Effects of incorporating and mulching green manure on soil characteristics and barley growth

MSc Thesis

K.H. Klompe

March 2017

Farming Systems Ecology Group

Droevendaalsesteeg 1 – 6708 PB Wageningen - The Netherlands

WAGENINGEN
UNIVERSITY & RESEARCH

Effects of incorporating and mulching green manure on soil characteristics and barley growth

Koen Klompe

Registration number: 910913444090

Study programme: MSc Organic Agriculture

Course code: MSc thesis FSE-80436

Supervisor: dr. ir. Egbert Lantinga

Examiner: dr. ir. Felix Bianchi

March, 2017

Farming Systems Ecology Group

Wageningen University, The Netherlands

Table of contents

Preface

This thesis is written as part of my master Organic Agriculture and done at the chair group of Farming System Ecology. Quite fast it was clear for me to do my thesis with this chair group since I am very interested in the total system of a farm and how to improve this. I come from an organic farm myself and I always liked to help my father with improving our farming system and try to make it more sustainable. When visiting the farm of the Westers family with one of my courses, I found it really interesting and inspiring to see how they make use of what nature gives them and how they try to close the cycle on their farm. When looking for a thesis subject I thought of this excursion again and I wanted to know more about the green manure since I think this is a good and sustainable way to improve your soil. When I heard that Harm Westers had some research questions about this subject I knew one of those research questions would be my research question.

I really want to thank the Westers family for their hospitality and a special thank to Harm Westers since he gave me the opportunity to do an experiment on his farm. Also Harm helped me to think about the experiment which was really nice and useful since he knows a lot about this subject. I really liked his enthusiasm about his farming system, which also made me enthusiastic for my research. I also want to thank Dr. Egbert Lantinga for his supervision during my thesis. He learned me about the important aspects of conducting a research. Without Egbert this thesis would not have been possible. Also I want to thank Hennie Halm who helped me with all analyses that needed to be done. I really enjoyed working with you. I also want to thank John van der Lippe and Frans Bakker from Unifarm for helping me with sowing the barley. The soil was very tough but with the help of John and Frans we made the best out of it. Another word of thank to all my friends and family who helped me in any kind of way to get this thesis done.

I hope you will enjoy reading this thesis report!

Abstract

Green manure is used more and more. This is due to regulations and raised awareness of the importance of soils and the influence of green manure on the soil. Also the minimum tillage system is gaining popularity because of its sustainable character. When combining the use of green manure and minimum tillage, one important question is: 'Which is the best way to apply a green manure?'. The two general options are mulching or incorporation. In this study incorporation of a green manure mixture is compared to mulching by flail mowing (small particles) and by normal mowing (big particles). After these treatments barley was sown as a test crop. The different effects measured were decomposition of the green manure, nutrient availability in the soil, ammonia emission, weed and barley soil cover, soil temperature and soil moisture. In this experiment mulching resulted in a slower nutrient decomposition compared to incorporation. The decomposition of the incorporated green manure would probably even be faster as measured since in reality the green manure is distributed throughout the upper 8 cm of the soil while the green manure measured was packed together in a mesh bag. This made it less accessible for the soil life. The soil temperature was lower and the soil moisture was higher when mulching, especially for the mowed mulch. However, soil moisture seems to be more dependent on soil tillage than on the way the green manure was applied. For all treatments there were a lot of weeds present and therefore the barley grew very poorly. This was also due to sowing techniques. However it was expected that mulching would result in less weed soil cover, this was not the case. The results gave some more in-sight in the differences between mulching and incorporation which might help the farmer to make the best choices for his/her situation.

1. Introduction

Nowadays there is a lot of attention for the use of green manures. There are legislations to increase the greening of agriculture (Janmaat and Kuijper, 2016) since the use of green manures is one of the solutions to make agriculture more sustainable (Cherr et al., 2006). The legislations forces farmers to use more cover crops/green manures. But next to that, the farmers are also more aware of the advantages of green manures. There are multiple positive influences like enhancing nutrients, increasing soil and water quality, reduction of weeds, reduction of pests and protection against erosion (Clark, 2008). Another way to be more sustainable is the use of a minimum or no-tillage production system. It can help to improve the organic C levels, the cation-exchange capacity, the hydraulic conductivity, the aggregate diameter and the water holding capacity (Mahboubi et al., 1993). When combining minimum tillage and the use of green manures the way of application of the green manure becomes an important aspect. In Table 1 all different ways of applying a green manure are given.

Also the Westers family who have an organic farm in the upper north of the Netherlands, have to deal with this aspect. They combine minimum tillage with the use of green manures. The target on this farm is to use no animal manure anymore and fertilize the soils only with green manures. The green manures are growing in situ, so no cut and carry fertilization is applied since they believe that it is not necessary to transport your green manure when it could also grow on the field itself. Although the Westers family already have a lot of experience with the use of green manures they are still searching for improvements for their production system. Therefore, they want to know what the effects are on the whole system when you are mulch the green manure instead of incorporating.

Table 1 Overview of different ways of applying green manures.

Cut-and-carry fertilizer: green manure grown on a different field and transferred directly to cash crop.
Cut-and-carry silage fertilizer: silage is made of the green manure and applied and incorporated the next year or later in the same year on crops.
In situ green manure: green manure is grown on the same field as the cash crop and incorporated when cash crop is sown. Here there is a difference in green manures that can survive winter, so they are still alive when incorporated (termination is needed) and green manures that cannot survive winter, so you are left with a dead green manure crop.
Transfer mulch: green manure is grown on a different field. It is mowed and transferred to the cash crop and left on top of the soil as a mulch.
In situ mulch: green manure is grown on the same field. It is mowed and left on top of the soil as a mulch.
Some crop specific methods: - *Potato planting in in situ mulch*: potatoes are planted into a living green manure. Just before the potato plant will come above soil surface the living green manure is terminated and used as mulch. - *Deceleration of green manure in vineyards*: green manure are decelerated to prevent competition of green manure on grape plants.

Because the system of minimum tillage and using green manure is getting to be more important (Cherr et al., 2006, Teasdale et al., 2007) it is valuable that research on this topic is done. There are already some studies done on the comparison of mulching and incorporation. One of these studies proved that mulching decreased the soil temperature, had a positive effect on soil moisture, it prevented crusting, decreased weed growth, but had little effect on the availability of the nutrients (Wade and Sanchez, 1983). However, this study was done in a humid tropical climate and in a different agricultural system:

no organic agriculture, use of slash and burn system and other crops were used. Therefore, these results might not be comparable to a Dutch climate situation.

Another research which is done in the Netherlands compared different ways of applying cut-and-carry fertilizers. The cut-and-carry fertilizer was applied at potatoes before ploughing, after ploughing before harrowing, and at one treatment the green manure was used as a mulch. From this experiment it was concluded that mulching made the green manure dry out which resulted in a slower and limited nutrient release which leaded to a lower yield. The highest yield was retained when the green manure was shallowly incorporated by harrowing (Vervisch et al., 2016).

As can be seen, there are pros and cons for mulching green manures. To study this more in-depth, an experiment with mulching and incorporating green manure was set-up. Several possible effects were measured: decomposition of the plant material, availability of soil nutrients, ammonia emission, barley growth, weed growth, soil temperature and soil moisture. In this report first the research questions will be formed, afterwards the material and methods are described. Next, each chapter describes the results, the discussion and conclusion for one possible effect. This is done to improve the readability. After all effects are treated, a total conclusion of the study is given.

2. Purpose of the study

In this study the purpose is to investigate the effects of incorporating or mulching green manure before sowing a new (cash) crop in an organic agricultural production system where the principles of minimum tillage are applied. Also different ways of mulching, mowing and flail mowing (smaller particles of plant material), are compared to see what will be more convenient. The effects focused on in this study are about different aspects of the soil quality, the nutrient release of the green manure and the effects on the germination of the (cash) crop.

The research question used to achieve this purpose of the study is:

What are the differences between mulching and incorporation of green manure on several important cultivation aspects?

The sub questions are:
What is the effect of green manure used as a mulch or when incorporated on:
- **the decomposition rate of the green manure (weight and nutrients)**?
- **nutrient availability in the soil**?
- **ammonia emission**?
- **the amount of weeds present**?
- **the germination of the barley plants**?
- **soil temperature**?
- **the soil moisture content**?

The corresponding hypotheses are:
- The **decomposition rate** of the green manure is expected to be higher in the treatment where the green manure is incorporated compared to the treatments where the green manure is used as mulch. From both types of mulching it is expected that the decomposition rate is higher in the treatment of flail mowing compared to the normal mowing treatment.
- The **nutrient availability** is expected to be higher in the treatment where the green manure is incorporated compared to the treatments where the green manure is used as mulch. From both mulching treatments it is expected that the nutrient availability is higher in the treatment of flail mowing compared to the normal mowing treatment.
- it is expected that there will be more **ammonia emission** at the treatments where no incorporation is done.
- It is expected that the **amount of weeds** will be higher in the treatment of incorporation compared to the treatments of mulching.
- The expectation is that the **soil cover due to barley** will be higher in the treatment of incorporation of the green manure compared to the mulching treatments.
- The **soil temperature** of the treatment where the green manure will be incorporated and the treatment where the green manure will be mowed and removed will be higher compared to the treatments where the green manure is used as a mulch. The soil temperature of the treatments where the green manure is used as mulch will be more stable.
- The **soil moisture content** is expected to be higher in the treatments with the mulch layers compared to the incorporation treatment.

Soil life is not taken into account since the change of the soil life is hard to measure in a few months and there is no money available for detailed methods which might detect changes in the 8 weeks of measurement.

3. Materials and methods

3.1 Experimental site

For the experiment a field with a self-composed green manure mixture is used. In Table 2 the composition of this green manure is shown. The green manure mixture is sown just after the carrots were harvested in 2015.

Table 2 The different components of the mixture with the amount of seeds sown per hectare.

Components	**Kg seeds/ha**
Winter rye *(Secale cereale)*	150
Field bean *(Vicia faba)*	150
Winter pea *(Pisum sativum)*	50
Hairy vetch *(Vicia Villosa)*	10
Tillage rammenas *(Brassica rapa)*	5
Phacelia *(Phacelia tanacetifolia)*	2

An overview of the crops which were grown before the green manure mixture is given in Table 3. The soil is a heavy loam soil with 18% of clay. The whole soil analysis of this field, conducted in September 1999 by BLGG can be found in Appendix 1. At that time there was 2,2% organic matter (OM).

Table 3 Crops grown before on the green manure mixture field.

2012	2013	2014	2015
Potato –GM[a]	Oats – GM	Pumpkin – GM	Carrot – GM

[a] - GM: green manure sown after primary crop

The field is close to the Wadden Sea at the utmost north coastline of the Netherlands, close to Hornhuizen, part of the province of Groningen. The coordinates of the field are 53°24'15.2"N 6°21'51.7"E. At the farm the system of minimum tillage is applied. Since 2010 there is no plough used anymore and before that a lot of trials were done with minimum tillage. Nowadays, there is no animal manure used at all at the farm, so the farmer relies on the nutrients given by green manures. There is also no green manure imported from outside the farm.

3.2 Experimental set-up

To answer the research questions a field experiment is done. In this field experiment 2 ways of mulching and one way of incorporation are compared. Also a control group is added. This resulted in the next 4 treatments:

1. The green manure mixture is flail mowed and incorporated in the 8 to 10 cm top soil by using a rotary harrow (**inc**).
2. The green manure is flail mowed and left on the soil surface, so without incorporation (**mfm**).
3. The green manure is mowed with a normal mowing machine (**mm**). This means that the mulch will be rougher compared to the second treatment.
4. The control treatment (**co**) is also mowed, but then the mowed green manure is removed from the field, so only some stubbles will be left over.

Directly after these treatments barley (*Hordeum vulgare*) is sown in at all treatments. This is done the third of June.

These treatments are applied at fields placed in a completely randomized design, since the experiment is in a homogeneous field according to the farmer. Each treatment have 4 replicates. So, there are 16 fields in total. The fields are placed in a block of 4x4 fields (see Figure 1). In the direction of driving there is 10 m of space in between the field, so application of the treatments could be done easily. The size of the fields are 10 x 3 m of which 1,5 m is sown and measured (see Appendix 2). Measurements are done in one, two, three, four, six and eight weeks after the start of the experiment. In the end this corresponded to 7, 13, 20, 27, 41 and 56 days after the start (DAS) of the experiment.

Figure 1 Experimental set-up.

3.3 Methods

To measure as much different aspects as possible of the soil sustainability, the nutrient availability and the germinating cash crop the next methods are used. For a list of all materials see Appendix 3.

Decomposition rate

To measure the decomposition rate of the green manure, mesh-bags were used. The 10x20 cm mesh-bags had a mesh size of 5 mm so also earthworms, including the *Lumbricus terrestris*, could enter the mesh-bags. The mesh-bags contained 25 g of fresh plant material. At the start of the experiment 4 mesh-bags of each treatment were randomly collected and weighted. The content of those bags were put in an oven at 70 °C for at least 24 hours to gain the dry weight. From this the initial moisture content is calculated, which is used to calculate the initial dry-weight of all bags of that treatment. Also the initial total N, P and K were measured. In each field 6 mesh-bags were placed after the mesh-bags have been weighted and labelled. At the fields where no incorporation is applied the bags were just put on top of the soil and at the fields where there is incorporation of the green manure, the mesh-bags were put 5-10 cm below soil surface. At each mesh-bag a recognition stick with a label is placed. The first 4 weeks each week one mesh-bag per field was taken and weighted, afterwards each 2 weeks one mesh-bag was taken and weighted. The content of the mesh-bags were oven dried at 70 °C. After drying the % dry weight remaining was calculated (Bocock et al., 1960, Karberg et al., 2008).
To correct for soil contamination in the samples the method of Potthoff and Loftfield (1998) was used. In this method the ash content of the soil, the ash content of the green manure before put into the ground and the ash content of the green manure after it was collected was measured. With the help of formula (1) the soil contamination could be calculated.

$$SC = \frac{AC_{AR} - AC_{BP}}{AC_S} \quad (1)$$

SC is the dry weight of the soil contamination (g), AC_{AR} is the ash content of the green manure (mg) in the mesh-bag after removal, AC_{BP} is the ash content of the green manure in the mesh-bags (mg) before placement, and AC_S is the ash content of the soil (mg g^{-1}).
To measure the ash content of the different samples, the samples were ashed at 600°C for 1 hour (for green manure before and after placement) or 2 hours (for soil samples).
To analyse the total N, P and K of the plant material another part of the dried plant material was grinded. The analysis of total N, P and K was done according to the method of Novozamsky et al. (1983). Next to this also three samples were taken to measure the total yield of the green manure. Of these samples the different species were separated to measure the contribution of each specie. Also, the C:N ratio per specie is determined. The %C is measured by the analysis according to Dumas. Also the total N, P and K is determined of these samples, again according to Novozamsky et al. (1983).

The decomposition in weight (% dry weight remaining) and nutrient content (g total nutrient per sample) of the green manure of the different treatments were compared to each other. Next to that the measurements over time are also compared to the initial value to see from which moment on there is significant decomposition.

Potential availability of mineral N, P and K

From the day of application of treatment till 4 weeks after application each week one soil sample of the 15 cm topsoil per field was taken. Afterwards once every 2 weeks a soil sample is taken. So altogether, 1, 2, 3, 4, 6 and 8 weeks after the day of application. This was done by taking 10 stabs per field, mix it and gather one cup of soil. From that sample available soil nutrients ($N\text{-}NH_4$, $N\text{-}NO_3$, $P\text{-}PO_4$ and K^+) were measured according to the method of Houba and Novozamsky (1998).

The measurements over time were compared to the initial value to see if there is any significant increase of the soil nutrient. The treatments were also compared to each other to see if there are significant differences between them.

NH_3 volatilization

Possible differences in NH_3 volatilization were measured by using Modified Palmes Diffusion tubes (Hofschreuder and Heeres, 2002). The tubes were placed for the first 3 days of the experiment, since in those days the most NH_3 volatilization was taking place (Rana and Mastrorilli, 1998, Shah et al., 2012). The tubes were hanged 20 cm above ground. There were 4 tubes per field (Shah et al., 2012). An extra control of 4 Palmes Diffusion Tubes were carried out to see the background ammonia emission. Also 3 tubes which had no contact with the air were measured to determine if any ammonia is already measured outside the field measurements. The tubes were analysed by using a spectrophotometer according to Hofschreuder and Heeres (2002). Since this method is sensible to outliers, a median was used per field instead of an average. The different treatments were compared with each other.

Germinating barley and weeds

The first three weeks the amount of barley plants were counted, but from the fourth week on the amount of plants became too much to count. Therefore, from that week on the barley and weed were determined as percentage soil coverage. A grid of 1 m^2 with 100 squares was placed at the field to help determine the soil coverage. To convert the data from the first weeks to percentages it was assumed that one plant would count for 0,1% soil coverage. The percentages soil coverage of barley and weeds of the different treatments were compared with each other per time of measurement. There was no weeding done, so a fair comparison between the treatments could be done.

Soil temperature

During 8 weeks the soil temperatures was measured at a depth of 10 cm with a copper-constantan thermocouple (Bussière and Cellier, 1994, Van Donk et al., 2004). Measurements were done from the start of the experiment till 8 weeks after application of the treatments. A data logger (*DataTaker*) was used and measurements were done every 30 minutes. Since the cables were not long enough to reach each field, only fields 5 till 12 could be measured on soil temperature. This means that there was only one replicate of the mm treatment, three replications for the co treatment and for inc and mfm both two replications. An automated weather station was used to measure air temperature, air humidity, wind speed, precipitation and solar irradiation.

The average soil temperatures over time of the different treatments were compared with each other. Also the minimum and maximum soil temperature are used to give an indication of the stability per treatment.

Soil moisture content

ThetaProbe sensors were used to measure the soil moisture content. The sensors were linked to the datalogger (*DataTaker*), so every 30 minutes a measurement could be done. Only 4 sensors were available, so for each treatment one. Calibration was done by measuring a block of soil, dry it afterwards to calculate the moisture content by weight and measure again the block of soil. In the end the soil moisture contents of the different treatments were compared with each other.

3.4 Statistical analysis

For each subject statistical analyses is done using IBM SPSS Statistics 24. The analysis of variance (ANOVA) is used in combination with Tukey's test with a significance level of 0.05 to conduct a multiple comparison test.

4. Decomposition patterns of the applied green manure

4.1 Results

Weight

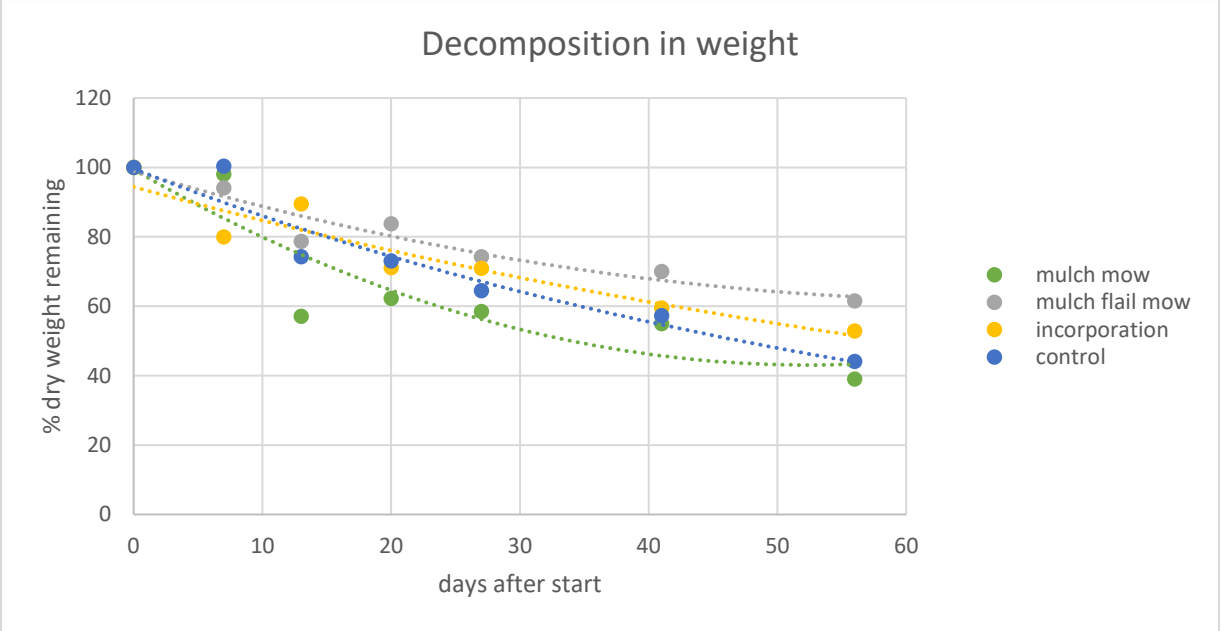


Figure 2 The average weight decomposition of the applied green manure over time per treatment. Each treatment contained 4 replicates. The decomposition is showed as % dry weight remaining.

Looking to the decomposition of the weight of the plant material over time (see Figure 2) it is shown that in the first week after the start the weight is decreasing faster than later on. In the end the treatments contains between the 35% and 65% of the initial weight. After a statistical analysis (Appendix 4.1) it can be seen that the mowed and the control treatment gives significant difference from the second week (13 DAS) on compared to the initial weight. The flail mowed treatment also shows in the second week a significant difference, but after three weeks (20 DAS) the measured weight is not significantly lower compared to the initial weight anymore because the measured weight was higher compared to the week before. The treatment of incorporation shows already at 7 DAS significant difference, but the week after there is no significance anymore.

From 13 DAS on it looks like the mowed treatment (mm) showed the lowest weights, so there the most decomposition has taken place. To prove this another statistical analysis is done to see if there is significant difference between the treatments (see Appendix 4.1). This analysis shows that mm is only at a few times of measurement significantly different from other treatments. In the second and eighth week (13 and 56 DAS) the mm treatment is significantly lower compared to the mfm and inc treatment. In the eighth week the co treatment is also significantly lower compared to mfm.

Nitrogen decomposition

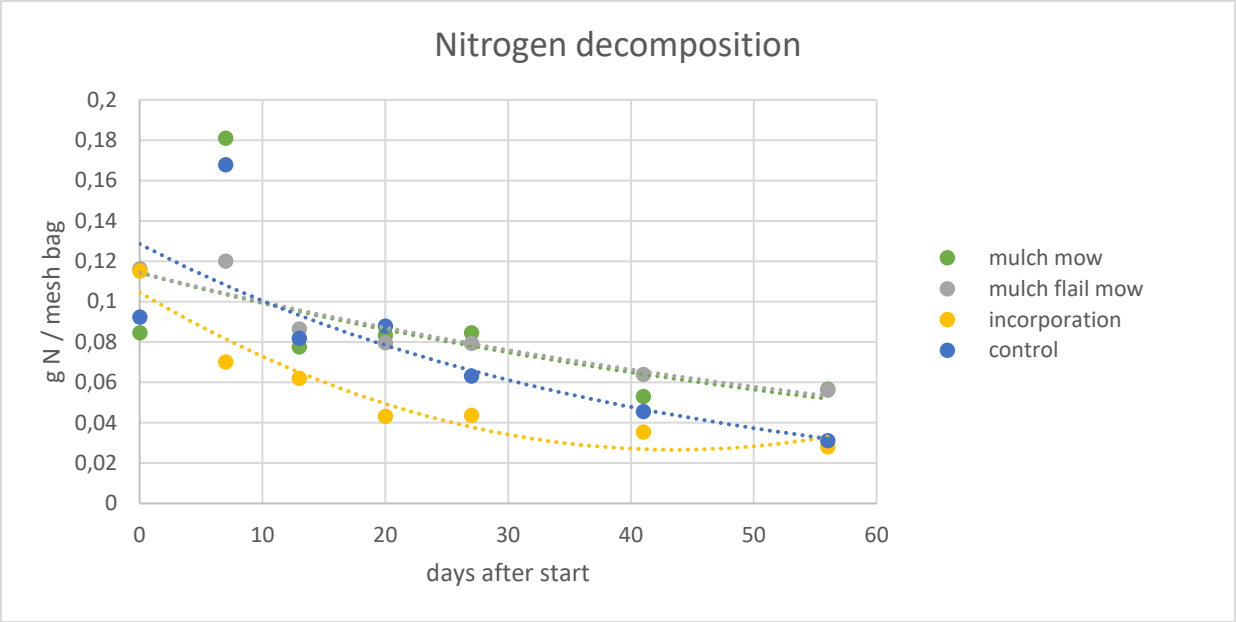


Figure 3 The amount of nitrogen per mesh bag (initially 25 gram green manure fresh weight) over time.

The decomposition of the nitrogen in the green manure is given in Figure 3. At 7 DAS the mm and co treatments where both mowed plant material is used, are increasing. However, afterwards they are decreasing again. Therefore trendlines are given which show the decrease in nitrogen per sample over time. The inc treatments shows in the first week a big drop, while the mfm treatment has the biggest decrease in the second week (13 DAS).

A statistical analysis (see Appendix 4.2) showed that the mm and co treatment over the whole time of measurement are not significantly different from the initial N-content of the plants, only in the first week because of the big increase. This means that for the mm and co treatments there was no proven N decomposition at all. Looking to the mfm treatment there is no significant difference in the first week, but afterwards there is significant difference. For the inc treatment it is proven that from the first week on there is decomposition because the amount of N is significantly lower at all weeks compared to the initial amount of N.

To compare the treatments with each other another statistical analysis is done (see Appendix 4.2). Here it is shown that there are just a few significant differences between the treatments per week. All these have to do with the inc treatment. In the third week (20 DAS) the amount of N is significantly lower in the inc treatment compared to the other treatments. In the fourth week (27 DAS) it is only significantly lower compared to the mm treatment and in the sixth week (41 DAS) it is significantly lower to the mfm treatment.

Phosphor decomposition

As seen in the decomposition of the nitrogen of the green manure also the phosphor in the green manure is sometimes increasing over time instead of decreasing, again in the first week (7 DAS) for the mm and co treatments there is quite a big increase (Figure 4). However, by plotting a trendline the overall decrease is shown.

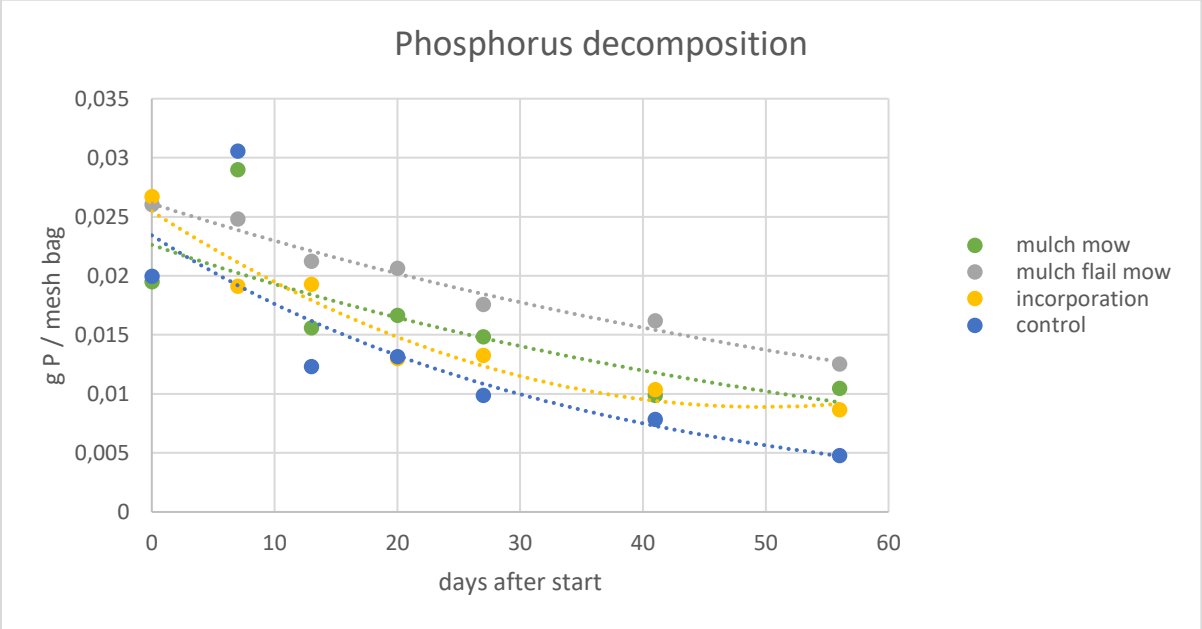


Figure 4 The decomposition of the amount of phosphor in the green manure over time. 03-06 was the start of the experiment.

To see if there is significant decomposition of the phosphor a statistical analysis is done (see Appendix 4.3). Here the p-values are given per treatment per time of measurement compared to the initial situation. It shows that the inc treatment is from the beginning on significantly lower compared to the initial P content. The mfm treatments shows significantly lower amount of P from the fourth week (27 DAS) on, the co treatment from the sixth week (41 DAS) on and the mm treatment is not significantly lower at all.

Also for the phosphor a statistical analysis is done to compare the treatments with each other (see Appendix 4.3). This shows that from 13 DAS on the mfm and co treatments are significantly different from each other. In the second week co is also significantly lower compared to the inc treatment. In this week also mm and mfm are significantly different from each other. The third week (20 DAS) shows a significant difference between the mfm and inc treatment.

Potassium decomposition

The decomposition of potassium is given in Figure 5. As can be seen only the mm and co treatments are shown. The other treatments (mfm and inc) contained too much soil in the sample so the measurements were not reliable anymore, since soil K and plant K measurements differ from each other.
Like the plant N and P content, also the K content shows in some cases an increase of amount of K instead of a decrease which is expected. However, when looking to the whole trend of the graph it does show decrease of K-content which indicates K decomposition.

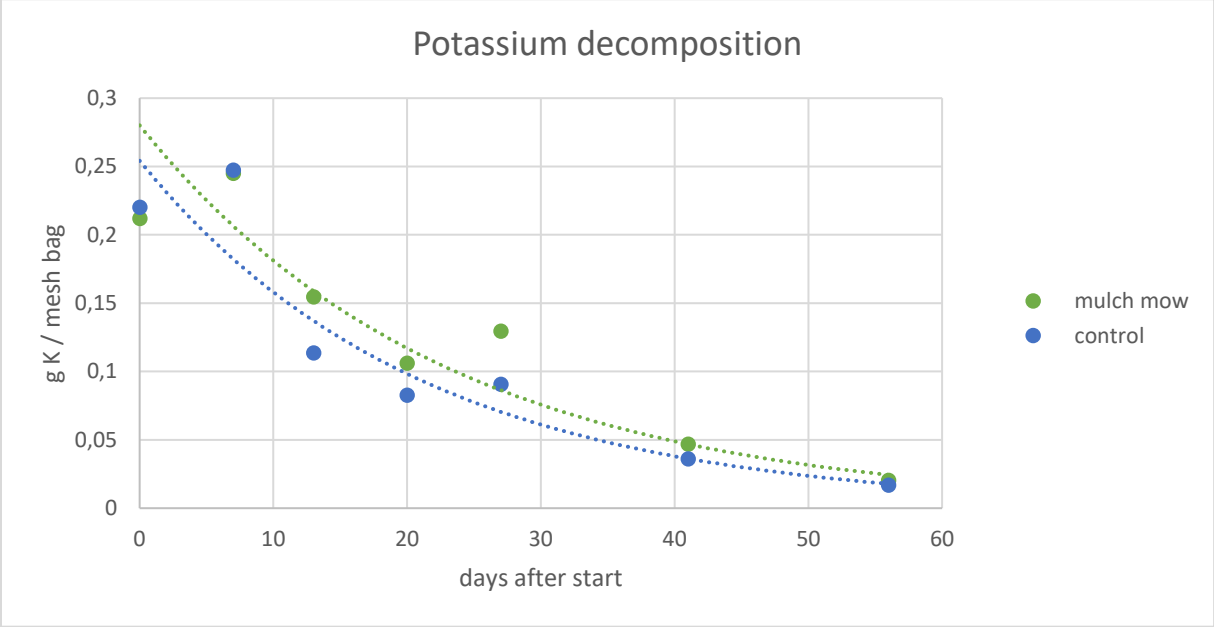


Figure 5 The decomposition of potassium in the green manure over time of the mm and co treatment.

To show if there is significant difference between the different times of sampling and the initial K content a statistical test is done (see Appendix 4.4). This test shows that the K content of the samples is significantly lower from 13 DAS on. In Figure 5 this can also be seen that in the first week after the start (7 DAS) there is no decrease, but even increase. Afterwards the slope is decreasing very quick and from then the amount of K is significantly lower. So from 13 DAS on we can speak of decomposition of potassium for both treatments.

To see if there is also a difference between the 2 treatments a statistical analysis is done to compare them per time of measurement (see Appendix 4.4). There was no significant difference between the treatments over time.

4.2 Discussion

Weight

Increase in weight

As the results of weight decomposition shows there is a gradual decrease over time. This is also what was expected. Although, in some cases there is an increase of weight from one week to another. This can for example be seen in the inc treatment where week two (13 DAS) gives a higher weight than week one (7 DAS), in the mm treatment at the second and third week after the start and in the mfm treatment also at the second and third week. According to the theory this is not logic at all, because dead plant material cannot increase in weight. It is only broken down and not build up. Although, it is impossible that there is an increase theoretically, practically it is possible due to the method used.

Bag filling problem

Each time of measurement a different bag is taken since it is a destructive method. Each time a bag is removed from the field and dried in an oven and grinded to do the nutrient measurements, so it cannot be replaced on the field. When putting the green manure into the mesh bags it is tried to put a representative mixture of the different plant species in one bag. For the flail mowed material it was easier compared to the mowed material, since flail mowing gives a much finer plant material. Some plant species would be decomposed much faster than other. For example, the Vicia faba would be degraded much faster than the rye since the C:N ratio of Vicia faba is much lower (see chapter 5 Table 5) (Hodge et al., 2000). The content of the bags is not so big (25 grams), so it is hard to put a good representative mixture of the green manure in the bags. Especially for the mowed green manure because you put big pieces of the plants in a bag. This bag filling problem also has an influence on the other aspects of decomposition of the plant material.

Significance decomposition

The decomposition of the weight in plant material is proven to be significant at 13 DAS. From 13 DAS on there is only no significant decomposition when there is an increase in weight as described before (for inc at 13 DAS and for mm and mfm at 20 DAS). So the real decomposition starts from 13 DAS on for most treatments, but for the inc treatment there is already significant decomposition at 7 DAS. This can also be seen in the graph (Figure 2) where from 13 DAS on there is a big decrease of the weight for most of the treatments, while for the inc treatment it is already at 7 DAS. In the second week (13 DAS) the inc treatment gives an increase which cause that it is not significantly different from the initial weight. Between the treatments there are only a few significant differences. In week two and eight (13 DAS and 56 DAS) the mm treatment has a significantly lower weight remaining compared to the mfm and inc treatments. The mowed plant material is in these cases broken down faster than flail mowed plant material. The reason that the co treatment do not show this is probably because there is a bit less active soil life since the mowed green manure is removed. However, in the last week (56 DAS) also co shows significance with mfm.

Decomposition surface

According to the hypothesis made it is not expected that the mowed plant material would break down faster compared to the flail mowed material since flail mowed material is much smaller. Because it is in smaller pieces there is more surface where decomposers can attach and break the material down. But what could be seen after the application of the different treatments is that the flail mowed material in the mfm treatment formed a closed dense sheet of plant material while the mowed plant material in the mm treatment was much less dense. Therefore it could be that in the end the mowed material had much more surface for decomposers to attach and break down the material. In the end it does not make that much difference since only in two of the eight times measured there is a significant

difference. But it is a very interesting result that might be worth to study in more detail. In this point of discussion it is important to mention one thing about the inc treatment. With the mesh bags the flail mowed plant material is also very dense, while in the rest of the fields the flail mowed plant material is spread in the top 10 cm soil layer. Therefore, the plant material is less dense which might cause a faster decomposition. But because of this method it could not be measured.

Nutrient decomposition

Increase of plant nutrients

At all nutrients measurements done the treatments mm and co show some (big) increases in plant nutrients in the first week after the start of the experiment (7 DAS). In the cases of nitrogen and phosphor this peak in the first week is quite big. Also in the case of potassium there is a peak in the first week, but this is a bit smaller. Next to that there is also increase shown in the other treatments and other weeks. Although, this is less extreme compared to the mm and co treatment in the first week. Since the plant material is decomposing and nutrients are given in grams per mesh bag it is not expected and theoretically even impossible that the amounts of nutrients will increase. Therefore, the increase indicates that the method is not accurate enough for this experiment. As already mentioned in the discussion about the plant weight decomposition there is a bag filling problem. This is probably also the reason for the increase given with the nutrient decompositions. What is interesting is that the same peaks can be seen at the different nutrient measured. Especially, the nitrogen and the phosphor show similar peaks. The potassium measurements also shows partly similar peaks, but to a less extent. This means that the increase of especially nitrogen and phosphor comes from probably the same species. So it seems like the plants which has a lot of nitrogen also contains a lot of phosphor. When checking this at the data this is not always the case (see Table 6). Although, it is the case that the winter rye contains the less nitrogen of all species and also the less phosphor. Winter rye also contains the less potassium. Since winter rye is the most present specie in the mixture it make sense that the peaks of the different nutrients are somewhat similar to each other. So probably there was less than average rye in the bags of the co and mm treatment.

Standard error

From week two or week three (13 or 20 DAS) on the amount of nitrogen and phosphor in all treatments look more or less the same, all decreasing gradually. The difference is that especially the amount of nitrogen at the treatments mm and co are not significantly lower, while for the mfm and the inc treatment it is significantly lower. This can also be seen at the phosphor measurements where the mm treatment is not significant at all to the initial situation and the co treatment only from week 6 (41 DAS) on. This is due to a big standard error, so a lot of variation within the treatments of mm and co. Here again the bag filling problem comes up. This problem is especially applicable to the mm and co treatment. Therefore, it is hard to get significant results out of this data. For the potassium the mm and mfm treatments do give significant difference already in the second week, but this do not have to mean that the standard error is much lower since the decomposition is much higher.

Speed of nutrient decomposition

The inc treatment shows the fastest decomposition of nitrogen and phosphor. Already in the first week (7 DAS) there is significantly less nitrogen and phosphor compared to the initial amount. For mfm the nitrogen becomes significantly lower at the second week (13 DAS) and for phosphor it becomes significantly lower in the fourth week (27 DAS). The only difference between these treatments is that in the inc treatment was put 5 cm belowground and in the mfm treatment the mesh bags were put on top of the soil. This shows that plant material which is put in the soil is decreased faster. Probably because you already help the soil life to take their food to them instead of waiting till they will get to

the food themselves on top of the soil. Also there will be a part of the soil life which usually do not come aboveground like bacteria and fungi. So when it is not incorporated by a machine it need to be incorporated by other soil life like earthworms, which takes more time.

Difference mesh bag method and reality

As mentioned before the nitrogen in the inc treatment is decreasing the fastest of all treatments. But in reality it might even be faster than measured because with the mesh bag method you still put the plant material packed together. In reality the plant material is distributed in the whole 8 cm layer of soil. Therefore, the plant material is easier to reach for the soil life. With the mesh bag method the soil life will start eating/decomposing from the outside to the inside of the pile of plant material. So it will probably decompose slower with the mesh bag method compared to reality. For the other treatments there is less difference between the mesh bag method and reality, since in reality the plant material is also packed together.

4.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on the decomposition rate of the green manure (weight and nutrients)?

Weight

The mowed plant material seems to degrade faster in weight compared to the flail mowed material. Probably because the flail mowed material is much denser than the mowed material. With this statement it must be taken into account that only two out of eight measurements shows significant difference, so there is no convincingly prove.

The statement above might not count for the incorporation treatment since in reality the plant material is not packed together but distributed through the soil. To get more representative results another method should be applied or this method should be adapted.

Nutrients

For the decomposition of the nutrients in the plant material it can be concluded that the treatments where flail mowed material was used the decomposition is faster. From these treatments the treatment where the plant material is incorporated shows the fastest decomposition. This is also as expected in the hypothesis.

For the potassium degradation there could not be made any conclusions about the decomposition between the treatments since only the mm and co treatments had trustable results. These treatments did not show any significant difference.

5. Biomass, C:N ratio and nutrient contents

5.1 Results

In Table 4 the dry weight per hectare is shown for the different components (4 most present components separated) of the mixture and the total dry weight per hectare.

Table 4 Dry weight per species and total dry weight including significant differences (*a* and *b*).

	dry weight (kg/ha)	
Field bean	1555	*ab*
Winter pea	1578	*ab*
Hairy vetch	354	*a*
Winter rye	3176	*b*
Other species	332	*a*
Total mixture	**6994**	

The C:N ratio of the different components of the mixture are given in Table 5. As can be seen, the leguminous plants (field bean, winter pea and hairy vetch) all have significant lower C:N ratios compared to the winter rye and other plants. Also the C:N ratio of the total mixture is calculated. This is done by first calculating the total %C and the total %N.

Table 5 C:N ratios of the different components of the green manure mixture and the total green manure.

	C:N ratio
Field bean	16
Winter pea	16
Hairy vetch	13
Winter rye	58
Other species	25
Total mixture	**24**

The nutrient contents are also analysed per component of the mixture (see Table 6). It is shown that the winter rye contains the less percentage of N, P and K of all species.

Table 6 Overview of the contents of N, P, K and C per species.

	%N	*%P*	*%K*	*% C*
Field bean	2,32	0,29	3,4	36
Winter pea	2,72	0,30	3,0	42
Hairy vetch	3,25	0,34	3,9	42
Winter rye	0,68	0,28	2,0	39
Other species	1,74	0,38	3,0	43

5.2 Discussion

Dry weight/ha

When the green manure mixture was applied the winter rye was the most present component looking to dry weight. The leguminous species in the mixture when applying were a bit less present while the kilogram leguminous plant seeds sown is more (see Table 2). This is probably due to the fact that the green manure had grown for a long time which resulted in a full-grown winter rye and maybe already dying leguminous plants. The Brassica rapa and the phacelia which were also sown could not be found back when applying the green manure. Probably the amounts of seeds were too low to develop well or the circumstances were not ideal for these species.

C:N ratio

The winter rye shows the highest C:N ratio, which was expected. The leguminous species have significantly lower C:N ratios since they contain more nitrogen because of the symbiosis with nitrogen fixing bacteria. Because of the lower C:N ratio the leguminous plants also decompose faster. This could also be seen over time where in the end almost only rye was still present at the top of the soil. With a C:N ratio of winter rye there will be nitrogen immobilisation, while with the leguminous plants there probably will be nitrogen mobilisation. This will depend on the bacteria:fungi ratio (Hodge et al., 2000). The total C:N ratio of the green manure is 23.9, so depending on the bacteria:fungi ratio this will in the end result in nitrogen mobilisation or nitrogen immobilisation.

The C:N ratio is quite high because the application of the green manure was very late. This was due to the wet spring which causes a late possibility to entrance the fields. When the weather became better there were first some other activities on the farm which had a priority, so the green manure also grew with some very good weather. An advantage of a high C:N ratio is that it will increase the soil organic matter.

Nutrient contents

The winter rye scores at all nutrients contents measured the lowest. Because the winter rye is a big part of the total green manure crop this has a big influence on the total nutrient contents. The differences for phosphor is not very big with the other species, but for K and N this is somewhat bigger. From these data it cannot be concluded that there is a coherence between the different nutrients.

The data discussed in this part are used to support other discussions and conclusions.

6. Soil nutrients

6.1 Results

Soil N-NH_4

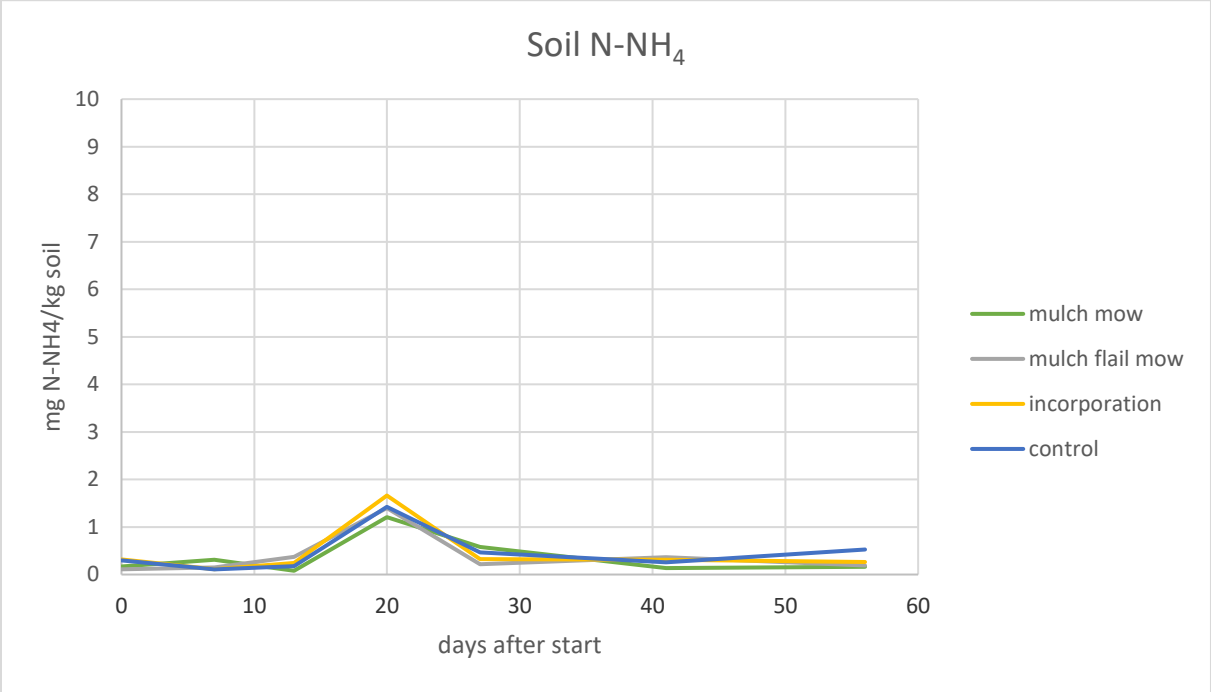


Figure 6 The N-NH_4 in the soil during the time of measurements.

According to the measurements done there is a peak at 20 DAS for all treatments (see Figure 6). The amount of N-NH_4 is much lower (around 5 times lower) at the other times of measuring. Although, the amount of N-NH_4 is overall very low compared to normal circumstances.

To prove if there is significantly more N-NH_4 in the soil compared to the start of the experiment a statistical analysis is done (see Appendix 4.5). According to this analysis the peak at 20 DAS is significantly different from the initial values, but at the other times of measurement no significant differences are measured.

To give a better sight on the different treatments also these are compared (see Appendix 4.5). Here almost no significant difference is measured, only at 20 DAS mm and mfm are significantly different: mfm is significantly higher than mm.

Soil N-NO_3

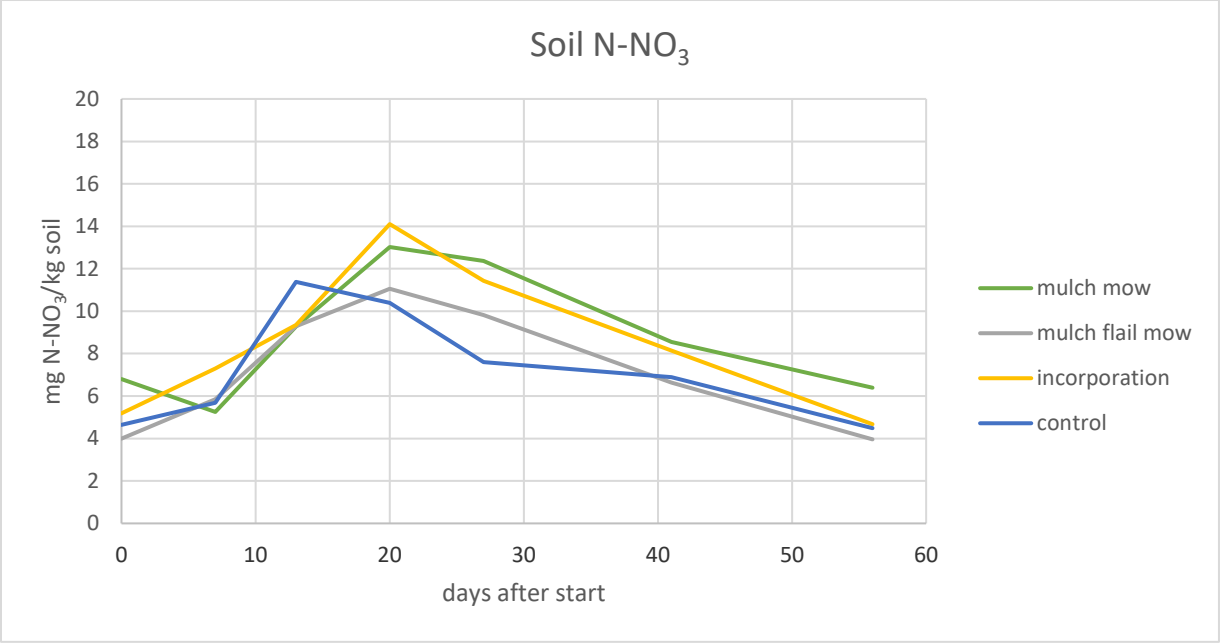


Figure 7 N-NO_3 content of the soil during the time of measurement.

The N-NO_3 in the soil shows an increase in the first weeks of the experiment but afterwards it is decreasing again to almost the same levels as the initial values (see Figure 7). The soil of the inc treatment gives the highest peak in N-NO_3. The peak of the co treatment is one week earlier than in the other treatments.

Also for the N-NO_3 in the soil a statistical analysis is done to show if there is a significant increase compared to the initial situation (see Appendix 4.6). The peak we see in Figure 7 is significantly higher compared to the initial state. Also the weeks before and after the peak in week 3 (20 DAS) shows significant difference. An exception is week 2 (13 DAS) in the mm treatment and week 4 (27 DAS) in the co treatment. For the co treatment the peak was one week earlier, so the N-NO_3 content of the soil is already lower compared to the other treatments.

The comparison between the treatments per time of measurement is shown in Appendix 4.6. In almost all comparisons there is no significant difference, only at 20 DAS there is a significant difference between the co and inc treatment (where inc is significantly higher) and at 27 DAS between mm and co (where mm is significantly higher). For all the other values there is no significant difference measured.

Soil available P ($P\text{-}PO_4$)

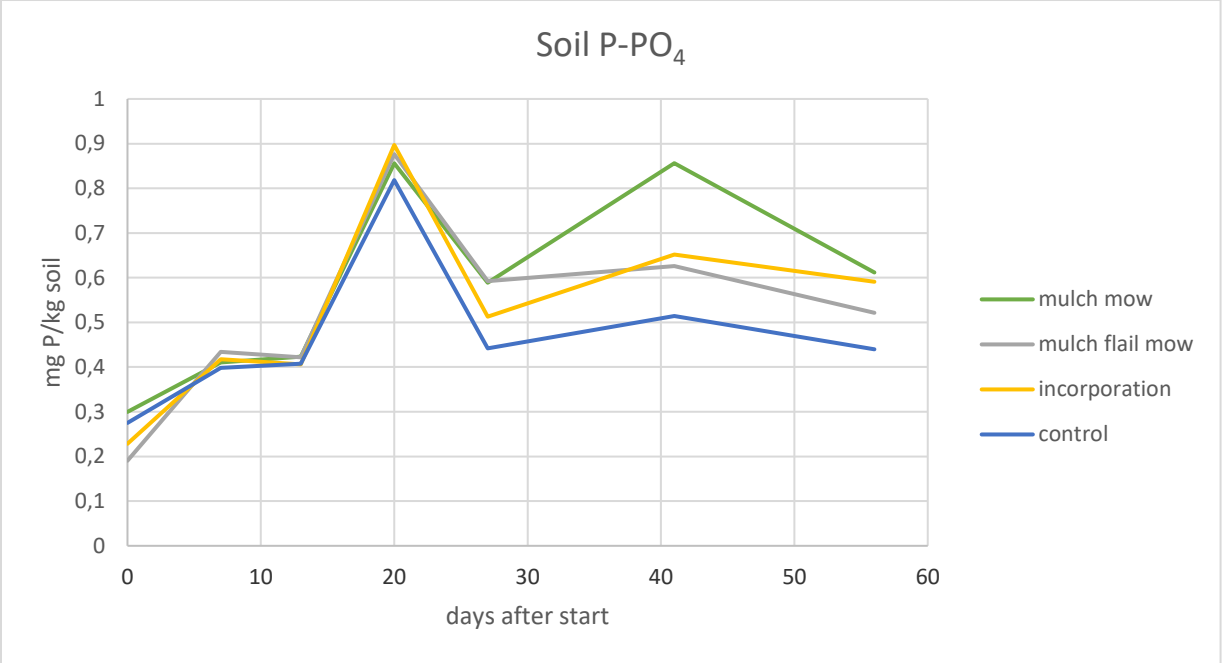


Figure 8 $P\text{-}PO_4$ content in the soil during time of measurement.

The $P\text{-}PO_4$ content in the soil gives in the first 3 weeks of the experiment an increase till more than 3 times higher compared to the initial situation (see Figure 8). After the third week (20 DAS) the $P\text{-}PO_4$ content of the soil is decreasing again. But for all treatments there is an increase afterwards at 41 DAS, which is again followed by a decrease.

To show if there is a significant difference a statistical analysis is done (see Appendix 4.7). This statistical analysis shows that the two peaks we see in Figure 8 are both significantly different (in this case higher) than the initial situation. For the mfm treatment all measurements after the start of the experiment gives significant difference with the initial situation, so there is an increase of $P\text{-}PO_4$ content in the soil at each time of measurement. At the inc treatment the $P\text{-}PO_4$ content of the soil is significantly higher from 20 DAS on. For the mm and co treatments it is harder to prove significant difference because of higher variation between the measurements within the treatment.

Also for the $P\text{-}PO_4$ content of the soil a comparison is made between the treatments per time of measuring (see Appendix 4.7). There is hardly any significant difference between the treatments per time of measurement. Only 41 DAS the treatments co and mm are significantly different (mm is significantly higher).

Soil available K

The available K-content of the soil is as well increasing as decreasing over time (see Figure 9). The first weeks an increase can be seen and during the last weeks there is a decrease. This is not the case for the inc treatment, here the available K-content of the soil keeps increasing a bit.

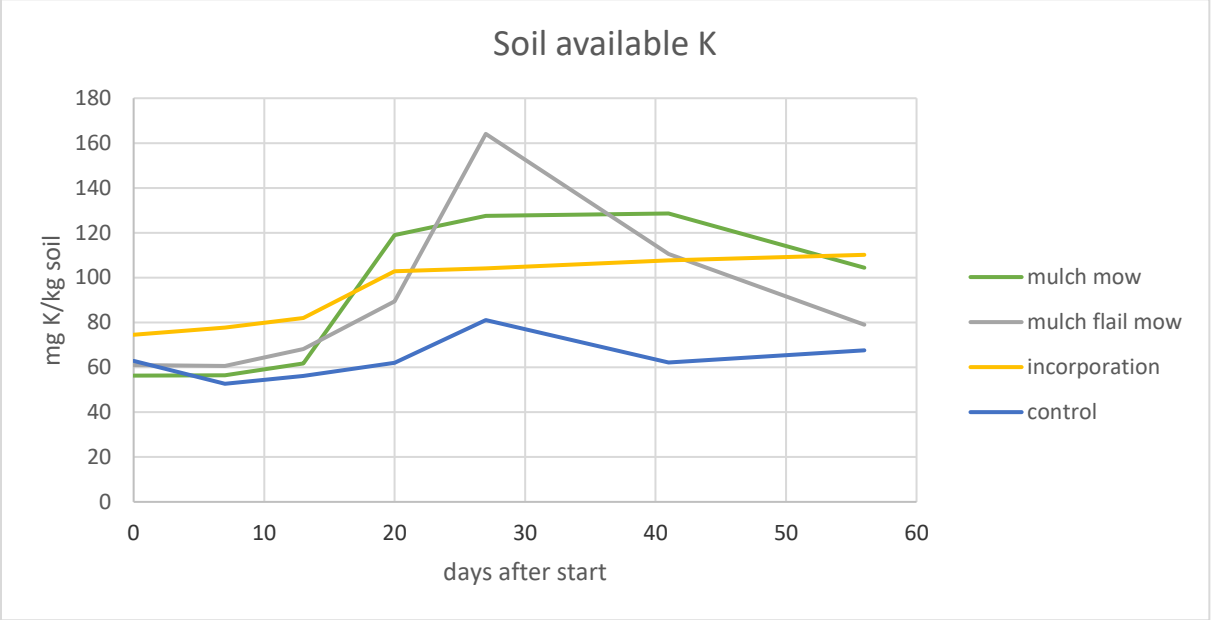


Figure 9 The available K-content of the soil during time of measurement.

To see if there is a significant increase in the different treatments a statistical analysis is done where the different times of measurement are compared with the initial values (see Appendix 4.8). According to this analysis it is shown that for almost all treatments for each measurement there is no significant difference with the start situation. Only for the mfm treatment at 27 DAS there is a significant difference with the initial value. In the graph (Figure 9) it is clearly shown that at this time of measurement the mfm treatment has a big peak which afterwards is decreasing directly.

In the mutually comparison of the treatments it is shown that there is almost no significant difference (see Appendix 4.8). The only significant difference is between mm and co at 41 DAS.

6.2 Discussion

Small fluctuations

When looking to the soil available nutrients over time a peak can be seen at 20 DAS for the $N\text{-}NH_4$, $N\text{-}NO_3$ and the $P\text{-}PO_4$. For soil available K there is not an obvious peak except for mfm and a little for co at 27 DAS. These peaks might seem very big compared to for example the initial state, but when the amount of soil available nutrients are converted to kg/ha it is shown that the amounts are very small anyway. For example at the peak of soil $N\text{-}NH_4$ there is 3,9 kg/ha. Comparing this with the amount of N applied by the green manure, which is 170 kg/ha, the peak is very low. When looking to the peak of $N\text{-}NO_3$ there is 33,8 kg/ha. Also the amount of phosphor measured (peak: 2,3 kg $P\text{-}PO_4$/ha) is very low compared to what brought on the land by the green manure (34 kg P/ha). The soil available K is not as low as the other nutrients measured, but the increase over time (about 180 kg K/ha) is still lower compared to what is brought on by the green manure (382 kg K/ha). From this, it can be concluded that the "peaks" can better be seen as fluctuations. When looking to the statistics, it is shown that there are just a few significant differences in soil nutrients between the treatments. These significant differences are not enough to draw conclusions that the different treatments have different effects on soil available nutrients. The different times of measurement are also compared to the initial state of soil nutrients. From this it can be concluded that only the "peaks" are significantly different from the initial state.

Plant uptake

One of the reasons that the fluctuations are not very big is that there are also plants growing on that soil. So there are not only nutrients added to the soil, but there are also nutrients removed. These nutrients are not measured. Because of this reason, the soil available nutrients does not show the complete picture of nutrients released by the green manure and no conclusions can be drawn from this data.

Nitrification

Another reason for the small fluctuation which only counts for $N\text{-}NH_4$, is nitrification. With nitrification $N\text{-}NH_4$ is converted to $N\text{-}NO_3$, so $N\text{-}NH_4$ will decrease. In Figure 11 an indication is given for the speed of this process. However, when comparing this with the $N\text{-}NH_4$ and $N\text{-}NO_3$ measured, it can be seen that there is not really an increase of $N\text{-}NO_3$ after 20 DAS, where the peak of $N\text{-}NH_4$ is. Probably this is due to the nutrient uptake of the plants.

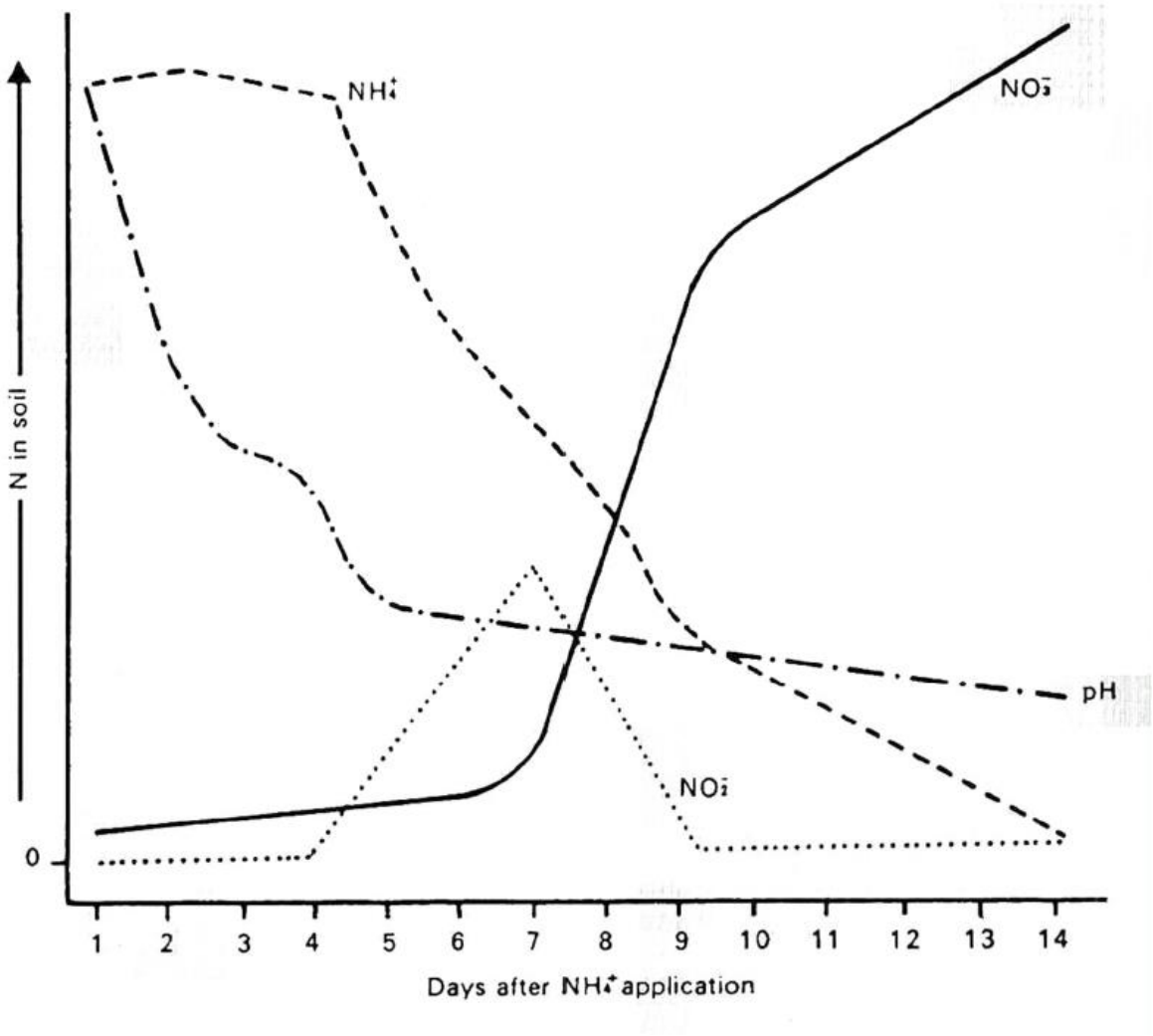


Figure 11 Conversion of NH_4 to NO_3 over time (Mengel et al., 2001). This gives an indication of the speed of the nitrification process. The actual nitrification rate will be different for each specific situation.

New versus old plant material

When looking to the graphs it can be seen that also the control treatment shows the fluctuations like the other treatments do. Also the statistical tests show that there is no significant difference between the control and the other treatments. Since the green manure was removed from the field at the control treatment it was expected that the soil available nutrients would be less. This might indicate that the soil available nutrients shown are for the biggest part nutrients that were already present in the soil as available nutrients or as organic matter from old plant material.

Temperature influence

At 20 DAS an increase of soil available nutrients can be seen at the N-NH_4, N-NO_3, P-PO_4 and a little bit at the soil available K. This increase is probably due to an increase in temperature. When there is an increase of soil temperature the soil life will be more active and the decomposition rate will be higher. For example, the optimum temperature for nitrification is 26 °C. Around 20 DAS the soil temperature was 24 °C, so very close to the optimum temperature for nitrification.

6.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on nutrients available in the soil?

From the data generated about the soil nutrients there are very little significant differences. Also, the control treatment shows mostly the same graph as the other treatment. This shows that most of the soil nutrient fluctuations measured are not coming from the green manure applied at the beginning of the experiment but from nutrients or organic matter already present in the soil. Next to that there is also nutrient uptake from the plants which is not measured. Therefore, no conclusions can be drawn if there is a difference between the treatments for the amount of soil available nutrients.

7. Ammonia emission

7.1 Results

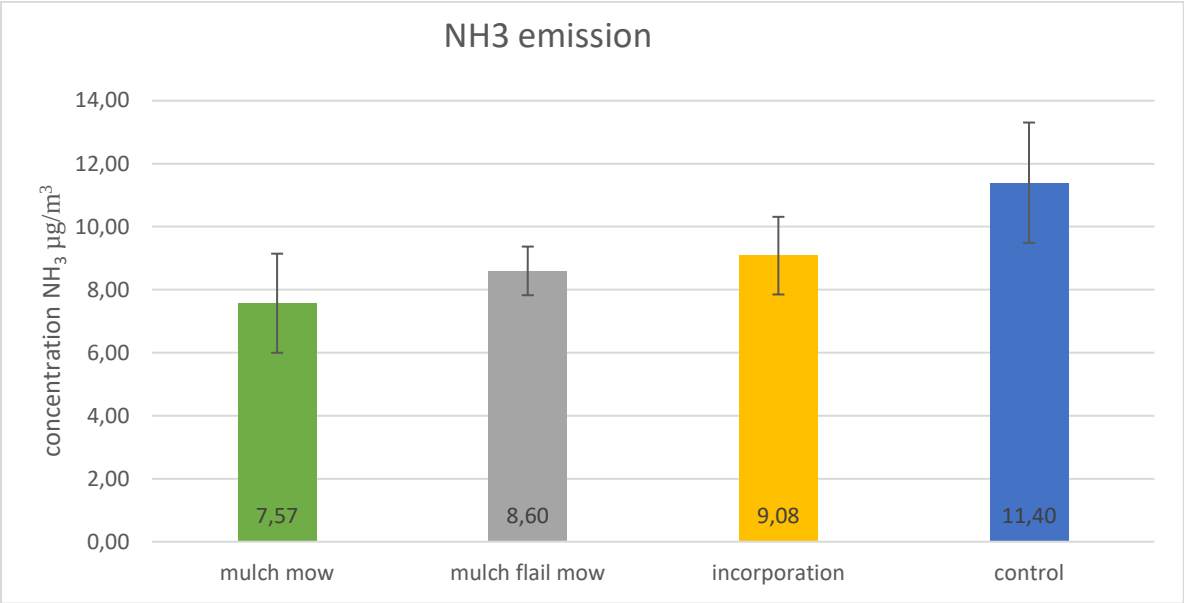


Figure 12 The mean of the ammonia concentration measured per treatment without a correction for the background value. There was no significant difference measured.

In the measurements of the ammonia emissions there was a high variation between the different diffusion tubes, even on one field a lot of variation occurred. Mostly there was one outlier per field. Therefore not the average was used to get one concentration per field, but the median. In some cases (field 5 and 13) there were more than one outlier, so the median is corrected for that. The medians of the different treatments given in Figure 12 are not corrected for the background value since the background value (11.47 µg/m^3) was not lower than most the measured values on the fields.

The mulching treatments (mm and mfm) are compared to the treatment of incorporation and no significant differences were measured. A more expanded analysis showed that there is no significance at all between all the different treatments (see Appendix 4.9). Also there is no significant difference between the background value and the treatments.

7.2 Discussion

Effect of design of the diffusion tubes on variation

It can be the case that in the process of making the Palmes diffusion tubes which is quite a precise work, some mistakes occurred. When making the tubes there were different types of caps and tubes and it had to be found out which combinations would create the best tubes. Also there were some different ways of making the tubes, for example if one or two grids would be needed. To find out which tube would be the best some trials were done. The tubes were tested by putting some manure at the place the tubes were standing and also without manure, so the background value, which was available through a weather station close by, could be checked. The problem with the tubes we still encountered after finding the best way of making the tubes was that the caps where the filter was placed did not always closed entirely, so turbulence could occur in the tube and disturb the molecular diffusion (Hofschreuder and Heeres, 2002). This can lead to unreliable data. Especially, on a windy place like the experiment fields, close to the coastline.

Effect of field placement on variation

The treatments of the green manure and the sowing of the barley did not happen directly after each other. On Thursday afternoon and evening the treatments of the green manure was done while the sowing of the barley was done on Friday afternoon. Because the ammonia volatilization is started from the moment the green manure is treated, the tubes had to be placed right after the treatments. Because the soil was quite hard, it was not very easy to get the stands where the tubes would be hanged on, into the soil. When the fields were sown the stands with the tubes had to be removed and replaced afterwards. With the removing and replacing some stands were broken and sometimes the tubes fell on the ground (and green manure). This might be a cause of the variation. Although, this does not explain variation within one field, since per field all tubes were placed on one stand.

High background values

To see if the different ways of treating the green manure would have an effect on the ammonia volatilization also the background value was measured. This was done by putting four tubes at a piece of land about 50 meter away from the experimental site. At this land some other green manure was growing, but one till two weeks before the green manure on that land was sown, so no extra ammonia emission was expected there. Still the ammonia concentration measured there (an average of 11.47 $\mu g/m^3$) was higher than on most fields which is not expected. However, a statistical test showed that the background concentration was not significantly different compared to the treatments.

Other type of nitrogen emissions

Next to ammonia there are also other types of nitrogen volatilization, like nitrous oxide (N2O) and nitrogen gas (N2). With the measurements done for this experiment these compounds are not measured, so the results cannot directly be used to say something about these nitrogen emissions. However, the ammonia emission could give an insight in nitrogen-losses through volatilization.

7.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on ammonia emission?

According to the measurements done there is no significant difference at all between the treatments. Not only between the treatments there is no significance, but also compared to the background ammonia concentration there is no significant difference. This means that these ways of applying the

green manure does not have any impact on ammonia emission. Another more precise method might give more reliable results, so a better conclusion could be made.

8. Barley growth

8.1 Results

As can be seen in Figure 13 the co treatment has the highest soil coverage of barley compared to the other treatments. The mfm treatment shows the lowest soil coverage of barley. It looks like the difference is very big but the X-axis is just going till 25%.

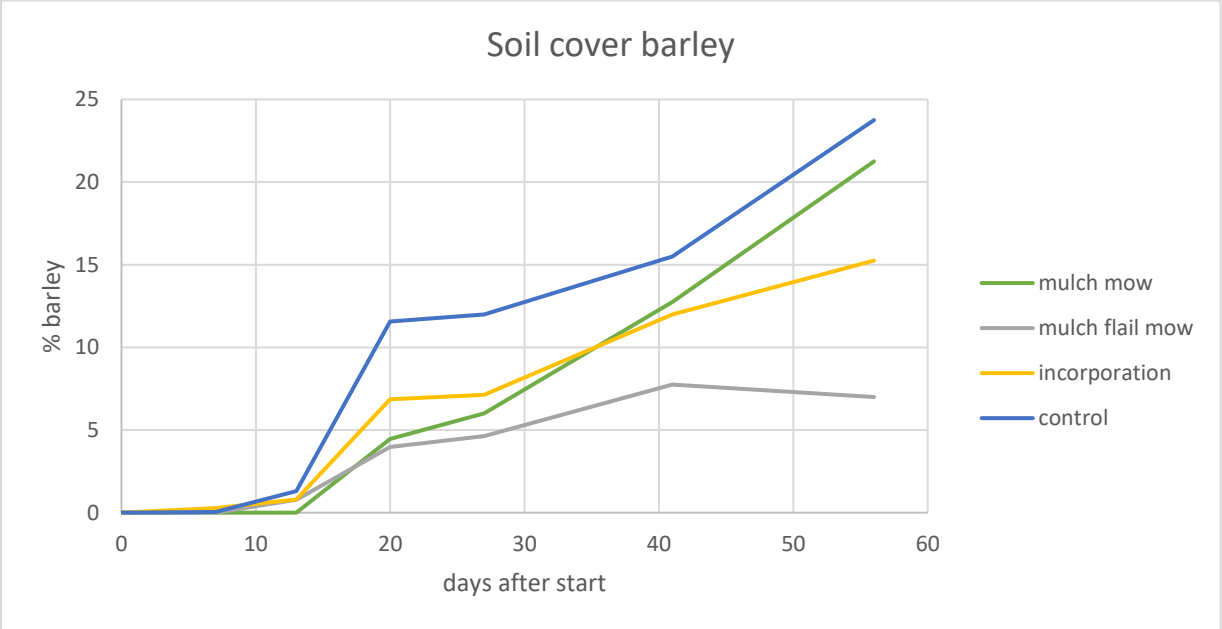


Figure 13 The soil coverage of barley in percentages over time.

To find out if there are significant differences between the treatments with each other a statistical analysis is done where per day of observation the treatments are compared (see Appendix 4.10). There is just one comparison significantly different: the control treatment show significantly higher soil coverage of barley compared to the mfm treatment at 20 DAS.

8.2 Discussion

Sowing problems

When looking to the data it can be seen that after eight weeks there is just a soil coverage between 7 and 24%. These low results are found because the germination of barley was very low. Just a small part of the plants made it to germinate and sometimes the plants who did germinate were overgrown by the weed plants. The low germination rate is probably due to the way and circumstances of sowing. Because most plots (except the inc treatment) were not tilled the soil was very compact. Also there was a dry period before which caused that the soil was even harder. The seeding machine was a normal disc seeder, so not a machine made for though soils. All that could be done to make the sowing better, like sharpening the discs and put extra pressure on the discs, was done. There were even extra discs at the front of the tractor to make slots in the hope that the seeding machine would follow these slots. Still after sowing it could be seen that the seeds were not nicely put in the soil, but instead they lay at the top (see Figure 14). At the mfm treatment this happened the most. The discs of the seeding machine did mostly not go through the layer of flail mowed plant material and also the soil was tough. In the mm treatment the soil was also though and the discs also did not always cut the plant material, but the seeds fell through the plant material so they lay still at a moist place which is positive for germination. At the inc treatment the sowing was already going better since the soil was loosened up by the incorporation of the green manure. With sowing the co treatment the only problem was the tough soil. There was no plant material to cut which made it easier to seed the barley. Still the soil was tough so there is also not a very high amount of germination.

Figure 14 The representation of the seeding bed just after seeding. In the red circle some barley seeds can be seen which lay on top of the soil instead of slightly below the soil surface. The cuts in the soil are not of the seeding machine but of some extra disc at the front of the tractor.

Significant difference

The only significant difference is probably also due to the successfulness of sowing. This significant difference is measured between the co and mfm treatment at 20 DAS. As said before, the sowing of barley was more successful in the co treatment than in the mfm treatment. Therefore, the influences of the different ways of application of the green manure is hard to prove.

Rye or barley?

In the green manure mixture which was applied for this experiment also rye grew. Since the soil was not tilled in most treatments there was still stubble, also of rye. Sometimes these rye stubble started to grow again. Since rye and barley are very similar crops (especially when it is small) it was hard to determine which of them were rye and which were barley. This might cause some incorrectness in the observation. Of course it is tried to look as good as possible if the plants were regrowth of rye or new-growing barley.

Two different methods

When setting up the experiment the idea was to count the number of barley and weed plants. For the first three weeks this was going well, but from the fourth week on the amount of barley and weed plants became very high, which made it impossible to count well. Therefore pictures were taken to finally come up with a percentage of barley and weed soil coverage. Since there were no pictures of

the first three weeks of each field, the counts had to be converted to percentage soil coverage. Therefore, an assumption was made that each plant would cover 0,1% of the soil (working with 1 m^2). Since there are no data about how big the plants were in the first three weeks there might be some incorrectness in the assumption. It was taken into account that the size of the plants were a bit smaller than on the pictures from week 4 (27 DAS).

8.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on the germination of barley?

The real influence of how the plant material is treated was hard to measure, since sowing had the most influence on the barley germination. When applying the method of mulching with no soil tillage it is important to have a good sowing machine which can sow into the hard soil. Also weeding would probably give a better barley soil coverage and growth since the weeds can overgrow the barley.

9. Weed growth

9.1 Results

In Figure 15 the weed soil cover is shown. It is clear that the weed growth is very high since in the end the soil coverage of weed is up to 70-95%. The inc treatment shows in the end the highest soil coverage by weeds, but shows in the beginning one of the lowest soil coverage by weeds. The opposite accounts for the co treatment.

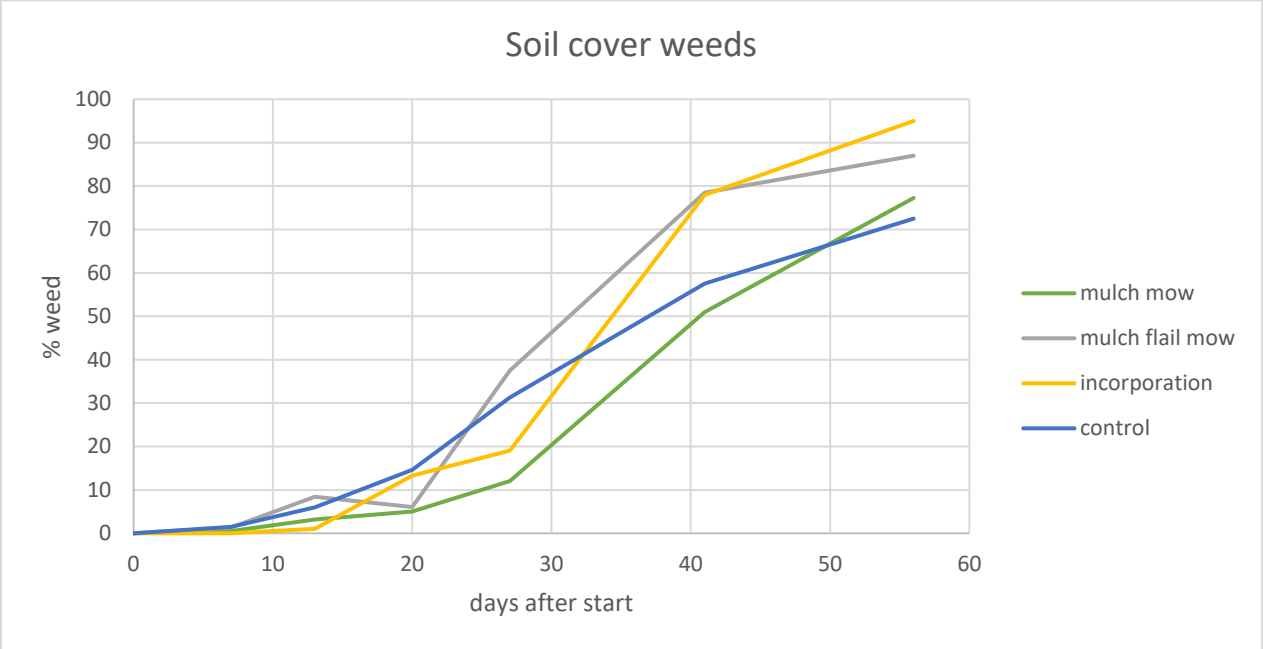


Figure 15 The soil coverage of weed in percentages over time.

To get an insight in differences between the treatments a statistical test is done (see Appendix 4.11). There is hardly any significant difference, only at 13 DAS where the mfm treatment is significantly higher compared to the inc treatment.

Looking to the weeds, there are several species who were dominating. In the first 4 weeks the two dominating weed species were thistle and butterbur. When looking to 6 to 8 weeks after the start also *Chenopodium album* and *Veronica* became more dominating, although this did differ per field. It is hard to say that some weed species were more present at one certain treatment. However, on eye it seems that *Chenopodium album* and *Veronica* were mostly present at the inc treatment fields (Figure 16). Since there is no counting per weed species, no statistical analysis could be done.

Figure 16 Weeds on a field with the inc treatment in the eighth week. Most present in this particular field is butterbur and Chenopodium album.

9.2 Discussion

Regrowing weed

As can be seen at the results the weeds take a big part of the soil coverage, much more than the barley. It can also be seen that the weed in the inc treatment starts with a low soil coverage. However, after four weeks (27 DAS) it starts to increase a lot, while the other, except for the mm treatment, are already in the beginning more covered with weeds. This is probably mainly due to weeds growing back. When the green manure was still growing there were also some weeds, but they were covered by the green manure, so they did not grow high. But when the green manure was mowed or flail mowed the weeds got some more light and space so they started to grow again. Especially at the co treatment where the green manure was removed, the weeds got all the space and light. Apparently it was not hard for the weeds to grow through the flail mowed plant material, since this shows a big amount of weeds.

Soil tillage

Finally the inc treatment do show a high amount of weeds. These weeds did not come from the weeds who grew back since the topsoil was mixed. This was also shown in the size of the weeds. They were all small at the first weeks. Although the weeds were small, there were a lot of them. This is probably due to the fact that with mixing/tilling the soil you bring the weed seeds from the soil bank at the surface, or at least give them a small amount of light, which make the seeds germinate. The soils of the other treatments were not tilled, so the weeds of the soil seedbank were not activated to grow here, so only the weeds at the top of the soil start growing. In the end this results in the highest amount of weed coverage for the inc treatment.

Mulching layer thickness

It is remarkable that the mm treatment shows a low weed soil coverage over time. It might be caused by the fact that the messy mulch made it sometimes hard to see all the weeds. Another cause could be that the messy mulch made it hard for the weeds to grow through. The mowed material created a bigger layer of plant material compared to flail mowed material. The flail mowed plant material was made so small that the layer was very thin, so when a weed was just through the plant material layer it catches a lot of light so it could grow very good. Weeds underneath the mowed material could maybe get easier through the first part of the layer, but could not catch all the sunlight because there was much more plant material above. One of the most abundant weeds was thistle. Since this is a root weed it can get a lot of his energy out of his roots. So for thistle it is easy to grow through the small layer of green manure of the flail mowed material, but it is already harder to get through the bigger layer of mowed material because it takes more time. This, in the end, results in a lower weed soil coverage compared to the mfm treatment.

The control treatment

At the last observation the weed soil coverage was the lowest at the co treatment. This was not as expected since the green manure was removed, so the weed could catch a lot of sunlight from the first week on. In the first weeks after the start of the experiment this can also be seen, but the increase the other treatments make after week 3 or 4 (20 and 27 DAS) is not so big at the co treatment. When looking to the barley growth it can be seen that the barley did grow very good at the co treatment. Probably the barley grew fast enough to claim the space before the weeds could do that, which results in a somewhat lower weed soil coverage and a relatively high barley soil coverage. When comparing to the other treatments it can be seen that the differences are not very big and also the statistical analysis shows that there are no significant differences between the treatment. The only significant difference measured was in the second week after the start where the mfm treatment was significantly

higher than the inc treatment. This was caused by the slow start of the weed growth in the inc treatment and the fast start of the weed growth in the mfm treatment.

Relation between weed and barley soil coverage

As mentioned before the “high” barley soil coverage at the co treatment was linked to the somewhat lower weed soil coverage. Also when looking to the other treatments the barley soil coverage is probably connected to the weed coverage. The mfm and inc treatments have high weed soil coverage at the last observation and also low barley soil coverage. When looking to the mm and co treatment, they have a lower weed soil coverage in the last week, but also a high(er) barley soil coverage.

Weed species

As mentioned in the results it is hard to put a connection between the weed species and the treatments. However, on eye the inc treatments did show some more *Chenopodium album* and *Veronica*. This is probably due to the soil tillage. Thistle and butterbur are weeds who spread through their roots, but *Chenopodium album* and *Veronica* are spread by the seeds. As said before, the soil tillage at the inc treatment resulted in a light exposure which made the seeds to germinate. The advantage of soil tillage is that the other weeds like thistle and butterbur were removed. Looking to mechanical weeding the weeds in the inc treatment will be easier to remove because harrowing will work on the smaller weeds like *Chenopodium album* and *Veronica*. Thistle and butterbur are harder to remove by a harrow. In this experiment the barley was sowed to close to each other to hoe them mechanically. So if mulching of the green manure is chosen it might be good to sow the barley less dense so it is possible to hoe.

9.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on the amount of weeds present?

Most of the weeds observed were from plants which were already growing there. Some thistles were already growing underneath the green manure, but also the plants of the green manure like rye, grew back. This made it easy for the weeds to overgrow the barley. The different treatments are all comparable according to weed growth. The only difference is that the inc treatment gives a slower start of weed growth and the weed plants are smaller since all weeds are tilled into the soil. This might make it easier to mechanically remove the weeds.

10. Soil temperature

10.1 Results

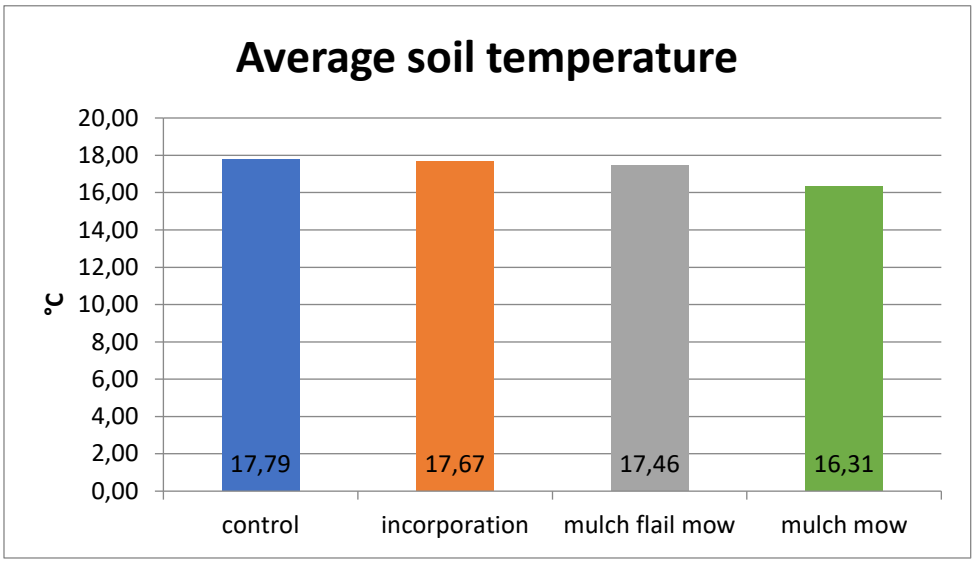


Figure 17 The mean soil temperature of the four different treatments.

As can be seen in Figure 17 some difference can be found between the different treatments. Between the mm and the co treatment there is almost 1,5 °C difference. The mm treatment shows clearly the lowest soil temperature. It is even 1,15 °C lower compared to the treatment with the second lowest soil temperature (mfm). Because of practical limitations there couldn't be a replicate of the mm treatment. The co treatment is done in triplicate and the inc and mfm treatments are done in duplicate. Because there was no duplicate of the mm treatment, no statistical test could be done.

Table 7 Overview of the minimum and maximum temperature measured of the different treatments.

	control	incorporation	mulch flail mow	mulch mow
Max temperature	29,26	27,04	27,03	22,20
Min temperature	11,47	11,48	11,49	12,65

In Table 7 the minimum and maximum temperatures are given for the different treatments. It shows that the mm treatment has the less fluctuations of all treatments. The co treatment has the most fluctuations, especially the maximum temperature is much higher than the other treatments.

For an overview of the soil temperature over time see Appendix 5.

10.2 Discussion

Mulching versus non-mulching

The results show that the mulched treatments (mm and mfm) give the lowest average soil temperatures. This is also what was hypothesized. With mulching, a cover of plant material is formed, so there is some more isolation. This isolation is missed when the plant material is incorporated or when the plant material is removed. This isolation also gives the mulching treatments a lower variability, so the soil temperature is more stable in mulched treatments compared to non-mulched treatments.

Flail mowing versus mowing

Comparing the two mulching treatments there is also a clear difference. The mm treatment shows more than 1 °C difference with the mfm treatment. Also, the minimum and maximum soil temperature are much closer to each other for the mm treatment. This suggests that the isolation capacity of the mowed plant material is higher compared to the flail mowed plant material. The reason could be that the layer of mowed plant material is less compact. Because it is less compact there will be multiple layers, so the soil will be isolated more.

Practical application

The soil temperature can have influence on different aspects of plant growth. Some examples are root growth (McMichael and Burke, 1998), seedling emergence (Singh and Dhaliwal, 1972) and nutrient uptake (Pregitzer and King, 2005). To give an example, the optimum soil temperature for root mass growth of maize is around 26 °C (McMichael and Burke, 1998). The influence of soil temperature will differ per crop. It is therefore depending per crop you grow if it is smart to mulch or not. It also depends on the weather conditions. For example, if you know the temperature will be very high, you might consider mulching to keep the soil temperature lower. But when you start sowing your crop and the soil is still very cold, it will be better to incorporate your green manure, so the soil can warm up. In Table 8 an overview is given about the effect of soil temperature on the seedling emergence of some different crops.

Table 8 The effect of soil temperature on seedling emergence of different crops (Singh and Dhaliwal, 1972).

	Soil temperature °C								
Crops	5	10	15	20	25	30	35	40	45
Gram	35.0	97.5	100.0	100.0	100.0	100.0	100.0	55.0	0.0
Wheat	40.0	97.5	97.5	100.0	100.0	97.5	85.0	17.5	0.0
Peas	37.5	97.5	100.0	97.5	97.5	62.5	0.0	0.0	0.0
Turnips	15.0	72.5	90.5	100.0	87.5	47.5	0.0	0.0	0.0
Cotton	0.0	0.0	17.5	92.5	95.0	97.5	97.5	42.5	0.0
Sorghum	0.0	0.0	55.0	95.0	97.5	97.5	92.5	82.5	0.0
Rice	0.0	0.0	85.0	97.5	97.5	100.0	97.5	17.5	0.0
Maize	0.0	0.0	92.5	100.0	100.0	95.7	85.0	60.0	0.0
Musk melon	0.0	0.0	55.0	82.5	97.5	97.5	92.5	75.0	0.0
Squash	0.0	0.0	0.0	35.0	75.0	97.5	90.0	62.5	0.0
Bottle gourd	0.0	0.0	0.0	43.9	96.7	96.7	96.7	52.8	0.0
Okra	0.0	0.0	0.0	72.5	100.0	97.5	100.0	85.0	0.0

10.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on soil temperature?

When mulching the soil temperature will be more constant and in this experiment lower. This is due to the isolating effect of the mulch layer. It is depending on crop and circumstances if it is favourable to mulch or to incorporate your green manure.

11. Soil moisture

11.1 Results

The difference in soil moisture measured can be seen in Figure 18. Because of a lack of sensors the soil moisture content could only be measured for one field, so no statistical analysis could be done. The mfm, co and mm treatment are very close to each other (0,02-0,03 m^3 moisture/m^3 difference), but the inc treatment is much lower compared to the second lowest treatment (0,07 m^3 moisture/m^3 difference).

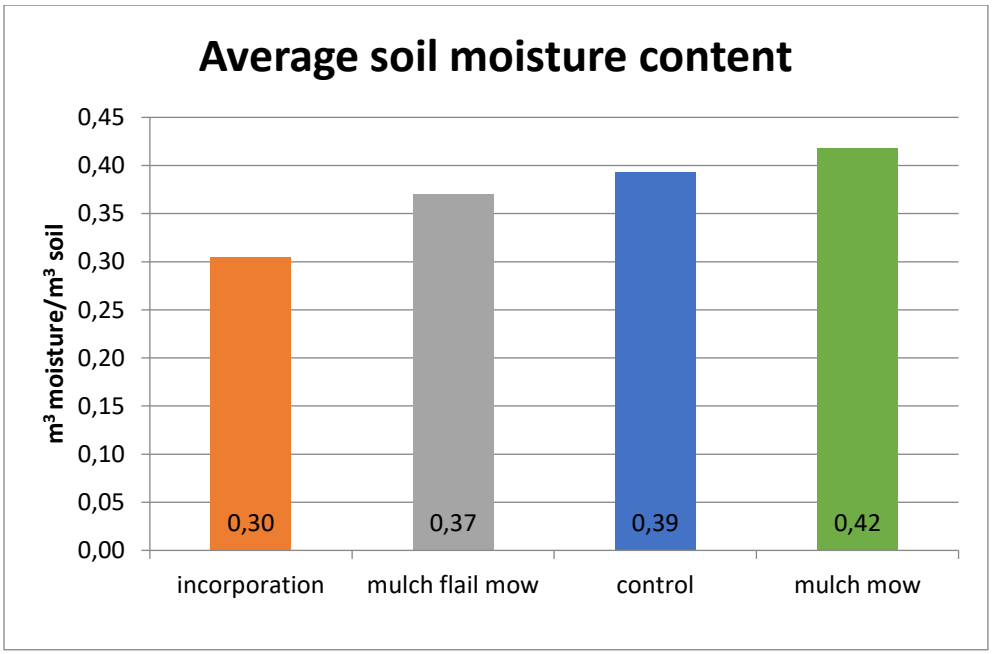


Figure 18 Average soil moisture of the different treatments.

For an overview of the soil moisture over time see Appendix 6.

11.2 Discussion

Mulching effect

The inc treatment shows the lowest soil moisture, the mfm treatment the second lowest soil moisture, the co treatment the second highest soil moisture and the mm treatment shows the highest soil moisture. It was expected that the fields where the green manure was incorporated or removed would show the lowest soil moisture since there is more transpiration because of a low soil coverage. The mulched treatments gave therefore higher soil moisture. The mowed treatment gave the highest soil moisture, so also here it looks like the mowed plant material cover the soil more compared to the flail mowed plant material. It is interesting that the difference between the inc treatment and the other treatments is higher than the mutually difference of the mfm, co and mm treatments. This shows that the difference between incorporating and mulching is quiet big. The question only is, is the difference in soil moisture depending on a mulching layer or not? Because also the co treatment shows a high soil moisture content while the soil coverage is more or less equal to the inc treatment.

Soil tillage

When looking to the data it can be seen that the soil moisture of the control treatment is close to the mfm treatment and the mm treatment. So apparently the soil coverage is not the only influence on soil moisture. If we compare the co treatment with the inc treatment there is a difference in soil treatment. The plant material of the inc treatment is incorporated and therefore also the soil is tilled, while in the co treatment nothing happened with the soil. Because there is more aeration in the soil of the inc treatment, the moisture will evaporate easier compared with the solid soil of the co treatment. This is probably also a big influence on soil moisture.

Practical application

Depending on the weather condition soil moisture could be very important for the growth of the crop. In a hot dry season you want your soil to be moist as long as possible, but when there is enough rain, this is not really necessary or you want your soil to evaporate as much as possible, because you do not want the soil to be too wet. In the Netherlands the weather is mostly hard to predict, so it is hard to choose the right way of applying your green manure. When you grow your crops in a climate which is mostly very dry it might be a good idea to mulch your green manure instead of incorporating, since it will protect your soil against evaporation, like in the study of Wade and Sanchez (1983). The choice of mulching or incorporation can also be dependent on the possibility of irrigation.

11.3 Conclusion

Research question: What is the effect of green manure used as a mulch or when incorporated on the soil moisture content?

Mulching do have an influence on the soil moisture, but next to that also soil tillage have an influence on soil moisture. This influence is higher than mulching. So, when a high soil moisture is preferred it is better to not till your soil and incorporate your green manure, but to mulch the green manure. Still, mulching do have an influence. Mulching of mowed material (mm treatment) will result in a higher soil moisture. Also here it is depending on the situation to see what is best to do.

12. General conclusion

This study was done to find an answer to the research question: 'What are the differences between mulching and incorporation of green manure on several important cultivation aspects? '. For some cultivation aspect there were some clear differences, for others there was no difference proven. To show how this study could be applied by a farmer an overview is made with farmer's preferences and best application for those preferences (see Table 9). In the end a farmer has to make a decision considering what he think is important for his soil since every soil is unique. Also climate can be an important reason for using a certain application. Also some forms of application can ask for an investment. If mulching is chosen, there need to be made and investment in a seeding machine which can sow in though untilled soils if the farmer do not own one yet.

Table 9 Overview of some situations and best application in that case according to the results of this study.

Preferences farmer	**Best application**
Minimum disturbance of soil (life)	No soil tillage, so mulching
Stable soil temperature	Mulching, preferably mowed material
Stable soil moisture (e.g. in climates with high soil evaporation)	Mulching, preferably mowed material
High decomposition rate of plant nutrients	Incorporation
No irrigation possible, but a moist soil is important	Mulching, preferably mowed material
Slow growth of weeds at the start	Incorporation

Looking to the whole system it is hard to conclude from this study if mulching or incorporation is better. No-tillage is likely to be better for the soil life and therefore for the soil, but with this research there is no soil life measured. No-tillage will also result in other negative effects like slower nutrient release which has to be taken into account.

To give an overview of the conclusions the effects studied, the hypotheses with their outcomes are given:

- The **decomposition rate** of the green manure is expected to be higher in the treatment where the green manure is incorporated compared to the treatments where the green manure is used as mulch. From both types of mulching it is expected that the decomposition rate is higher in the treatment of flail mowing compared to the normal mowing treatment.

Weight decomposition: *not accepted:* for the decomposition is weight no evidence is found to prove acceptance.

Nutrient decomposition mulch vs. incorporation: *accepted:* for nitrogen and phosphor the decomposition was faster when the green manure was incorporated.

Nutrient decomposition mulch flail mow vs mulch mow: *accepted:* for nitrogen and phosphor the flail mowed green manure showed faster decomposition compared to mowed green manure.

- The **nutrient availability** is expected to be higher in the treatment where the green manure is incorporated compared to the treatments where the green manure is used as mulch. From both mulching treatments it is expected that the nutrient availability is higher in the treatment of flail mowing compared to the normal mowing treatment.

Mulch vs incorporation: *not accepted:* no differences were found for nutrient availability between mulching and incorporation.

Mulch flail mow vs mulch mow: *not accepted:* also between these treatments no convincing evidence were found to accept the hypothesis.

- it is expected that there will be more **ammonia emission** at the treatments where no incorporation is done.

Not accepted: there were no differences found between the different treatments.

- It is expected that the **amount of weeds** will be higher in the treatment of incorporation compared to the treatments of mulching.

Not accepted: no differences were found between the treatments.

- The expectation is that the **soil cover due to barley** will be higher in the treatment of incorporation of the green manure compared to the mulching treatments.

Not accepted: also here no differences were found.

- The **soil temperature** of the treatment where the green manure will be incorporated and the treatment where the green manure will be mowed and removed will be higher compared to the treatments where the green manure is used as a mulch. The soil temperature of the treatments where the green manure is used as mulch will be more stable.

Temperature differences: *partly accepted:* because of a lack of measurements no statistical prove could be given. However, the results show that especially the mulch mowed treatment shows more than 1 °C difference with the other treatments. The control and incorporation treatment shows the highest soil temperature.

Temperature stability: *partly accepted:* also for this hypothesis no statistical prove could be given. Although, when look to the minimum and maximum temperature, the mulch mow treatment shows the less fluctuation, so the most stability. For the other treatments the stability was more or less equal.

- The **soil moisture content** is expected to be higher in the treatments with the mulch layers compared to the incorporation treatment.

Partly accepted: no repetitions could be done so no statistical prove can be given. Although, when looking to the results the incorporation treatment shows the lowest soil moisture content. The control treatment shows similar soil moisture with the mulching treatments. Differences are probably due to soil tillage.

12.1 Recommendations for further research

To gain more insight in all the processes more research need to be done. One important part is the nutrient decomposition and availability. To get a complete in-sight in the nutrient allocation also the plants grown on the fields need to be analysed. In this study most results were not significantly different and some methods did not work as good as theoretically was expected. Since most of these results did not differ a lot from each other and the standard error was very high some more replications are recommended. The effect on soil life is also an interesting and important aspect which could not be included in this study, but will be a valuable addition in a next study. Next to that, a research over more years is necessary to see the long-term influences of the different applications.

References

BOCOCK, K. L., GILBERT, O., CAPSTICK, C. K., TWINN, D. C., WAID, J. S. & WOODMAN, M. J. 1960. CHANGES IN LEAF LITTER WHEN PLACED ON THE SURFACE OF SOILS WITH CONTRASTING HUMUS TYPES. *Journal of Soil Science,* 11**,** 1-9.

BUSSIÈRE, F. & CELLIER, P. 1994. Modification of the soil temperature and water content regimes by a crop residue mulch: experiment and modelling. *Agricultural and Forest Meteorology,* 68**,** 1-28.

CHERR, C. M., SCHOLBERG, J. M. S. & MCSORLEY, R. 2006. Green Manure Approaches to Crop Production Florida Agric. Exp. Stn. Journal Series no. R-10702. *Agronomy Journal,* 98.

CLARK, A. 2008. *Managing cover crops profitably*, DIANE Publishing.

HODGE, A., ROBINSON, D. & FITTER, A. 2000. Are microorganisms more effective than plants at competing for nitrogen? *Trends in Plant Science,* 5**,** 304-308.

HOFSCHREUDER, P. & HEERES, P. 2002. Measurement of NH3 in ambient air using a modified palms diffusion tube. 4rd version of the protocol for the Interreg study. *Meteorology and Air Quality Group, Wageningen University, the Netherlands***,** 14.

HOUBA, G. V. J. & NOVOZAMSKY, I. 1998. Influence of storage time and temperature of air-dried soils on pH and extractable nutrients using 0.01 mol/L CaCl2. *Fresenius' Journal of Analytical Chemistry,* 360**,** 362-365.

JANMAAT, R. & KUIJPER, F. 2016. *Vergroening* [Online]. toekomstglb.nl: Ministerie van EZ. Available: http://toekomstglb.nl/glb-in-de-praktijk/vergroening/ [Accessed 20-03-17].

KARBERG, N. J., SCOTT, N. A. & GIARDINA, C. P. 2008. Methods for estimating litter decomposition. *Field measurements for forest carbon monitoring.* Springer.

MAHBOUBI, A. A., LAL, R. & FAUSSEY, N. R. 1993. Twenty-Eight Years of Tillage Effects on Two Soils in Ohio. *Soil Science Society of America Journal,* 57.

MCMICHAEL, B. & BURKE, J. 1998. Soil temperature and root growth. *HortScience,* 33**,** 947-951.

MENGEL, K., KIRKBY, E. A., KOSEGARTEN, H. & APPEL, T. 2001. Nitrogen. *In:* MENGEL, K., KIRKBY, E. A., KOSEGARTEN, H. & APPEL, T. (eds.) *Principles of Plant Nutrition.* Dordrecht: Springer Netherlands.

NOVOZAMSKY, I., HOUBA, V. J. G., VAN ECK, R. & VAN VARK, W. 1983. A novel digestion technique for multi-element plant analysis. *Communications in Soil Science and Plant Analysis,* 14**,** 239-248.

POTTHOFF, M. & LOFTFIELD, N. 1998. How to quantify contamination of organic litter bag material with soil? *Pedobiologia,* 42**,** 147-153.

PREGITZER, K. S. & KING, J. S. 2005. Effects of Soil Temperature on Nutrient Uptake. *In:* BASSIRIRAD, H. (ed.) *Nutrient Acquisition by Plants: An Ecological Perspective.* Berlin, Heidelberg: Springer Berlin Heidelberg.

RANA, G. & MASTRORILLI, M. 1998. Ammonia emissions from fields treated with green manure in a Mediterranean climate. *Agricultural and Forest Meteorology,* 90**,** 265-274.

SHAH, G. M., SHAH, G. A., GROOT, J. C. J., OENEMA, O. & LANTINGA, E. A. 2012. Irrigation and lava meal use reduce ammonia emission and improve N utilization when solid cattle manure is applied to grassland. *Agriculture, Ecosystems & Environment,* 160**,** 59-65.

SINGH, N. T. & DHALIWAL, G. S. 1972. Effect of soil temperature on seedling emergence in different crops. *Plant and Soil,* 37**,** 441-444.

TEASDALE, J. R., COFFMAN, C. B. & MANGUM, R. W. 2007. Potential Long-Term Benefits of No-Tillage and Organic Cropping Systems for Grain Production and Soil Improvement. *Agronomy Journal,* 99.

VAN DONK, S. J., TOLLNER, E. W., STEINER, J. L. & EVETT, S. R. 2004. Soil temperature under a dormant bermudagrass mulch: Simulation and measurement. *Transactions of the American Society of Agricultural Engineers,* 47**,** 91-98.

VERVISCH, B., BEECKMAN, A., RAPOL, J. & DELANOTE, L. 2016. Maaimeststoffen blijven het best aan de oppervlakte. Available: http://www.ccbt.be/?q=node/699.

WADE, M. K. & SANCHEZ, P. A. 1983. Mulching and Green Manure Applications for Continuous Crop Production in the Amazon Basin1. *Agronomy Journal,* 75.

Appendix

1. Soil analysis

Bemestingsonderzoek
Bouwland
Perceel 4

Blgg Oosterbeek

Postbus 115
6860 AC Oosterbeek

Meer informatie:
U kunt bellen: 026-3346440
of faxen: 026-3346419
Uw klantnummer is: 233.708.8

H.1. Westers
Dyksterwg 12
9978 TB HORNHUIZEN

* 2015; pelle

Onderzoek	Onderzoek-/ordernummer:	Datum verslag:
	523859/000859318	15-09-1999

Monster	Grondsoort:	Datum monstername:	Monster genomen door:	Contactpersoon monstername:
	Jonge zeeklei	02-09-1999	Blgg	Lambert Ubels: 0594-505828

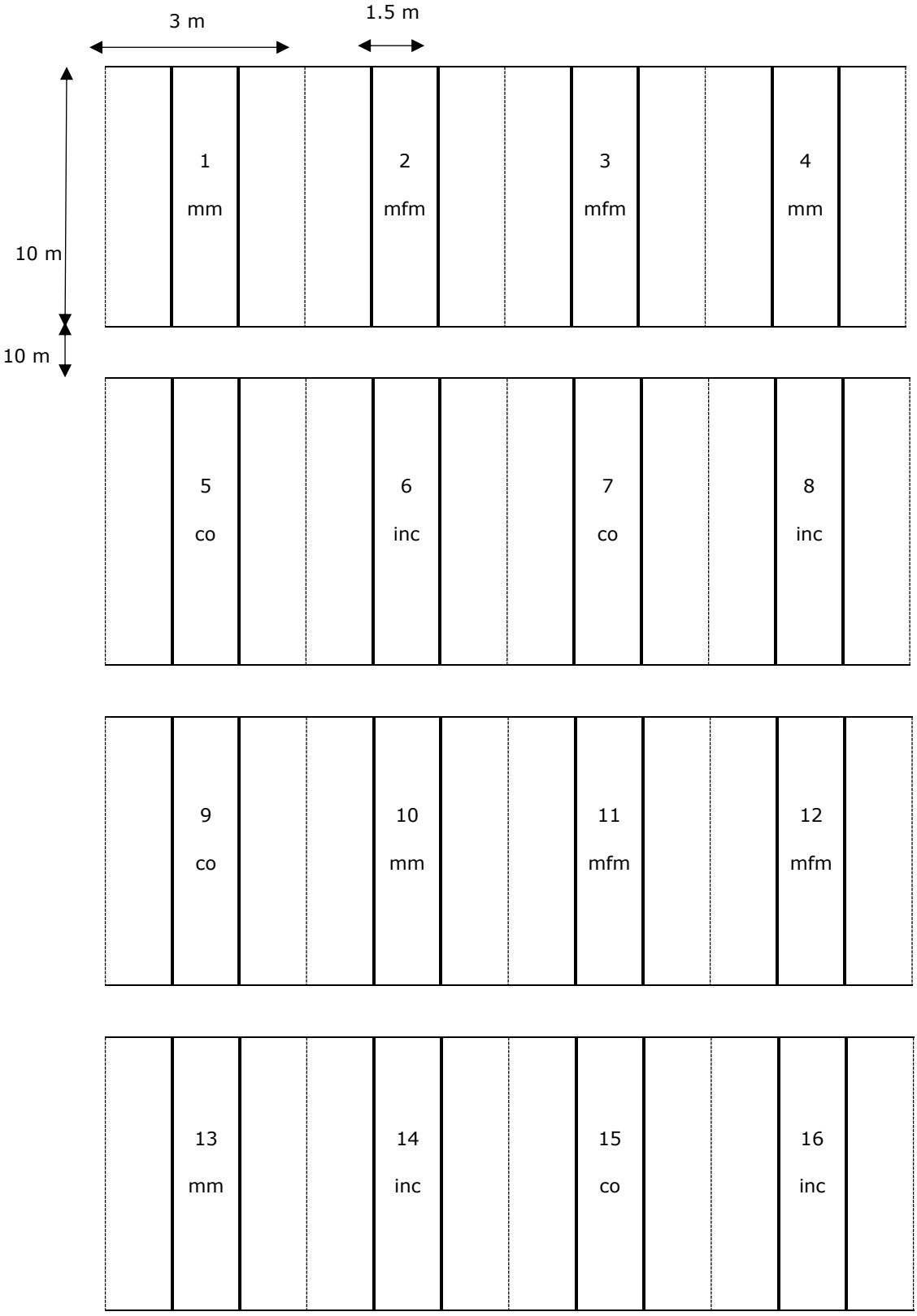
Bemonsterde laag:
0 - 25 cm

Resultaat		Eenheid	Methode	Resultaat	Streef-niveau	Waardering
bepaald in droge grond volgens voor-geschreven methode	Fosfaat	mg P_2O_5/l	Pw	25	25 - 45	voldoende
	Kali	mg K_2O/100 g	K-HCl	20		
	K-getal			21	18 - 26	vrij hoog
	Koper	mg Cu/kg	Cu-HNO_3	4,7	4,0 - 9,9	goed
	Zuurgraad		pH-KCl	7,6	6,6	zeer goed
	Koolzure Kalk	%	Koolzure kalk elem.	5,0		
	Organische stof	%	Humus elementair	2,2		
	Lutum	%	Lutum	18		
	Berekend slib	%		24 - 31		

VF61-24-4-98-BLW

Pagina 1
Totaal aantal pagina's: 2

2. Experimental set-up fields



inc = incorporation of green manure
mfm = mulching flail mow
mm = mulching mow
co = control

roadside

3. Materials

Treatments

- 3,6 kg barley seeds (=150 kg/ha)
- Flail mower (farmer)
- Mower (farmer)
- Sowing machine (Unifarm)
- Tractor (farmer)

Decomposition rate

- 96 mesh-bags (mesh-size: 5 mm)
- Scale
- 96 labels
- 96 small sticks
- Plastic bags
- Oven
- Ash oven
- Grinder

Potential availability of mineral N, P and K

- 80 tubes to collect soil samples
- Marker
- Soil probe

NH_3 volatilization

- 68 Modified Palmes Diffusion Tubes
- Stands to install the tubes on
- Spectrophotometer

Germinating barley and weeds

- Grid of 1 m^2 to make it easier to count the barley and weeds
- Camera

Soil temperature and soil moisture content

- 8 soil temperature sensors
- 4 soil moisture sensors
- Data logger
- Usb-stick

General material

- Automated weather station (the Alecto WS-4050) for measuring air temperature, air humidity, wind speed and precipitation.

4. Statistical results

4.1 Decomposition in weight

Table 1 P-values of statistical t-test where for each treatment the measurements over time are compared to the start of the experiment. Red blocks indicate no significant different and green blocks indicate that there is significant difference (p < 0,05).

3-jun vs	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	1,000	0,000	0,001	0,000	0,000	0,000
co	1,000	0,012	0,008	0,000	0,000	0,000
mfm	0,918	0,010	0,075	0,001	0,000	0,000
inc	0,015	0,448	0,000	0,000	0,000	0,000

Table 2 P-values of the comparisons between the treatments per time of measurement from one week after the start of the experiment. Red cells shows no significance and green cells do show significance (p<0,05).

	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm vs co	0,986	0,076	0,587	0,734	0,993	0,481
mm vs mfm	0,942	0,022	0,098	0,080	0,326	0,000
mm vs inc	0,094	0,001	0,718	0,199	0,947	0,008
co vs mfm	0,806	0,894	0,591	0,383	0,458	0,001
co vs inc	0,053	0,126	0,996	0,699	0,993	0,106
mfm vs inc	0,229	0,357	0,463	0,940	0,613	0,111

4.2 Decomposition of nitrogen

Table 3 P-values of the different treatments where measurements over time are compared to the initial N-content of the plant material. Red cells shows no significance and green cells do show significance (p<0,05).

3-6 vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,041	1,000	1,000	1,000	0,922	0,955
co	0,041	0,999	1,000	0,847	0,401	0,143
mfm	0,999	0,039	0,007	0,007	0,000	0,000
inc	0,000	0,000	0,000	0,000	0,000	0,000

Table 3 P-values of the statistical analysis for comparing the treatments with each other per moment of measurement. Red cells shows no significance and green cells do show significance (p<0,05).

	3-6	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	0,947	0,989	0,985	0,964	0,363	0,831	0,130
mm vs mfm	0,177	0,494	0,886	0,982	0,975	0,611	1,000
mm vs inc	0,195	0,087	0,607	0,007	0,030	0,240	0,081
mfm vs co	0,382	0,675	0,981	0,833	0,585	0,209	0,139
co vs inc	0,415	0,145	0,413	0,003	0,437	0,664	0,991
mfm vs inc	1,000	0,642	0,250	0,014	0,062	0,031	0,086

4.3 Decomposition of phosphor

Table 5 P-values of statistical tests where the P-content of the different dates is compared with the initial situation. Red cells shows no significance and green cells do show significance (p<0,05).

3-6 vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,149	0,920	0,980	0,829	0,132	0,185
co	0,047	0,261	0,382	0,065	0,017	0,002
mfm	0,999	0,499	0,366	0,040	0,012	0,000
inc	0,001	0,001	0,000	0,000	0,000	0,000

Table 6 P-values of statistical test where the treatments are compared with each other per time of measurement. Red cells shows no significance and green cells do show significance (p<0,05).

	3-6	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	0,998	0,987	0,311	0,344	0,274	0,791	0,118
mm vs mfm	0,144	0,819	0,038	0,245	0,718	0,056	0,808
mm vs inc	0,098	0,218	0,227	0,309	0,929	0,996	0,860
mfm vs co	0,185	0,638	0,002	0,013	0,050	0,011	0,026
co vs inc	0,127	0,131	0,010	1,000	0,574	0,666	0,377
mfm vs inc	0,995	0,641	0,709	0,011	0,382	0,082	0,376

4.4 Decomposition of potassium

Table 7 P-values of t-tests between the different dates of measurement and the initial amount of K in the green manure for the mm and the co treatment. Red blocks indicate no significant difference and green block indicate significant difference.

3-6 vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,940	0,018	0,002	0,000	0,000	0,000
co	0,953	0,001	0,000	0,000	0,000	0,000

Table 8 The mm and co treatment compared for every time of measurement. The red blocks indicate that there is no significance between the treatments (p<0,05).

	3-6	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	1,000	0,999	0,346	0,834	0,987	0,983	0,932

4.5 Soil N-NH_4

Table 9 P-values of a statistical analysis between the different times of measurement compared to the begin situation for each treatment. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

3-jun vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,993	0,999	0,001	0,421	1,000	1,000
co	0,953	0,995	0,000	0,979	1,000	0,915
mfm	1,000	0,681	0,000	0,993	0,568	0,999
inc	0,932	1,000	0,000	1,000	1,000	1,000

Table 10 P-values of statistical analysis between the treatments per time of measurement. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

	3-6	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	0,638	0,361	0,639	0,818	0,955	0,969	0,136
mm vs mfm	0,937	0,529	0,020	0,861	0,413	0,840	0,997
mm vs inc	0,571	0,381	0,249	0,308	0,683	0,925	0,914
mfm vs co	0,329	0,988	0,150	1,000	0,702	0,980	0,185
co vs inc	0,999	1,000	0,862	0,777	0,927	0,998	0,355
mfm vs inc	0,281	0,992	0,451	0,728	0,962	0,996	0,967

4.6 Soil N-NO_3

Table 11 P-values of the comparison between the different times of measurement and the start of the experiment. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

3-jun vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,953	0,707	0,012	0,029	0,921	1,000
co	0,990	0,002	0,011	0,424	0,713	1,000
mfm	0,615	0,001	0,000	0,000	0,183	1,000
inc	0,636	0,042	0,000	0,001	0,261	0,999

Table 12 P-values of statistical t-tests to compare the different treatments at each time of measurement. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

	3-jun	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm vs co	0,629	0,988	0,346	0,108	0,016	0,541	0,563
mm vs mfm	0,427	0,970	1,000	0,289	0,270	0,427	0,366
mm vs inc	0,803	0,466	1,000	0,735	0,893	0,987	0,638
mfm vs co	0,983	0,999	0,352	0,917	0,372	0,997	0,982
co vs inc	0,989	0,648	0,376	0,018	0,056	0,733	0,999
mfm vs inc	0,906	0,719	1,000	0,056	0,628	0,614	0,958

4.7 Soil P

Table 13 P-values of comparison between the different times of measuring compared with the initial values. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

3-jun vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	0,941	0,905	0,001	0,142	0,001	0,096
co	0,523	0,456	0,000	0,192	0,021	0,205
mfm	0,000	0,000	0,000	0,000	0,000	0,000
inc	0,268	0,340	0,000	0,025	0,001	0,003

Table 44 P-values of comparison between the treatments per time of measurement. Red blocks indicate that there is no significant difference and green blocks indicate that there is significant difference.

	3-jun	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm vs co	0,968	0,999	0,994	0,960	0,174	0,036	0,100
mm vs mfm	0,242	0,993	1,000	0,996	1,000	0,212	0,560
mm vs inc	0,596	1,000	0,994	0,952	0,681	0,287	0,982
mfm vs co	0,443	0,975	0,991	0,887	0,164	0,715	0,624
co vs inc	0,845	0,995	1,000	0,744	0,702	0,595	0,182
mfm vs inc	0,885	0,998	0,991	0,991	0,659	0,997	0,772

4.8 Soil K

Table 55 P-values of the comparison of the different times of measurement with the initial values. Red blocks indicate no significance and green blocks indicate significant differences.

3-jun vs ...>	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm	1,000	1,000	0,369	0,237	0,222	0,660
co	0,997	1,000	1,000	0,944	1,000	1,000
mfm	1,000	1,000	0,718	0,000	0,444	0,954
inc	1,000	1,000	0,895	0,874	0,806	0,752

Table 66 P-values of comparisons between treatments per time of measurement. Red blocks indicate no significance and green blocks indicate significant differences.

	3-jun	10-jun	16-jun	23-jun	30-jun	14-jul	29-jul
mm vs co	0,978	0,996	0,996	0,194	0,465	0,031	0,257
mm vs mfm	0,991	0,995	0,994	0,687	0,647	0,815	0,552
mm vs inc	0,694	0,616	0,866	0,927	0,872	0,743	0,990
mfm vs co	1,000	0,966	0,967	0,736	0,081	0,139	0,928
co vs inc	0,892	0,490	0,761	0,447	0,876	0,173	0,162
mfm vs inc	0,845	0,754	0,951	0,956	0,262	0,999	0,388

4.9 Ammonia emission

Table 79 P-values of the statistical test to see if there is significant difference between the different treatments. In this case there is no significant difference between the treatments.

mm vs. mfm	0,961
mm vs. Inc	0,889
mm vs. Co	0,319
mfm vs. Inc	0,994
mfm vs. Co	0,506
inc vs. Co	0,649

4.10 Barley growth

Table 20 P-values of statistical test where the different treatments are compared to each other for soil coverage by barley per time of observation. Red blocks indicate no significant difference and green block do indicate significant difference.

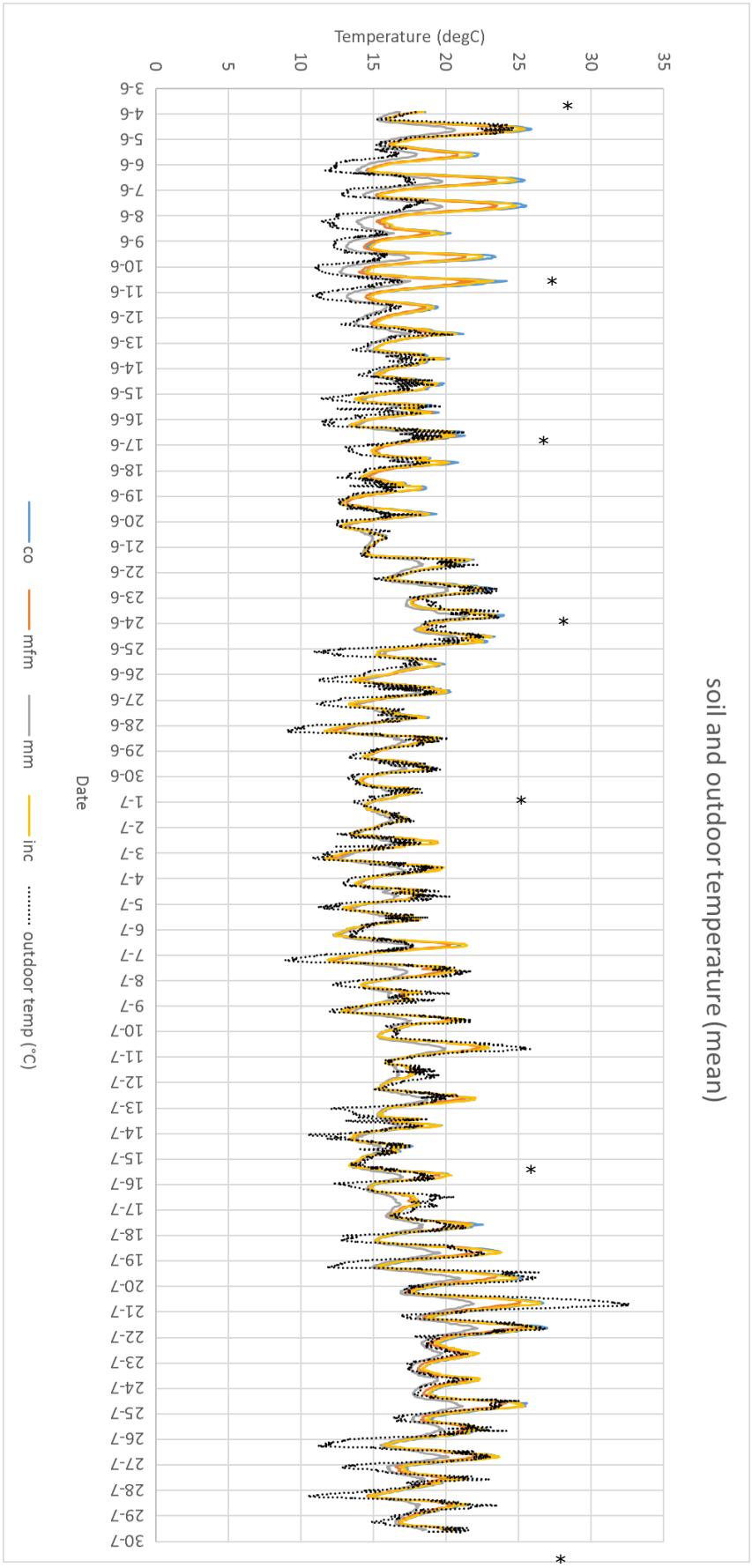
	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	0,983	0,430	0,068	0,143	0,939	0,985
mm vs mfm	1,000	0,786	0,998	0,949	0,733	0,246
mm vs inc	0,244	0,771	0,785	0,971	0,999	0,836
co vs mfm	0,983	0,919	0,050	0,059	0,413	0,144
co vs inc	0,400	0,929	0,299	0,278	0,886	0,647
mfm vs inc	0,244	1,000	0,682	0,766	0,815	0,667

4.11 Weed growth

Table 21 P-values of statistical test where the different treatments are compared to each other for soil coverage by weeds per time of observation. Red blocks indicate no significant difference and green block do indicate significant difference.

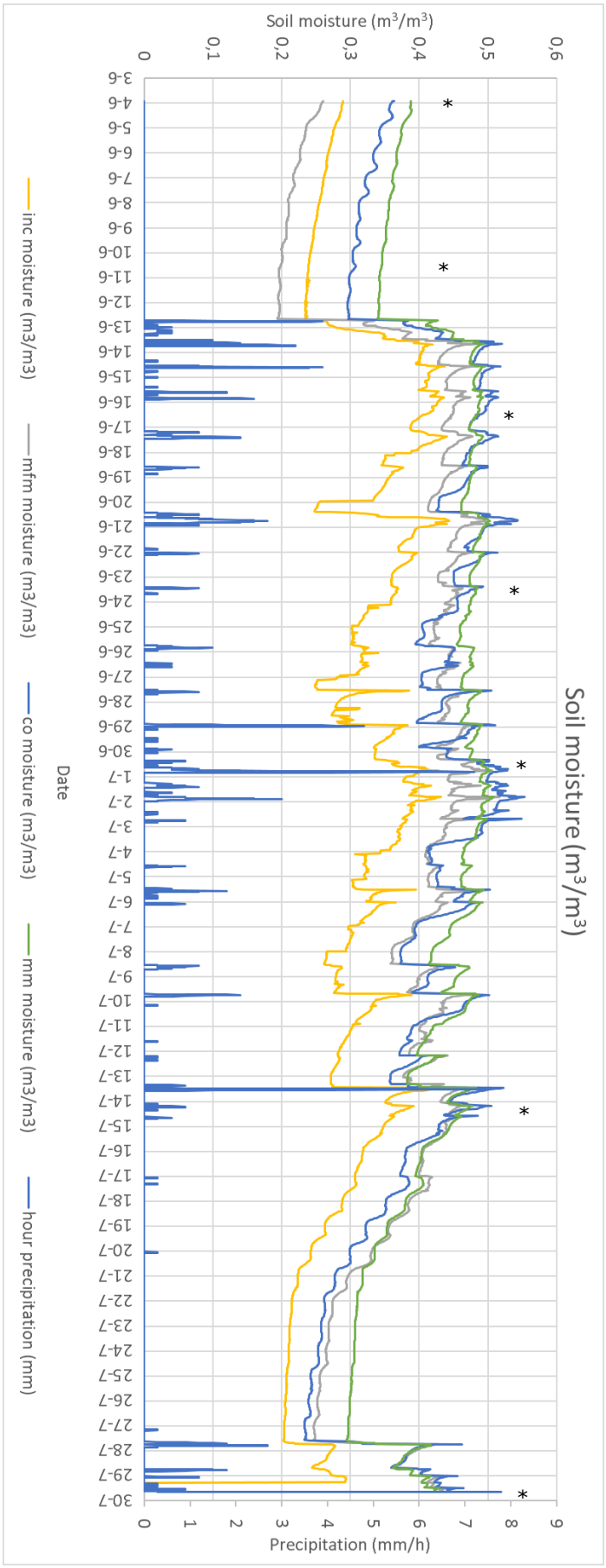
	10-6	16-6	23-6	30-6	14-7	29-7
mm vs co	0,633	0,578	0,163	0,328	0,975	0,977
mm vs mfm	0,730	0,117	0,995	0,139	0,342	0,840
mm vs inc	0,893	0,735	0,257	0,914	0,357	0,462
co vs mfm	0,998	0,660	0,234	0,937	0,559	0,619
co vs inc	0,273	0,144	0,990	0,677	0,578	0,273
mfm vs inc	0,344	0,020	0,356	0,360	1,000	0,903

5. Outside temperature + soil temperature



* = dates of sampling

6. Precipitation + soil moisture



* = dates of sampling