Potential of boreholes combined with deep-rooted cover crops to ameliorate subsoil compaction: year 2022

Results from the final year of the experiments; 2022

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Contents

Summary

This document summarises the results from the year 2022 of the experiments on amelioration of subsoil compaction in Lelystad and Vredepeel as part of the PPS Climate Adaptation. The results of the experiments are briefly described and interpreted. Potatoes were grown at both trial sites in 2022 and it has been about two years since the experimental treatments were applied (both mechanical treatments and green manures).

In Lelystad in 2022 there were no significant effects from the 2019-2020 cover crop treatments on potato yields, bulk density or soil moisture. There were minor but statistically significant differences in penetration resistance between the cover treatments. There were no major differences between the mechanical treatments that can be interpreted using only 2022 data, due to lack of repetitions.

In Vredepeel we saw an effect from the experimental treatments on the penetration resistance in the subsoil and nitrate leaching, but not on crop growth, bulk density and soil moisture. Large boreholes appear to have the largest decreasing effect on the penetration resistance in the subsoil in combination with the black oats and tall fescue + English ryegrass cover crops. The choice of cover crop seems to influence the effect of the mechanical treatment, and vice versa. In order to substantiate effects on penetration resistance and nitrate leaching, data from previous years need to be taken into account. Additionally, in 2022 the soil was not compacted, hence in order to be able to conclude whether the measures can ameliorate subsoil compaction, we need to look at the level of compaction in previous years.

Across both experiments the preliminary conclusion is that effects from previous years' treatments are not apparent and that differences between the treatments are either too small to be interesting or too variable in order to be able establish clear and meaningful relation with our hypothesized effects from the treatments. It is advisable to look at the effects seen in previous years to be able to draw final conclusions on where observed effects are coming from and what the developments over time were.

The full analysis and conclusions from the experiments over the full duration (2019-2022) will follow in the final report later in 2023.

Samenvatting

Dit document geeft een samenvatting van de resultaten vanuit 2022 van de experimenten naar ondergrondverdichting in Lelystad en Vredepeel in het kader van de PPS Klimaatadaptatie. De resultaten van de experimenten worden kort beschreven en geïnterpreteerd. In 2022 werden op beide proeflocaties aardappelen geteeld en het is ongeveer twee jaar geleden dat de experimentele behandelingen werden toegepast (zowel mechanische behandelingen als groenbemesters).

In Lelystad waren er in 2022 geen significante effecten van de groenbemesterbehandelingen uit 2019-2020 op aardappelopbrengsten, bulkdichtheid of bodemvocht. Er waren kleine maar statistisch significante verschillen in indringingsweerstand tussen de groenbemesters. Er waren geen grote verschillen tussen de mechanische behandelingen die geïnterpreteerd kunnen worden aan de hand van alleen de gegevens van 2022.

In Vredepeel zagen we een effect van de behandelingen op de indringingsweerstand rond de ploegdiepte en op de nitraatuitspoeling, maar niet op gewasopbrengsten, bulkdichtheid en bodemvocht. Het boren van grote gaten blijkt het grootste afnemende effect te hebben op de indringingsweerstand in combinatie met de groenbemesters Japanse haver en rietzwenkgras + Engels raaigras. De keuze van groenbemester lijkt het effect van de mechanische behandeling te beïnvloeden, en ook omgekeerd. Voor een goede onderbouwing van effecten op de indringingsweerstand en nitraatuitspoeling moet ook gekeken worden naar data uit voorgaande jaren. Bovendien was de bodem volgens metingen aan bulkdichtheid en indringingsweerstand 2022 niet verdicht, dus om te kunnen concluderen of de maatregelen de verdichting van de ondergrond kunnen verbeteren, moeten we kijken naar de mate van verdichting in voorgaande jaren en de ontwikkeling daarvan.

In beide experimenten is de voorlopige conclusie dat effecten van de behandelingen van de voorgaande jaren moeilijk aantoonbaar zijn en dat de verschillen tussen de behandelingen ofwel te klein zijn om interessant te zijn, ofwel te variabel om een duidelijk en zinvol verband te kunnen leggen met de door ons veronderstelde effecten van de behandelingen. Het is raadzaam om te kijken naar de effecten in voorgaande jaren om definitieve conclusies te kunnen trekken over de oorzaken van de waargenomen effecten en wat de ontwikkelingen in de tijd waren.

De volledige analyse en conclusies uit de experimenten over de volledige looptijd (2019-2022) volgen in het eindrapport later in 2023.

1 Introduction

This document summarizes the results from the experiments for investigating the potential of various measures to ameliorate subsoil compaction. The results from the experiments in Lelystad and Vredepeel are shortly described and interpreted. In 2022 potatoes were grown at both experimental sites and it has been around two years since the experimental treatments were applied (mechanical treatments as well as cover crops). The complete analysis and conclusions from the experiments over the full duration of the experiment (2019-2022) will follow in the final report later in 2023.

2 Method

On each location twelve treatments were compared with four mechanical treatments combined with three cover crop treatments (Table 1). In Vredepeel there were also four extra treatments without replications for statistical analysis. The Vredepeel experiment had a randomized block design and data was analysed by using a linear model that was optimized with variable selection. The Lelystad experiment was not randomized across mechanical and cover crop treatments and only had one replication of the mechanical treatments. Therefore, only the cover crop treatments could be statistically analysed, although these should be interpreted with care as there is a risk for influence of gradients in the field. The statistical analysis will be described in the final report.

Table 1. *Overview of experimental treatments. The extra treatments were only tested in Vredepeel and were not included for statistical comparison as they were not scientifically replicated and randomized.*

Treatment code	Mechanical treatment	Cover crop Lelystad	Cover crop Vredepeel
1a	Subsoiling (SS)	Diverse perennial mixture	Annual taproot
1b	Subsoiling (SS)	Perennial with fibrous roots	Annual with fibrous roots
1c	Subsoiling (SS)	Perennial with tap root	Perennial with fibrous roots
2a	Small boreholes (SB)	Diverse perennial mixture	Annual taproot
2b	Small boreholes (SB)	Perennial with fibrous roots	Annual with fibrous roots
2c	Small boreholes (SB)	Perennial with tap root	Perennial with fibrous roots
3a	Large boreholes with substrate (LB)	Diverse perennial mixture	Annual taproot
3b	Large boreholes with substrate (LB)	Perennial with fibrous roots	Annual with fibrous roots
3c	Large boreholes with substrate (LB)	Perennial with tap root	Perennial with fibrous roots
4a	Untreated (Ref)	Diverse perennial mixture	Annual taproot
4b	Untreated (Ref)	Perennial with fibrous roots	Annual with fibrous roots
4c	Untreated (Ref)	Perennial with tap root	Perennial with fibrous roots
Extra treatments			
LBS	Large boreholes with substrate (LB Sand)	N.a.	Annual with tap root
LBExt	Large boreholes with substrate (LB Extensive)		
Comp	N.a. (see main text)		
SSC	Subsoiling with caterpillar (SS Caterpillar)		
Ref	Untreated (Ref)		

3 Results

3.1 Lelystad

Due to the lack of replications on the mechanical treatments, statistical analysis was only performed to compare the cover crop treatments. It is important to note that the cover crop treatments were not properly randomized which could cause errors in the interpretation in case a gradient was present in the field, as was the case in this experiment. Effects from the mechanical treatment will be discussed in the final report, looking at the data from all years of measurements.

3.1.1 Potato yield and quality

There were no significant differences between the cover crop treatments on the net- and gross yield or the product tare of potato (Figure 1; Table 2). The fibrous root treatment had a significantly higher yield than the mixture and the taproot crop ($p<0.01$) for potatoes of the size 35-60 mm (Table 2). The blocks, which overlap with the mechanical treatment, appear to show a gradient in yield effects which makes it difficult to interpret the results.

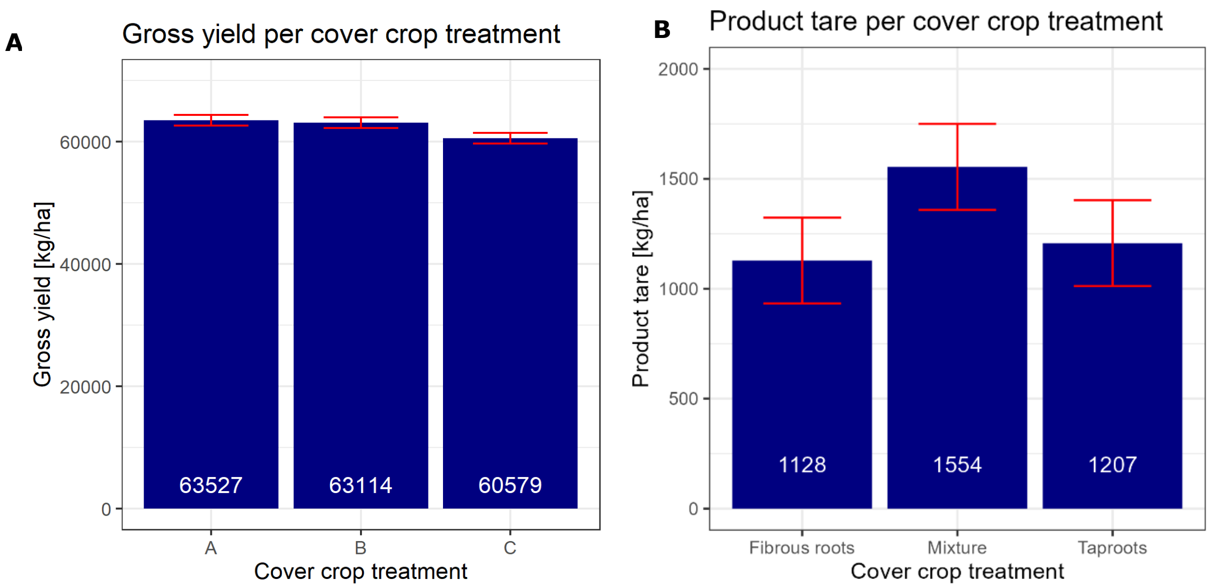

Figure 1. (A) Gross potato yield in kg/ha averaged for all mechanical treatments based on estimated marginal means (EMM) with the standard error in the error bars. (B) Potato product tare in kg/ha based on estimated marginal means (EMM) with the standard error in the error bars. There were no statistically significant differences. A= Mixture, B=Fibrous roots, C=Taproots.

Table 2. Overview of mean results on potato crop variables in kg/ha for all treatments. NB: Mechanical treatments do not have any replications. The different colours do not indicate statistical differences but indicate relative differences between the values of that column.

Mechanical treatment	Cover crop treatment	Gross yield [kg/ha]	Net yield [kg/ha]	Product tare [kg/ha]	<35 mm [kg/ha]	35-60 mm [kg/ha]	>60 mm [kg/ha]
Reference	Mixture	64050	61591	2459	945	18433	42213
Reference	Fibrous roots	62674	60603	2071	1105	20928	38570
Reference	Taproots	62742	60889	1852	1198	20077	39614
Large boreholes	Mixture	65631	64001	1630	943	19276	43782
Large boreholes	Fibrous roots	64455	63569	886	1011	22090	40468
Large boreholes	Taproots	63305	61874	1431	948	17846	43080
Small boreholes	Mixture	62847	61951	895	951	18304	42697
Small boreholes	Fibrous roots	64407	63583	823	1169	22788	39627
Small boreholes	Taproots	60751	59972	778	1079	18912	39981
Subsoiling	Mixture	61579	60346	1233	1066	17608	41673
Subsoiling	Fibrous roots	60920	60187	733	918	19273	39996
Subsoiling	Taproots	55519	54751	768	1030	18786	34935

3.1.2 Cover crop biomass

There was no cover crop grown in 2022 due to the late harvesting moment of potato.

3.1.3 Penetration resistance

The mean penetration resistance across all treatments was higher than in previous years (not shown) which could be caused by re-compaction or be related to the potato crop. Compaction (>2.5 MPa) was reached at around 40 cm depth. Statistical analysis was done per 5 cm and showed (Figure 2):

- 11-25 cm: Fibrous roots had a significantly higher resistance than other treatments ($p<0.01$)
- 36-40 cm: Fibrous roots had significantly higher resistance than the taproots treatment ($p<0.01$)
- 51-55 cm: Mixture had significantly higher resistance than taproots ($p<0.01$)
- 56-60 cm: Mixture had significantly higher resistance than other treatments ($p<0.01$)

These significant differences are in the range of 0.1-0.3 MPa which is a minor difference.

Also, for the yield (35-60 mm), significant effects were seen from the fibrous root crop compared to the other treatments. Whether the higher penetration resistance in the upper soil could have caused this yield effect is unclear. It is also unclear whether fibrous roots are less effective in increasing the porosity in the non-compacted layers. To be able to conclude this, this needs to be confirmed by previous years data. In the lower layers the mixture treatment was more compacted than the other treatments, it is unclear if this could have to do with rooting effects as the depth of the roots in the cover crop treatments was not determined at the end of the cover crop treatments is not known.

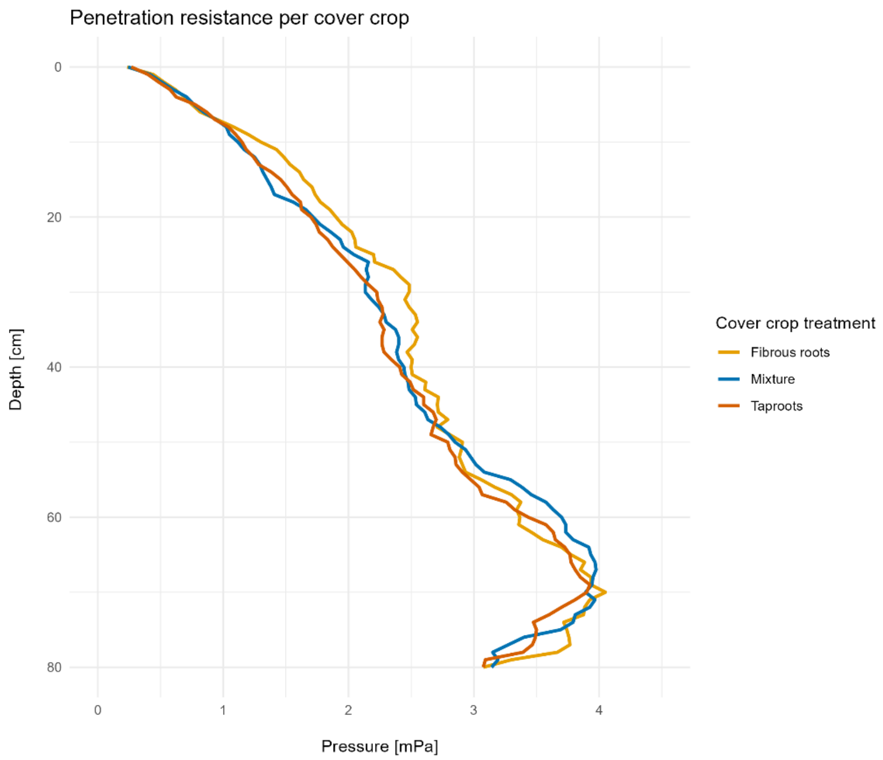

Figure 2. Penetration resistance per cover crop treatment averaged over the mechanical treatments in MPa in the layer of 0-80 cm based on means.

The mechanical treatments, although lacking repetitions, do not show major differences between the treatments (Figure 3). Differences in effects from the mechanical treatments on the penetration resistance will be discussed in the final report, alongside data from previous years due to the gradient in the field.

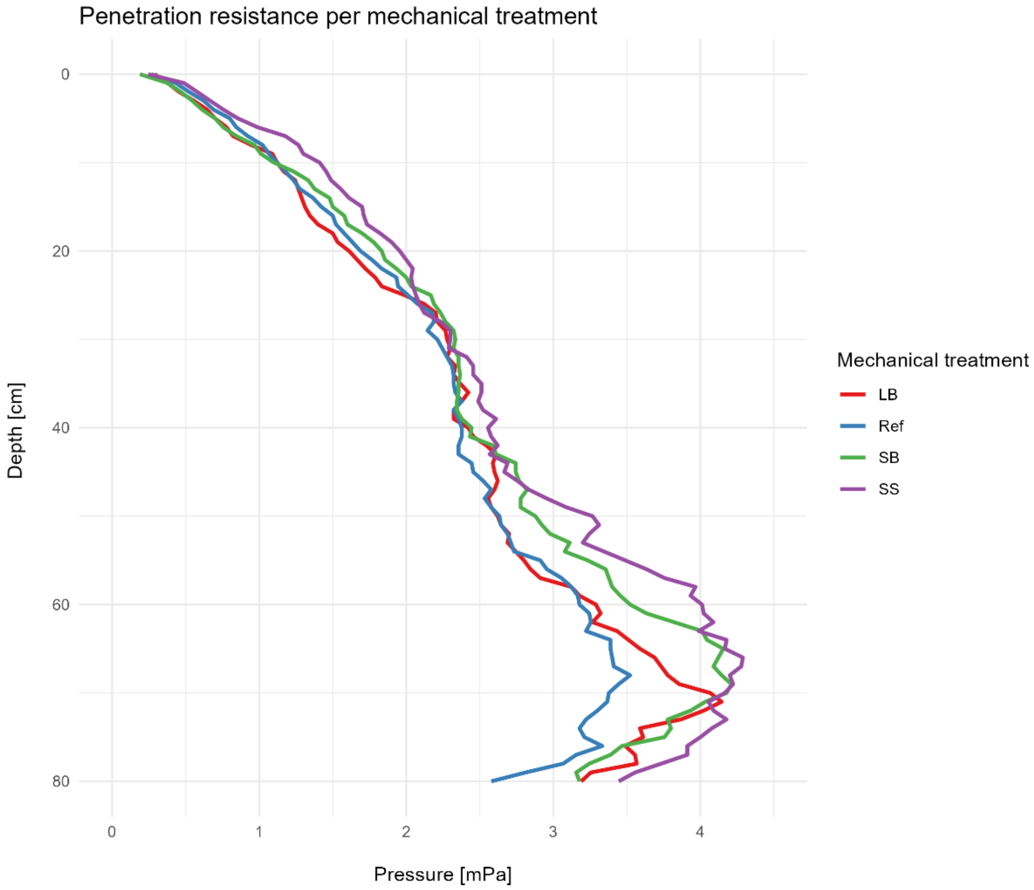

Figure 3. Penetration resistance per mechanical treatment with only one repetition averaged over the cover crop treatments in MPa in the layer of 0-80 cm based on means. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

3.1.4 Dry bulk density

In 2022 the soil was not compacted according to the bulk density measurements. There were no significant differences between the cover crop treatments in bulk density (Table 3).

Table 3. Dry bulk density in g/cm3 based on the means on the soil depths 5-10 cm and 20-25 cm. There were no statistically significant differences between the cover crop treatments within any of the mechanical treatments. The different colours do not indicate statistical differences but indicate relative differences between the values of that column.

Mechanical treatment	**Cover crop**	**5-10 cm**	**25-30 cm**
Reference	Mixture	1.41	1.38
Reference	Fibrous roots	1.34	1.37
Reference	Taproots	1.40	1.43
Large boreholes	Mixture	1.41	1.42
Large boreholes	Fibrous roots	1.40	1.42
Large boreholes	Taproots	1.35	1.38
Small boreholes	Mixture	1.35	1.40
Small boreholes	Fibrous roots	1.41	1.37
Small boreholes	Taproots	1.45	1.41
Subsoiling	Mixture	1.36	1.38
Subsoiling	Fibrous roots	1.41	1.40
Subsoiling	Taproots	1.33	1.50

3.1.5 Soil moisture

There were no significant differences between the cover crop treatments on the soil moisture (Table 4). Measurements were done at suitable soil moisture conditions (~20%) for the measurement to be performed.

Table 4. Water percentage based on the means on the soil depths 5-10 cm and 20-25 cm. There were no statistically significant differences between the cover crop treatments within any of the mechanical treatments. The different colours do not indicate statistical differences but indicate relative differences between the values of that column.

Mechanical treatment	Cover crop	5-10 cm	25-30 cm
Reference	Mixture	20.4	22.5
Reference	Fibrous roots	21.2	21.5
Reference	Taproots	20.8	20.7
Large boreholes	Mixture	21.0	21.8
Large boreholes	Fibrous roots	21.5	22.1
Large boreholes	Taproots	21.1	22.0
Small boreholes	Mixture	21.0	21.2
Small boreholes	Fibrous roots	20.7	21.0
Small boreholes	Taproots	19.9	22.2
Subsoiling	Mixture	20.9	22.8
Subsoiling	Fibrous roots	21.1	22.7
Subsoiling	Taproots	22.2	20.2

3.2 Vredepeel

3.2.1 Potato yield and quality

There were no significant effects from the experimental treatments on the gross (Figure 4A) or net yield or the yield in the size classes <40 mm 40-70 mm and >70 mm (Table 5). The experimental treatments also showed no significant effects on the product tare (Figure 5A). The four additional treatments show similar results as the experimental treatments (Figure 4B and Figure 5B).

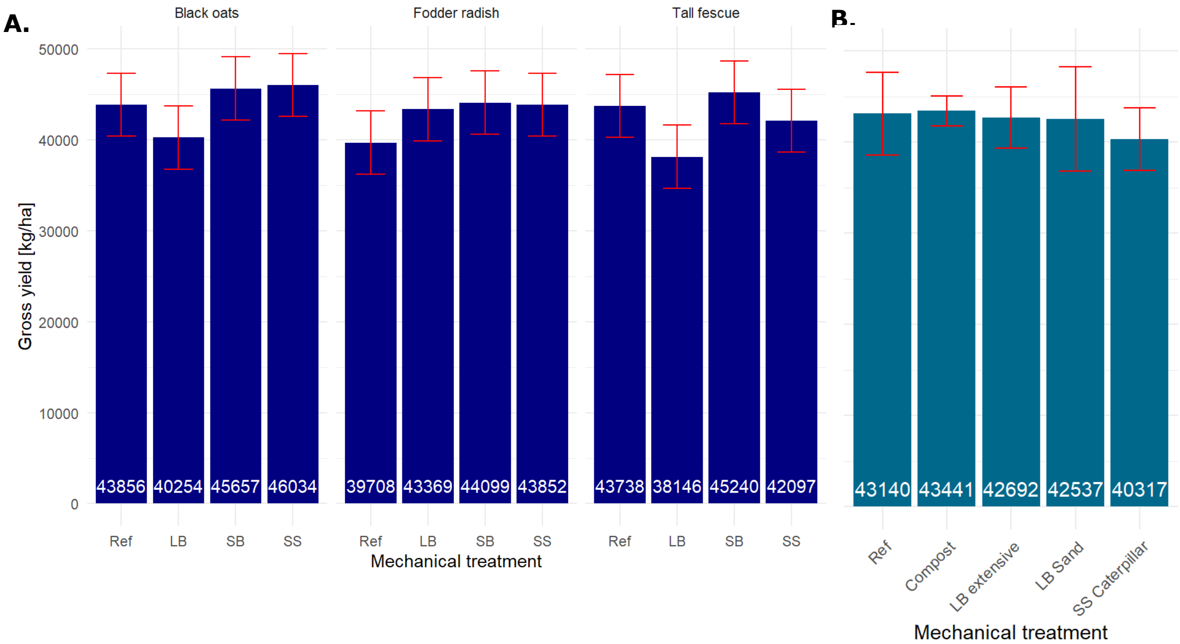

Figure 4. (A) Gross potato yield [kg/ha] based on estimated marginal means (EMM) with the standard error in the error bars. There were no statistically significant differences. (B) Gross potato yield with standard deviation in the error bars. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

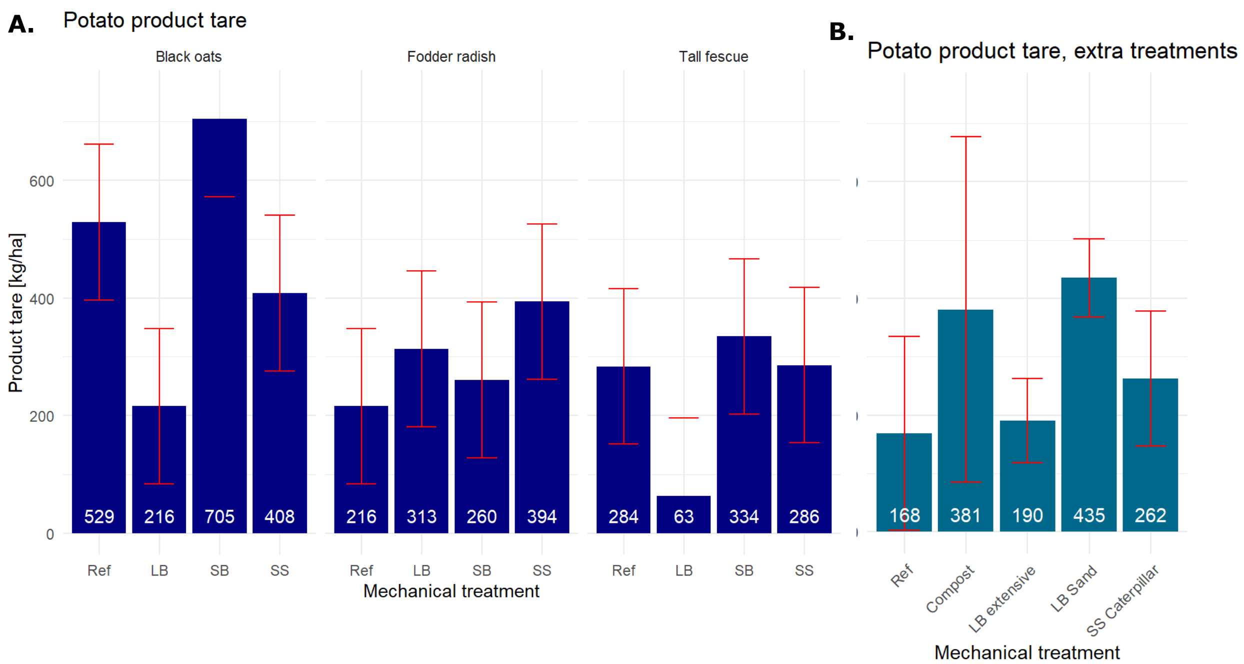

Figure 5. (A) Potato yield losses based on estimated marginal means (EMM) with the standard error in the error bars. There were no statistically significant differences. Error bars for SB – Black oats and LB – Tall fescue reach outside the visible plot. (B) Potato yield losses with standard deviation in the error bars. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

Table 5. Overview of mean results on potato crop variables in kg/ha for all treatments.

Mechanical treatment	Cover crop	Gross yield [kg/ha]	Net yield [kg/ha]	Product tare [kg/ha]	<40 mm [kg/ha]	40-70 mm [kg/ha]	>70 mm [kg/ha]
Reference	Black oats	43856	39881	529	3446	39137	745
Reference	Fodder radish	39708	36237	216	3255	35767	470
Reference	Tall fescue	43738	40296	284	3158	39949	347
Compost	Fodder radish	43441	41105	381	1956	40127	978
Large boreholes	Black oats	40254	36652	216	3386	36097	554
Large boreholes	Fodder radish	43369	39589	313	3467	39479	110
Large boreholes	Tall fescue	38146	34396	63	3687	33672	724
Small boreholes	Black oats	45657	41964	705	2988	41346	618
Small boreholes	Fodder radish	44099	40546	260	3293	39975	571
Small boreholes	Tall fescue	45240	41393	334	3513	41168	224
Subsoiling	Black oats	46034	42828	408	2798	42248	580
Subsoiling	Fodder radish	43852	39928	394	3530	39856	72
Subsoiling	Tall fescue	42097	39043	286	2768	38734	309
Extra treatments							
Compost	Fodder radish	43441	41105	381	1956	40127	978
Large boreholes extensive	Fodder radish	42692	39632	190	2870	39048	584
Large boreholes Sand	Fodder radish	42537	39663	435	2438	38825	838
Subsoiling Caterpillar	Fodder radish	41446	37864	225	3357	37498	366

3.2.2 Cover crop biomass

There were no significant effects of the treatments on the cover crop aboveground biomass (Figure 6) or belowground biomass (see data output link of final report). The cover crop in 2022 was a mixture of fodder radish and black oats.

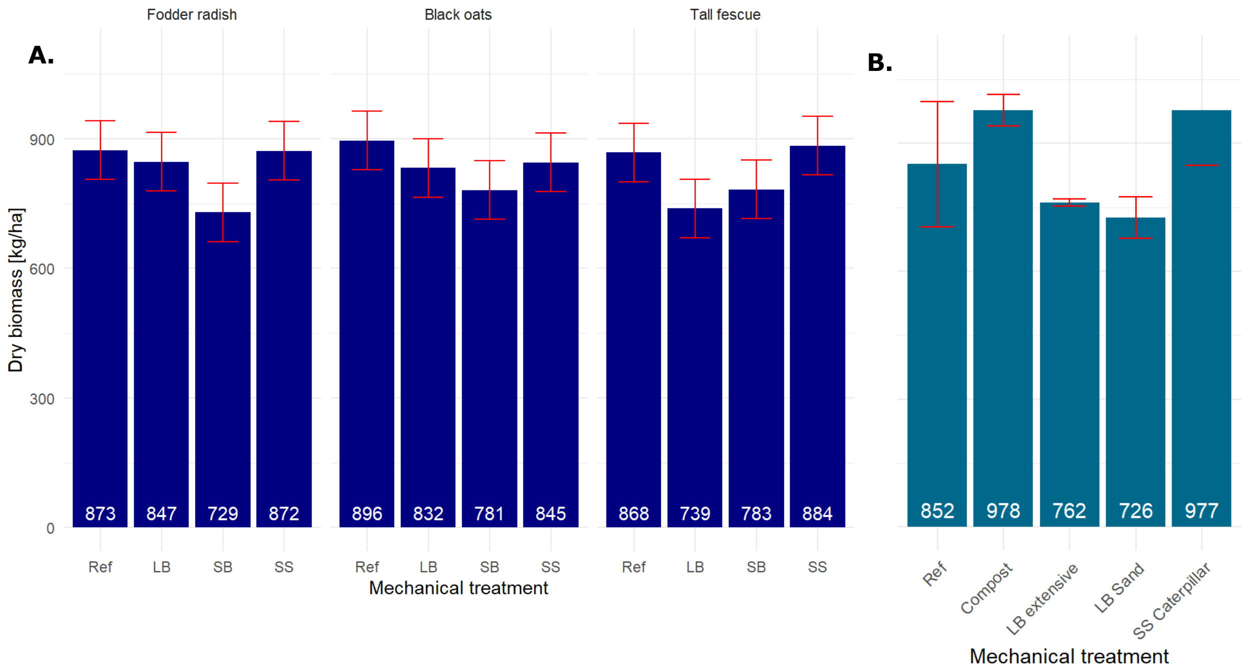

Figure 6. (A) Dry cover crop aboveground biomass in kg/ha based on estimated marginal means (EMM) with the standard error in the error bars. There were no statistically significant differences. (B) Dry cover crop biomass in kg/ha with standard deviation in the error bars. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

3.2.3 Nitrate concentration in groundwater

Nitrate leaching levels were on average very high for all the treatments which is common following a potato crop (Figure 7). The plots that had the fodder radish treatment in 2020 had a significantly lower nitrate leaching (83 mg/L) than the plots with tall fescue + English ryegrass (190 mg/L), in the subsoiling treatment (SS) (p=0.02). The subsoiling treatment show contrasting effects for the different cover crops. That the cover crop could have effects on nitrate levels two years after it was grown is unexpected which makes these results difficult to explain.

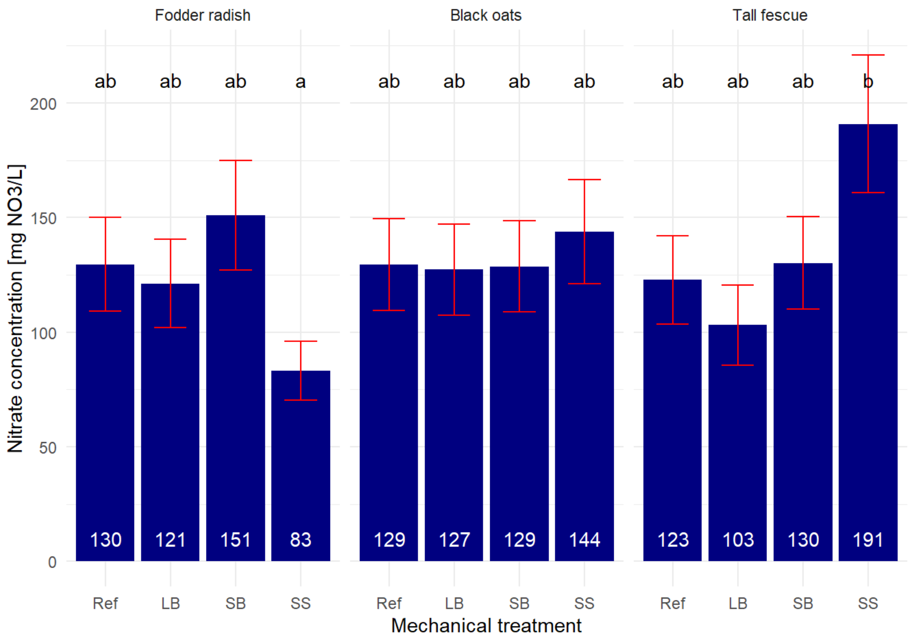

Figure 7. Nitrate concentration in groundwater based on estimated marginal means (EMM) with the standard error in the error bars. Statistically significant differences between treatments are indicated with different letters. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

3.2.4 Penetration resistance

The differences in penetration resistance was generally larger between the mechanical treatments than for the cover crop treatments. There were no significant differences between mechanical or cover crop treatments but there were interaction effects between the two ($p<0.01$). In the 11-15 cm layer, the fodder radish in the small boreholes treatment has a higher penetration resistance than the fodder radish in the reference treatment ($p=0.02$) (not shown). In the 21-30 cm layer the large borehole treatment together with the black oats

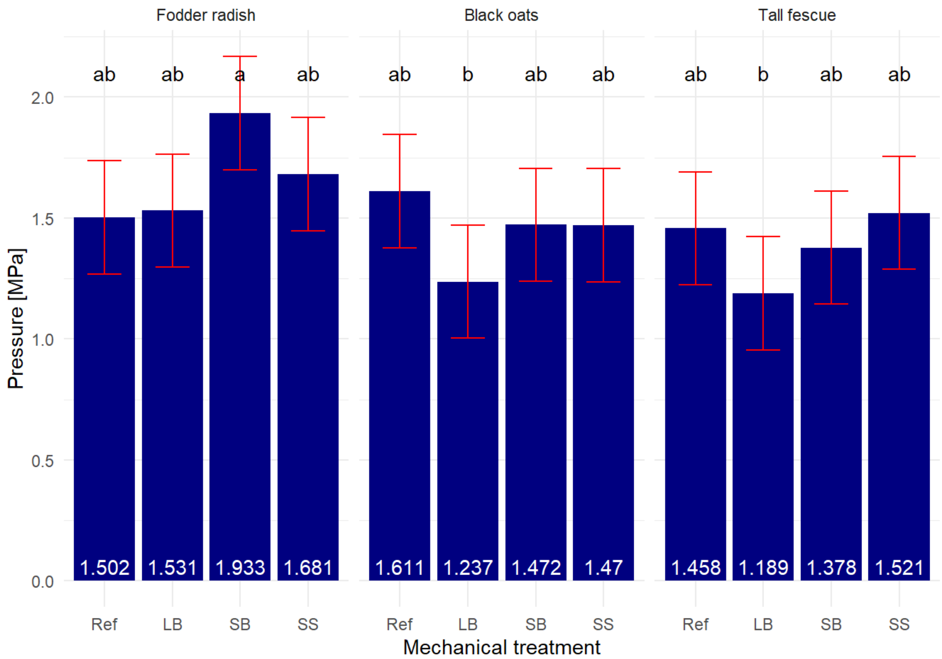

Figure 8. Penetration resistance in the layer of 26-30 cm based on estimated marginal means (EMM) with the standard error in the error bars. Statistically significant differences between treatments are indicated with different letters. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

($p<0.01$) or tall fescue ($p<0.01$) cover crops treatment had a significantly lower penetration resistance compared to treatment with small boreholes and fodder radish (Figure 8). The differences were around 0.5-0.8 MPa. However, the soil was not compacted in this layer as the maximum penetration resistance was below 2,5 MPa. In lower soil layers the penetration resistance increases to 2.5-3.5 MPa which can be considered to be compacted, however in these layers no significant effects from the treatments were found.

In the extra treatments, the subsoiling with caterpillar treatment showed lower resistance across the layers compared to the other treatments (not statistically tested) (Figure 10).

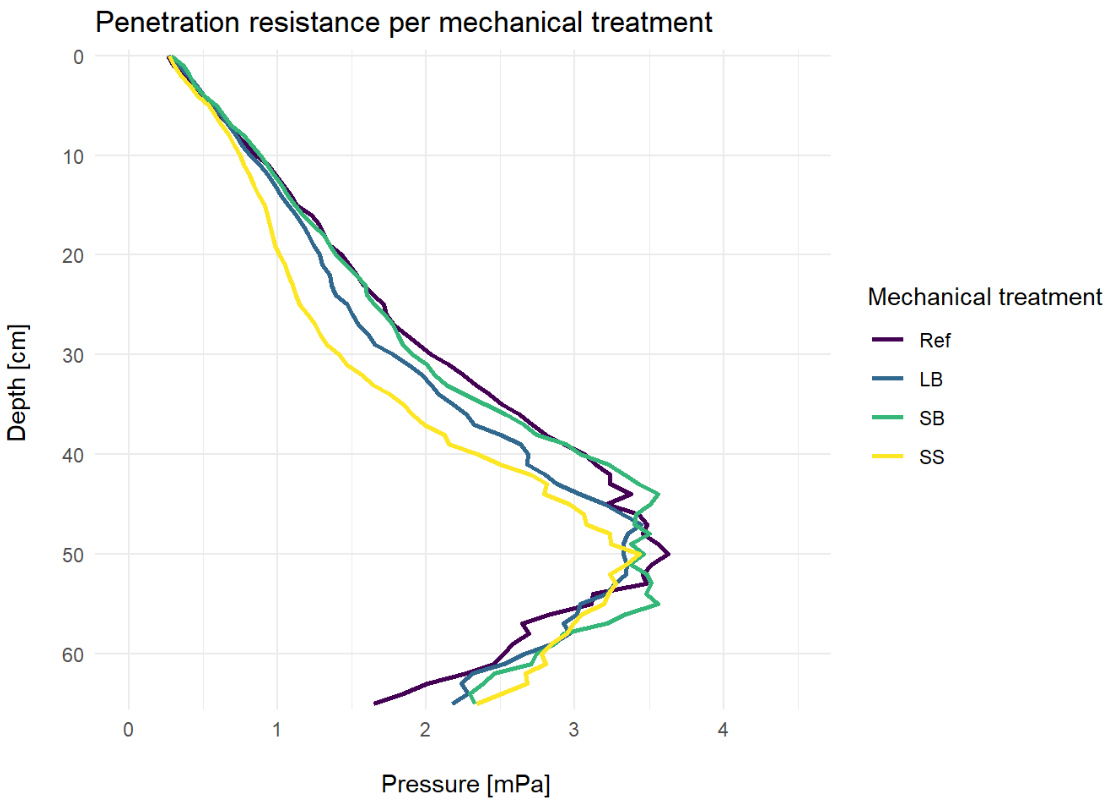

Figure 10. Mean penetration resistance across the soil profile 0-70 cm for the replicated treatments. Ref = No treatment, LB = Large Boreholes, SB = Small Boreholes, SS= Subsoiling.

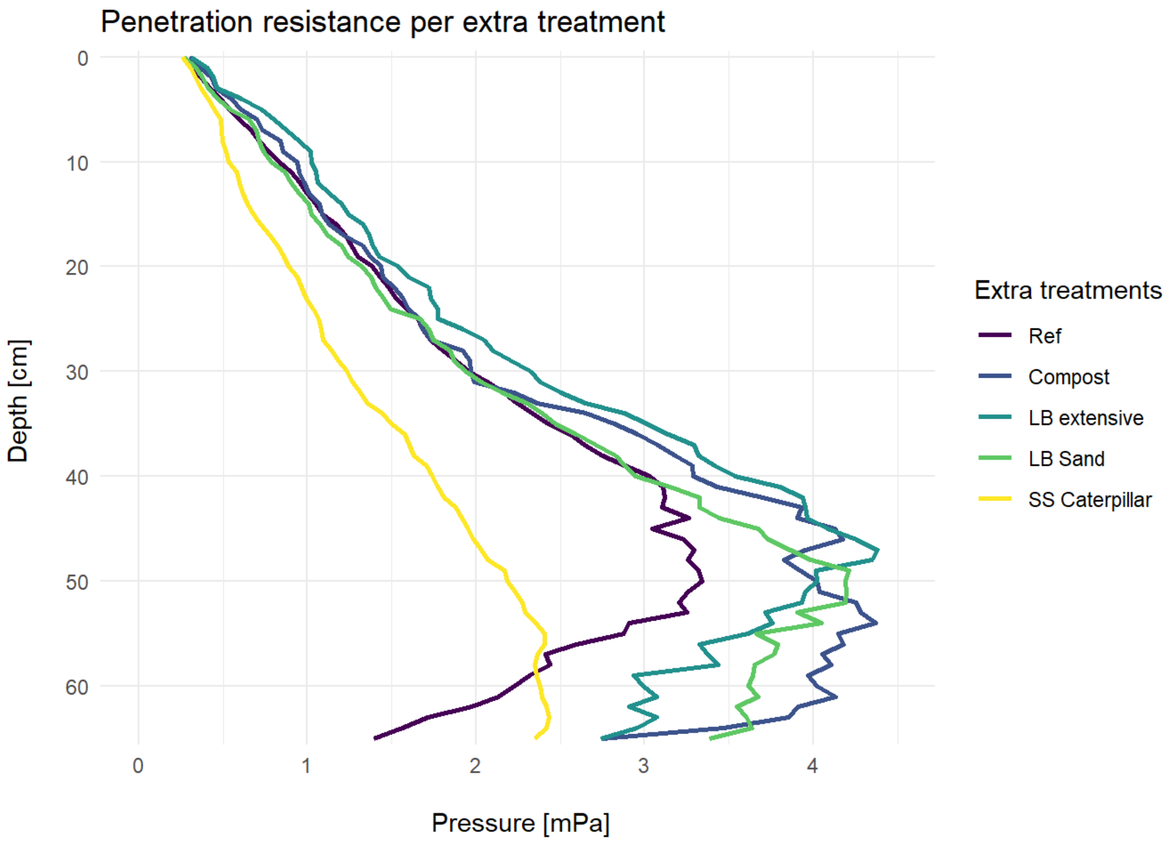

Figure 10. Mean penetration resistance across the soil profile for the extra treatments. Ref=No treatment, LB = Large Boreholes, SS= Subsoiling.

3.2.5 Dry bulk density

There were no significant effects from the experimental treatments on the dry bulk density at 5-10 cm and 20-25 cm depth (Table 6).

Table 6. Dry bulk density in g/cm³ based on estimated marginal means (EMM) on the soil depths 5-10 cm and 20-25 cm. There were no statistically significant differences. Root growth is reduced from 1.69 g/cm³ and severely obstructed from 1.85 g/cm³ and higher.

Mechanical treatment	Cover crop	5-10 cm	20-25 cm
Reference	Fodder radish	1.38	1.39
Reference	Black oats	1.30	1.34
Reference	Tall fescue	1.36	1.41
Large boreholes	Fodder radish	1.32	1.35
Large boreholes	Black oats	1.31	1.42
Large boreholes	Tall fescue	1.37	1.43
Small boreholes	Fodder radish	1.30	1.36
Small boreholes	Black oats	1.32	1.46
Small boreholes	Tall fescue	1.32	1.42
Subsoiling	Fodder radish	1.32	1.44
Subsoiling	Black oats	1.32	1.42
Subsoiling	Tall fescue	1.31	1.38
Extra treatments			
Compost	Fodder radish	1.30	1.39
Large boreholes extensive	Fodder radish	1.31	1.42
Large boreholes Sand	Fodder radish	1.30	1.41
Subsoiling Caterpillar	Fodder radish	1.29	1.43

3.2.6 Soil moisture

There were no significant effects from the experimental treatments on the soil water fraction (Table 7). There was a marginally significant difference between black oats (0.13) and tall fescue (0.20) in the reference mechanical treatment (p=0.05) at 5-10 cm depth.

Table 7. Fraction of water based on estimated marginal means (EMM) on the soil depths 5-10 cm and 20-25 cm. There were no statistically significant differences. E.g.: 1.00=100% moisture, 0.00=0% moisture, 0.20=20% moisture.

Mechanical treatment	Cover crop	5-10 cm	20-25 cm
Reference	Fodder radish	0.19	0.18
Reference	Black oats	0.13	0.14
Reference	Tall fescue	0.20	0.22
Large boreholes	Fodder radish	0.16	0.18
Large boreholes	Black oats	0.17	0.19
Large boreholes	Tall fescue	0.18	0.17
Small boreholes	Fodder radish	0.19	0.18
Small boreholes	Black oats	0.19	0.16
Small boreholes	Tall fescue	0.17	0.19
Subsoiling	Fodder radish	0.18	0.21
Subsoiling	Black oats	0.15	0.18
Subsoiling	Tall fescue	0.18	0.20
Extra treatments			
Compost	Fodder radish	0.16	0.11
Large boreholes extensive	Fodder radish	0.15	0.13
Large boreholes Sand	Fodder radish	0.16	0.16
Subsoiling Caterpillar	Fodder radish	0.16	0.14

4 Conclusions

In Lelystad in 2022 there were no significant effects from the 2019-2020 cover crop treatments on potato yields, bulk density or soil moisture. There were minor but statistically significant differences in penetration resistance between the cover treatments. There were no major differences between the mechanical treatments that can be interpreted using only 2022 data, due to lack of repetitions.

In Vredepeel we saw an effect of the experimental treatments on the penetration resistance in the subsoil and nitrate leaching, but not on crop growth, bulk density and soil moisture. Large boreholes appear to have the largest decreasing effect on the penetration resistance in the subsoil in combination with the black oats and tall fescue + English ryegrass cover crops. The choice of cover crop seem to influence the effect of the mechanical treatment, and vice versa. In order to substantiate effects on penetration resistance and nitrate leaching, data from previous years need to be taken into account. Additionally, in 2022 the soil was not compacted, hence in order to be able to conclude whether the measures can ameliorate subsoil compaction, we need to look at the level of compaction in previous years.

Across both experiments the preliminary conclusion is that effects from previous years' treatments are not apparent and that differences between the treatments are either too small to be interesting or too variable in order to be able to establish clear and meaningful relation with our hypothesized effects from the treatments. It is advisable to look at the effects seen in previous years to be able to draw final conclusions on where observed effects are coming from and what the developments over time were.

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The mission of Wageningen University & Research is "To explore the potential of nature to improve the quality of life". Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,200 employees (6,400 fte) and 13,200 students and over 150,000 participants to WUR's Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.