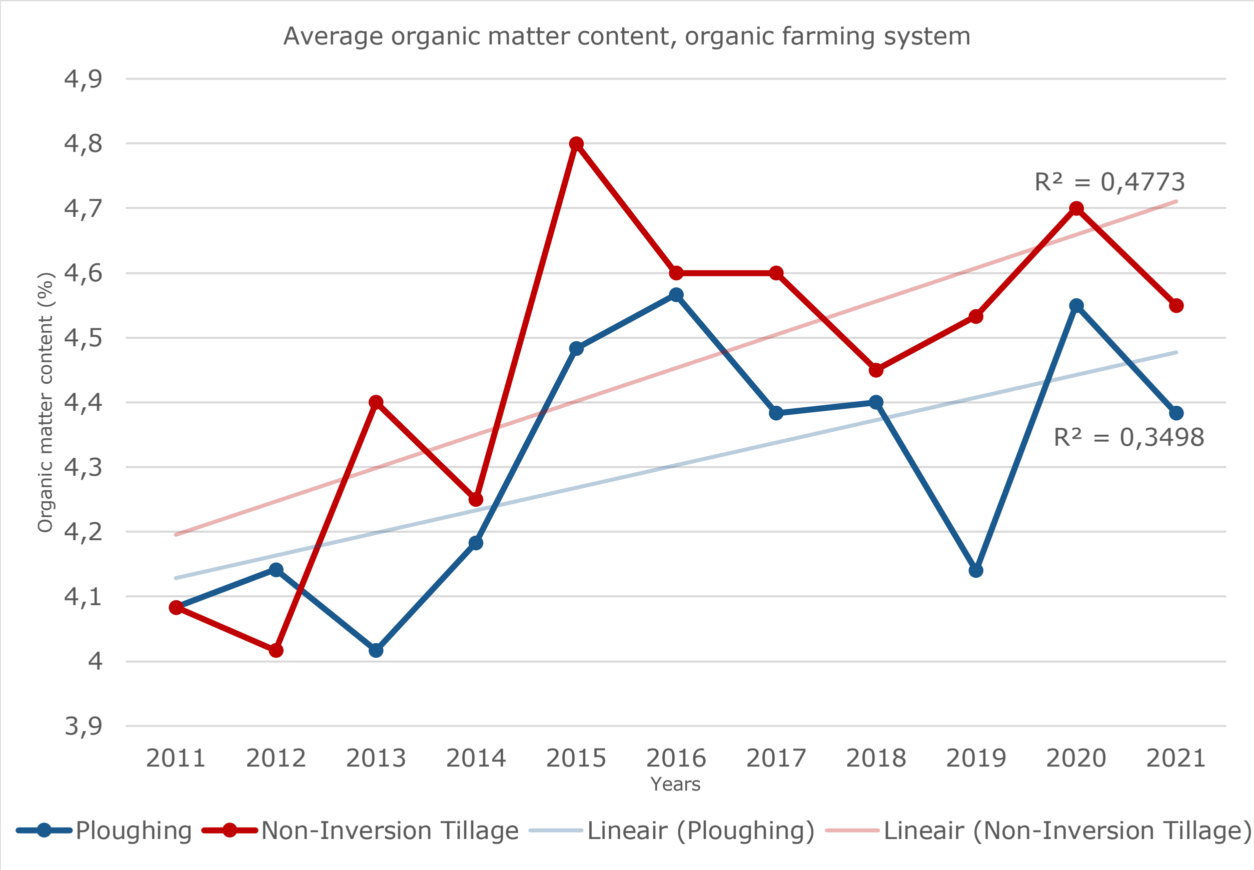

Figure 10 *Average organic matter content, expressed in percent, in an organic farming system since 2011 up and until 2021. A linear trendline is added for both practices.*

3.2.2 Chemical

3.2.2.1 Conventional

Table 12 presents the averages of several chemical soil quality parameters for the two conventional systems for both the tillage treatments. It shows that in a system with a low organic matter input (conventional low), the organic matter content in the soil significantly increases with a reduced tillage system. However, in a system with sufficient organic matter input, the difference is not significant. Likewise, the total N content is significantly higher under non-inversion tillage in a system where the nutrient input is low, while this does not differ in a standard system. Additional data on the chemical soil quality is presented in Annex 4. No trends over the years were seen.

Table 12 *Averages of chemical soil quality parameters for the two conventional systems for both tillage treatments*

Soil parameter	Unit	Conventional-low			Conventional-standard		
		Ploughing	Non-inversion tillage	P-value	Ploughing	Non-inversion tillage	P-value
Organic matter	%	3.42	3.82	<0.05	4.01	3.94	0.47
pH	-	5.42	5.46	0.4	5.60	5.50	0.07
Total N	mg N/kg	966.03	1112.29	<0.01	1109.38	1144.79	0.35
C:N	-	20.23	19.90	0.45	20.86	19.48	<0.01
PW	mg P_2O_5 /liter	37.96	37.77	0.89	45.70	48.86	0.04
K number	-	12.26	14.02	0.09	12.24	13.44	0.21
CEC	mmol/kg	46.63	55.71	<0.01	61.75	50.63	0.02

3.2.2.2 Organic

Table 13 presents the averages of chemical soil quality parameters for the organic system for both tillage treatments. Except for the PW value, there is no significant difference between the two tillage systems for the presented parameters. Additional data on the chemical soil quality is presented in Annex 4. No trends over the years were seen.

Table 13*.* *Averages of chemical soil quality parameters for the organic system for both tillage treatments.*

Soil parameter	Unit	Ploughing	Non-inversion tillage	P-value
Organic matter	%	4.18	4.19	0.92
pH	-	5.63	5.67	0.36
Total N	mg N/kg	1296	1315	0.59
C:N	-	18.3	18.2	0.88
PW		44.5	47.78	0.03
K number	-	17.95	18.54	0.65
CEC	mmol/kg	68	69	0.58

3.2.3 Mineral nitrogen content in the soil

3.2.3.1 Conventional

Table 14 shows the N-min content in the soil measured in spring (depth 0-30 cm), after harvest (depth 0-60 cm), and in autumn (depth 0-90 cm). In 2011 and 2018 there were no measurement during spring. Moreover in 2013, 2014, 2015, 2016, and 2017 there were no measurements in spring on field where Non-Inversion Tillage was implemented.

Table 14 *N-min content in the soil measured in spring (0-30 cm), after harvest (0-60 cm), and in autumn (0-90 cm) in kg N/ha per system per year for a conventional farming system.*

	Spring		**After harvest**		**Autumn**	
	PL	NIT	PL	NIT	PL	NIT
2011	-	-	44.1	30.2	60.2	22
2012	11.7	10.5	28.6	18.5	38.7	30.8
2013	7.0	-	34.9	31.4	30.8	11.8
2014	12.4	-	30.2	36.1	44	17
2015	6.4	-	39.9	34.6	39.1	25
2016	6.4	-	41.2	38.1	29.8	30.5
2017	12.7	-	24.4	23.8	38.1	33
2018	-	-	44.2	49	48.4	46.2
2019	8.5	10	30	23.8	32.7	29.8
2020	3.1	3.5	22.5	24.1	18.7	14.3
2021	6.6	6.3	19	17.3	45.1	40.8
Average	8.3	7.6	32.4	29.7	38.7	27.4

The limited dataset for the spring measurements did not provide sufficient data for a statistical analysis. Based on the available data, there did not appear to be a notable difference in the N-min content between the ploughing and non-inversion tillage plots.

Statistical analyses were possible for the measurements taken after harvest and in autumn. According to the ANOVA test results, there was no significant difference in the N-min content between the two tillage treatments after harvest (p=0,46). The measurements taken in autumn did significantly differ (p=0.02). However, this can partly be explained by the fact that for NIT only two out of the six fields were measured, and therewith also only two out of the six crops in the crop rotation under NIT are compared to the results of the whole crop rotation in ploughing. Still, it stands out that in all the years, except 2016 the mineral nitrogen in the soil was lower for non-inversion tillage compared to ploughing.

3.2.3.2 Organic

In Table 15 the N-min content in the soil is displayed, the N-min content is measured in spring (depth 0-30 cm), after harvest (depth 0-60 cm), and in autumn (depth 0-90 cm). In 2011 and 2018 there were no measurement during spring. Moreover in 2012, 2013, 2014, 2015, 2016, 2017, and 2019 there were no measurements in spring on field where Non-Inversion Tillage was implemented.

Table 15. *N-min content in the soil measured in spring (0-30 cm), after harvest (0-60 cm), and in autumn (0-90 cm) in kg N/ha per system per year for an organic farming system.*

	Spring		After harvest		Autumn	
	PL	NIT	PL	NIT	PL	NIT
2011	-	-	31.5	33.7	55.5	41.7
2012	24.6	-	47.6	31.5	30.2	49.5
2013	9.79	-	33.5	27.3	23.5	14.7
2014	12	-	49.7	39.1	54.2	47.7
2015	9.8	-	45.1	38.4	40.8	34.5
2016	9.8	-	47.7	37.6	42	42
2017	16.7	-	41.8	45.4	68.9	27.9
2018	-	-	73	57.5	54.8	39.5
2019	11.8	-	59.5	43	46	41
2020	3.5	4.5	30.6	34.5	52.2	48
2021	8.8	13	41.8	35.8	46	40.5
Average	11.9	8.8	45.6	38.5	46.7	38.8

Just as for the conventional system, the limited dataset collected in spring did not allow for a statistical analysis. Based on the two samples, no definitive conclusions can be drawn on the effects of tillage on the N-min content. Both the measurements taken after harvest and in autumn did differ significantly. However, just as in the conventional system, the substantial variance between the years make it difficult to draw reliable conclusions from the dataset. For instance, the N-min content in 2014 was 3 times larger than in 2013. Nevertheless, with the exception for 2012, N-min content values in autumn taken from Non-inversion tillage plots were consistently lower than the values in the ploughing plots. A partial explanation for the differences found is the fact that for NIT only two out of the six fields were measured, and therewith also only two out of the six crops in the crop rotation under NIT are compared to the results of the whole crop rotation in ploughing.

3.2.4 Physical

3.2.4.1 Soil profiles 2018

The soil structure was visually analysed by digging soil pits in 2018 in the conventional low system and in the organic system, for both the tillage treatments. Visual differences between the treatments were minimal. In conventional low there was a slight difference in presence of grassroots; in non-inversion tillage there were less roots in the topsoil, they were although somewhat bigger than under ploughing. The general structure of the soil was a bit sharper for non-inversion tillage (Figure 11).

Figure 11. *Soil pit in conventional-low under ploughing (left) and non-inversion tillage (right).*

3.2.4.2 Bulk density and moisture content at field capacity

In general soil density increases when a reduced form of tillage is applied, because of a lack of loosening of the soil (Crittenden, 2015). This might change over the longer term, when a new equilibrium situation is reached. Because of the incidental measurements, no conclusions can be drawn on the effects of different tillage types on bulk density. In Table 16 measurements done in 2020 are presented. Differences between the tillage treatments in the organic system are small, except for the moisture content in the deeper soil, which is considerably lower in NIT. The data set did not show a very clear relation between the bulk density and moisture content at field capacity.

Table 16. *Bulk density and soil moisture content at field capacity at two depths in the organic system. Based on measurements done in 2020, n=12 for ploughing, n=16 for non-inversion tillage.*

	Bulk density (g/cm^3)		Moisture content (%)	
Depth	10-15 cm	30-35 cm	10-15 cm	30-35 cm
Organic – Ploughing	1.39	1.52	28.66	27.93
Organic – Non inversion tillage	1.42	1.53	27.94	22.62

3.2.4.3 Penetration resistance

Figure 12 and Figure 13 present the penetration resistance measured with the penetrometer for the organic and conventional system. The small figures indicate an individual measurement at a certain layer of measurement, the larger figure shows the mean penetration resistance at the soil layer. The tables containing the supporting data are provided in annex 4.

According to Zwart et al. (2011), soil conditions based on penetration resistance can be classified as follows:

- Root hindrance occurs when the depth at which penetration resistance exceeds 1.5 Mpa
- Root inhibition occurs when penetration resistance values are 3.0 Mpa or higher

Based on this classification, it can be concluded that the difference in the non-inversion tillage and ploughing system are neglectable. Especially in the standard conventional system, penetration resistance in both fertilization treatments is similar. In the organic system, differences are visible between the mean penetration resistance of the two tillage treatments in deeper soil layers. Nevertheless, it’s important to acknowledge the uncertainty of this data because of the considerable variability in the measurements.

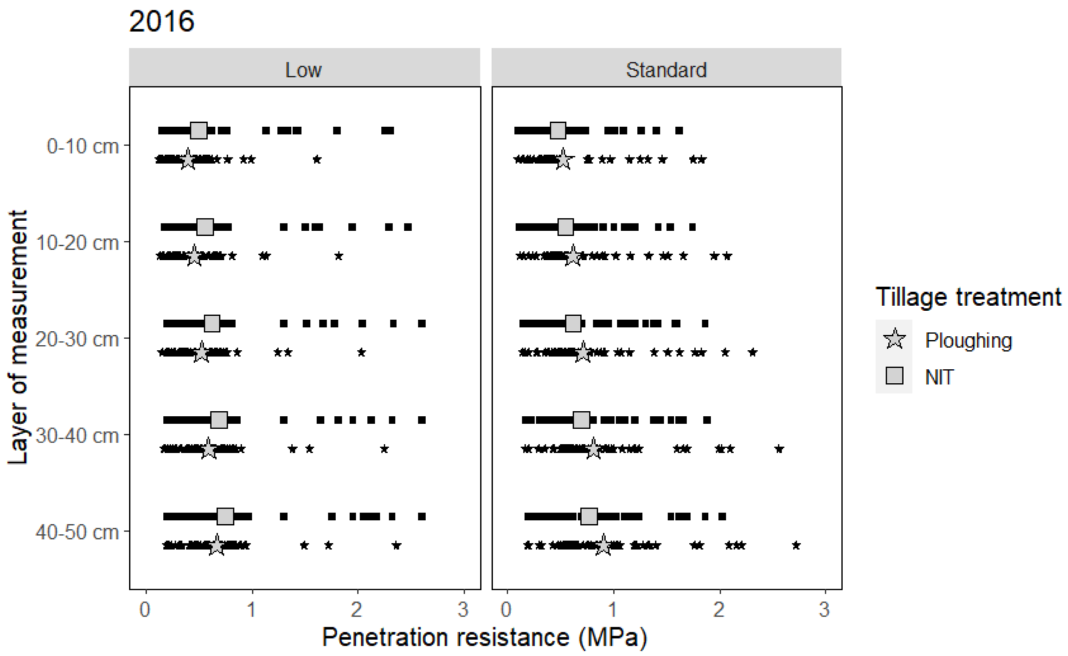

Figure 12. *Penetration resistance for soil layers of 10 cm in the conventional system for both the fertilization treatments (low and standard) and both the tillage treatments (ploughing (stars) and non-inversion treatment (squares)). The smaller figures represent individual measurements, while the larger figure represents the mean of the soil layer.*

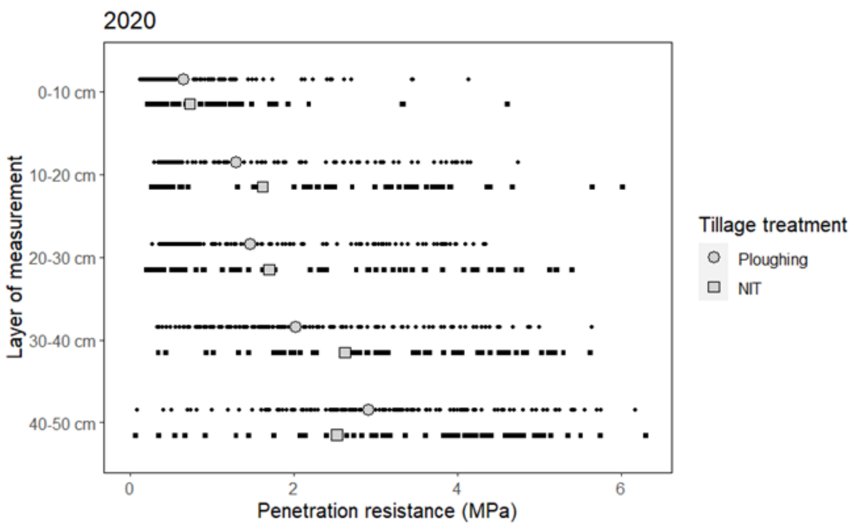

Figure 13. *Penetration resistance for soil layers of 10 cm in the organic system for both tillage treatments (ploughing (circles) and non-inversion treatment (squares)). The smaller figures represent individual measurements, while the larger figure represents the mean of the soil layer.*

3.2.5 Biological

In 2011 soil biology parameters were measured, before the different tillage strategies were implemented. Results of these measurements are described in Visser et al. (2014). Only in the organic system ploughing and non-inversion tillage plots were sampled, in the conventional system only the ploughing plots were sampled. Confirm hypotheses there were little differences between the tillage systems at the start.

3.2.5.1 Soil Microbiology

As in 2011, in 2020 microbial measurements in both tillage treatments were done in the organic system. Just as in 2011, there was little difference between non-inversion tillage and ploughing. The results of the measurements are presented in annex 4.

Microbial measurements were done for the different tillage treatments in the conventional systems in 2021. The results are presented in annex 4. It shows that several microbiological parameters, such as microbial biomass, the number of bacteria and fungi were on average higher with non-inversion tillage

3.2.5.2 Plant parasitic nematodes

To study the effects of the different tillage types on the plant parasitic nematode populations, different nematode species that are generally present in sandy soils were infested in the fields. The species that were found were the root knot nematodes *Meloidogyne chitwoodi*, *M. fallax* and *M. hapla*, the root lesion nematode *Pratylenchus penetrans* and the stubby-root nematodes (or trichodorids) *Paratrichodorus pachydermus*, *P. teres* and *Trichodorus similis*. These nematode species are rather polyphagous, meaning that they are able to multiply on many arable crops and vegetables, and they also may cause damage. This complicates management of these species by a well-designed crop rotation. Due to the extensive crop rotation, the occurrence of other well-known troublesome nematodes, such as potato cyst nematodes (*Globodera* sp.) and beet cyst nematodes (*Heterodera* sp.), was limited.

The effect of the crop rotation in BKZ on the development of plant parasitic nematodes and the risks for yield and quality loss are described in De Haan *et al*. (2018). The choice of crops strongly affected the level of infestation with plant parasitic nematodes. The amount of fertilization in the conventional system (standard *versus* low) did not have an effect on the development of the plant parasitic nematodes. Therefore, an average was calculated for the conventional system (for both the standard and low fertilization system).

To give an impression of the effect of soil tillage on the development of the nematodes, for every year the average density of plant parasitic nematodes in the two tillage types (non-inversion tillage and ploughing) was calculated. The results are presented in annex 3. Overall the tillage type did not have an effect on the development or the level of infestation with trichodorids.

3.2.5.3 Nematode community

In addition to studying the plant parasitic nematodes, the nematode community was also examined. Just as for the plant parasitic nematodes, the effect of the choice of crop in the preceding year in many cases seemed to have a stronger effect on the nematode community than the farming system, tillage or addition of compost. After growing spring barley and black oat, the total number of active nematodes was higher than after growing leek. This concerned a higher number of herbivores (plant feeders), but also bacterial feeders. In the organic system, the total number of nematodes and the number of bacterial feeders (bacterivores) seemed to be somewhat lower in the non-inversion tillage than in the ploughing treatment after spring barley and black oat, but the reverse pattern was found after leek. Tillage did not have a consistent effect on the other feeding groups. Addition of compost did not have an effect on the nematodes. The supporting data and supplementary analyses involving the count of CP- (colonizer-persister) and PP- (plant-parasitic) nematode groups, various indices including the Maturity Index, and a food web analysis are provided in Annex 3. Also for the supplementary analyses, it was determined that the selection of the previous year's crop had a larger impact than the choice of tillage treatment.

3.3 Nitrogen balance

3.3.1 Nitrogen supply

The total nitrogen supply for both Non-inversion Tillage and ploughing was similar for each crop within in the same farming system, since the fertilisation was the same. Detailed results of the nitrogen supply can be found in Annex 3 Nitrogen balance.

3.3.2 Nitrogen removal

Since a higher crop yields leads to more nitrogen removal, the nitrogen removal shows a similar pattern as the crop yield. Nevertheless, some crops show a higher nitrogen removal in the non-inversion tillage system, both for conventionally and organically produced crops. The results of the average nitrogen removal per crop are presented in Table 17 and Table 18.

Especially potatoes, green beans, and spring barley show a higher nitrogen removal.The nitrogen removal of conserved peas in non-inversion tillage is 13% lower in the organic system, while this was 5% higher in the conventional system. However, because of the differences between the organic and conventional plots, no substantial conclusions can be drawn out of this data. For the other crops, the difference in nitrogen removal is minimal. The yearly average nitrogen removal per tillage system is presented in annex C, but does not show significant differences for both the conventional (p=0.79) nor the organic system (p=0.64).

Table 17. *Nitrogen removal through harvest, per crop per system over the years 2011-2021 in a conventional farming system relative to the ploughing system.*

Crop	NIT	PL
Potato	106%	100%
Conserved peas	105%	100%
Spring barley	106%	100%
Carrot	98%	100%
Leek	98%	100%
Silage maize	97%	100%
Green beans	111%	100%
Sugar beets	105%	100%

Table 18. *Average nitrogen removal through harvest, per crop per system over the years 2011 up an till 2021 in an organic farming system (kg/ha/year).*

	NIT	PL
Potato	110%	100%
Conserved peas	87%	100%
Spring barley	112%	100%
Carrot	99%	100%
Leek	98%	100%
Silage maize	99%	100%

3.3.3 Nitrogen balance

The different tillage systems seemed to have a minimal effect on the nitrogen balance. ANOVA tests were conducted, indicating that in both the conventional (p=0.92) and organic (p=0.46) systems the difference between the yearly nitrogen balance was not significant. Supplementary data supporting this analysis is included in annex 3.

3.3.4 Nitrogen efficiency

Just as for the nitrogen balance, the different tillage systems minimally affected the nitrogen balance. ANOVA tests showed that for both the conventional (p=0.87) and the organic system (p=0.57) was not significant. Supplementary data on the nitrogen efficiency is presented in annex 3.

3.4 Nitrate in groundwater

3.4.1.1 Conventional

The nitrate concentrations for a conventional farming system in the groundwater are shown in Figure 14. These concentrations were only measured since 2017 for Non-inversion Tillage. The concentrations were measured in winter. The European nitrate norm for groundwater is 50 mg NO3/L. Since 2017 the levels have been underneath the norm for both Non-Inversion Tillage and ploughing. There is a trend (unsignificant) that the nitrogen concentrations are lower when Non-Inversion Tillage was applied than when ploughing was applied in a conventional farming system. There is hardly any difference in the concentrations between the two treatments in the year 2019.

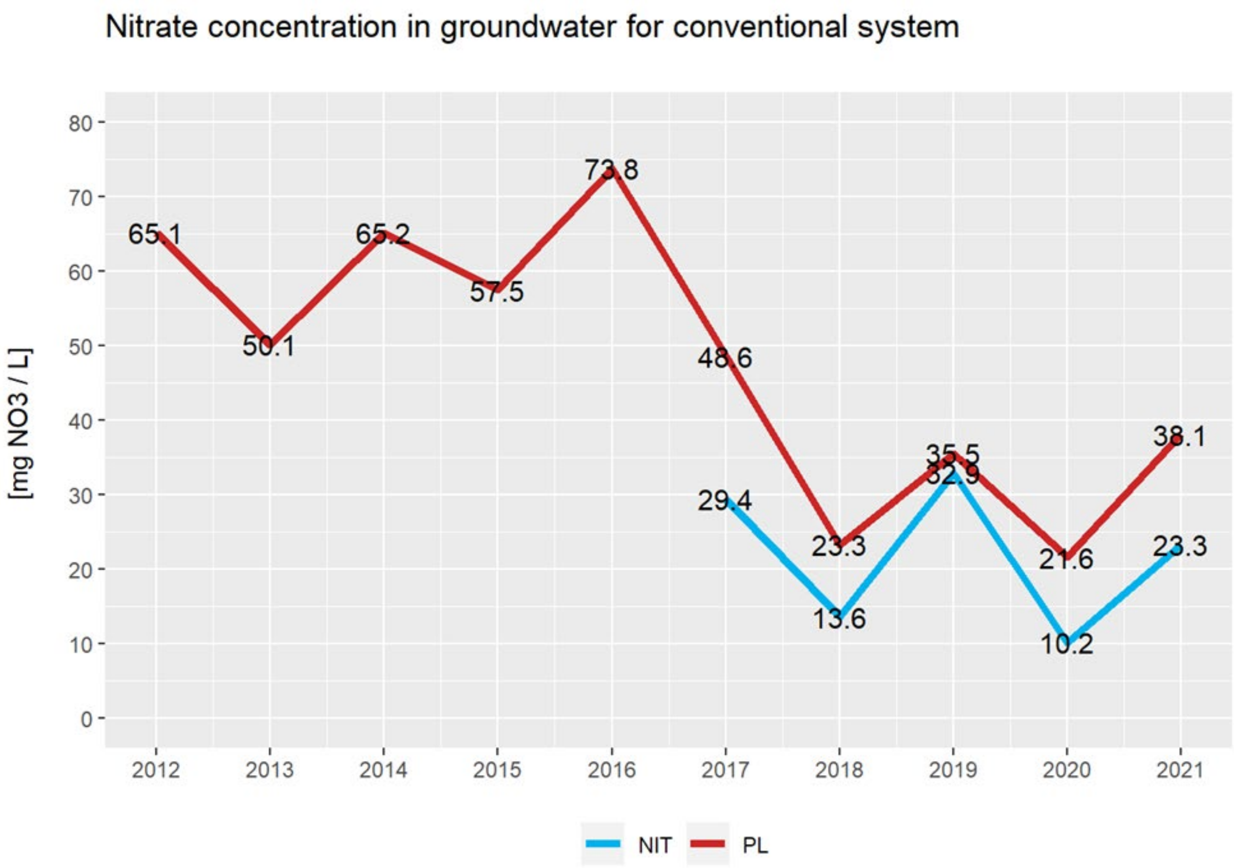

Figure 14. *Nitrate concentration in the groundwater (mg NO3/L) for Non-inversion Tillage and ploughing in a conventional farming system over the years 2012 up and till 2021.*

3.4.1.2 Organic

The nitrate concentrations for an organic farming system in the groundwater are shown in Figure 15. These concentrations were only measured since 2017 for Non-inversion Tillage. These concentrations were measured in winter. The European nitrate norm for groundwater is 50 mg NO3/L. Since 2017 the levels of Non-Inversion Tillage have been underneath the norm except for the year 2021. For ploughing the levels of nitrate in the groundwater have been under this nitrate norm since 2018. There is no clear difference between the two treatment systems.

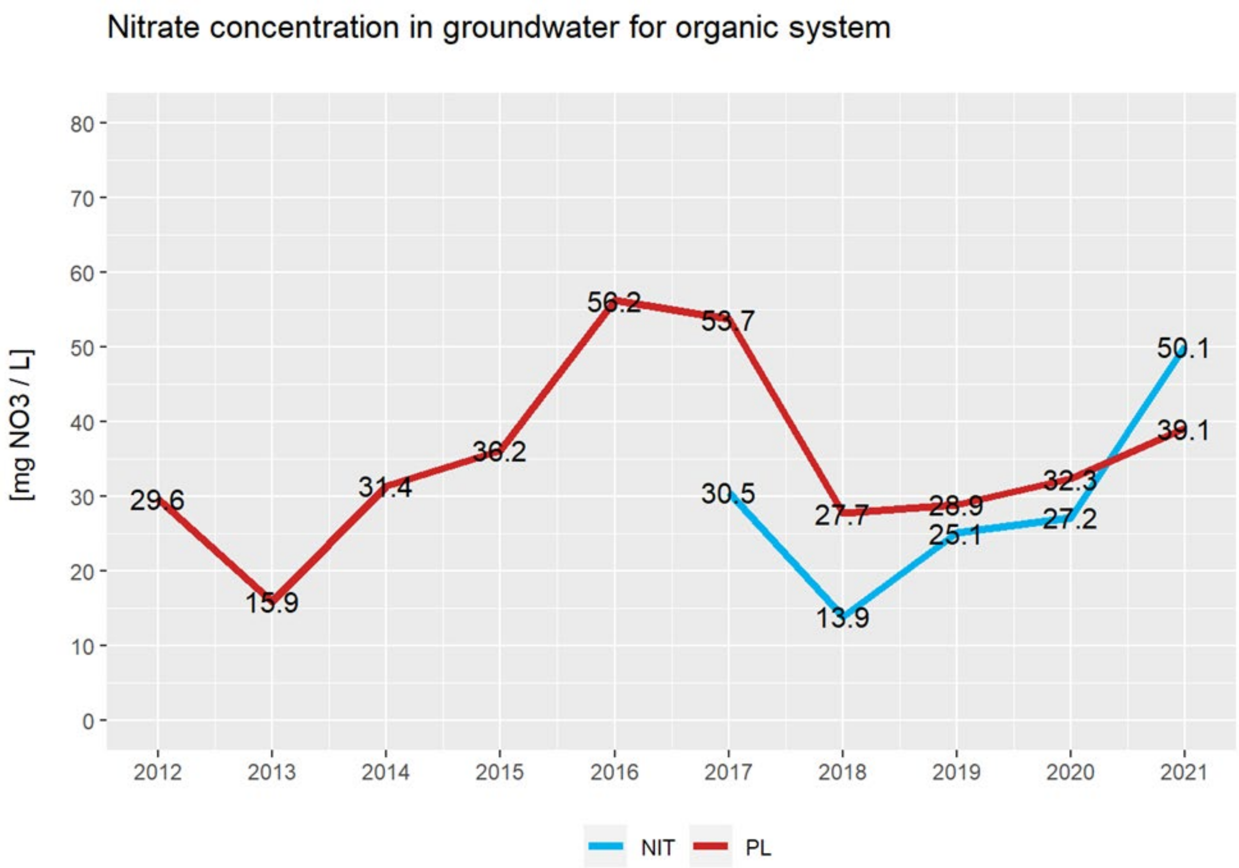

Figure 15. *Nitrate concentration in the groundwater (mg NO3/L) for Non-inversion Tillage and ploughing in an organic farming system over the years 2012 up and till 2021.*

3.5 Weed seed bank

In the conventional system, a clear trend was found towards higher weed densities in the 0-10 cm layer when non-inversion tillage was applied compared to lower weed densities (Figure 17). For the top layer, non-inversion tillage resulted in weed seedbank densities that were approximately two times higher compared to ploughing. The same effect was found for the organic system (Figure 16). Between the two management systems, the weed densities in the top layer were approximately two times higher in the organic compared to the conventional system. The explanation of the abbreviations used in the graphs can be found in Annex 5, **Table 33**.

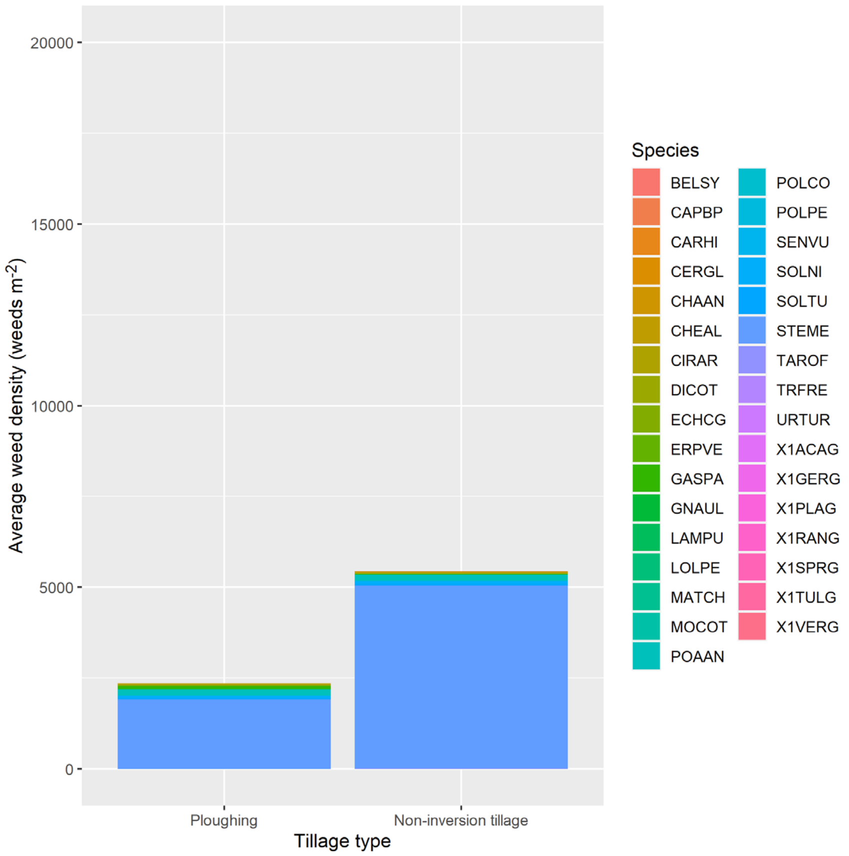

Figure 17. Weed density in the 0-10 cm soil layer as affected by tillage type for the conventional system.

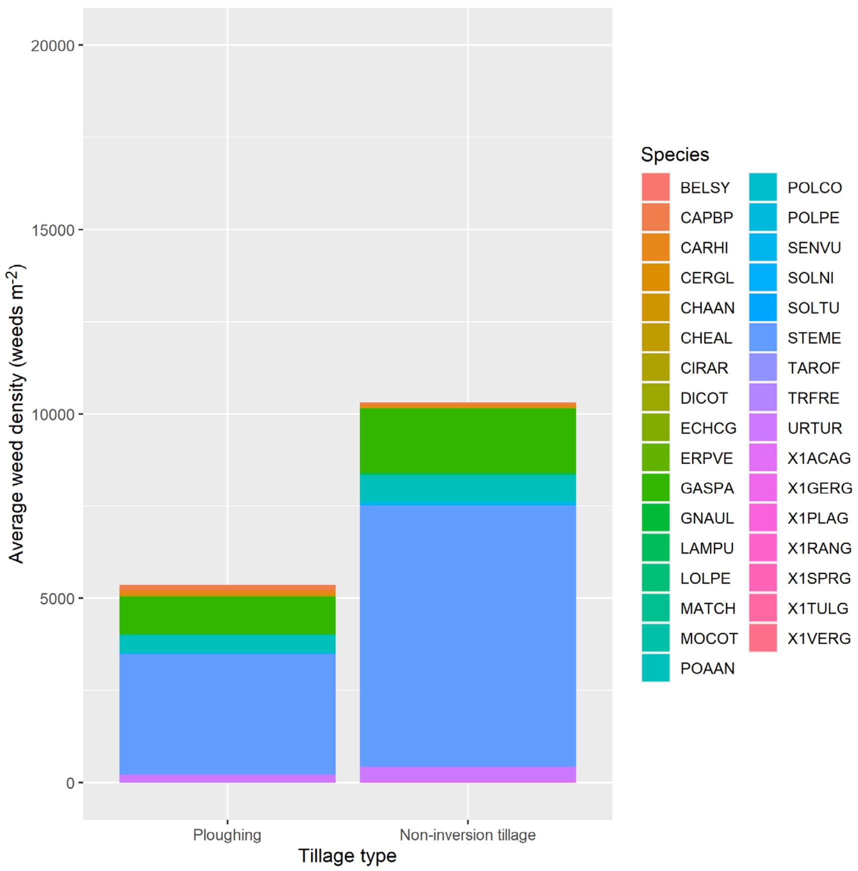

Figure 16. Weed density in the 0-10 cm soil layer as affected by tillage type for the organic system

For the deeper soil layer between 10 and 30 centimetres, the weed seedbank density that was observed for the conventional system was approximately equal for ploughing and non-inversion tillage (Figure 18). For the organic system as well, the seedbank density was equal for ploughing and non-inversion tillage (Figure 19). Comparing the conventional and organic system, weed densities in the 10-30 cm layer are more than two times higher in the organic system.
In total 33 different weed species were identified during the greenhouse germination period. The most abundant species were *Stellaria media* (chickweed), *Poa annua* (pathgrass), *Galinsoga parviflora* (kew weed) and *Chenopodium album* (goosefoot). The top soil layer in the conventional system was mainly dominated by *Stellaria media*, whereas for the organic system higher numbers of particularly *Galinsoga parviflora*, *Poa annua* and *Urtica urens* (burning nettle) were found. For the deeper layer (10-30 cm) higher numbers of the other species besides *Stellaria media* were counted. Again, in the organic system *Galinsoga parviflora* was found in high numbers.

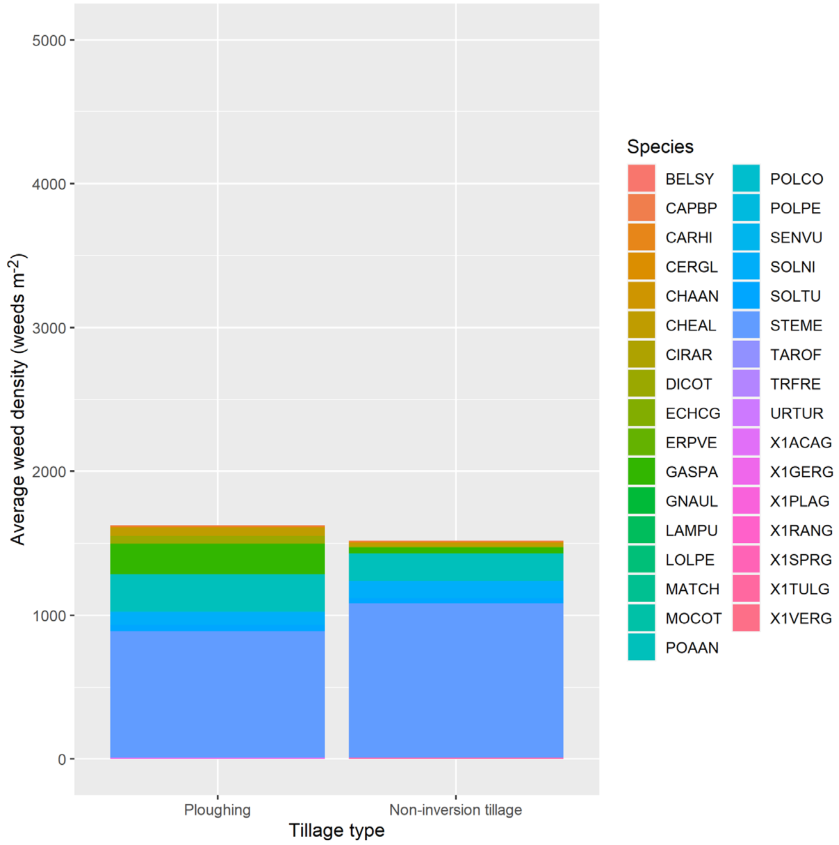

Figure 18. Weed density in the 10-30 cm soil layer as affected by tillage type for the conventional system.

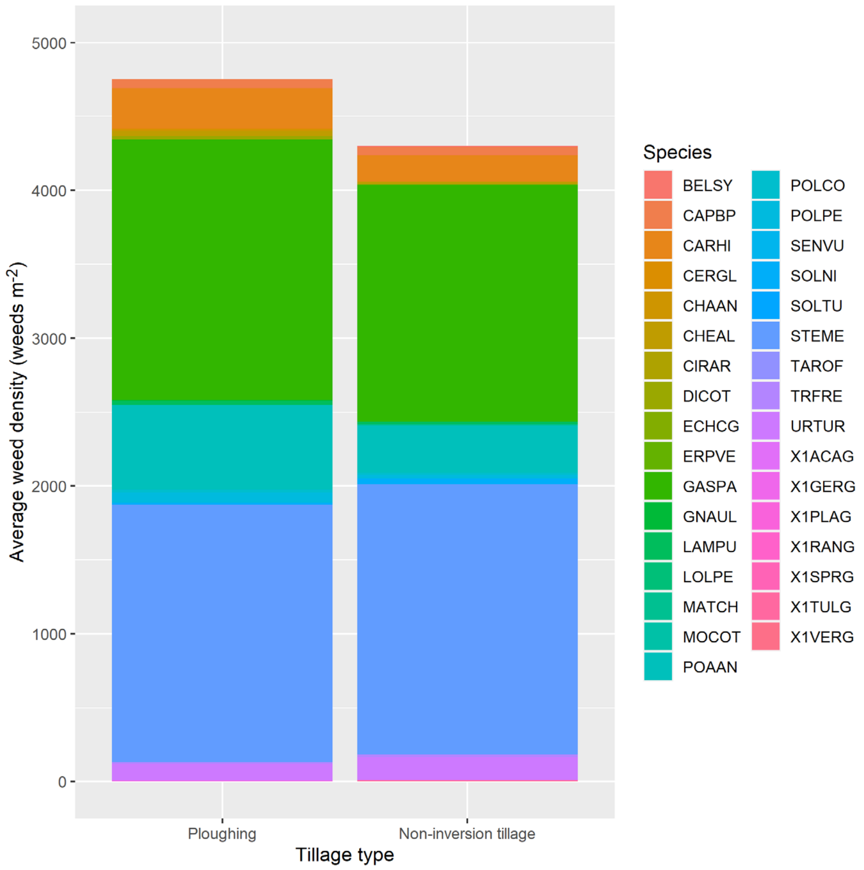

Figure 19. *Weed density in the 10-30 cm soil layer as affected by tillage type for the organic system.*

4 Discussion

4.1 Limitations in experimental set-up and data availability

4.1.1 System approach versus one factor approach

The experiment 'Bodemkwaliteit op Zand' was set up as a systems approach experiment, where a combination of management factors (= a system) is compared to another combination of other management factors. The management factor tillage was added later to the already existing systems. In fact, the tillage comparison, within a system, is a one factor comparison; only the main tillage factor is adjusted, everything else was kept the same. In practice farmers might adapt other management factors as well when they are changing their tillage system. A different tillage system might for example ask for a different crop protection system and/or another irrigation regime. This was not done in the trial in Vredepeel; on the one hand because there were specific research questions on comparing solely the tillage methods, on the other hand there were practical reasons, the trial set up made it impossible to differ in irrigation strategy per tillage method for example.

4.1.2 Statistical limitations of set-up

When possible, statistical analyses were performed. Though, the experimental set-up resulted in some limitations. First, the experiment knows no repetitions. The combination of crop type x tillage method occurs each year only once. But every crop in the six-year crop rotation was grown every year (with minor exceptions), so the different years can be seen as repetitions. The analysis was done for the years 2011-2021, which means that almost two full crop rotations are taken into account.

The experiment has a conventional as well as an organic cropping system. Those systems are comparable in terms of crop rotation and tillage methods amongst others, but because of the physical distance between the plots, the systems do not allow for comparison. Previous analyses have shown that the difference in location of the systems explains (some of) the differences in soil quality and groundwater levels, therefore making it hard to distinguish between treatment effects and location effects. Therefore, it was decided not to compare the different systems directly with one another.

4.1.3 Data availability

The set of research questions of an experiment determine the parameters that need to be measured to be able to give conclusive answers to these research questions, in an ideal situation. In practice new research questions can arise, especially with long-term experiments. On the other hand there are budgets that unfortunately can limit the amount of measurements that can be done.

Since ploughing has been the main tillage treatment in the experiment for a long time and non-inversion tillage was added later, there are less measurements available. Not all parameters were measured from the start of the introduction of NIT, also because effects of the practice were expected only after some years. Not all parameters were measured on all the fields, because of lack of budget. For some parameters, like chemical soil quality, it was chosen to measure every year in NIT, but only on the so called 'measurement fields, of which there are two in the conventional system and two in the organic system. With an unequal amount of data for the two treatments it is hard to do a statistically sound analysis. Where possible a statistical analysis was done, the other data presented can only be seen as an indication, and no solid conclusions can be drawn from them.

4.2 Research questions

4.2.1 Effects of non-inversion tillage on crop yields and quality

Overall, non-inversion tillage did not seem to have large effects on crop yields. While some crops, such as potatoes and spring barley, had an on average slightly higher yield, this was counterbalanced by crops as silage maize and carrots. A similar yield from ploughed and non-inversion tilled fields is in line with the already existing literature on the effects of reduced tillage on crop yields. Although a limited amount of studies is conducted to study the effects of reduced tillage on crop yields in North-western Europe, the effects seem to vary per crop type. Van den Putte et al. (2010) conducted a meta-analysis on the effects of soil tillage on crop growth in Europe and stated that root and tuber crops appear to be the least affected by conservation tillage. This is also supported by Selin Norén et al. (2022), who found that potatoes grown in non-inversion tillage systems yielded on average 1.5% more than potatoes grown in tilled soils. Nevertheless, Selin Norén et al. add to this the effects of reduced/non-inversion tillage on crop yields are usually minimal and depend on additional factors such as soil type and climatic circumstances. This also affects the profitability of non-inversion tillage. Bijker et al. (2022) conclude that non-inversion tillage on sandy soils has a minor positive effect on profits because of the generally slight reduction in costs with a similar crop yield. However, due to variations in crop yields the yield stability decreases slightly.

The marginal impact on crop yields applies to both organic and conventional farming systems. Armengot et al. (2014) conducted a study in which the effects of reduced tillage and conventional tillage were compared in an organic farming system. Despite a weed increase, they did not find a decrease in crop yields. Likewise, Mäder and Berner (2011) observed no decrease in yields in organically grown crops in a reduced tillage system. This is in line with the findings of this study, where the differences in effect on crop yield in both organic and conventional farming systems were minimal.

4.2.2 Effects of non-inversion tillage on soil quality

4.2.2.1 Organic matter content

The data showing the organic matter content in the soil when ploughing was performed shows more variation between the years and fluctuates more. This could have been influenced by a small variation of sample depth or by a large in field variation. Nevertheless, these variations seem to be much smaller when looking at Non-inversion Tillage, making it plausible that the organic matter content in the soil is less stable when ploughing is performed. Moreover, an interesting result was observed in 2021, at that time the organic matter content in the soil where Non-Inversion Tillage was performed dropped to a level which is almost equal to that of the soil where ploughing is practiced.

4.2.2.2 Chemical soil quality

The results showed that the total N contents in soils with a low nutrient input arehigher in the non-inversion tillage system compared to the ploughing system. Based on different studies performed on the effects of reduced tillage, this was to be expected. For instance, van Eerd et al. (2014) discovered that total N contents in the soil were greater under no-till practices compared to moldboard ploughing. Notably, their study revealed that the influence of the tillage method had a more pronounced effect on total nitrogen levels than the choice of crop rotation.

Mondal & Chakraborty (2022) conducted a global-scale meta-analysis focusing on the impact of no-tillage practices and concluded that total nitrogen concentration increased by 21% in no-tillage systems. This effect was observed in the top 0-10 cm layer of soils in different soil types but was particularly visible in regions with temperate climates. The notable rise in total nitrogen content was attributed to two key factors: the presence of crop residues on the soil surface and the retention of soil organic carbon. Soil organic carbon serves as a source of nitrogen in the form of soil organic nitrogen. During the decomposition of soil organic matter, the nitrogen is mineralized resulting in an increase of the total N content. The increased N content generally results in a decreased C:N ratio in less disturbed soils (Lou et al., 2012; Gajda & Przewloka, 2012). This was also observed during this study, as in most years the C:N ratio was smaller in fields that were non-inversion tilled than in ploughed fields. Though, as the experiment extended over a longer period, the difference in ratio diminished.

For similar reasons as the total N content, P and K values in the topsoil generally increase in reduced tillage systems. For instance, Deubel, Hofmann and Orzessek (2011) found that in a reduced tillage system, P and K concentrations sharply increased because of the relocation of plant residues to the topsoil. Although the Pw and K-numbers in some years were higher in non-inverted fields than ploughed fields, this pattern was not constant over the entire study. This could possibly be explained by the crop grown in the preceding year. Furthermore, no separate measurements were made for the topsoil, while most studies indicate a change in this layer. Likewise, the CEC generally increases in the top layers of less disturbed soils (Bartlova et al., 2015). Yet, the results of this study seem to indicate an increase in the CEC in non-inversion tilled fields.

There seems to be no consensus on the effects of different tillage types on soil pH. Carr et al. (2013) state that the impact of tillage on soil pH is minimal, but that the results vary per study. For instance, Gadermaier et al. (2012) found a significant reduction of pH in soils under reduced tillage. They suggest that long-term use of reduced tillage could lower pH levels in top-soil layers because of near-surface accumulation of organic acids and leaching of basic cations to deeper depths. Likewise, Berner et al. (2008) and Romaneckas (2016) found a significant reduction in soil acidity at 0-10 cm depth caused by accumulation of organic acids.

In a meta-analysis conducted by Li et al. (2020), it was found that no-till practices generally result in a decrease in soil pH, especially during the first 6 years of adoption. However, they also note that in regions with consistently high rainfall and in soils with a low clay content where initial soil pH values are already low, the impact of reduced tillage on soil pH may be limited. This could potentially explain the minimal changes in soil pH observed in this study, as the initial pH values were already at a low level. But moreover, pH can and was easily and actively influenced by liming.

Overall, non-inversion tillage does not consistently improve the chemical composition of the soil. Some aspects, particularly the total N content, improved because of a reduction in soil disturbance in the sandy soils in Vredepeel. Other factors, such as the Pw- and K-values, are less affected, despite expectations from existing literature. Most of the literature studies mentioned compared no-till to ploughing and did not research non-inversion tillage. Non-inversion tillage should be positioned between no-till and ploughing, in terms of intensity of disturbing the soil. Although chemical composition does not decrease because of non-inversion tillage, it is not definitively proven to have a consistently positive effect.

4.2.2.3 Physical soil quality

The results of this study did not show any differences on physical soil quality parameters for non-inversion tillage systems or ploughed systems. Selin Norén et al. (2022) summarized the physical soil quality measurements done by others over the years in BKZ and drew the same conclusions. These conclusions contradict with the existing international literature on this topic. For instance, López-Garrido et al. (2014) found an increase in soil compaction in a reduced tillage system. The penetration resistance for plant roots reached prohibitive values resulting in substantial crop yield losses. For this study, the penetration resistance in the conventional system did not reach prohibitive values. In the organic system, the penetration resistance increased in both the non-inversion tilled fields and the ploughed fields, indicating that this increase might be caused by other factors. Similarly, Celik (2011) found that both the penetration resistance and bulk density increased in less disturbed soils. However, due to the limited amount of data available on bulk density, no conclusions can be drawn on this parameter.

4.2.2.4 Biological soil quality

Soil Microbiology

Only in the measurements in 2021 a difference was detected between ploughing and non-inversion tillage in the conventional system. A higher microbial biomass with non-inversion tillage could be due to higher concentrations of organic matter in the upper soil layer and the lack of disturbance of the fungal mycelial network. In 2020, there was no difference between ploughing and non-inversion tillage. However, in that year ploughing and non-inversion tillage were only measured in the organic system.

Plant parasitic nematodes

The average population density of *P. penetrans* varied from year to year due to seasonal differences in e.g. temperature and length of the growing season and differences in levels of infestation among the fields. Depending on whether a good host or a non-host is grown on an infested field, the average population density may increase or decrease. In the conventional system, *Tagetes* was grown as a cover crop following canning peas a few times. *Tagetes* acts as a catch crop for *P. penetrans*, leading to a very strong decrease in the level of Infestation. *Tagetes* was grown among others in the years 2014 and 2019, which caused a strong decrease in the average density of *P. penetrans* in these years. Among others due to the cultivation of *Tagetes* in the conventional system, the average density of *P. penetrans* in this system was somewhat lower than in the organic system, where *Tagetes* was not grown.

Tillage type did not have a clear effect on the development of the most important plant parasitic nematode species. This does not imply that tillage may not have an effect on the degree of damage that these nematode species may cause. The level of damage in a crop is not only determined by the density of the nematodes in the soil, but also by other factors such as organic matter content, soil moisture and soil structure that are influenced by tillage type.

Nematode community

The preceding crop had the largest effect on the composition of the nematode community. As could be expected, plant feeding nematodes responded to the crops; the numbers were higher after growing spring barley and black oat than after leek. It is supposed that plant feeders are affected more by the preceding crop than by tillage (D'Hose *et al*., 2018). When developing nematode community analysis as an indication of soil quality, it seems advisable to choose sampling after one specific crop.

After the growth of two crops, spring barley-black oat and leek, we found a contrasting effect of tillage on bacterial feeders and nematodes in CP1- and CP2-groups. The amount of information on the effect of soil tillage on the nematode community is limited. A comparison of field experiments showed that 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 topsoil 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, caution is advised in the interpretation of the results, considering the confounding effect of location (field) and treatment.

4.2.3 Effects of non-inversion tillage on nitrogen losses

The effects of non-inversion tillage on nitrogen losses were studied in the conventional system and the organic system. Between the systems there is a difference in fertilisation products and doses, but the amount and products applied were always the same for the two tillage treatments within one system. The results show that the nitrogen supply, removal, and the difference in the nitrogen balance are negligible. Yet, both the mineral nitrogen content in the soil after harvest and in autumn and the nitrate concentration in the groundwater was lower for non-inversion tillage in both the organic and the conventional system.

Although it is not possible to firmly identify the exact reason, it is hypothesised that the reduction in mineral nitrogen in the soil and nitrate concentration in the groundwater is due to a decreased mineralization. Mineralization is the process by which ammonium (NH_4^+) is converted into nitrate (NO_3^-). Nitrate is highly soluble in water and can be easily leached into surface waters. This process of mineralization is carried out by soil organisms, which require oxygen to perform their metabolic functions. However, due to reduced soil disturbance as a result of non-inversion tillage, less oxygen is available in the upper soil layer. Additionally, the presence of crop residues on the soil surface can create a mulch layer, limiting oxygen exposure further. As a result, when crop residues are incorporated into the soil, less oxygen is available for soil organisms to carry out the mineralization process.

Fully anaerobic circumstances can in turn stimulate the denitrification of NO_3^-. Denitrification is the process in which NO_3^- is converted into N_2 and O_2 and happens in anaerobic circumstances. Denitrification could explain the gap in nitrogen supply and discharge. However, the amount of denitrification taking place highly varies per location, as denitrification is also affected by soil temperature and soil moisture levels. In case of partial anaerobic circumstances denitrification does not work optimally and nitrous oxide (N_2O) is formed (Slier & Velthof, 2021). In a meta-analysis of Mei et al (2018) it was indeed concluded that non-inversion tillage, and other forms of reduced tillage led to a significant increase in N_2O emissions.

Bösch et al (2022) found that after 40 years of non-inversion tillage the soil microbial community changed; an increase of diversity and abundance of fungal denitrifier communities was found, and therewith denitrification and nitrous oxide emissions increased.

4.2.4 Effects of non-inversion tillage on weed seedbank

Weeds compete with crops and could potentially cause yield losses up to 32% if not controlled (Oerke and Dehne 2004). 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 are an important part of the toolbox for weed management. An integrated approach is needed to for sustainable weed management. Riemens et al. (2022) proposed an integrated weed management (IWM) framework consisting of five pillars that contribute to weed management. Field and soil management can be a component of an IWM approach, of which primary tillage is one of the measures. Especially in organic systems, weed management has often been indicated as a major challenge for sustainable crop production (Liebman and Davis 2009; Bàrberi 2002; Bond and Grundy 2001).

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 a trial period of 11 years. 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. The results presented should be interpreted as such.

Comparing the overall effect of non-inversion tillage versus standard tillage practices, it can be concluded that non-inversion tillage results in higher weed seedbank densities in the top layer than ploughing. The organic cropping system has higher weed seedbank densities compared to the conventional system. The higher densities for the organic system in the deeper soil layer underpin this statement. The weed density in the top layer is a clear indicator of the potential weed infestation levels that could be found in following cropping seasons. Higher weed densities during the growing season may be expected under non-inversion tillage practices compared to ploughing.

For non-inversion tillage practices 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). Accordingly, this study showed that with non-inversion tillage most germinating seeds were found in the 0-10 cm layer. Under ploughing, the vertical distribution of seeds was more uniform compared to non-inversion tillage, yet highest seedbank density was found for the top layer. The higher seedbank densities in the organic fields may be explained by the fact that in organic farming the efficacy of direct weed control measures is more variable than in an herbicide-based weed control strategy. In years with dry spring conditions, mechanical control will likely be effective but in wet springs mechanical weeding is more difficult. The higher abundance of *Galinsoga parviflora* and *Urtica urens* in the organic system may also be a result of this when control of these species is insufficient in certain years. In addition, for *Galinsoga* species germination is strongly affected by light. Mechanical weeding techniques such as harrowing or hoeing will expose the seeds to light. A recent study by De Cauwer et al. (2021) showed that control of *Galinsoga* species may be improved under non-inversion tillage, especially when fertilisation strategies are optimised simultaneously. However, no effect of tillage type under organic management on these species is observed. Again, this is a result of a whole system approach including many operations that make a mechanistic analysis impossible.

4.3 Overall discussion

Overall it turns out that the effects of non-inversion tillage versus ploughing on a sandy soil are rather small. The biggest differences found were the decrease in nitrogen losses, and the increase in weed densities. The latter was experienced as a real challenge in the organic cropping system, more than in the conventional cropping system where chemical weed control could sufficiently control the higher number of weeds. The decrease of nitrogen losses under non-inversion tillage is interesting in the light of the challenges that the region is facing with nitrate leaching to the groundwater. More in depth understanding of the processes by measuring e.g. soil biology and gaseous emissions is needed to fully understand what is causing the differences.

5 Conclusion

This report gave answer on the question on the effect of non-inversion tillage, compared to ploughing on effects of 1) crop yield and quality, 2) soil quality, 3) the weed seed bank and 4) nitrogen losses in a long-term experiment in the southeast of the Netherlands on sandy soils.

1. What is the effect of non-inversion tillage on crop yield and quality*?*
There are no significant effects of non-inversion tillage on crop yields and quality.

2. What is the effect of non-inversion tillage on soil quality?
Non-inversion tillage does not consistently improve nor decline the chemical soil quality. No clear effects of tillage on soil physical parameters were found, but this conclusion is based on a very small number of measurements. Factors other than tillage (for example the preceding crop) had the most effect on soil biological parameters.

3. What is the effect of non-inversion tillage on the weed seed bank?
There is a clear effect of non-inversion tillage on the weed seed bank: non-inversion tillage leads to higher weed densities compared to ploughing.

4. What is the effect of non-inversion tillage on nitrogen losses?
There are indications that non-inversion tillage decreases the nitrogen losses, in terms of mineral nitrogen content in the soil, and nitrate concentrations in the groundwater.

In general: non-inversion tillage is applicable in an arable system on the south-eastern sandy soils. The effects of this tillage method are minor and barely significant.

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Annex 1 Sowing, planting and harvesting dates from 2011 onwards

Printed obliquely = assumption. Assumptions are based on among others data from other years or crops.
In the table below the harvest dates of the test plots are mentioned below the heading Harvest. Harvest dates of the whole parcel are always be executed after the yields of the test plots. Mainly for leek this date is often further away. Very often it has happened a parcel of leek or pea for tinning is not harvested.

Table 17 *Organic farming system*

	Fields	Sow/plant date	Emergence	Harvest	Gmn sowing	Gmn work in
2011						
Leek	32.1	22-june-11	-	10-oct-11	-	-
Spring barley	32.2	22-mar-11	*1-apr-11*	1-aug-11	1-sept-11	12-dec-11
Maize	33.1	2-may-11	*15-may-11*	30-sept-11	*10-oct-11*	20-mar-12
Carrot	33.2	25-may-11	3-june-11	30-sept-11	-	-
Pea for tinning	34.1	9-apr-11	21-apr-11	28-june-11	14-july-11	5-june-12
Potato	34.2	30-mar-11	27-apr-11	28-july-11	1-sept-11	12-dec-11
2012						
Spring barley	32.1	15-mar-12	29-mar-12	24-july-12	15-aug-12	5-dec-12
Carrot	32.2	23-may-12	1-june-12	23-oct-12	-	-
Potato	33.1	23-mar-12	5-may-12	26-july-12	10-aug-12	7-mar-13
Maize	33.2	7-may-12	17-may-12	17-sept-12	9-oct-12	22-mar-13
Leek	34.1	27-june-12	-	25-oct-12	-	-
Pea for tinning	34.2	16-mar-12	4-apr-12	22-june-12	29-june-12	7-june-13
2013						
Carrot	32.1	23-may-13	1-june-13	14-oct-13	-	-
Maize	32.2	8-may-13	29-may-13	4-oct-13	22-oct-13	11-mar-14
Pea for tinning	33.1	1-apr-13	24-apr-13	28-june-13	31-july-13	26-may-14
Potato	33.2	10-apr-13	12-may-13	9-aug-13	4-sept-13	19-feb-14
Spring barley	34.1	4-apr-13	20-apr-13	2-aug-13	4-sept-13	19-feb-14
Leek	34.2	28-june-13	-	31-oct-13	-	-
2014						
Maize	32.1	2-may-14	18-may-14	23-sept-14	13-oct-14	12-mar-15
Potato	32.2	28-mar-14	26-apr-14	17-july-14	25-aug-14	12-mar-15
Leek	33.1	26-june-14	-	5-nov-14	-	-
Pea for tinning	33.2	21-mar-14	5-apr-14	20-june-14	18-july-14	19-may-15
Carrot	34.1	21-may-14	1-june-14	3-oct-14	20-oct-14	20-apr-15
Spring barley	34.2	17-mar-14	20-apr-14	18-july-14	25-aug-14	20-apr-15
2015						
Potato	32.1	11-apr-15	8-may-15	18-aug-15	28-aug-15	15-mar-16
Pea for tinning	32.2	16-apr-15	29-apr-15	7-july-15	30-july-15	17-may-16
Spring barley	33.1	24-mar-15	10-apr-15	1-aug-15	28-aug-15	11-mar-16
Leek	33.2	25-june-15	-	4-nov-15	-	-
Maize	34.1	5-may-15	16-may-15	9-oct-15	15-oct-15	*11-mar-16*

Carrot	34.2	29-may-15	8-june-15	26-oct-15	-	-
2016						
Pea for tinning	32.1	22-mar-16	8-apr-16	13-june-16	15-july-16	7-june-17
Leek	32.2	8-july-16	-	1-nov-16	-	-
Carrot	33.1	26-may-15	19-june-16	11-oct-16 en 27-oct-16	-	-
Spring barley	33.2	21-mar-16	5-apr-16	20-july-16	24-aug-16	29-nov-16
Potato	34.1	8-apr-16	6-may-16	18-july-16	24-aug-16	29-nov-16
Maize	34.2	4-may-16	11-may-16	16-septt-16	*1-oct-16*	*29-nov-16*
2017						
Pea for tinning	34.1	30-mar-17	14-apr-17	14-june-17	29-june-17	3-may-18
Leek	32.1	27-june-17	-	13-nov-17	-	-
Carrot	33.2	26-may-17	2-june-17	18-oct-17	-	-
Spring barley	32.2	24-mar-17	4-apr-17	18-july-17	24-aug-17	*6-apr-18*
Potato	34.2	3-apr-17	12-may-17	18-aug-17	26-aug-17	*21-mar-18*
Maize	33.1	5-may-17	17-may-17	2-oct-17	20-oct-17	*12-mar-18*
2018						
Pea for tinning	34.2	10-apr-18	20-apr-18	13-june-18	26-june-18 16-aug-18	8-aug-18 10-oct-18
Leek	34.1	22-june-18	-	6-nov-18	-	-
Carrot	32.2	31-may-18	6-june-18	23-oct-18	-	-
Spring barley	32.1	30-mar-18	11-apr-18	6-july-18	23-aug-18	13-nov-18
Potato	33.1	18-apr-18	7-may-18	15-aug-18	21-sept-18	1-mar-19
Maize	33.2	3-may-18	10-may-18	5-sept-18	12-sept-18	1-mar-19
2019						
Pea for tinning	33.1	9-apr-19	23-apr-19	24-june-19	12-july-19 8-aug-19	6-aug-19 25-sept-19 25-may-20
Leek	34.2	26-june-19	-	12-nov-19 en 3-dec-19	-	-
Carrot	32.1	31-may-19	7-june-19	29-oct-19	-	-
Spring barley	34.1	1-apr-19	14-apr-19	22-july-19	3-sept-19	12-dec-19
Potato	33.2	12-apr-19	6-may-19	12-aug-19	3-sept-19	19-mar-20
Maize	32.2	26-apr-19	15-may-19	25-sept-19	12-oct-19	24-mar-20
2020						
Pea for tinning	33.2	30-mar-20	15-apr-20	24-june-20	7-july-20 9-sept-20	18-aug-20 27-oct-20 21-may-21
Leek	33.1	23-june-20	-	23-nov-20	-	-
Carrot	34.1	29-may-20	9-june-20	22-oct-20	-	-
Spring barley	34.2	28-mar-20	8-apr-20	20-july-20	2-sept-20	17-dec-20
Potato	32.2	10-apr-20	3-may-20	17-aug-20	2-sept-20	23-mar-21
Maize	32.1	25-apr-20	10-may-20	14-sept-20	26-sept-20	*29-mar-21*
2021						
Pea for tinning	32.2	13-apr-21	29-apr-21	1-july-21	22-july-21	4-sept-21
Leek	33.2	30-june-21	-	17-nov-22	-	-
Carrot	34.2	1-june-21	9-june-21	2-nov-21	-	-
Spring barley	33.1	30-mar-21	15-apr-21	20-july-21	24-aug-21	28-oct-21
Potato	32.1	2-apr-21	8-may-21	6-aug-21	24-aug-21	28-oct-21
Maize	34.1	1-may-21	13-may-21	23-sept-21	8-oct-21	*1-mar-22*

Conventional:

	Parcels	Sow/plant date	Emergence	Harvest	Gmn sowing	Gmn work in
2011						
Potato	27.1&27.2	6-apr-11	11-may-11	14-septt-11	28-sept-11	*1-mar-12*
Pea for tinning	18.1&18.2	9-apr-11	21-apr-11	28-june-11	13-july-11	28-june-12
Leek	17.1&17.2	29-june-11	-	9-nov-11	-	-
Spring barley	28.1&28.2	22-mar-11	*1-apr-11*	1-aug-11	12-aug-11	12-dec-11
Sugar beet	16.1&16.2	25-mar-11	*8-apr-11*	15-sept-11	28-septt-11	16-mar-12
Maize	26.1&26.2	28-apr-11	*10-may-11*	26-sept-11	10-oct-11	16-mar-12
2012						
Potato	26.1&26.2	4-mar-12	14-may-12	7-sept-12	9-oct-12	7-mrt-13
Pea for tinning	27.1&27.2	17-mar-12	4-apr-12	26-june-12	29-june-12	7-june-13
Leek	18.1&18.2	3-july-12	-	28-nov-12	-	-
Spring barley	17.1&17.2	12-mar-12	4-apr-12	24-july-12	15-aug-12	5-dec-12
Sugar beet	28.1&28.2	23-mar-12	6-apr-12	24-sept-12	-	-
Maize	16.1&16.2	2-may-12	15-may-12	17-sept-12	9-oct-12	7-mar-13
2013						
Potato	16.1&16.2	15-apr-13	20-may-13	18-sept-13	30-sept-13	18-feb-14
Pea for tinning	26.1&26.2	1-apr-13	24-apr-13	28-june-13	5-july-13	3-june-14
Leek	27.1&27.2	26-june-13	-	14-nov-13	-	-
Spring barley	18.1&18.2	28-mar-13	19-apr-13	1-aug-13	20-aug-13	18-feb-14
Sugar beet	17.1&17.2	5-apr-14	18-apr-13	4-nov-13	-	-
Maize	28.1&28.2	8-may-13	27-may-13	4-oct-13	22-oct-13	19-feb-14
2014						
Potato	28.1&28.2	11-apr-14	14-may-14	15-sept-14	20-oct-14	5-mar-15
Pea for tinning	16.1&16.2	21-mar-14	5-apr-14	20-june-14	17-july-14	5-mar-15
Leek	26.1&26.2	1-july-14	-	17-nov-14	-	-
Spring barley	27.1&27.2	17-mar-14	1-apr-14	18-july-14	25-aug-14	5-mar-15
Sugar beet	18.1&18.2	20-mar-14	5-apr-14	21-oct-14	31-oct-14	19-mar-15
Maize	17.1&17.2	19-apr-14	29-apr-14	23-septt-14	13-oct-14	19-mar-15
2015						
Potato	17.1&17.2	20-apr-15	19-may-15	16-sept-15	15-oct-15	15-mar-16
Pea for tinning	28.1&28.2	16-apr-15	30-apr-15	7-july-15	30-july-15	17-may-16
Leek	16.1&16.2	23-june-15	-	11-nov-15	-	-
Spring barley	26.1&26.2	24-mar-25	10-apr-15	1-aug-15	31-aug-15	9-mar-16
Sugar beet	27.1&27.2	27-mar-15	10-apr-15	20-oct-15	23-oct-15	*20-mar-16*
Maize	18.1&18.2	24-apr-15	8-may-15	9-oct-15	15-oct-15	*5-mar-16*
2016						
Potato	18.1&18.2	15-apr-16	17-may-16	16-aug-16	24-aug-16	30-nov-16
Pea for tinning	17.1&17.2	22-mar-16	4-apr-16	13-june-16	14-july-16	12-may-17
Leek	28.1&28.2	30-june-16	-	8-nov-16	-	-
Spring barley	16.1&16.2	21-mar-16	6-apr-16	20-july-16	24-aug-16	30-nov-16
Carrot	26.1&26.2	26-may-16	4-june-16	28-oct-16	-	-
Maize	27.1&27.2	30-apr-16	11-may-16	16-septt-16	-	-
2017						
Potato	27.1&27.2	7-apr-17	16-may-17	17-aug-17	24-aug-17	*21-mrt-18*
Pea for tinning	18.1&18.2	30-mar-17	14-apr-17	14-june-17	29-june-17	3-may-18
Leek	17.1&17.2	28-june-17 en 30-june-17	-	13-nov-17	-	-
Spring barley	28.1&28.2	24-mar-17	4-apr-17	18-july-17	24-aug-17	*18-may-18*
Carrot	16.1&16.2	24-may-17	1-june-17	27-oct-17	-	-

	Parcels	Sow/plant date	Emergence	Harvest	Gmn sowing	Gmn work in
Maize	26.1&26.2	6-may-17	18-may-17	15-sept-17	3-oct-17	*21-mar-18*
2018						
Potato	26.1&26.2	28-apr-18	22-may-18	27-aug-18	21-sept-18	28-mar-19
Pea for tinning	27.1&27.2	10-apr-18	21-apr-18	8-june-18	20-july-18	13-nov-18
Leek	18.1&18.2	29-june-18	29-june-18	12-nov-18	-	-
Spring barley	17.1&17.2	29-mar-18	10-apr-18	16-july-18	23-aug-18	28-mar-19
Carrot	28.1&28.2	25-may-18	5-june-18	29-oct-18	-	-
Maize	16.1&16.2	3-may-18	11-may-18	4-sept-18	12-sept-18	28-mar-19
2019						
Potato	16.1&16.2	27-apr-19	22-may-19	19-aug-19	3-sept-19	10-dec-19
Pea for tinning	26.1&26.2	9-apr-19	23-apr-19	25-june-19	15-july-19	18-mar-20
Leek	27.1&27.2	27-june-19 en 28-june-19	-	12 nov-19 en 3-dec-19	-	-
Spring barley	18.1&18.2	1-apr-19	14-apr-19	22-july-19	4-sept-19	18-mar-20
Carrot	17.1&17.2	22-may-19	3-june-19	31-oct-19	-	-
Maize	28.1&28.2	26-apr-19	16-may-19	18-sept-19	8-oct-19	19-mrt-20
2020						
Potato	28.1&28.2	22-apr-20	17-may-20	17-aug-20	1-sept-20	17-dec-20
Pea for tinning	16.1&16.2	30-mar-20	15-apr-20	25-june-20	6-july-20	7-jan-21
Leek	26.1&26.2	23-june-20 en 24-june-20	-	30-nov-20	-	-
Spring barley	27.1&27.2	28-mar-20	8-apr-20	21-july-20	1-sept-20	17-dec-20
Carrot	18.1&18.2	25-may-20	3-june-20	23-oct-20	-	-
Maize	17.1&17.2	25-apr-20	9-may-20	14-sept-20	18-june-20	26-jan-21
2021						
Potato	17.1&17.2	23-apr-21	29-may-21	19-aug-21	1-sept-21	*??*
Green bean	28.1&28.2	7-june-21	12-june-21	30-aug-21	9-sept-21	15-apr-22
Leek	16.1&16.2	29-june-21	-	23-nov-21	-	-
Spring barley	26.1&26.2	26-mar-21	10-apr-21	20-july-21	1-sept-21	*15-dec-21*
Carrot	27.1&27.2	28-may-21	5-june-21	2-nov-21	-	-
Maize	18.1&18.2	26-apr-21	3-may-21	23-sept-21	8-oct-21	19-mrt-22

Annex 2 Fertilisation strategy

A fertilization and cultivation plan is made every year. The same amount of effective nitrogen is applied for both systems standard and low, where's the low system relies more heavily on artificial fertilizers. To calculate the amount of nitrogen application a nitrogen balance method is used. On the basis of target yield of the crop the nitrogen requirement is estimated, from which other nitrogen sources (as mineralization, deposition, nitrogen fixation) are deduced:

Effective N-application = N-need – N-min – N-mineralisation – N-deposition
– N in planting material or seed – N- fixation

The nitrogen need is based on total nitrogen uptake by the crop (including crop residues and by-products) at target yields and nitrogen utilized by the crop. Target yield is assumed to equal an average good yield obtained in the Vredepeel region on the same soil. The utilization of nitrogen is the percentage of what a crop takes up from the total effective nitrogen which is available in the nitrogen uptake period of the crop. Effects of previous years are not taken into account, but a lump sum value of soil mineralization is. The nitrogen utilization is dependent on the crop and growth circumstances.

The Nmin is equal to the Nmin content in the soil before the cultivation period starts. This Nmin is measured at 3 times of the year at different depths. The mineralization of nitrogen on the one side consist of a basic mineralization of the soil and on the other side of mineralization from fresh organic matter from crop residues, green manure crops and organic fertilization. The basic mineralization is calculated at 100 kg/year and is based on measurements of potential mineralization and model outcomes (Smit & Zwart, 2003). It is to be expected that this number decreases in time for conventional system low, because no substantial amount of organic matter are added to the soil. Mineralization of crop residues and green manure crops is estimated based on expert knowledge and rules of thumb from the Handboek Bodem en Bemesting and the Handboek Groenbemesters. The basic mineralization as well as the deposition of nitrogen are calculated over the nitrogen uptake period of the crop. Nitrogen binding from atmospheric nitrogen occurs during the tillage of legumes such as pea and clover. This is due to Rhizobium bacteria, on basis of Wijnands & Holwerda (2003).

Up to and including 2013 the conventional systems standard and low are fertilized according to the system without taking the standards of nitrogen application set by the government ('Gebruiksnormen') into account. From 2014 onwards, the restriction is made that the levels of nitrogen application set by law are not exceeded on the level of rotation. The nitrogen application standards are 20% lower in comparison with the years before for crops that are sensitive to leaching. In situations an application standard is available for a green manure, but this nitrogen is not used, this nitrogen is divided over the crops on the basis of the measured and expected need.

The nitrogen application as calculated is as efficient as possible applied with division of application times and/or application techniques as fertilization in rows. In the standard system, the basal fertilization is executed with pig slurry and/or cattle slurry complemented by artificial fertilizer. In the low system, concentrate of pig manure (mineralenconcentraat) and precipitation of air washing systems in stables (spuiwater) is used, complemented by chemical fertilizer. The slurry, concentrate of pig manure and precipitation of air washing systems in stables are injected into the soil. In the organic system cattle slurry and solid cattle manure are used. For leek vinassekali has been added, to have enough readily available nitrogen.

For the organic system the exact amount of applied cattle slurry depends on the nitrogen levels in the manure. The amount of applied phosphate and potassium largely is determined by the nitrogen supply, although it is strived to a balance in fertilization for phosphate and a maximum surplus of 40 kg/ha for potassium.

For the conventional systems standard and low, the phosphate fertilization is based on balance fertilization (supply of phosphate is equal to carrying off of phosphate). The fertilization with other nutrients was aimed at preventing shortage and is executed in accordance with the advice of fertilization (www.handboekbodemenbemesting.nl).

Next to the described fertilization, all crops in the organic system are fertilized with Borax (10 kg/ha) for boron supply. In the sugar beet crop, before seeding a fertilization of rock salt (steenzout) is applied, to serve the sodium supply. In the crops carrot, leek and spring barley fertilization is complemented by Epsom salt (bitterzout = Epso microtop). In spring barley also Manganese (Mantrac) is given.

Annex 3 Nitrogen balance

Method

Nitrogen supply

The nitrogen input factors used to determine the nitrogen surplus are the input of nitrogen from organic and inorganic fertilizers, deposition, nitrogen from sowing seeds and planting material, and nitrogen fixation by legumes.

A sample of each fertilizer applicated was tested on both organic and mineral nitrogen contents and the total nitrogen input was calculated by multiplying the fertilizer application per hectare with the measured nitrogen content. The input of (first-year) effective nitrogen from organic and inorganic fertilizers was also calculated. The amount was calculated based on effective application coefficients for the mineral and organic nitrogen fraction in the fertilizer (www.handboekbodemenbemesting.nl).

A fixed value of 5 kg/ha was used for the nitrogen in seed and planting material. The deposition was derived from measurements by RIVM for Southeast Netherlands and was determined to be 25 kg/ha (geodata.rivm.nl/gcn).

An attempt was made to estimate nitrogen fixation by grass-clover as accurately as possible. This is complicated by the fact that crop yield for grass-clover has only been determined in a few cases. When no yield estimation has been made at all, the average production of well-known grass-clover yields is used as a reference. It is assumed that the share of clover is 15% in the autumn and 40% in the spring. Finally, it is assumed that leaving the partially decomposing autumn crop has no effect on nitrogen fixation by the spring crop. This results in a nitrogen fixation rate of 12 kg of nitrogen per ton of dry matter of grass-clover.

The nitrogen fixation in peas has been calculated based on the nitrogen uptake in the dry seed x 1.17 (Baddeley et al. 2014). It is assumed that all nitrogen in the field peas is biologically fixed. This probably overestimates the amount of nitrogen fixation because fertilization also occurs and mineral nitrogen is present in the soil. Additionally, it should be noted that this determination is based on dry peas with a moisture content of 14%, while in this experiment, field peas were grown with a moisture content of 75-80%.

In addition to the total nitrogen input for calculation of the soil surplus, the effective nitrogen input from fertilizers is also calculated to compare it with the use norm for effective nitrogen. For this, a comparison is made between the legal input calculated with the default effectiveness coefficients as determined in the fertilizer legislation (www.rvo.nl) and the agricultural input based on effectiveness coefficients for the mineral and organic nitrogen fraction in the fertilizer (www.handboekbodemenbemesting.nl).

Nitrogen output

The items in the nitrogen output used to determine the soil surplus are the nitrogen output with the harvested product and the ammonia loss from the applied synthetic and organic fertilizers. The nitrogen content of the harvested products was determined and the nitrogen output was calculated by multiplying the gross yield by the nitrogen content. When the nitrogen content was not determined, the average of the years in which it was determined was used.

The ammonia-N loss from fertilizers is estimated at 0.9% of the total nitrogen application from artificial fertilizers, and at 22% and 2% of the ammonium-N applied in the form of incorporated and injected manure, respectively (Velthof et al., 2009). Ammonia loss from the grown crops is not included in the calculations.

Nitrogen balance

The nitrogen soil surplus is defined as the difference between the total nitrogen supplied by organic fertilizers and synthetic fertilizers, deposition, seed and planting material, and nitrogen fixation by legumes as calculated in section 2.2.4.1, and the nitrogen that is removed in the form of harvested products and ammonia as calculated in section 2.2.4.2.

The target value for the nitrogen soil surplus is derived from the nitrate standard (50 mg/l): for dry sandy soils such as those in the southern sandy area, with a precipitation surplus of 322 mm and a leaching fraction of 75%, the permissible nitrogen soil surplus is approximately 50 kg/ha (Schröder et al., 2015; Fraters et al., 2012).

Nitrogen efficiency

To determine the nitrogen efficiency of the crop relative to the nitrogen supplied from external sources (animal manure, fertilizer, deposition, seed/plant material, and nitrogen fixation, see also section 2.2.4.1), the nitrogen content of the marketable crop is divided by the nitrogen input from external sources.

Mineralization of organic nitrogen in manure, crop residues and cover crops
In the calculation of the soil surplus, no account is taken of mineralization from organic matter on the input side. This is because an equilibrium situation is assumed. To maintain mineralization, new organic matter needs to be invested in annually through manure and crop residues. In the case of equilibrium, the amount of nitrogen mineralized in year n from previously applied manure, crop residues, and green manure averaged over a number of years is equal to the amount of organic nitrogen applied in manure and taken up by crop residues and green manure. The mineralization and investment then balance each other out (see also **Table 18**, italicized cross-references).

***Table 19**. Nitrogen input and output terms, taking into account mineralization.*

Nitrogen input Nitrogen output	Nitrogen input Nitrogen output
N from organic fertilizer	N in crops
N from synthetic fertilizer	N in emissions
N from deposition	
N from seed/planting material	
N from nitrogen fixation	
N from mineralization of crop residues	N uptake in crop residues
N from mineralization of cover crops	N uptake in cover crops
N from mineralization of organic fertilizer	N in organic fertilizer

Results

Nitrogen supply

Figure 23 shows the nitrogen supply by fertilization per crop in the conventional system. The nitrogen supply consisted of both manure and chemical fertilizer. The source of the nitrogen supply for the conventional farming system per year is displayed in **Figure 22**. This figure shows that in 2014 new standards for the nitrogen supply in sandy soil in the South-East of The Netherlands were introduced. In the conventional system the nitrogen supply primarily consisted of manure and chemical fertilizers. A limited amount was added by of deposition, fixation from legumes, and seeds.

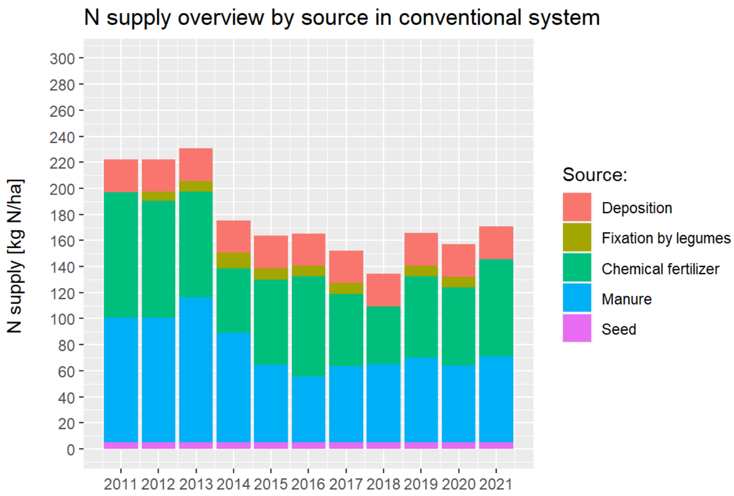

***Figure 20**. An overview of the sources of nitrogen in a conventional system per year.*

The nitrogen supply for both Non-inversion Tillage and ploughing was similar for each crop. ***Figure 25*** shows the nitrogen supply by fertilization per crop in an organic farming system. The nitrogen supple consisted of both manure and very limited chemical organic fertilizer.
The source of the nitrogen supply for the organic farming system per year is displayed in **Figure 24**. In the organic system the nitrogen supply primarily consisted of manure. A limited amount was added by deposition, fixation from legumes, and seeds.

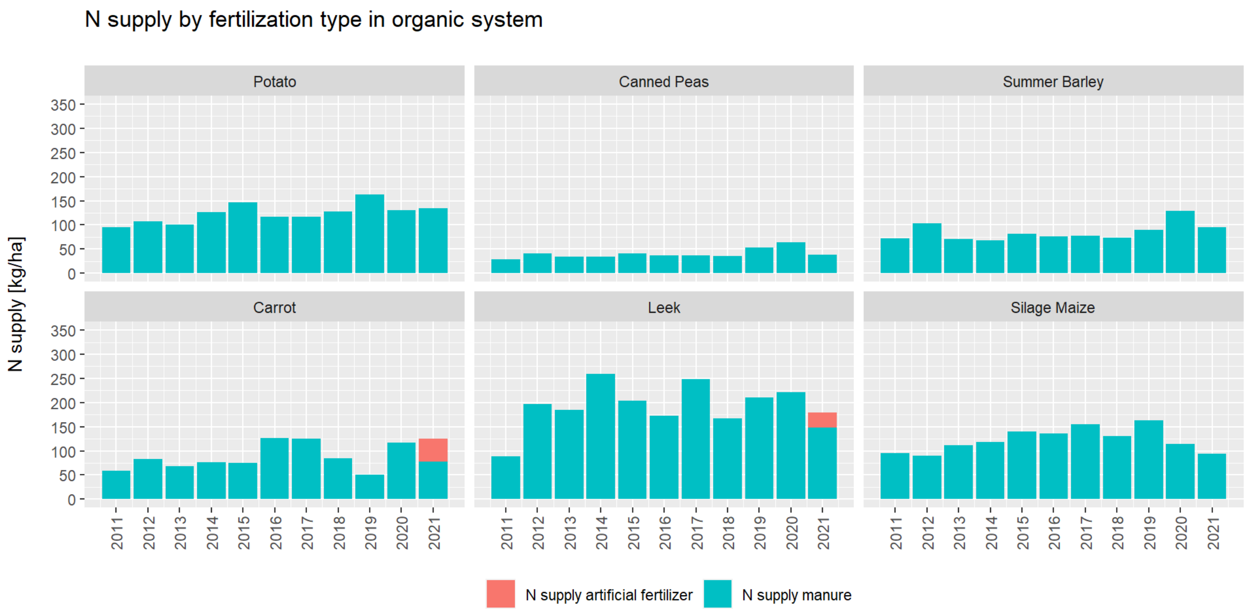

***Figure 21**. Distribution of the nitrogen supply between artificial fertilizer and manure per crop. The nitrogen supply is illustrated in kg/ha and states the years 2011 up and till 2021.*

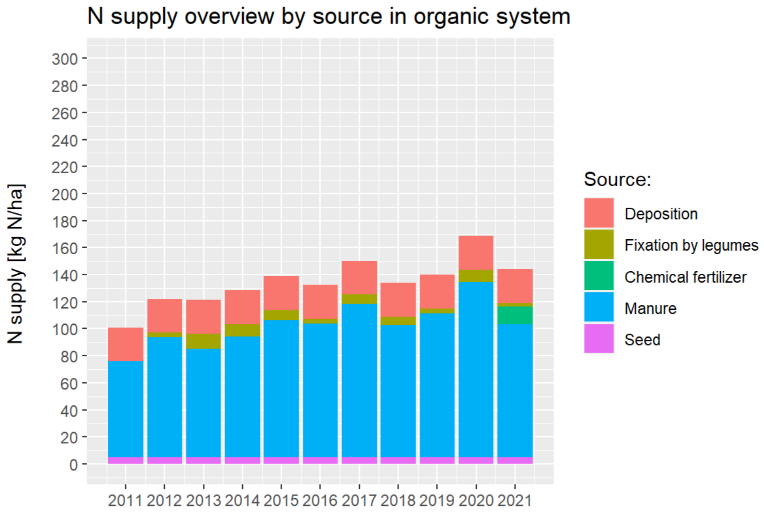

Figure 22*. An overview of the sources of nitrogen in the organic system per year*

Nitrogen removal

Conventional

Table 20*. Yearly nitrogen removal through harvested crops (kg/ha/year) in a conventional farming system. An ANOVA test showed that the difference is not significant (p=0.79).*

	NIT	PL
2011	-	-
2012	99%	100%
2013	103%	100%
2014	100%	100%
2015	99%	100%
2016	98%	100%
2017	103%	100%
2018	100%	100%
2019	100%	100%
2020	106%	100%
2021	110%	100%
Average	102%	100%

Organic

Table 21. *yearly nitrogen removal through harvested crops (kg/ha/year) in an organic farming system. An ANOVA test shows that the difference is not significant (p=0.64).*

	NIT	PL
2011	-	-
2012	97%	100%
2013	103%	100%
2014	103%	100%
2015	104%	100%
2016	108%	100%
2017	97%	100%
2018	103%	100%
2019	92%	100%
2020	113%	100%
2021	108%	100%
Average	102%	100%

Nitrogen balance

Table 22 *Difference in yearly nitrogen balance (kg/year/ha) between Non-Inversion Tillage and Ploughing in a conventional farming system*

Year	NIT	PL
2011	-	-
2012	143	142
2013	155	160
2014	80.7	81.2
2015	71.6	70.2
2016	47.4	44.9
2017	40.1	43.8
2018	28	27.6
2019	75.2	76.2
2020	46.2	50.6
2021	59.6	69.1
Average	74.7	76.6

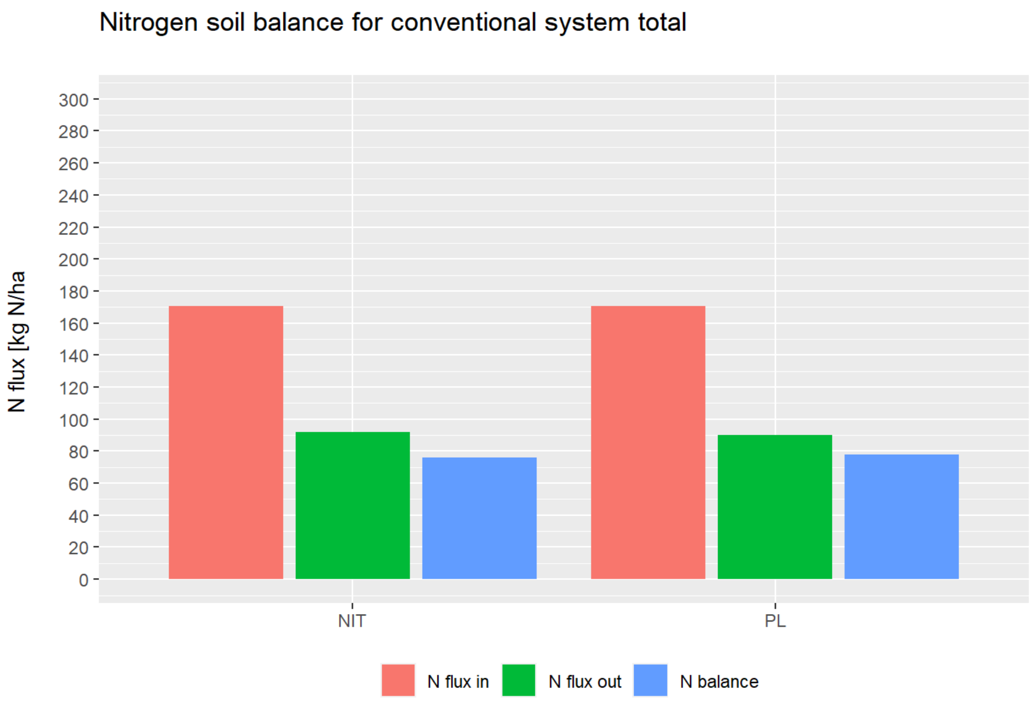

Figure 23. *Nitrogen balance (kg N/ha/year) for Non-Inversion Tillage and ploughing, the average over the years 2011 up and till 2021 for a conventional farming system*

Organic

Table 23 *difference in yearly nitrogen balance (kg/year/ha) between Non-Inversion Tillage and Ploughing in an organic farming system*

Year	NIT	PL
2011	-	-
2012	75.3	74.2
2013	60.8	64.9
2014	86.8	89.6
2015	81	82.6
2016	76	83.2
2017	76	75.7
2018	58.5	61.4
2019	85.2	82.4
2020	81.5	94.3
2021	75.3	80.9
Average	75.6	78.9

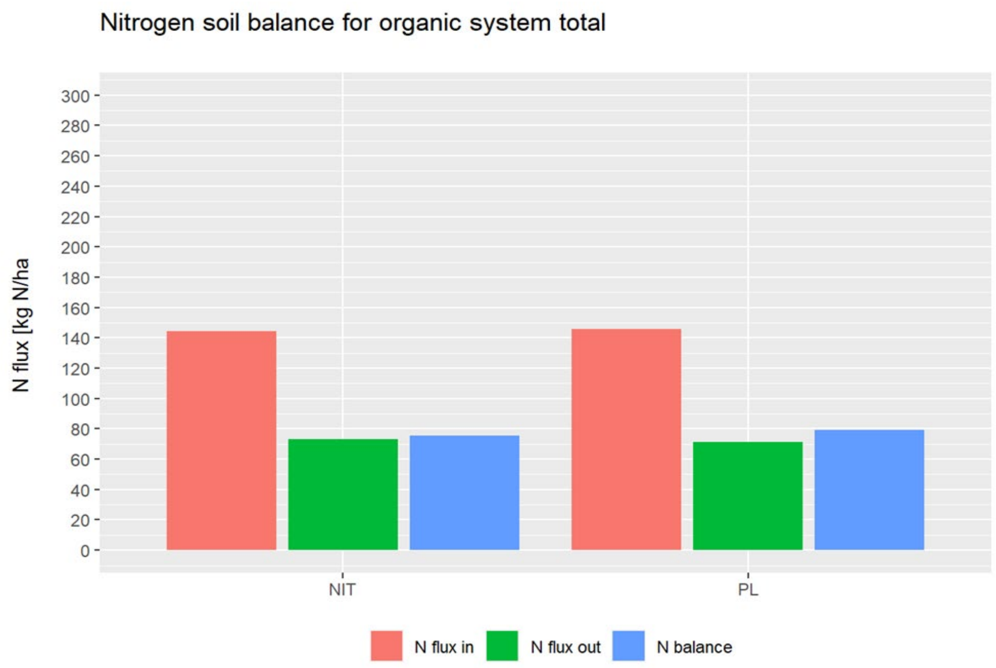

***Figure 24**, Nitrogen balance (kg N/ha/year) for Non-Inversion Tillage and ploughing, the average over the years 2011 up and till 2021 for an organic farming system*

Nitrogen efficiency

Conventional

The nitrogen efficiency was calculated as the nitrogen removal (through harvested crops) divided by the nitrogen supply (taking into account the deposition, fixation, artificial fertilizer, manure and seed additions). The average of nitrogen efficiency over all the years does not show any difference between the treatments Non-inversion Tillage and ploughing (Table 23). There is no data available for the nitrogen efficiency in the year 2011, this is due to the lack of data of the nitrogen removal in 2011. The variation between the years is big (34% -80%) this can be explained by the new operating standard of nitrogen fertilizantionfertilization introduced in 2014. After this year it is visible that the nitrogen efficiency increases a lot compared to the years before 2014. There is no significant difference between ploughing and Non-inversion Tillage over the years.

***Table 24** Nitrogen efficiency: the nitrogen removal divided by the total nitrogen supply per year per treatment in a conventional farming system*

Year	PL	NIT
2011	-	-
2012	36%	37%
2013	35%	34%
2014	61%	60%
2015	58%	58%
2016	69%	70%
2017	76%	74%
2018	80%	79%
2019	54%	53%
2020	78%	74%
2021	66%	63%
Average	61%	60%

Organic

The nitrogen efficiency was calculated as the nitrogen removal (through harvested crops) divided by the nitrogen supply (taking into account the deposition, fixation, artificial fertilizer, manure and seed additions). The average of nitrogen efficiency over all the years does not show any difference between the treatments Non-inversion Tillage and ploughing (Table 24). There is no data available for the nitrogen efficiency in the year 2011, this is due to the lack of data of the nitrogen removal in 2011. The variation between the years is small (42% -59%). There is no significant difference between ploughing and Non-inversion Tillage over the years.

Table 25 *Nitrogen efficiency: the nitrogen removal divided by the total nitrogen supply per year per treatment in an organic farming system*

year	PL	NIT
2011	-	-
2012	46%	47%
2013	59%	57%
2014	49%	48%
2015	50%	46%
2016	46%	42%
2017	58%	58%
2018	56%	54%
2019	48%	53%
2020	53%	46%
2021	46%	44%
Average	51%	50%

Annex 4 Soil quality

Method

Table 26 *Overview of measurements in 2011, 2020 and 2021.*

Year	Objects	Analyses
2011	Organic Ploughing (org pl), Organic Non inversion tillage (org nit), Conventional-standard Ploughing (con-std pl), Conventional-low Ploughing (con-low pl)	Microscopical analysis of soil life, PNM, PCM, HWC. C mineralisation (Alterra)
2020	Organic Ploughing (org pl), Organic Ploughing (org pl)+ Compost, Organic Non inversion tillage (org nit), Organic Non inversion tillage (org nit)+ Compost, Conventional-standard Ploughing (con-std pl), Conventional-low Ploughing (con-low pl)	PLFA (Eurofins)
2021	Conventional-standard Ploughing (con-std pl), Conventional-standard Ploughing (con-std pl)+ Compost, Conventional-low Ploughing (con-low pl), Conventional-low Ploughing (con-low pl)+ Compost, Conventional-standard non inversion tillage (con-std nit), Conventional-standard non inversion tillage (con-std nit) + Compost	PLFA, Bemestingwijzer (Eurofins), SOM, PMN, HWC, NH4, NO3 (Jaap Bloem)

Table 27 *Overview of sampled treatments*

Year	Plot	System	Tillage	Compost	Corp before	Crop sample year
2011	34.1a	Organic	Ploughing	no	Potato	Conservation pea
2011	34.1b	Organic	Non inversion tillage	no	Potato	Conservation pea
2011	34.2a	Organic	Non inversion tillage	no	Spring barley	Potato
2011	34.2b	Organic	Ploughing	no	Spring barley	Potato
2011	18.1a	Conventional-Standard	Ploughing	no	Potato	Conservation pea
2011	18.2b	Conventional-Low	Ploughing	no	Potato	Conservation pea
2011	27.1b	Conventional-Standard	Ploughing	no	Sugar beet	Potato
2011	27.2a	Conventional-Low	Ploughing	no	Sugar beet	Potato
2020	34.1a	Organic	Ploughing	no	Spring barley t + Japanese oats	Carrot
2020	34.1a	Organic	Ploughing	yes	Spring barley + Japanese oats	Carrot
2020	34.1b	Organic	Non inversion tillage	no	Spring barley + Japanese oats	Carrot
2020	34.1b	Organic	Non inversion tillage	yes	Spring barley + Japanese oats	Carrot
2020	34.2a	Organic	Non inversion tillage	no	Grasklaver + prei	Spring barley + Japanese oats
2020	34.2a	Organic	Non inversion tillage	yes	Grasklaver + prei	Spring barley + Japanese oats
2020	34.2b	Organic	Ploughing	no	Grasklaver + prei	Spring barley + Japanese oats
2020	34.2b	Organic	Ploughing	yes	Grasklaver + prei	Spring barley + Japanese oats
2020	18.1a	Conventional-Standard	Ploughing	no	Spring barley + Japanese oats	Carrot
2020	18.2b	Conventional-Low	Ploughing	no	Spring barley + Japanese oats	Carrot
2020	27.1b	Conventional-Standard	Ploughing	no	Leek	Spring barley + Japanese oats
2020	27.2a	Conventional-Low	Ploughing	no	Leek	Spring barley + Japanese oats

2021	18.1a	Conventional-Standard	Ploughing	no	Carrot	Silage maize + barley
2021	18.1a	Conventional-Standard	Ploughing	yes	Carrot	Silage maize + barley
2021	18.1b	Conventional-Standard	Non inversion tillage	no	Carrot	Silage maize + barley
2021	18.1b	Conventional-Standard	Non inversion tillage	yes	Carrot	Silage maize + barley
2021	18.2a	Conventional-Low	Non inversion tillage	no	Carrot	Silage maize + barley
2021	18.2a	Conventional-Low	Non inversion tillage	yes	Carrot	Silage maize + barley
2021	18.2b	Conventional-Low	Ploughing	no	Carrot	Silage maize + barley
2021	18.2b	Conventional-Low	Ploughing	yes	Carrot	Silage maize + barley
2021	27.1a	Conventional-Standard	Non inversion tillage	no	Spring barley + Japanese oats	Carrot
2021	27.1a	Conventional-Standard	Non inversion tillage	yes	Spring barley + Japanese oats	Carrot
2021	27.1b	Conventional-Standard	Ploughing	no	Spring barley + Japanese oats	Carrot
2021	27.1b	Conventional-Standard	Ploughing	yes	Spring barley + Japanese oats	Carrot
2021	27.2a	Conventional-Low	Non inversion tillage	no	Spring barley + Japanese oats	Carrot
2021	27.2a	Conventional-Low	Non inversion tillage	yes	Spring barley + Japanese oats	Carrot
2021	27.2b	Conventional-Low	Ploughing	no	Spring barley + Japanese oats	Carrot
2021	27.2b	Conventional-Low	Ploughing	yes	Spring barley + Japanese oats	Carrot

Results

Organic matter

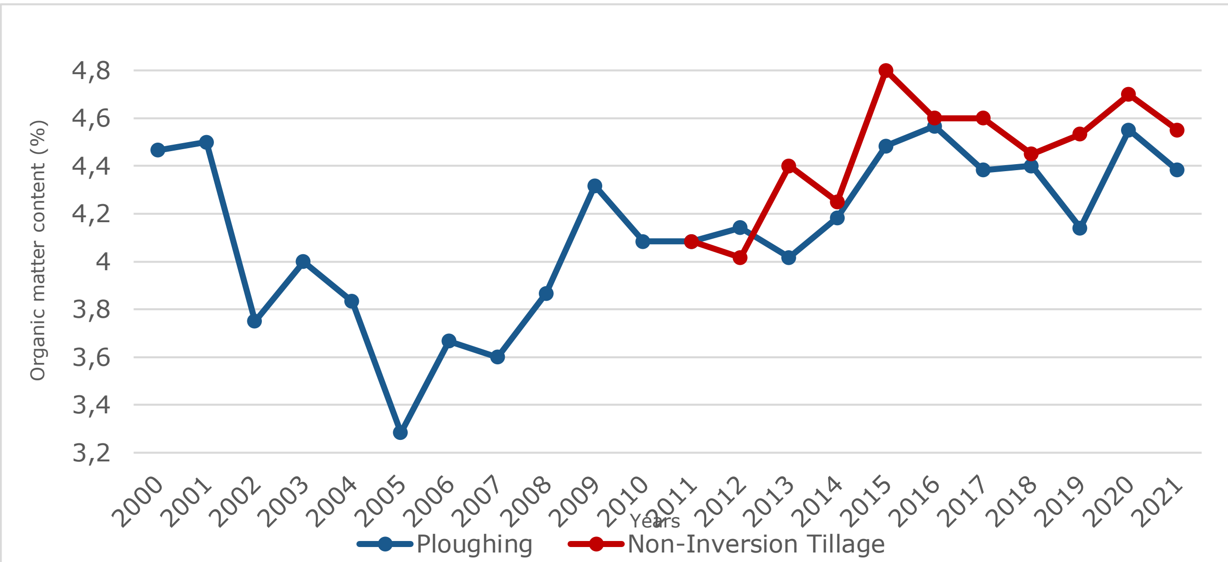

Figure 29. *Average organic matter content for tillage treatments in the organic farming system*

Chemical

Table 28. Overview of all chemical soil parameters for the conventional systems, averaged over the period 2011-2021.

Soil parameter	Unit	Conventional-low			Conventional-standard		
		Ploughing	**Non-inversion tillage**	**P-value**	**Ploughing**	**Non-inversion tillage**	**P-value**
Organic matter	%	3.42	3.82	<0.01	4.01	3.94	0.47
pH	-	5.42	5.46	0.4	5.60	5.50	0.07
N total	mg N/kg	966.03	1112.29	<0.01	1109.38	1144.79	0.35
C:N	-	20.23	19.90	0.45	20.86	19.48	<0.01
PW	mg P_20_5 /liter	37.96	37.77	0.89	45.70	48.86	0.04
K getal	-	12.26	14.02	0.09	12.24	13.44	0.21
CEC	mmol/kg	46.63	55.71	<0.01	61.75	50.63	0.02
N levering	Kg/ha	28.38	31.83	0.25	30.31	33.58	0.25
P-PAE	Mg p/kg	1.54	1.4	0.17	1.78	1.97	0.03
K available	Mg k/kg	48.58	59	0.1	51.44	60.11	0.1
CEC occupied		93.31	88.89	0.2	95.4	96.22	0.47
CA occupied	Mg/kg	76.18	70.83	0.14	77.99	78.72	0.69
Mg occupied	Mg/kg	11.38	11.42	0.96	12.32	13.15	0.24
K occupied	Mg/kg	3.2	3.29	0.72	3.01	3.49	0.02
Na occupied	Mg/kg	0.96	0.89	0.56	0.82	0.94	0.33
Al occupied	Mg/kg	0.1	0.1	No difference	0.1	0.1	No difference
S total	Mg/kg	183.3	204.2	<0.01	217.4	216.3	0.86
S-PAE	Mg/kg	7.37	8.29	0.3	7.98	8.46	0.57
Mg available	Mg/kg	116.2	140.6	<0.01	152.6	153.7	0.9
Na available	Mg/kg	10.5	13.9	0.2	13.5	13.4	0.99
Ca available	Mg/kg	80.12	99.39	0.33	104.7	116.2	0.54
B available	Mg/kg	127.6	158.4	<0.01	161.3	180.3	0.54
Compaction		7.68	7.8	<0.01	7.79	7.8	0.82
C-org		1.91	2.25	0.03	2.23	2.27	0.74
C-anorg		0.05	0.04	0.59	0.04	0.04	0.17

Table 29. Overview of all chemical soil parameters averaged over the period 2011-2021 for the organic system.

Soil parameter	Unit	Ploughing	Non-inversion tillage	P-value
Organic matter	%	4.18	4.19	0.92
pH	-	5.63	5.67	0.36
Total N	mg N/kg	1296	1315	0.59
C:N	-	18.3	18.2	0.88
PW	mg P_2O_5 /liter	44.5	47.78	0.03
K number	-	17.95	18.54	0.65
CEC	mmol/kg	68	69	0.58
N delivery	Kg/ha	43.7	42.3	0.69
P-PAE	Mg p/kg	1.76	1.75	0.93
K available	Mg k/kg	83.42	91.95	0.3
CEC saturated		95.4	96.7	0.21
CA delivery	Mg/kg	73.8	78.7	0.02
Mg delivery	Mg/kg	13.49	14.22	0.26
K delivery	Mg/kg	3.36	3.21	0.2
Na delivery	Mg/kg	0.84	1.05	0.31
Al delivery	Mg/kg	0.1	0.1	No difference
S total	Mg/kg	249.2	248.1	0.88
S-PAE	Mg/kg	3.83	3.53	0.47
Mg available	Mg/kg	166.4	183	0.1
Na available	Mg/kg	13.98	13.23	0.72
Ca available	Mg/kg	104.2	143	0.17
B available	Mg/kg	200.9	201.1	0.99
Compaction	Mg/kg	7.87	7.87	No difference
C-org		2.3	2.34	0.79
C-anorg		0.04	0.04	0.61

Physical

Table 27 *Penetration resistance in MPa per soil layer of 10 cm in the conventional system (con) for the treatments low and standard (st) measured in 2016.*

Depth	Con-Low - Ploughing	Con-low – Non-inversion tillage	Con-st – Ploughing	Con-st – Non-inversion tillage
0-10	0.39	0.50	0.52	0.48
10-20	0.45	0.56	0.61	0.55
20-30	0.52	0.62	0.71	0.62
30-40	0.59	0.68	0.81	0.69
40-50	0.67	0.75	0.90	0.77

Table 28 *Penetration resistance in MPa per soil layer of 10 cm in the organic system measured in 2020.*

Depth	Organic – Ploughing	Organic – Non inversion tillage
0-10	0.57	0.74
10-20	1.28	1.41
20-30	1.63	1.86
30-40	2.46	2.72
40-50	3.43	2.15

Biological

Table 30, Average of the measured parameters in 2020 in the three systems and two tillage treatments.

19.1: microbial biomass

System	Tillage	Average
Organic	Non inversion tillage	7.17
Organic	Ploughing	7.13
Conventional-standaard	Ploughing	6.27
Conventional-low	Ploughing	5.67

19.1: Number of bacteria (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	6.71
Organic	Ploughing	6.64
Conventional-standaard	Ploughing	5.71
Conventional-low	Ploughing	5.04

19.3: Gram-negative bacteria (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	4.09
Organic	Ploughing	4.03
Conventional-standaard	Ploughing	3.39
Conventional-low	Ploughing	2.93

19.4: Gram-positive bacteria (µg PLFA/g)

Organic	Non inversion tillage	2.62
Organic	Ploughing	2.61
Conventional-standaard	Ploughing	2.32
Conventional-low	Ploughing	2.11

19.5: Actinobacteria (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.57
Organic	Ploughing	0.57
Conventional-standaard	Ploughing	0.48
Conventional-low	Ploughing	0.39

19.6: Number of fungi (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.98
Organic	Ploughing	0.97
Conventional-standaard	Ploughing	0.68
Conventional-low	Ploughing	0.59

19.7: Saprophytic fungi (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.43
Organic	Ploughing	0.46
Conventional-standaard	Ploughing	0.26
Conventional-low	Ploughing	0.23

19.8: AMF (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.55
Organic	Ploughing	0.52
Conventional-standaard	Ploughing	0.42
Conventional-low	Ploughing	0.36

19.9: Monounsaturated PLFA (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	2.88
Organic	Ploughing	2.76
Conventional-standaard	Ploughing	2.26
Conventional-low	Ploughing	1.96

19.10: Polyunsaturated PLFA (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.59
Organic	Ploughing	0.61
Conventional-standaard	Ploughing	0.39
Conventional-low	Ploughing	0.36

19.11: Saturated PLFA (µg PLFA/g)

System	Tillage	Average

Organic	Non inversion tillage	2.84
Organic	Ploughing	2.96
Conventional-standaard	Ploughing	2.85
Conventional-low	Ploughing	2.76

19.12: Protozoa (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	0.08
Organic	Ploughing	0.08
Conventional-standaard	Ploughing	0.06
Conventional-low	Ploughing	0.06

19.13: Desulfovibrio (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	2.62
Organic	Ploughing	2.54
Conventional-standaard	Ploughing	2.08
Conventional-low	Ploughing	1.80

19.14: Rhizobia (µg PLFA/g)

System	Tillage	Average
Organic	Non inversion tillage	1.02
Organic	Ploughing	1.04
Conventional-standaard	Ploughing	0.91
Conventional-low	Ploughing	0.78

19.15: Microbial biomass C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	154.06
Organic	Ploughing	153.29
Conventional-standaard	Ploughing	134.93
Conventional-low	Ploughing	121.87

19.16: Bacterial biomass C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	63.73
Organic	Ploughing	63.07
Conventional-standaard	Ploughing	54.23
Conventional-low	Ploughing	47.86

19.17: Fungal biomass C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	66.48
Organic	Ploughing	64.56
Conventional-standaard	Ploughing	48.83
Conventional-low	Ploughing	42.31

19.19: AMF biomassa C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	52.87

Organic	Ploughing	50.21
Conventional-standaard	Ploughing	40.72
Conventional-low	Ploughing	34.97

19.19: Fungal/Bacterial biomass C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	1.03
Organic	Ploughing	1.01
Conventional-standaard	Ploughing	0.90
Conventional-low	Ploughing	0.88

19.20: Saprophytic biomass C (µg C/g)

System	Tillage	Average
Organic	Non inversion tillage	13.61
Organic	Ploughing	14.35
Conventional-standaard	Ploughing	8.11
Conventional-low	Ploughing	7.34

19.21: Gram-positive/Gram-negative bacteria

System	Tillage	Average
Organic	Non inversion tillage	0.64
Organic	Ploughing	0.64
Conventional-standaard	Ploughing	0.69
Conventional-low	Ploughing	0.72

19.22: i/ai15:0

System	Tillage	Average
Organic	Non inversion tillage	1.60
Organic	Ploughing	1.60
Conventional-standaard	Ploughing	1.64
Conventional-low	Ploughing	1.66

19.23: Saturated/Unsaturated

System	Tillage	Average
Organic	Non inversion tillage	0.82
Organic	Ploughing	0.88
Conventional-standaard	Ploughing	1.08
Conventional-low	Ploughing	1.21

19.24: 19:1w7-t/c

System	Tillage	Average
Organic	Non inversion tillage	0.02
Organic	Ploughing	0.02
Conventional-standaard	Ploughing	0.03
Conventional-low	Ploughing	0.03

19.25: 16:1w7-t/c

System	Tillage	Average
Organic	Non inversion tillage	0.04

Organic	Ploughing	0.03
Conventional-standaard	Ploughing	0.03
Conventional-low	Ploughing	0.03

19.26: Mono/polysaturated

System	Tillage	Average
Organic	Non inversion tillage	5.07
Organic	Ploughing	4.65
Conventional-standaard	Ploughing	5.91
Conventional-low	Ploughing	5.74

19.27: C13/C19 ratio

System	Tillage	Average
Organic	Non inversion tillage	0.94
Organic	Ploughing	0.95
Conventional-standaard	Ploughing	0.97
Conventional-low	Ploughing	0.97

19.28: Cy17/precy17 ratio

System	Tillage	Average
Organic	Non inversion tillage	0.55
Organic	Ploughing	0.59
Conventional-standaard	Ploughing	0.62
Conventional-low	Ploughing	0.62

19.29: Cy18X/precy18X ratio

System	Tillage	Average
Organic	Non inversion tillage	1.00
Organic	Ploughing	1.04
Conventional-standaard	Ploughing	1.11
Conventional-low	Ploughing	1.10

Table 31 *Averages of the measured parameters in 2021 over compost treatments in the two systems and two tillage treatment.*

20.1: Dry matter (%)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	86.44
Conventional-standaard	Ploughing	86.35
Conventional- low	Non inversion tillage	85.78
Conventional- low	Ploughing	86.38

20.2: PMN (mg/kg)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	16.46
Conventional-standaard	Ploughing	17.55
Conventional- low	Non inversion tillage	16.20
Conventional- low	Ploughing	15.86

20.3: HWC (mg/kg)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	546.38
Conventional-standaard	Ploughing	594.50
Conventional- low	Non inversion tillage	555.75
Conventional- low	Ploughing	510.25

20.4: NH4-N (mg/kg)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.16
Conventional-standaard	Ploughing	0.21
Conventional- low	Non inversion tillage	0.24
Conventional- low	Ploughing	0.27

20.5: NO3-N (mg/kg)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	6.20
Conventional-standaard	Ploughing	6.59
Conventional- low	Non inversion tillage	5.32
Conventional- low	Ploughing	5.82

20.6:Microbial biomass (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	5.85
Conventional-standaard	Ploughing	4.78
Conventional- low	Non inversion tillage	5.01
Conventional- low	Ploughing	4.48

20.7: Number of bacteria (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	5.15
Conventional-standaard	Ploughing	4.45
Conventional- low	Non inversion tillage	4.65
Conventional- low	Ploughing	4.03

20.8: Gram-positive bacteria (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	2.16
Conventional-standaard	Ploughing	1.80
Conventional- low	Non inversion tillage	1.90
Conventional- low	Ploughing	1.79

20.9: Gram-negative bacteria (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	3.18
Conventional-standaard	Ploughing	2.70
Conventional- low	Non inversion tillage	2.75
Conventional- low	Ploughing	2.33

20.10: Actinobacteria (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.48
Conventional-standaard	Ploughing	0.40
Conventional- low	Non inversion tillage	0.42
Conventional- low	Ploughing	0.36

20.11: Number of fungi (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.69
Conventional-standaard	Ploughing	0.58
Conventional- low	Non inversion tillage	0.56
Conventional- low	Ploughing	0.48

20.12: Saprophytes (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.28
Conventional-standaard	Ploughing	0.29
Conventional- low	Non inversion tillage	0.23
Conventional- low	Ploughing	0.20

20.13: AMF (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.40
Conventional-standaard	Ploughing	0.31
Conventional- low	Non inversion tillage	0.34
Conventional- low	Ploughing	0.28

20.14: Protozoa (mg PLFA)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.06
Conventional-standaard	Ploughing	0.06
Conventional- low	Non inversion tillage	0.06
Conventional- low	Ploughing	0.06

20.15: Fungi/Bacteria

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.95
Conventional-standaard	Ploughing	0.90
Conventional- low	Non inversion tillage	0.91
Conventional- low	Ploughing	0.83

20.16: Gram-positive/Gram-negative bacteria

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.70
Conventional-standaard	Ploughing	0.69
Conventional- low	Non inversion tillage	0.69
Conventional- low	Ploughing	0.79

20.17: Microbial biomass C (mg/C)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	122.63
Conventional-standaard	Ploughing	104.13
Conventional- low	Non inversion tillage	108.38
Conventional- low	Ploughing	94.38

20.18: Bacterial biomass C (mg/C)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	50.75

Conventional-standaard	Ploughing	42.88
Conventional- low	Non inversion tillage	44.38
Conventional- low	Ploughing	39.13

20.20: Fungal biomass C (mg/C)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	47.25
Conventional-standaard	Ploughing	38.13
Conventional- low	Non inversion tillage	39.63
Conventional- low	Ploughing	32.63

20.20: pH

System	Tillage	Average
Conventional-standaard	Non inversion tillage	5.75
Conventional-standaard	Ploughing	5.78
Conventional- low	Non inversion tillage	5.69
Conventional- low	Ploughing	5.59

20.21: Organic carbon (%)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	2.21
Conventional-standaard	Ploughing	2.31
Conventional- low	Non inversion tillage	2.15
Conventional- low	Ploughing	1.98

20.22: Organic matter (%)

System	Tillage	Average
Conventional-standaard	Non inversion tillage	3.96
Conventional-standaard	Ploughing	4.10
Conventional- low	Non inversion tillage	3.93
Conventional- low	Ploughing	3.59

20.23: C/Organic matter

System	Tillage	Average
Conventional-standaard	Non inversion tillage	0.56
Conventional-standaard	Ploughing	0.57
Conventional- low	Non inversion tillage	0.55
Conventional- low	Ploughing	0.55

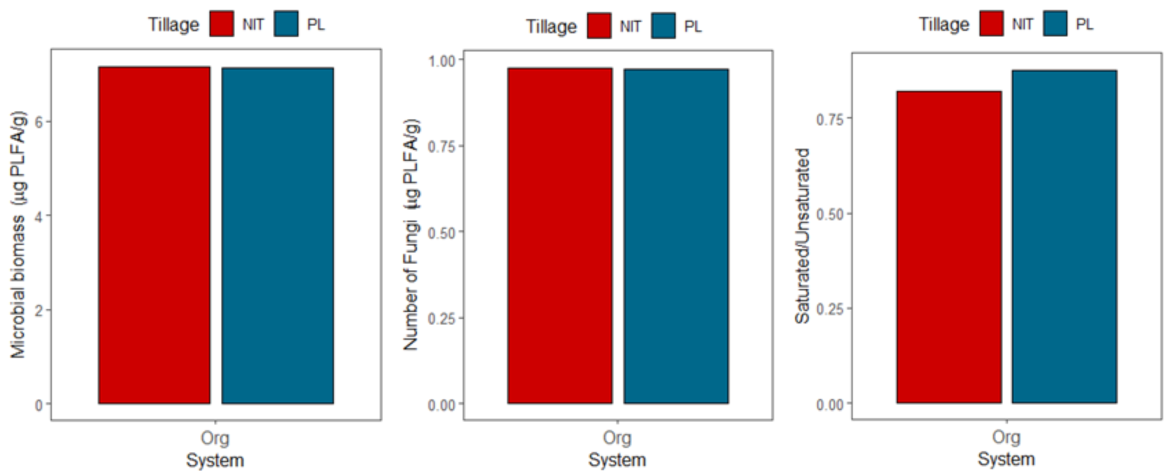

Figure 25*.* *Averages of microbial biomass (left), number of Funghi (middle) and saturated/unsaturated ratio (right) measured in the organic system in 2020*

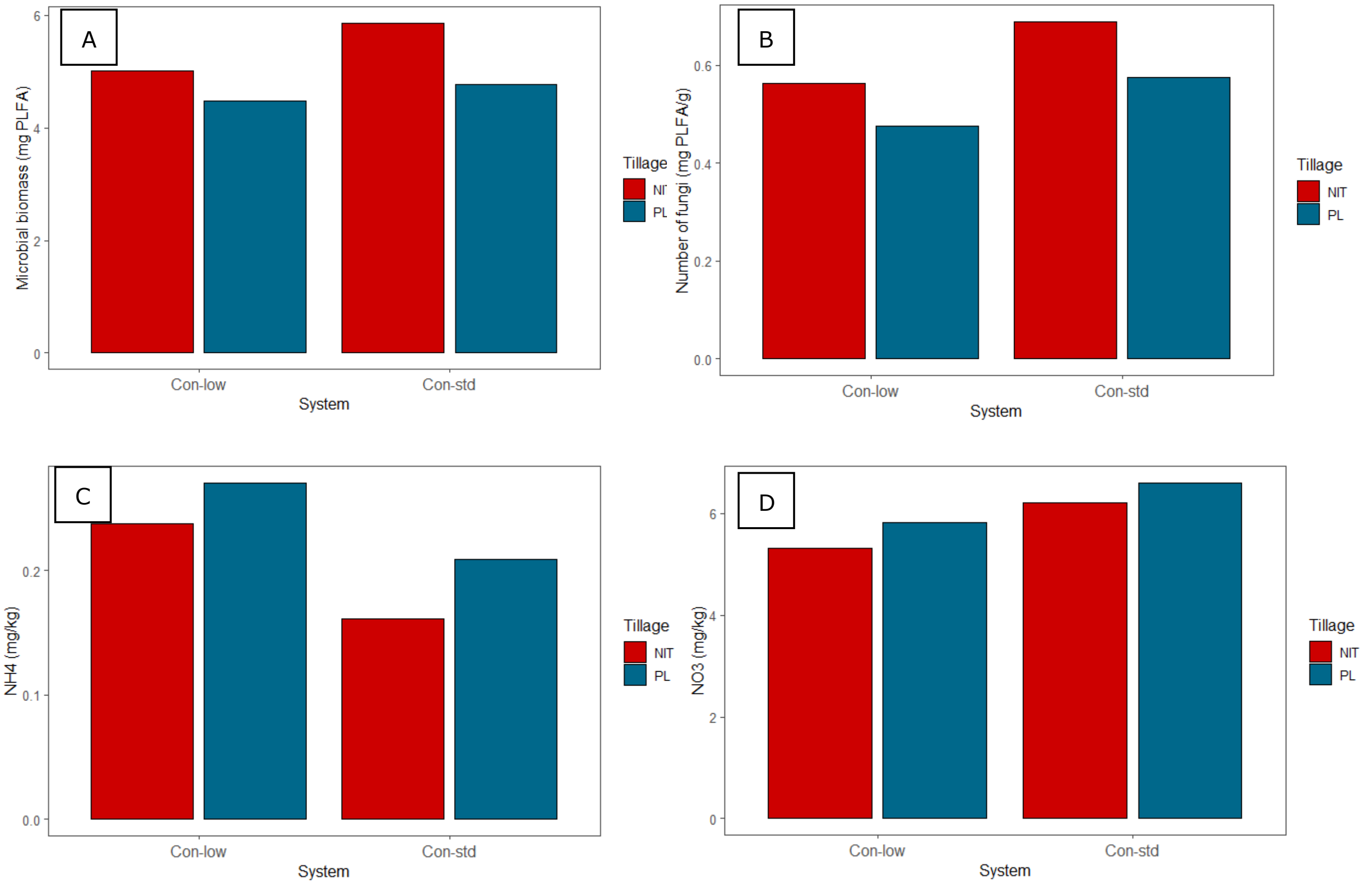

Figure 26. *Averages of a) microbial biomass, b) number of fungi, c) NH_4 and d) NO_3 in the two conventional systems for both tillage treatments in 2021*

Nematodes

The population development of *P. penetrans*, *Meloidogyne* spp. and trichodorids, presented in **Figure 27** - **Figure 32**, is shown for each tillage type in the organic and the conventional system.

The density of *P. penetrans* fluctuated from around 100 to over 500 · 100 mL soil^{-1}. There was no clear effect of tillage type on the development of the population of *P. penetrans*: the same trend was visible in both non inversion tillage and ploughing, **Figure 27** and **Figure 28**.

From 2014 onwards, in the organic system the average infestation with *M. chitwoodi* and *M. fallax* was rather low (**Figure 30**). Only in 2016 the density slightly increased to about 50 *Meloidogyne* spp. · 100 mL soil^{-1}. Tillage type did not have an effect on the development of the density of *M. chitwoodi* and *M. fallax* in the organic system.

In the conventional system, the density of *M. chitwoodi* and *M. fallax* was somewhat higher than in the organic system (**Figure 29** and **Figure 30**). In the conventional system, the period of cultivation of potato was longer, leading to the development of more generations and a stronger increase of the density of nematodes in the soil.

As the level of infestation with *Meloidogyne* spp. differed among the fields, the average density of *M. chitwoodi* and *M. fallax* fluctuated over the years. In years when potato was grown on fields with an infestation with *M. chitwoodi* and *M. fallax*, the average population strongly increased. With the exception of 2020 and 2021, non-inversion tillage and ploughing showed the same trend in the development of *M. chitwoodi* and *M. fallax*. The difference between non inversion tillage and ploughing in the last two years was caused by a rather high infestation in one field (strip) with non-inversion tillage.

The infestation with trichodorids was rather low and varied between 0 and 30 trichodorids · 100 mL soil^{-1}. This level of infestation in general does not cause damage or only leads to minor damage in the crops, **Figure 31** and **Figure 32**.

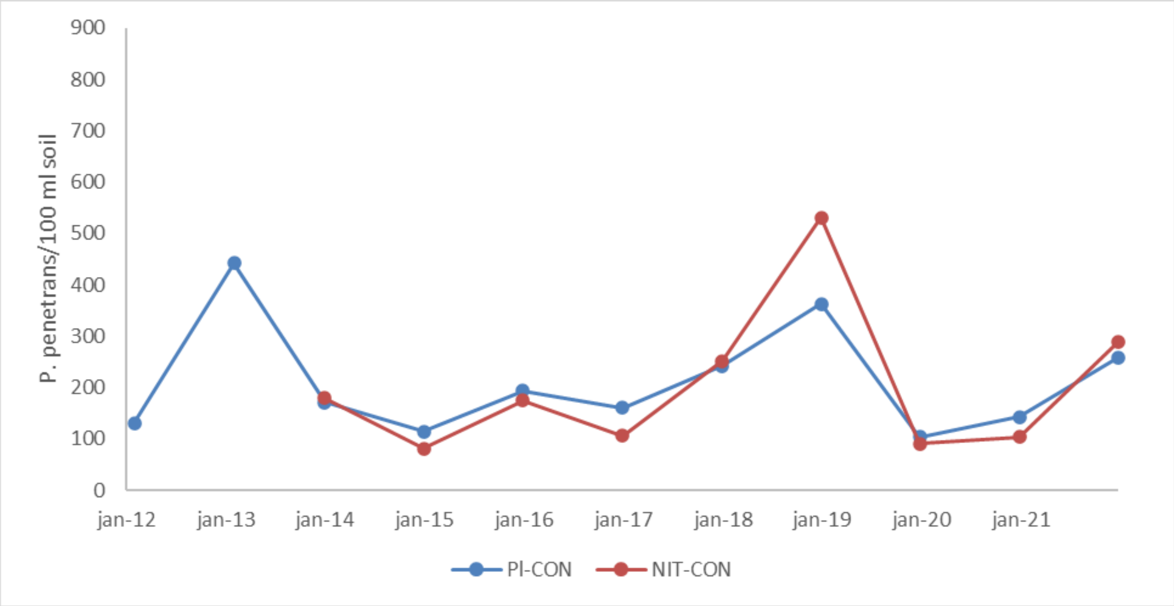

Figure 27*. Density of Pratylenchus penetrans under tillage treatments ploughing (PI) and non-inversion tillage (NIT) in the conventional system.*

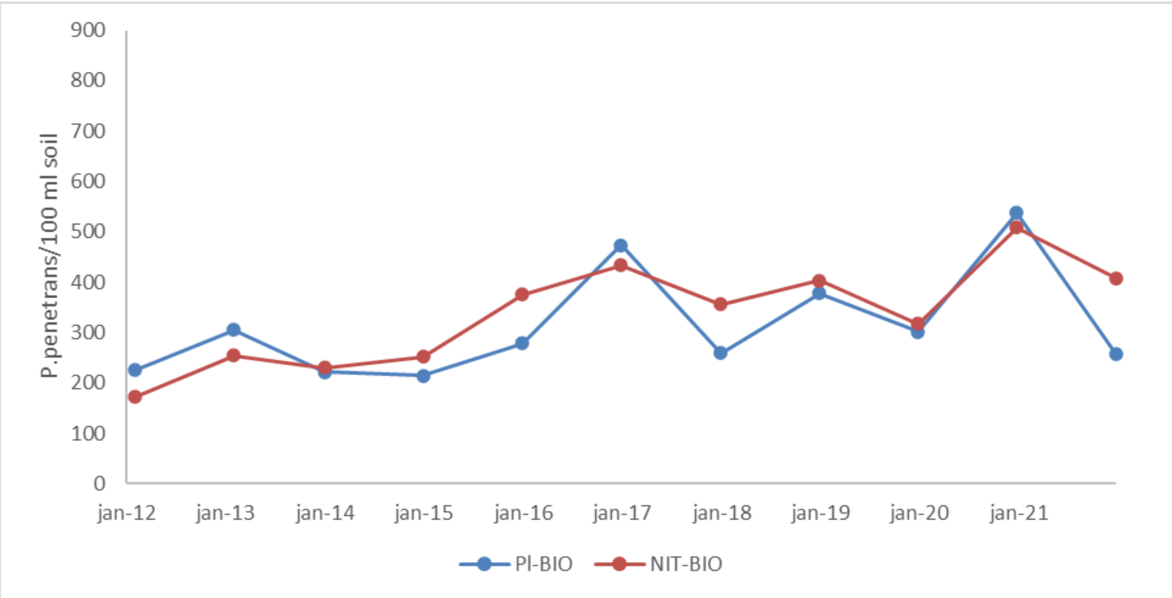

Figure 28 *Density of Pratylenchus penetrans under tillage treatments ploughing (PI) and non-inversion tillage (NIT) in the organic system.*

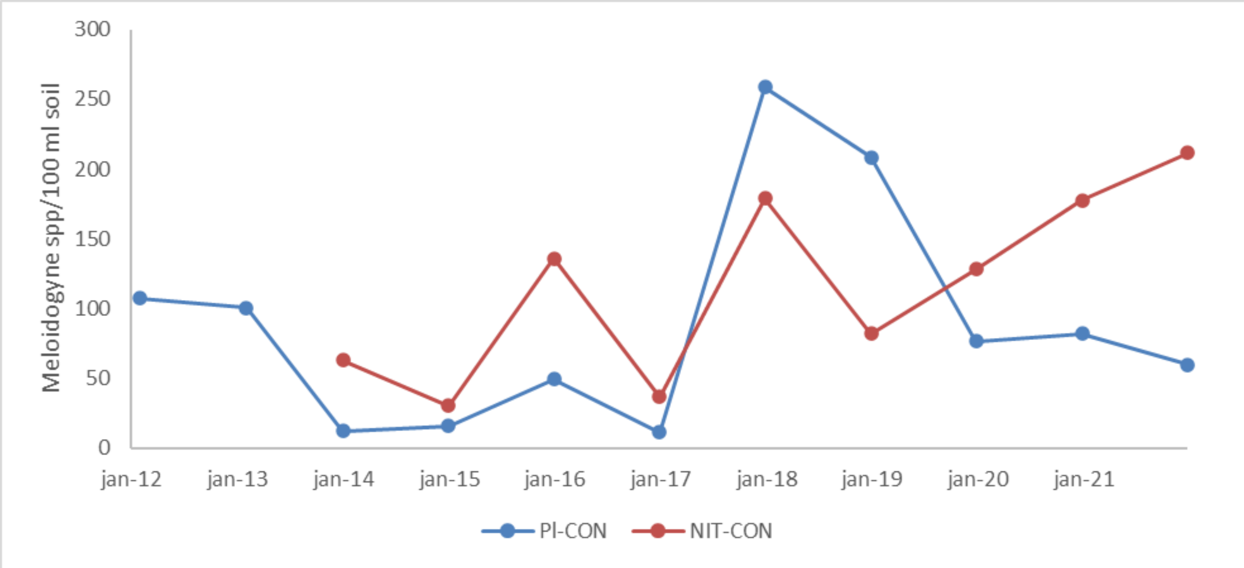

Figure 29*. Density of Meloidogyne chitwoodi under tillage treatments ploughing (Pl) and non-inversion tillage (NIT) in the conventional system.*

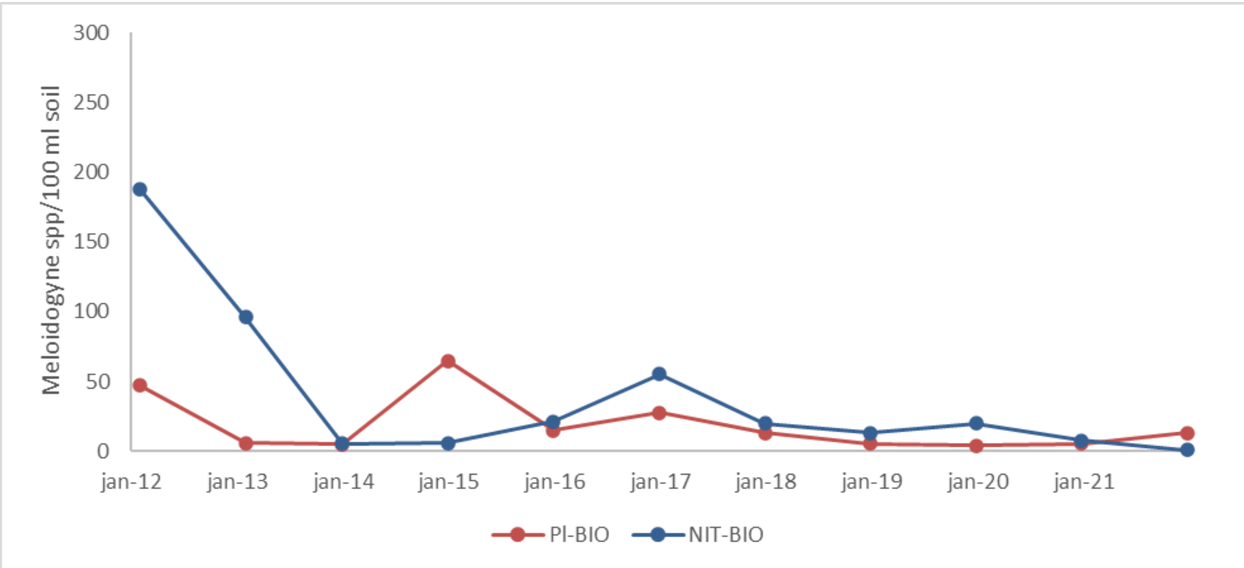

Figure 30*. Density of Meloidogyne chitwoodi under tillage treatments ploughing (Pl) and non-inversion tillage (NIT) in the organic system.*

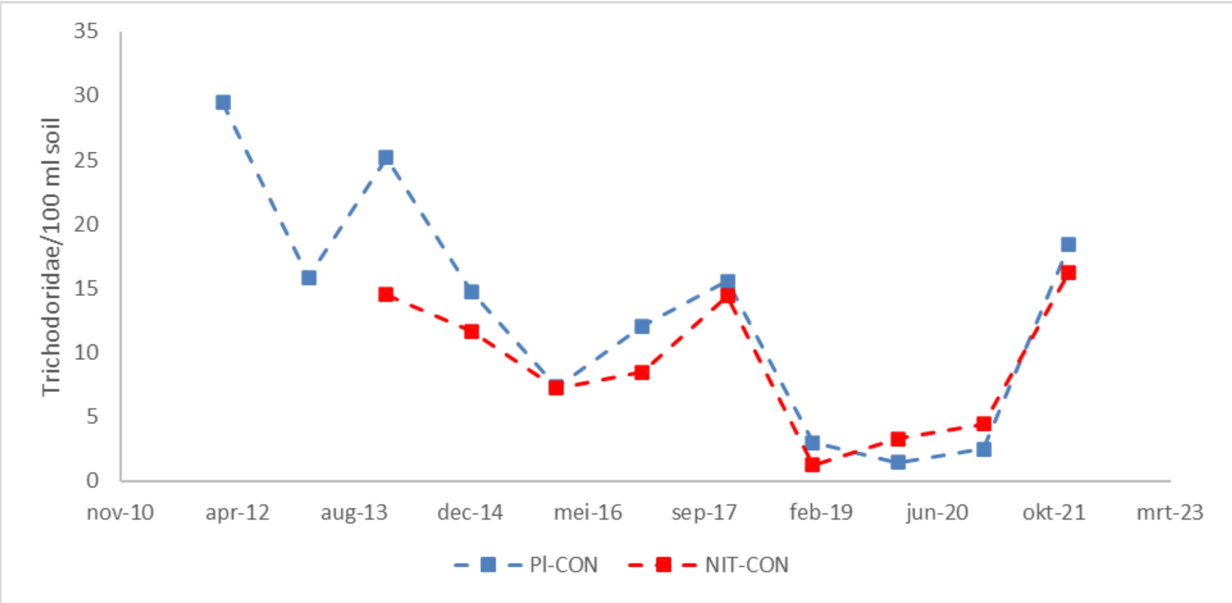

Figure 32*. Density of Trichodoridae under tillage treatments ploughing (PI) and non-inversion tillage (NIT) in the conventional system.*

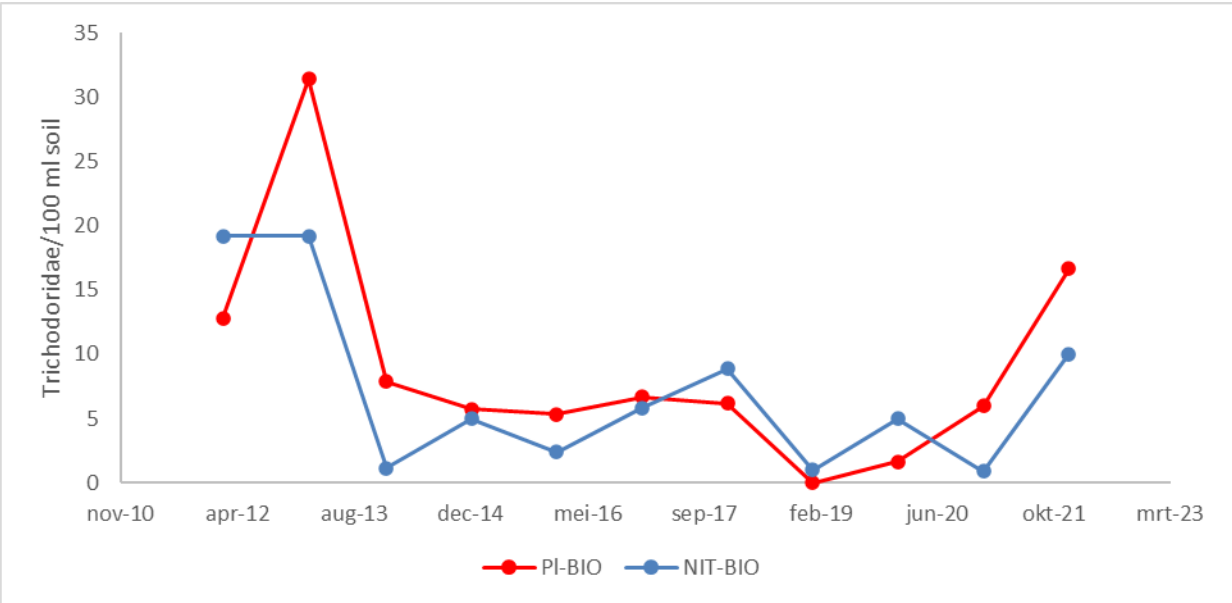

Figure 31*. Density of Trichodoridae under tillage treatments ploughing (PI) and non-inversion tillage (NIT) in the organic system.*

5.1.1.1 **Nematode community**

The results of the analysis of the nematode community, as referred to in chapter 3.2.4, are presented in table 21. It shows that the effect of the preceding crop on nematode populations was larger than the effect of tillage type.

Table 32. *Total number of nematodes · 100 g fresh soil^{-1} (excluding dauer larvae=resting stage), number of dauer larvae and numbers of nematodes in different feeding groups in March 2020, after growing two crops (spring barley followed by black oat, and leek) in plots with different treatments the previous year. Numbers are medians (back transformed values after log10-transformation) and therefore do not add up to the total number.*

Treatment[#]	Crop	Dauer larva	Total	Herbivore	Fungivore	Bacterivore	Predator	Omnivore	Sedentary endoparasite	Migratory endoparasite	Ectoparasite	Root hair feeder
org-nit	Barley-Black oat	149	2075	563	86	1312	0.0	81	0.0	54	373	133
org-pl	Barley-Black oat	383	2373	647	182	1428	3.1	98	0.0	54	448	113
org-nit-comp	Barley-Black oat	189	2025	551	182	1176	0.0	71	0.0	51	307	190
org-pl-comp	Barley-Black oat	535	2354	600	174	1446	0.0	101	0.0	64	277	243
org-nit	Leek	16	1719	227	77	1281	3.3	122	0.0	54	93	70
org-pl	Leek	15	1351	226	92	923	0.0	85	0.0	98	43	77
org-nit-comp	Leek	218	1677	338	100	1086	3.1	118	0.0	89	93	140
org-pl-comp	Leek	171	1271	191	90	870	0.0	110	0.0	105	32	49
con-std-pl	Barley-Black oat	16	2520	630	87	1660	17.6	74	0.0	111	430	83
con-low-pl	Barley-Black oat	119	1960	696	36	1093	23.3	104	0.0	32	533	130
con-std-pl	Leek	1438	2184	257	170	1636	4.3	78	0.0	20	50	186
con-low-pl	Leek	1495	1802	287	108	1135	26.3	224	3.5	20	32	224

[#] The organic and conventional systems were located on different fields.

In addition, the number of nematodes in the different CP- and PP-groups were studied. Again, those nematodes seemed to be more influenced by the choice of the preceding crop than by the farming system, tillage or addition of compost (**Table 32**). Numbers of CP1- nematodes were higher after growing leek, whereas numbers of CP2-, CP3 and CP-4 nematodes were higher after growing spring barley and black oat. The number of plant feeding nematodes in all PP-groups generally were higher after growing spring barley and black oat than after growing leek. These were mainly root hair feeding Tylenchidae (PP2), ectoparasitic Dolichodoridae (e.g. *Tylenchorhynchus*; PP3), migratory endoparasitic *Pratylenchus* (both PP3), and ectoparasitic Trichodoridae (PP4).

After growing spring barley and black oat, the number of nematodes in CP-groups 1, 2 and 3 were somewhat lower in the non-inversion tillage field than in the field that was ploughed (**Table**). The reverse was found for the groups CP1 and 2 after growing leek: the numbers were higher in the non-inversion tillage field.

Table 33 *Number of nematodes · 100 g fresh soil^{-1} in five Colonizer-Persister (CP) and four Plant Parasite (PP) groups in March 2020, after growing two crops (spring barley followed by black oat, and leek) in plots with different treatments the previous year. Numbers are medians (back transformed values after log10-transformation).*

Treatment#	Crop	CP1	CP2	CP3	CP4	CP5	PP2	PP3	PP4	PP5
org-nit	Barley-Black oat	282	1109	14	63	28	133	413	13.5	0.0
org-pl	Barley-Black oat	363	1169	45	74	28	113	484	27.3	0.0
org-nit-comp	Barley-Black oat	344	1023	23	64	0	190	354	3.1	0.0
org-pl-comp	Barley-Black oat	440	1127	76	57	5	243	357	0.0	0.0
org-nit	Leek	770	614	15	19	35	70	136	11.1	0.0
org-pl	Leek	592	476	2	30	17	86	124	8.7	0.0
org-nit-comp	Leek	543	720	19	35	5	147	176	4.6	0.0
org-pl-comp	Leek	500	510	14	29	17	57	127	2.2	0.0
con-std-pl	Barley-Black oat	373	1365	29	41	23	98	506	6.0	3.1
con-low-pl	Barley-Black oat	214	911	18	55	45	130	527	29.7	0.0
con-std-pl	Leek	1024	784	3	41	13	214	3	28.7	2.9
con-low-pl	Leek	604	802	51	36	11	245	5	16.1	2.8

The organic and conventional systems were located on different fields.

Likewise, the calculated nematode indices responded more strongly to the preceding crop than to the farming system, tillage and addition of compost. The Maturity Index (MI) was lower after growing leek than after growing spring barley and black oat, but there was almost no difference in the Maturity Index 2-5 (MI2-5). The low MI and lack of difference in MI2-5 can be explained by a high proportion of bacterial feeders in the group CP1. The Plant Parasite Index (PPI) was higher after growing spring barley and black oat than after leek, but only in the conventional field. This could be attributed to differences in relative densities of PP2- and PP3-nematodes. The Basal Index (BI) was higher after growing spring barley than after leek. A higher BI means there were relatively more nematodes that do not show a strong response to changes in food availability or disturbance. The Enrichment Index (EI) was higher after growing leek than after growing spring barley and black oat, which is an indication of high food availability after leek. The Structure Index ranged between 24-40 and did not seem specifically affected by a particular treatment.

Table 34 *Calculated indices of the nematode community, number of identified groups (taxa) and biomass (mg · 100 g fresh soil^{-1}) in March 2020 after growing two crops (spring barley followed by black oat, and leek) in plots with different treatments the previous year.*

Treatment#	Crop	Maturity Index	Maturity Index 2-5	Plant Parasite Index	Channel Index	Basal Index	Enrichment Index	Structure Index	Taxa	Biomass
org-nit	Barley-Black oat	1.98	2.21	2.79	7.32	40	52	30	33	3.02
org-pl	Barley-Black oat	1.98	2.25	2.85	9.96	33	58	37	37	3.30
org-nit-comp	Barley-Black oat	1.87	2.15	2.67	13.58	35	61	24	34	2.35
org-pl-comp	Barley-Black oat	1.90	2.20	2.60	8.19	31	63	32	31	3.32
org-nit	Leek	1.60	2.28	2.71	2.96	16	83	37	31	4.40
org-pl	Leek	1.58	2.23	2.64	3.46	15	84	34	35	3.18
org-nit-comp	Leek	1.69	2.17	2.60	4.59	22	76	27	31	2.88
org-pl-comp	Leek	1.66	2.23	2.72	4.85	18	80	34	31	2.85
con-std-pl	Barley-Black oat	1.91	2.14	2.89	5.14	41	53	23	36	3.77
con-low-pl	Barley-Black oat	2.07	2.28	2.87	4.00	38	49	40	37	2.88
con-std-pl	Leek	1.53	2.17	2.34	4.97	15	84	28	30	6.11
con-low-pl	Leek	1.71	2.18	2.25	5.03	22	76	30	29	3.91

The organic and conventional systems were located on different fields.

The data points in the food web analysis diagram mainly were positioned in the upper left corner (**Figure 34**), which is typical for many farming systems with a high nutrient input and tillage. This quadrant is indicative of systems with a high nutrient availability and a food web with a limited level of complexity. It especially shows the higher food availability after growing leek than after spring barley and black oat.

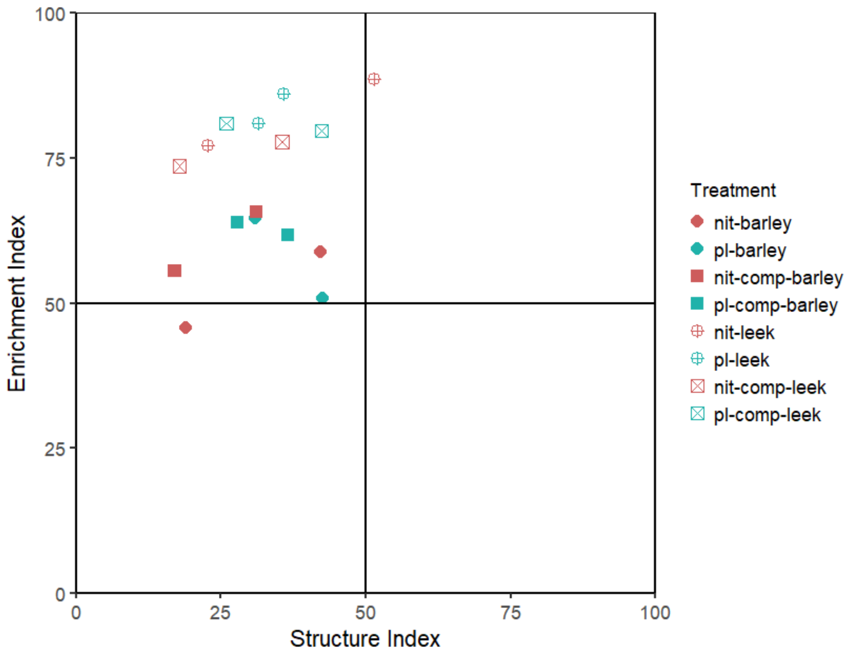

Figure 33 *Food web analysis diagram with the Enrichment and Structure Index in March 2020 after growing two crops (spring barley followed by black oat, and leek) in an organic farming system, with two tillage treatments (non-inversion tillage [nit] and ploughing [pl]), and addition of compost (comp). Points with the same symbol and colour were two samples taken in one treatment field.*

Annex 5 Weed seed bank

Table 35*.* *EPPO coding and corresponding scientific and English naming of weed species observed during seed bank germination.*

EPPO	SCIENTIFIC NAME	ENGLISH NAME
BELSY	*Bellis sylvestris*	Southern daisy
CAPBP	*Capsella bursa-pastoris*	Shepherd's purse
CARHI	*Cardamine hirsute*	Bristly bittercress
CERGL	*Cerastium glomeratum*	Sticky mouse-ear chickweed
CHAAN	*Chamerion angustifolium*	Rosebay
CHEAL	*Chenopodium album*	Goosefoot
CIRAR	*Cirsium arvense*	Californian thistle
DICOT	Unidentified dicotyledons	
ECHCG	*Echinochloa crus-galli*	Barnyard grass
ERPVE	*Draba verna*	Common whitlowgrass
GASPA	*Galinsoga parviflora*	Kew weed
GNAUL	*Gnaphalium uliginosum*	Brown cudweed
LAMPU	*Lamium purpureum*	Purple archangel
LOLPE	*Lolium perenne*	English ryegrass
MATCH	*Matricaria chamomilla*	Wild chamomile
MOCOT	Unidentified monocotyledons	
POAAN	*Poa annua*	Pathgrass
POLCO	*Fallopia convolvulus*	Bearbind
POLPE	*Persicaria maculosa*	Red-leg
SENVU	*Senecio vulgaris*	Birdseed
SOLTU	*Solanum tuberosum*	Potato
STEME	*Stellaria media*	Chickweed
TAROF	*Taraxacum officinale*	Blowball
TRFRE	*Trifolium repens*	White clover
URTUR	*Urtica urens*	Burning nettle
X1ACAG	*Acacia spp.*	Acacia
X1GERG	*Geranium ssp.*	Geranium
X1PLAG	*Plantago ssp.*	Plantago
X1RANG	*Ranunculus ssp.*	Ranunculus
X1SPRG	*Spergula ssp.*	Spergula
X1TULG	*Tulipa ssp.*	Tullip
X1VERG	*Veronica ssp.*	Veronica

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