The Eco-Plough

A better alternative for conventional ploughing

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Abstract

To feed the world now and in the future, soil quality needs to improve. Therefore, soil degrading agricultural practices need to change. One of these practices is conventional ploughing (25-30 cm depth). Two possible alternatives for this are non-inversion tillage (till 10 cm depth) and eco-plough tillage (till 15-18 cm depth). These possible alternatives were studied on a sandy soil at the organic research farm Droevendaal in Wageningen, The Netherlands. Potato stem length and tuber characteristics (starch and dry matter content) were determined in 2015. Also, data of yields of four crops in six growing seasons (2011-2016) was analysed. Furthermore, soil organic matter till 30 cm was determined. Potato stems were significantly longer with conventional ploughing than with the eco-plough or non-inversion tillage. Potato tuber characteristics did not differ significantly. Total soil organic matter (0-30 cm) after six years was significantly lower with conventional ploughing. Total soil organic matter in the other treatments did not differ significantly. Non-inversion tillage had most SOM in the 0-10 cm layer. Average relative yield with the eco-plough was highest (107%), followed by conventional ploughing (100%). Average relative yield of non-inversion tillage was more than 10% lower than of conventional ploughing. In conclusion, for yield as well as for soil quality, using the eco-plough is a better alternative for conventional ploughing.

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1. Introduction

1.1. General Context

Feeding the world now and in the future is a challenge, since world population is increasing and the preferred diet in most developing countries is changing to more animal products (Lal 2001).

Meeting this food demand requires high yields per area of land, higher than current yields or at least equally high.

1.2. Soil Quality

In turn, high yields require soil with a good quality. Soil quality can be defined as: *the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (*Karlen *et al.* 1997; cited by Schjønning et al. (2004)). In the Proposal for a Directive of the European Parliament and of the Council Establishing a Framework for the Protection of Soil (2006) even more soil functions were added: *(i) biomass production, (ii) storing, filtering, and transforming nutrients, (iii) maintaining biodiversity, (iv) sequestering C, (v) providing a physical and cultural environment for humans, (vi) providing raw materials, and (vii) preserving geological and archeological heritage.*

However, soils are degrading rapidly at a global scale (Gardiner and Miller 2008). According to the Proposal for a Directive of the European Parliament and of the Council Establishing a Framework for the Protection of Soil (2006) soil degradation can be divided in eight main soil threats: *erosion, organic matter decline, contamination, salinization, compaction, soil biodiversity loss, sealing, landslides and flooding*.

1.3. Problem Description

Agriculture can be held accountable for at least half of the soil degradation processes that are described above.

One of the management tools of conventional agriculture that deteriorates the soil most is deep ploughing, especially with heavy machinery when the field is wet. Ploughing is a way of tillage that inverts the soil, thereby mixing the topsoil and the subsoil. In The Netherlands ploughing is usually done till a depth of 25-30 cm (Sukkel and Timmermans 2012).

Ploughing has a number of positive effects to the soil for growing a crop. The goals of ploughing are firstly loosening of the soil for a proper seedbed, good root growth and functioning and improved water infiltration, secondly soil inversion for a) weed control and b) 'incorporation of crop residues, green manure, animal manure or other substances'(Guul-Simonsen et al. 2002).

However, negative effects of ploughing can be erosion, organic matter decline, compaction in different soil layers, and soil biodiversity loss (Vakali et al. 2011; Håkansson and Reeder 1994; Tiessen et al. 2007). Therefore, soil quality goes down. In most parts of The Netherlands erosion is not a problem, since there hardly any hilly regions. The other mentioned negative effects of ploughing do occur in The Netherlands.

In organic agriculture the use of artificial chemicals is prohibited. These include herbicides, therefore weeds need to be controlled mechanically. Ploughing is an effective way of mechanical weed control.

1.4. Solutions?

Finding a solution to the negative effects of conventional ploughing without losing the positive effects is a challenge. Conservation agriculture (CA) can be a solution according to the FAO (2015a). Kouwenhoven et al. (2002) suggest the eco-plough is a good option. Therefore, these two methods are explained below.

1.5. Conservation Agriculture and Conservation Tillage

'Conservation agriculture (CA) *may be defined as resource saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment'* (FAO, 2008; as cited in (Van den Putte et al. 2010)). CA exists of three components: 1) crop rotation, 2) maximum soil cover and 3) reduced tillage or minimal soil disturbance (FAO 2015b). '*The term reduced tillage covers a range of tillage practices, but it never involves inverting the soil'* (Van den Putte et al. 2010).

1.5.1. Advantages of CA

As the words say, non-inversion tillage (NIT) does not invert the soil, thereby not mixing different soil layers and leaving crop residues mostly on top of the land or close to the soil surface. This has a beneficial effect on soil life, or rather, this has a less disturbing effect on soil life than ploughing has. Other advantages of NIT are an improved soil structure, improved water infiltration and transport and a better carrying capacity for machinery. Furthermore, NIT is supposed to have lower fuel use, less need of labour, less minerals leaching, and it prevents wind and water erosion (Bernaerts et al. 2008).

In the meta-regression analysis by Van den Putte et al. (2010) reduced tillage (NIT in this case) is divided into treatments <15 cm depth and >15 cm depth. However, NIT in The Netherlands is usually not deeper than 12 cm (Bernaerts et al. 2008).

After some years of NIT, some farmers in Flanders noticed tillage takes less time, since the increased SOM content improves the workability of the soil (Beeckman 2012).

1.5.2. Disadvantages of CA

Using NIT in conventional agriculture can lead to yields 4.5% lower than inversion tillage (Gruber et al. 2012). Some risks of NIT, as described by Bernaerts et al. (2008), are higher weed pressure, problems with slugs or mice, and a less suitable top soil for mechanical weed control. The higher weed pressure and difficulties with mechanical weed control are also experienced by farmers in Flanders (Beeckman 2012).

1.6. The Eco-plough

The eco-plough (Eco) is a mouldboard plough specifically made for shallow ploughing (0.12-0.20 m). It was developed by Rumptstad Industries BV in The Netherlands to still have a good soil inversion at these depths. With this plough the tractor runs on top of the land instead of in the furrow (Kouwenhoven et al. 2002).

According to Vian et al. (2009) shallow inversion tillage with the eco-plough is *not* conservation tillage. And neither according to Peigné et al. (2007), who state that usually conservation tillage is not inversion tillage, the only exception being inversion tillage till a depth of 10 cm, since not all residues are incorporated then.

1.6.1. Advantages of the Eco-plough

In an experiment in the nineties ploughing with the eco-plough (in this case till a depth of 12 cm) was compared to ploughing with a two and a four share mouldboard plough (Van der Werff and Kouwenhoven 1996). In this experiment root growth in the top soil was better with the eco-plough, which in turn resulted in a higher nitrogen uptake.

Soil life, organic matter and minerals are concentrated in the layer closer to the surface than with deep ploughing (Sukkel 2012). However, in non-inversion tillage (a conservation agriculture characteristic) there is even more stratification.

The chance of soil compaction is less because the tractor drives on top of the land. Also, less nitrate leaches than in conventional tillage (Sukkel 2012).

Because of the shallower ploughing depth and the relatively flat soil surface after using the eco-plough, less weathering of the soil is needed. Therefore ploughing in spring is possible, which, in turn, has the advantage of a longer growing season for green manures. A longer growing season for green manures can lead to a higher SOM content and to even less nitrate leaching.

However, hardly any significant difference in yield was noticed with different crops (Sukkel 2012).

Sukkel (2012) also mentions less fuel use as an advantage of shallower ploughing. However, this might be the case for the ploughing, but after shallow ploughing weeds emerge earlier and mechanical weed control needs to take place more often (thereby also using fuel)(Vermeulen et al. 2013).

1.6.2. Disadvantages of the Eco-plough

In the article mentioned earlier, ploughing till 12 cm depth seemed to be hardly deep enough. Weed pressure was higher with the eco-plough treatment than with conventional ploughing and wildshoots from the previous crop could emerge earlier in the first case too. They gave no yield results in that paper, though (Van der Werff and Kouwenhoven 1996).

Compacted soil layers near the surface are more difficult to solve, since the eco-plough then rises from the soil. Also, the soil surface will not become flat when holes and wheel tracks are present in the field. In case the field is wet, ploughing on top of the land is hardly possible, because the tractor wheels will slip then. Therefore, only a limited part of the time the eco-plough can be used. However, also deep ploughing is usually avoided in wet circumstances (Sukkel 2012).

Another disadvantage is that the eco-plough does not incorporate crop residues properly if these are present in large amounts. Chopping those first is necessary then. Furthermore, regrowth of grass-clover or alfalfa can occur.

Lastly, it is difficult to make sure that each next furrow is in line with the previous one. To improve this, GPS on the eco-plough is needed (so not just GPS on the tractor).

Comparisons

Yields were higher for deep mouldboard ploughing (28 cm) compared to shallow mouldboard ploughing (15 or 22 cm) in a long-term experiment on sandy soil in Southern Sweden (Håkansson et al. 1998). The researchers assume this is caused by a more loose soil in the deeper ploughing treatment. Rydberg (1992) concludes from an earlier experiment that ploughless tillage should not be used on sandy soil, since then it results in lower yields than conventional tillage.

Crittenden and de Goede (2016) report that non-inversion tillage has a higher plant-available water content in the surface soil than mouldboard ploughing. This is in contrast with Drakopoulos et al. (2016) who write about a comparison of non-inversion tillage with conventional tillage in potatoes: '*it could be argued that tuber bulking was hampered under reduced tillage mainly because of higher soil bulk density and increased vulnerability to drought stress*'. They argue that non-inversion tillage probably led to water-limited conditions. However, the soil in the two studies differs, one being a marine clay loam and the other being sandy.

In a recent meta-analysis shallow non-inversion tillage (till 10 cm depth) had no significant yield reduction compared to deep ploughing (25 cm or deeper). Also in different types of soil and with different types of crops no significant reduction occurred. Cover crops and leys even had a significant increase in yield. However, weed incidence was significantly higher in non- inversion tillage. Soil C stocks did not significantly differ. In the same meta-analysis shallow ploughing (till 25 cm depth) was compared to deep ploughing and to non-inversion tillage. Compared to deep ploughing shallow ploughing had a significant yield reduction (5.5%). Shallow ploughing did not significantly differ from shallow non-inversion tillage. However, this shallow ploughing was not done with the eco-plough (Cooper et al. 2016)

Figure 1: An example of potato ridges. This is not a picture from the field in the described experiment.
Source: http://www.wur.nl/nl/show/Kaliumfosfiet-remt-Phytophthoraaantasting-in-aardappel.htm

1.7. Potatoes

Potatoes that are grown in The Netherlands are usually ridged several times during the season (for potato ridges see Figure 1). So the soil is tilled more than just for seedbed preparation (ploughing for example), Most other crops do not need this extra tillage. Therefore, initial tillage will probably be of less importance for the potatoes than for e.g. cereals.

1.8. Research Questions

Three different tillage systems on a sandy soil in Wageningen (The Netherlands) are compared in this thesis:

- conventional tillage with a mouldboard plough till a depth of 25-30 cm (this treatment is referred to as Con).
- inversion tillage with the eco-plough till a depth of 15-18 cm (this treatment is referred to as Eco).
- non-inversion tillage till a depth of more or less 10 cm (this treatment is referred to as NIT).

The main question addressed is:

What are effects of the three different tillage systems on the yield of a range of crops?

Additional questions about this comparison are:

- What effect do the treatments have on the soil organic matter content and stratification?
- What effect do the treatments have on potato stem length and tuber characteristics?

1.9. Hypotheses.

Based on the literature it is expected that the average relative yield of Con will be highest, followed by Eco, and that NIT will have the lowest yield.

The hypotheses for the additional questions are as follows.

- Total soil organic matter content in NIT will be highest, followed by Eco and then Con. Stratification will occur in NIT between 0-10 cm and 10-30 cm; in Eco between 0-20 cm and 20-30 cm. No stratification will occur in Con.
- All treatments are expected to have the same effect on potato stem length and tuber characteristics.

2. Materials and Methods

2.1. Experimental site and treatments

The experiment was done in the Netherlands at organic farm Droevendaal (51°59'33.68"N, 5°39'34.59"E). Droevendaal has sandy soil. Three different treatments were used in spring: Conventional mouldboard ploughing (Con; 25-30 cm deep), Eco-plough ploughing (Eco; 15-18 cm deep), Non-inversion tillage (NIT; 10 cm deep) (Fig. 1). Before the potatoes were planted in spring 2015, the treatments were applied for 4 years already. In these years cereals were grown (Table 1). Each autumn before spring crops were grown, green manure was sown.

Ploughing was done in spring (except for the time a winter cereal was grown). For conventional ploughing a four-share plough of Lemken was used. For the Eco-treatment a seven-share eco-plough of Rumpdstadt was used. NIT was done with the 'Smaragd', a cultivator of Lemken (for pictures see Appendix B).

For the potatoes (*Solanum tuberorsum* Carolus) first the rotary cultivator was used on the 9^{th} of April. Eight days later the discs were used. On the 30^{th} of April solid farmyard manure was spread (30 ton/ha, including 6.57 kg nitrogen/ton manure and 14.73 kg phosphate/ton manure). The 1^{st} of May the potatoes were planted and ridges were made. However, since the number of available seed-potatoes of Carolus was too small to plant the entire field, only the middle of the three differently treated sub-fields was planted (Figure 2). Potato cultivar Carolus is resistant against late blight (*Phytophthora infestans*). On the 1st of May the discs and the rotary cultivator were used against weeds. The potatoes were ridged again on 11 and 26 June.

The following variables were assessed: wheat yield, potato stem length, potato tuber yield and characteristics, soil organic matter (SOM), and yield and relative yield of 2011, 2012, 2014, 2015.

Table 1: Cropping and manure plan of the Droevendaal field where the experiment took place.

Year	2011	2012	2013	2014	2015	2016
Crop	Spring Wheat	Spring Barley	Spring Barley	Spring Wheat	Potato	Winter Triticale
Manure in spring	Solid manure (10 t/ha; (NPK: 6.09 – 3.37 – 7.9 kg/t)	Solid manure (10 t/ha; NPK: 6.09 – 3.37 – 7.9 kg/t)	Solid manure (10 t/ha; NPK: 6.09 – 3.37 – 7.9 kg/t)	Cattle slurry (15 t/ha; NPK: 4.64 – 1.43 - 5 kg/t)	Solid manure (25 t/ha; NPK: 6.09 – 3.37 – 7.9 kg/t)	Cattle slurry (20 t/ha; NPK: 4.64 – 1.43 - 5 kg/t)
Other applications	-	-	-	Lime (Miramag 55% 3380/ha)	-	-

2.2. Potato stem length

Potato stem length was measured as an indicator for crop growth. Three rows were selected where every ten steps a potato stem was measured (Figure 3). The potato field was about 180 m long and the steps a bit less than 1 m long, so more or less 20 measurements per row were taken. At some spots potatoes did not sprout, resulting in less measurements.

2.3. Potato yield

Nine blocks of potatoes were harvested, three blocks per treatment. The blocks of 12 m^2 were randomly chosen. The potatoes were weighed and the average total yield per hectare per treatment was calculated. Also the marketable yield was determined by subtracting the weight of the culls and of the potatoes smaller than 40 mm or bigger than 65 mm (the marketable yield then consisted of healthy potatoes between 40 and 65 mm).

2.4. Tuber characteristics

2.4.1. Size

All harvested tubers were sorted according to their size by sieving. Culls of all sizes were taken out and weighed separately. For estimation of the marketable yield healthy looking potatoes between 40 and 65 mm were weighed.

2.4.2. Starch content

Starch content is a tuber quality characteristic. It was calculated from the fresh weight (g) in air and the underwater weight (g). The underwater weight was determined of a subsample of more or less 5 kg of the total yield (so including small and large potatoes and culls). This subsample was washed in a potato scraping machine. Then the potatoes were weighed under water. After most water leaked from the potatoes these were weighed in air (fresh weight). Starch content was calculated according to the following formulas (Simmonds 1977):

$$SG = fresh\ weight\ /\ (fresh\ weight - underwater\ weight)$$

SG is specific gravity.

$$Starch\ content\ (\%) = -1.39 + 0.196 * [1000 * (SG - 1)]$$

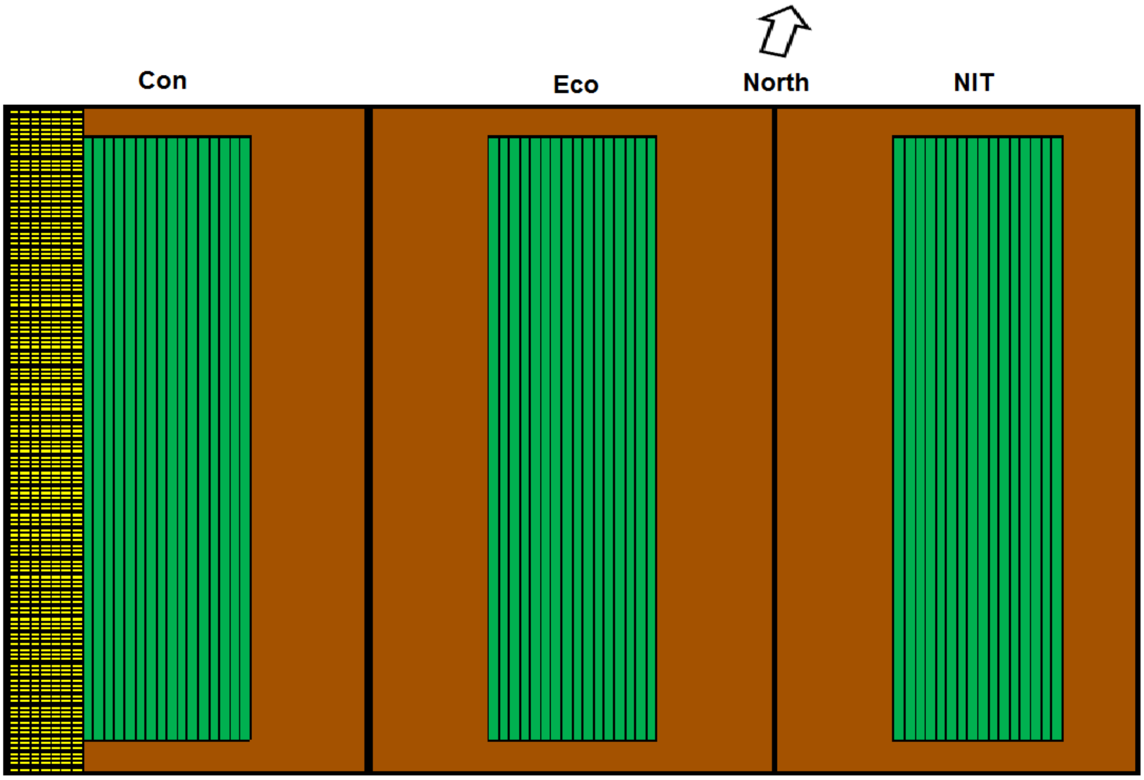

Figure 2: Lay-out of experimental site during potato growing in 2015. The upper part is the North. The green, striped rectangles are the potato fields, 16 rows per treatment. The rectangle at the East side was non-inversion tillage (NIT), the middle eco-plough tillage (Eco) and the rectangle at the West was conventional tillage (Con). The brown parts were bare soil. The yellow, chequered part was another potato experiment under conventional tillage.

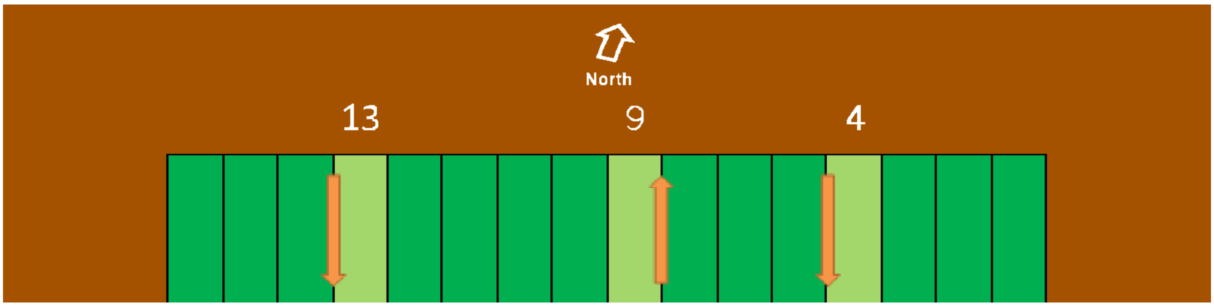

Figure 3: Walking and measuring pattern for potato stem length. Each ten steps stem length of the plant at the left side in row 4, 9 and 13 was measured. For row 4 and 13 the walking pattern was from North to South, for row 9 from South to North. Each time the stem selected was at the front left side. The walking pattern was the same for each treatment.

2.4.3. Dry matter content

Dry matter content is another tuber quality characteristic. It was determined by drying tubers in an oven at 105 °C for 24 hours. The tubers were cut into slivers the size of chips by a potato tuber cutting machine before drying them (between 400 and 650 g of fresh potatoes were used). To calculate dry matter content in % the following formula was used:

$$Dry\ matter\ content\ (\%) = \frac{Dry\ weight\ (g)}{Fresh\ weight\ (g)} * 100\%$$

2.5. Soil organic matter (SOM)

SOM was determined, since it influences soil structure and the water holding capacity of the soil. Both in turn can influence crop performance.

For measuring SOM the entire field was divided in nine different parts. Three with potatoes and the East and West parts without potatoes (Appendix A). For repetitions each part was divided in six subplots. Soil cores were taken at three depths (0-10cm, 10-20cm, 20-30cm) while walking in parallel diagonal lines over each subplot. A composite sample of 40 cores per subplot per depth made 162 samples in total.

The length of the field was about 220 m. However, not the entire length was used for potato growing, consequently a buffer zone of 20 m at each side of the field was kept. So only the middle 180 m was used for measurements.

SOM content in percentages was determined by loss on ignition according to the method described by Hoogsteen et al. (2015)

Nundu (2016) collected data in November and December 2015 and compared the East and West part of each treatment field where no potatoes were grown (these are the blue and green parts of the fields in Appendix A). He found no significant differences within each treatment. Therefore, it is assumed no SOM gradient existed before the start of the experiment.

Average total SOM (in g/cm^3 0-30 cm) was calculated from SOM per depth and from the bulk density which was determined by Nundu (2016).

2.6. Relative yields

The yield of Con was set at 100%. Relative yields of Eco and NIT were calculated with the following formulas:

$$Relative\ Yield\ \ NIT = \frac{Yield\ NIT}{Yield\ Con} * 100\%$$

$$Relative\ Yield\ \ Eco = \frac{Yield\ Eco}{Yield\ Con} * 100\%$$

The yields of three of the previous years were also calculated – the data of 2013 and 2016 were lost.

2.7. Statistical analyses

The statistical analyses were done using IBM SPSS Version 23. One-way between groups analysis of variance (ANOVA) was used to check whether differences in stem length, potato total and marketable yield and tuber characteristics were significant. For testing significance of difference in SOM a univariate analysis of variance (general linear model) was used. As Post Hoc Test Tukey’s HSD was used. No statistical test was done with the relative yield data.

3. Results

3.1. Potato stem length

Potato stem length at 12 weeks after planting was significantly different between NIT and Con (59.4 and 69.8 cm on average respectively, p = 0,001, Figure 4.I). This indicates that crop growth in Con was faster than in NIT. Stem length of Eco (64.1 on average) did not differ significantly from those of NIT and Con (p = 0.190 and p = 0.089 respectively). The difference in stem length between the three treatments was visible in the field.

3.2. Potato yield

The average marketable potato yield (tubers between 40 and 65 mm and without a disease or green spots) did not differ significantly between treatments. However, marketable yield in Con did tend to be higher than those of Eco and NIT (α =0.05, p = 0.058, Figure 4.II). Average total yield also was not significantly different (data not shown; α =0.05, p = 0.193).

3.3. Tuber characteristics

Average starch content as well as average dry matter content of the tubers was not significantly different between the three treatments (α =0.05, p = 0.271 and p= 0.097 respectively, Figures 4.III and 4.IV). This indicates that tuber quality is not or is hardly influenced by initial tillage method.

3.4. Winter triticale

No yield was determined for triticale, which was grown in 2016. However, on the 22nd of June pictures were taken of the different treatments (Figure 5). These show that the ears of the triticale treated with Con were more abundant and larger than in either Eco or NIT. Also, the leaves were more yellow than in the other treatments. Furthermore, NIT had a much higher weed density (see also Nundu (2016) for weed density and weed biomass).

3.5. Soil organic matter

Treatment as well as depth of the soil explained part of the values of SOM (the SOM percentages between different treatments and depths were significantly different (α =0.05, p = 0.000 in a univariate general linear model)). Also the total average SOM differed significantly, that of Con was lower than those of NIT and Eco (p = 0.000; Figure 6-II).

Stratification occurred in both NIT and Eco, although not always significantly. NIT 0-10 cm depth had the highest SOM content; NIT 20-30 cm and Con 0-10 cm the lowest. In the layer 10-20 cm Eco tended to have the highest SOM content . In the deepest layer Con and Eco tended to contain more SOM than NIT (Figure 6-I).

No significant difference was proven between blocks where potatoes were grown and blocks where no potatoes were grown ($\alpha = 0.05$, $p = 0.494$).

3.6. (Relative) yields

The average yield of the field treated with the eco-plough was highest in three out of four years. In these years summer cereals were sown, only potato had the highest yield with conventional tillage (Table 2 and 3). Furthermore, in 2014 so many weeds were seen in the wheat crop, that only for the experiment a part was harvested. The rest of the wheat was worked into the soil.

Average relative yield of Eco was highest, followed by Con. Average relative yield of NIT was more than 10% lower than Con (Table 3).

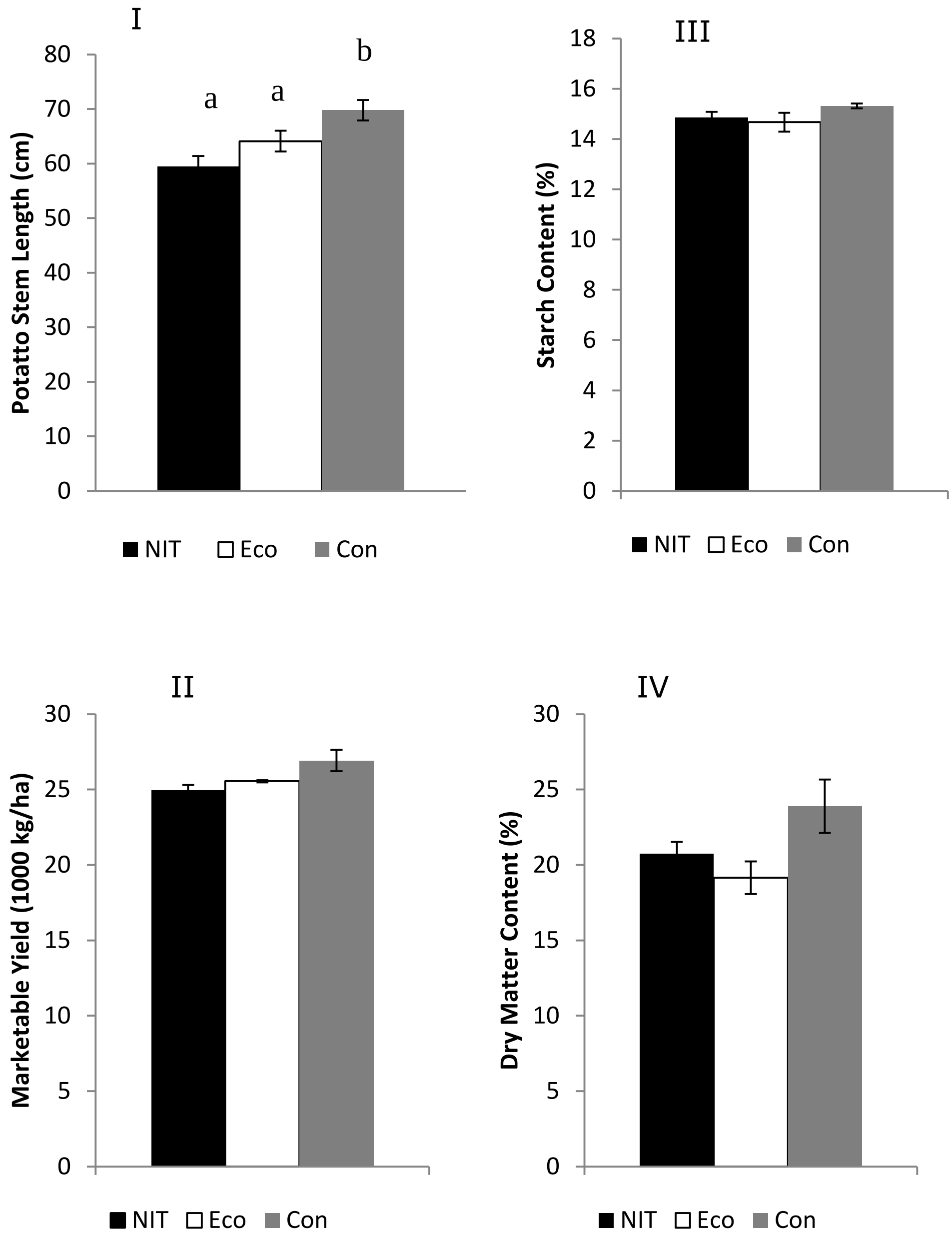

Figure 4: Average potato stem length (I) and tuber characteristics (II- IV) for three different treatments (non-inversion tillage (NIT), eco-plough tillage (Eco), conventional tillage (Con)). The error bars are standard errors of the mean. I: Average potato stem length in cm per treatment. Different letters indicate significant differences according to Tukey's HSD ($p < 0.05$). II: Average marketable yield in 1000 kg/ha per treatment. Marketable yield is the yield of healthy, whole potatoes between 40 and 65 mm. III: Average starch content in % per treatment. IV: Average dry matter content in % per treatment.

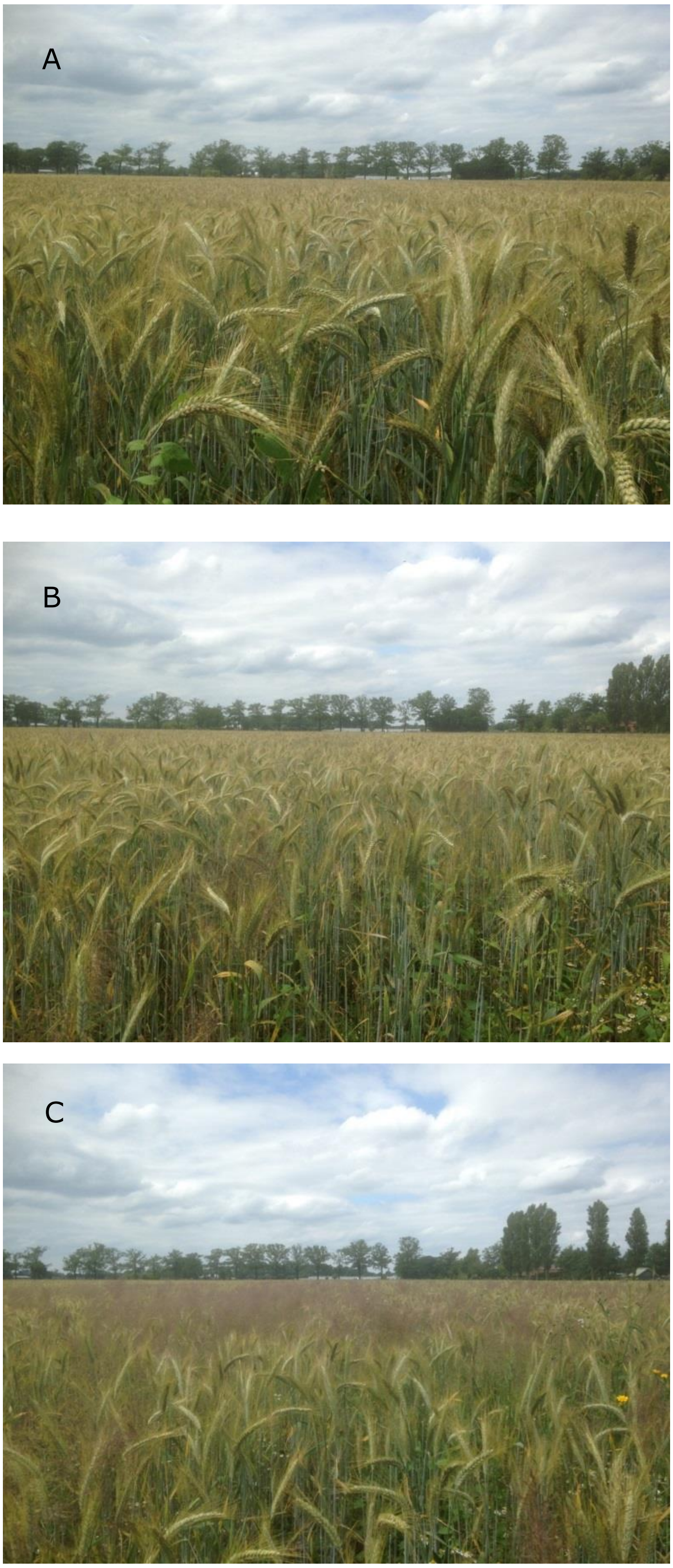

Figure 5: Triticale on the 22nd of June 2016 for the three different treatments.

Table 2: Average yield (t/ha) per treatment per crop during 2011 – 2016. ND means no data available. Treatments: non-inversion tillage (NIT), eco-plough tillage (Eco), conventional tillage (Con).

	2011	2012	2013	2014	2015	2016
	Spring wheat	Spring barley	Spring barley	Spring wheat	potato	Winter triticale
NIT	2.75	7.37	ND	2.37	24.94	ND
Eco	4.41	7.71	ND	3.04	25.56	ND
Con	4.16	6.68	ND	2.76	26.92	ND

Table 3: Relative yield (%) per treatment per crop during 2011 - 2016. ND means no data available. Treatments: non-inversion tillage (NIT), eco-plough tillage (Eco), conventional tillage (Con).

	2011	2012	2013	2014	2015	2016	
	Spring wheat	Spring barley	Spring barley	Spring wheat	potato	Winter triticale	Average relative yield
NIT	66%	110%	ND	86%	93%	ND	89%
Eco	106%	115%	ND	110%	95%	ND	107%
Con	100%	100%	ND	100%	100%	ND	100%

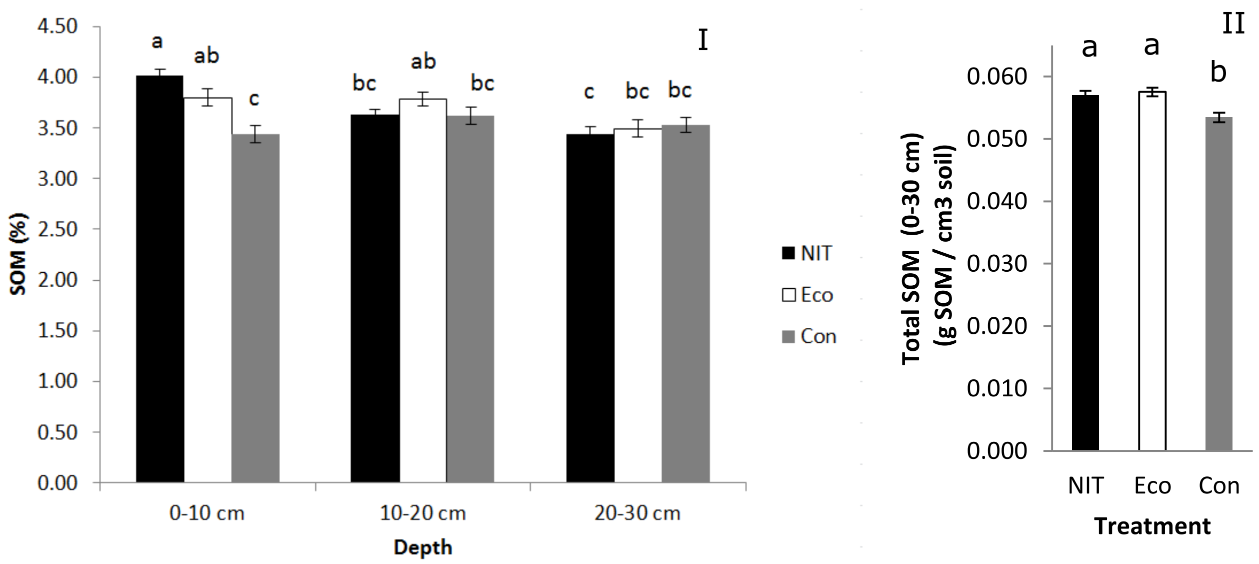

Figure 6-I: Soil organic matter (SOM) percentage per depth (0-10, 10-20, 20-30 cm) and treatment (NIT= non-inversion tillage, Eco = eco-plough tillage, Con = conventional tillage). Figure 6-II: Total average SOM in g SOM per cm^3 soil for the entire sampling depth (0-30 cm). Different letters indicate significant differences; also between different depths. The error bars are standard errors of the mean.

4. Discussion and Conclusions

4.1. Main conclusion: Eco on average highest relative yield

Eco-plough tillage (Eco) had the highest average relative yield; non-inversion tillage (NIT) had the lowest. The hypothesis was that conventional tillage (Con) would result in the highest average relative yield and NIT in the lowest.

Shallow ploughing seems to be the best reduced tillage system for organic farming on "active" soils conclude Kouwenhoven et al. (2002). "Active" soils are soils with a large clay content that expand under wet conditions and shrink under dry conditions. In Kouwenhoven's experiment hardly any difference existed between yields of eco-ploughing and ploughing at conventional depth. According to them, deep ploughing is necessary on inert sandy soils when perennial weeds are present in large numbers.

Droevendaal farm has a sandy soil, so Eco having the highest average yield, is in contrast with the findings of Kouwenhoven et al. (2002) and of the results of the meta-analysis by (Cooper et al. 2016).

That Eco resulted in a higher average yield than Con could possibly be explained by the soil organic matter content (SOM) and its soil improving characteristics.

Yield reduction in NIT compared to Con was more than 4.5%, which was the average yield reduction between those tillage systems in conventional agriculture (Gruber et al. 2012). This is in line with Peigné *et al* (2007) who concludes: '*Weakly structured soils containing high proportions of sand and silt, particularly in a wet climate' are less suitable or not suitable at all*'. Therefore they advise to first identify whether soil and climate are suitable for the adoption of conservation tillage.

Furthermore, Nundu (2016) measured the soil penetration resistance at the same experimental field in early May 2016. His data showed that the field treated with NIT had a higher penetration resistance than the fields treated with Eco and Con at 10 – 30 cm depth. Assuming that field conditions in previous years did not differ much from those measured in spring 2016, it can be concluded that the poorer performance of crops in the NIT-plot was partly due to a shallower rooting system (roots could not penetrate the deeper soil layers as easily as in Eco and Con).

'Ploughing deeper than 18-20 cm does not significantly improve crop yields' conclude Guul-Simonsen et al. (2002) in their review about plough design and ploughing in Northern Europe. However, mean yields of various crops do tend to have a higher yield with deeper ploughing in different soils (Kouwenhoven et al. 2002).

A different story altogether was winter triticale. As can be seen on the pictures (Figure 5) triticale did not function well under NIT. This is similar to the result of

Arvidsson et al. (2014) about winter wheat. They argue that this is because of problems with residues of the previous crop. However, in this experiment the preceding crop was potato, which hardly leaves over residues. Therefore, the cause of the poor crop performance of winter cereals in non-inversion tillage should be examined more closely.

4.2. Soil organic matter (SOM) in Eco and NIT similarly high

Average SOM was expected to be highest in NIT, followed by Eco and to be lowest in Con. Con indeed significantly resulted in the lowest average SOM in the layer from 0-30 cm. However, average SOM in Eco was similar to that in NIT. A cause for this could be the balancing out of two different processes. On the one hand the NIT-treated field produced less biomass than the Eco-field, in NIT resulting in less residues that could turn into SOM. On the other hand did the eco-plough disturb the soil more than the cultivator in NIT, which results in more SOM decomposition. A high amount of residues and a high SOM turnover could then end up with the same SOM content as a low SOM turnover and a lower amount of residues.

SOM stratification in NIT was significant and in Eco it tended to stratification (Figure 6-I). Stratification of SOM is an indicator of soil quality according to Franzluebbers (2000). Therefore, soil quality in NIT and Eco is better than in Con.

A side note on the conclusions about SOM content is about the depth of the measurements taken (0-30 cm). Zikeli *et al.* (2013) state that soil samples should also be taken at least deeper than 30 cm, since results of soil samples at 30 cm or less do not take possible C depletion in deeper soil layers into account. Thereby, C accumulation could be overestimated. However, looking at Zikeli et al.'s own results, such overestimation hardly could have been made, because no significant differences existed in the deeper soil layers (40-60 cm) between the different treatments.

Therefore, it is reasonable to conclude that using conventional tillage on average results in SOM depletions, while using the eco-plough or non-inversion tillage maintains or increases SOM.

4.3. Potato stem length differed

It was expected that potato stem length would not be significantly affected by the different tillage treatments. In contrast with this hypothesis potato stem length did differ significantly between Con and Eco, and between Con and NIT, potato stems in Con being longer. Stem length of Eco did not differ significantly from NIT, although in Eco it tended to be longer.

However, as expected, tuber characteristics (including average marketable yield) did not differ significantly. This can indicate that the difference in stem length (as an indicator for crop growth) between the treatments was not large enough to affect the tuber characteristics. It could also mean that in all treatments a certain minimum shoot biomass for good tuber characteristics was already reached by the potatoes.

4.4. Missing yield data does not change direction of conclusions

Only yield samples were taken of four out of six years. Therefore, one could question whether or not the missing data would change the average relative yield of the treatments.

However, one of the years a spring cereal was grown which per treatment probably would have had an average relative yield similar to the other years. Furthermore, Kouwenhoven et al. (2002) state that cereals and potatoes do not require deep ploughing, whereas e.g. sugar beet and peas do need that. The winter triticale grown in 2016 would probably have increased the differences per treatment, since the NIT treatment had many weeds and smaller ears (Figure 5).

4.5. No effect of crop failure in 2014

The sown spring wheat in 2014 resulted in crop failure, because of the weed abundance. When the spring wheat yield is not taken into account the average relative yield of Eco is 2% lower, and that of NIT 2% higher. However, the overall trend between the treatments does not change.

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6. Appendix A

Experimental plan SOM ploughing experiment: Droevendaal farm (51°59'33.68"N, 5°39'34.59"E)

East

30m	30m	30m	30m	30m	30m	
						Buffer (1m)
1	2	4	4	5	6	Measurements (8m)
						Buffer (1m)
						Buffer (1m)
7 NIT potatoes	8	9	10	11	12	Measurements (8m)
						Buffer (1m)
						Buffer (1m)
13	14	15	16	17	18	Measurements (8m)
						Buffer (1m)

						Buffer (1m)
19	20	21	22	23	24	Measurements (8m)
						Buffer (1m)
						Buffer (1m)
25 Eco potatoes	26	27	28	29	30	Measurements (8m)
						Buffer (1m)
						Buffer (1m)
31	32	33	34	35	36	Measurements (8m)
						Buffer (1m)

						Buffer (1m)
37	38	39	40	41	42	Measurements (8m)
						Buffer (1m)
						Buffer (1m)
43 Con potatoes	44	45	46	47	48	Measurements (8m)
						Buffer (8m)
						Buffer (1m)
49	50	51	52	53	54	Measurements (1m)
						Buffer (1m)

West

7. Appendix B

Pictures of the tillage equipment of the three different treatments.

Figure 7 - A: The four-share plough used for conventional tillage

Figure 7 - B: The eco-plough produced by Rumpstadt

Figure 7 - C: The 'Smaragd', a kind of cultivator, used for non-inversion tillage

8. Appendix C

Materials and Methods Wheat yield

Wheat was grown in 2011 and in 2014 (Table 1). In 2014 three times random plots of 15 m^2 in each treatment were harvested, ending up with nine samples. These wheat kernel samples were weighed, cleaned, weighed again, and the thousand kernel weight was determined. The cleaning was done with a Röber D-4950 Minden.

Results Wheat yield

Eco had the highest mean fresh wheat kernel yield. However, the difference with NIT and Con was not significant ($p = 0.687$, Figure 8-A). Also, the difference between the mean cleaned seed yield of NIT, Eco and Con was not significant ($p = 0.678$, Figure 8-A). However, the mean thousand kernel weight of NIT and Con did differ significantly ($p = 0.022$, Tukey HSD = Tukey's Honestly Significant Difference test, Figure 8-B). Eco did not differ significantly from either ($p = 0.103$ and $p = 0.453$, respectively, Tukey HSD).

The average thousand kernel weight range in this experiment was similar to the lower part of the range in research by Peigné et al. (2014).

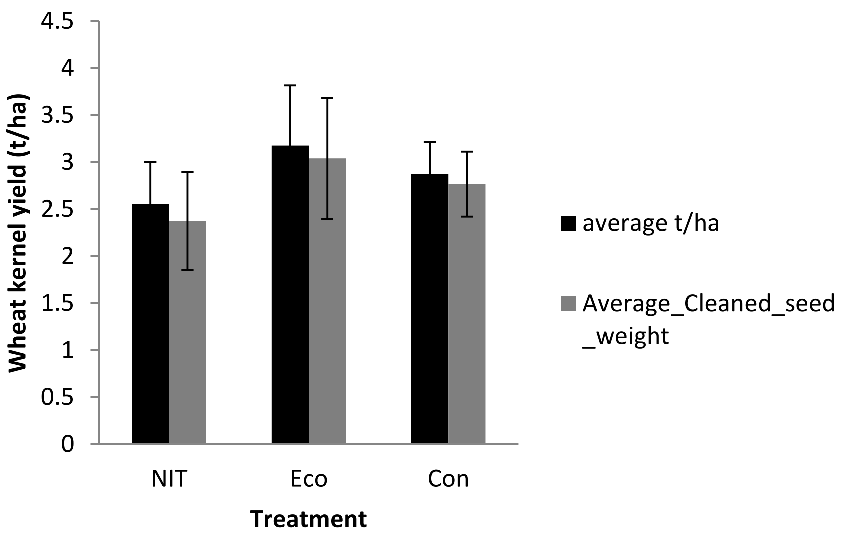

Figure 8 - A: Wheat 2014 average kernel yield and average cleaned seed yield (t/ha). The error bars are standard errors of the mean.

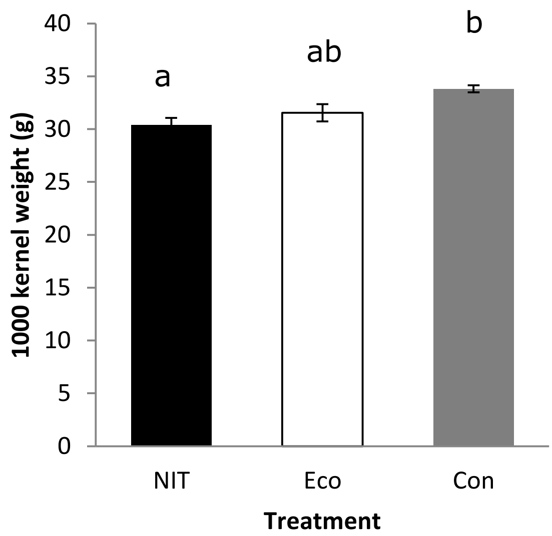

Figure 8 – B: Average thousand kernel weight for wheat 2014. The error bars are standard errors of the mean.

9. Appendix D

Wheat yield 2014 ploughing experiment, measured on 2 November 2015. Each sample is 15 m^2 of the field. The fresh weight was sometimes measured in two times. In Con3 the label was first measured with the grain, so it was subtracted later on.

Treatment	Plot	Fresh weight (g)	Cleaned seed weight (g)	1000 kernel weight (g)
NIT	1	2539	2018	30.9
NIT	2	4756	4563	29.0
NIT	3	4195	4095	31.2
Eco	1	4244	3930	30.1
Eco	2	6624	6455	31.7
Eco	3	3418	3283	32.9
Con	1	4120	3934	34.5
Con	2	5275	5134	33.6
Con	3	3518	3371	33.3

Potato stem length in cm measured in July 2015, 12 weeks after planting. Not all rows have the same number of measurements, probably because the length of the steps taken were not of the same length every time.

NIT			Eco			Con		
Row	No.	Stem length (cm)	Row	No.	Stem length (cm)	Row	No.	Stem length (cm)
4	1	80	4	1	87	4	1	73
4	2	45	4	2	52	4	2	58
4	3	79	4	3	63	4	3	64
4	4	60	4	4	70	4	4	97
4	5	27	4	5	82	4	5	66
4	6	62	4	6	45	4	6	71
4	7	72	4	7	57	4	7	86

4	8	52	4	8	67	4	8	75
4	9	60	4	9	72	4	9	45
4	10	64	4	10	37	4	10	57
4	11	71	4	11	59	4	11	69
4	12	61	4	12	69	4	12	72
4	13	69	4	13	62	4	13	60
4	14	69	4	14	42	4	14	72
4	15	64	4	15	79	4	15	61
4	16	45	4	16	29	4	16	79
4	17	53	4	17	74	4	17	30
4	18	58	4	18	62	4	18	44
4	19	51	4	19	59	4	19	62
4	20	62	4	20	73	9	1	75
4	21	62	4	21	50	9	2	54
9	1	41	9	1	75	9	3	65
9	2	60	9	2	62	9	4	48
9	3	42	9	3	52	9	5	51
9	4	51	9	4	47	9	6	80
9	5	77	9	5	75	9	7	57
9	6	58	9	6	56	9	8	64
9	7	84	9	7	74	9	9	56
9	8	52	9	8	66	9	10	50
9	9	70	9	9	61	9	11	92
9	10	75	9	10	54	9	12	70
9	11	77	9	11	72	9	13	66
9	12	62	9	12	61	9	14	70
9	13	67	9	13	88	9	15	90

9	14	96
9	15	84
9	16	79
9	17	57
9	18	73
9	19	56
9	20	78
13	1	46
13	2	40
13	3	66
13	4	38
13	5	82
13	6	no plant
13	7	no plant
13	8	42
13	9	65
13	10	55
13	11	47
13	12	57
13	13	41
13	14	28
13	15	58
13	16	40
13	17	44
13	18	57
13	19	37
13	20	58

9	14	85
9	15	60
9	16	62
9	17	64
9	18	94
9	19	82
9	20	80
9	21	78
9	22	102
13	1	79
13	2	78
13	3	62
13	4	74
13	5	68
13	6	50
13	7	50
13	8	87
13	9	70
13	10	53
13	11	60
13	12	52
13	13	59
13	14	67
13	15	41
13	16	50
13	17	55
13	18	37

9	16	72
9	17	100
9	18	77
9	19	84
9	20	86
13	1	86
13	2	69
13	3	71
13	4	63
13	5	60
13	6	67
13	7	63
13	8	70
13	9	72
13	10	82
13	11	65
13	12	91
13	13	90
13	14	80
13	15	83
13	16	84
13	17	62
13	18	56
13	19	61
13	20	93

13	19	42

Potato harvest in kg weighed by Rianne Prinsen on 2 September 2015.

treatment	units sample nr.	kg bag1	kg bag2	kg green/diseased	kg <40mm	kg 40<x <65mm	kg >65mm
NKG	1	23.8	12.3	0.7	5.7	29.4	0.3
NKG	2	18.3	20.6	1.4	6.3	30.8	0.4
NKG	3	14.8	20.2	0.3	4.6	29.6	0.5
Eco	1	15.0	20.7	0.6	4.3	30.5	0.3
Eco	2	18.9	19.2	1.5	3.9	30.8	1.9
Eco	3	16.7	19.7	0.7	4.2	30.7	0.8
Con	1	18.2	20.3	0.9	3.3	31.3	3.0
Con	2	21.5	20.9	1.0	3.6	34.0	3.8
Con	3	21.4	16.5	1.5	3.7	31.6	1.1

Potato subsample fresh weight, underwater weight, and subsubsample fresh and dry weight in g. Measured in September 2015 by Rianne Prinsen.

	units	subsample in g	g	subsubsample in g	g
treatment	sample	fresh weight	under water weight	fresh weight	dry weight
NKG	1	4897	384	580.2	123.4
NKG	2	4938	371	568.8	109.2
NKG	3	4892	372	608.0	132.3
Eco	1	4467	347	622.6	120.3
Eco	2	4763	345	538.4	92.5
Eco	3	4972	383	428.2	89.7
Con	1	4943	387	524.6	142.5
Con	2	4886	381	647.6	151.7
Con	3	4892	388	616.1	129.8

Soil organic matter content in %. Samples were taken in November and December 2015 by Raya Nundu and Rianne Prinsen. Triticale was growing in the field at the moment of sampling.

		SOM		
Block	Treatment	0-10cm	10-20cm	20-30cm
1	NIT	3.88	3.41	3.13

2	NIT	4.22	3.75	3.4
3	NIT	3.83	3.45	3.5
4	NIT	3.6	3.46	3.23
5	NIT	3.81	3.55	3.24
6	NIT	3.74	3.42	3.22
7	NIT	3.89	3.36	3.16
8	NIT	4.59	3.59	3.67
9	NIT	4.08	3.84	3.4
10	NIT	4.07	3.74	3.43
11	NIT	4.18	3.55	3.28
12	NIT	4.22	3.6	3.67
13	NIT	3.51	3.41	3.02
14	NIT	4.13	3.97	3.35
15	NIT	4.24	3.85	3.92
16	NIT	4.22	4.03	4.05
17	NIT	4.1	3.71	3.62
18	NIT	4.07	3.73	3.67
19	Eco	3.04	3.17	3.04
20	Eco	3.97	3.83	3.61
21	Eco	3.8	3.96	3.75
22	Eco	3.96	3.94	3.79
23	Eco	3.7	3.61	3.36
24	Eco	3.88	3.68	3.55
25	Eco	3.12	3.38	2.79
26	Eco	4.1	4.12	3.93
27	Eco	4.1	3.96	3.53
28	Eco	4.13	4.06	3.73

29	Eco	3.92	3.73	3.58
30	Eco	3.98	3.92	3.77
31	Eco	3.21	3.24	2.72
32	Eco	4.22	4.13	3.86
33	Eco	3.97	3.95	3.46
34	Eco	3.92	3.97	3.78
35	Eco	3.67	3.87	3.34
36	Eco	3.7	3.63	3.28
37	Con	2.95	3.18	2.94
38	Con	3.78	3.76	3.65
39	Con	3.84	4.03	3.78
40	Con	3.81	4.32	3.87
41	Con	3.47	3.48	3.42
42	Con	3.28	3.39	3.48
43	Con	2.74	2.85	2.97
44	Con	3.65	3.61	3.54
45	Con	3.8	3.91	3.65
46	Con	3.65	3.9	3.87
47	Con	3.29	3.39	3.57
48	Con	3.18	3.58	3.38
49	Con	2.63	2.94	2.94
50	Con	3.38	3.58	3.53
51	Con	3.63	3.85	3.78
52	Con	3.69	3.9	3.84
53	Con	3.57	3.86	3.76
54	Con	3.53	3.61	3.61