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Termination of cover crops with reduced tillage methods in organic agriculture

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Preface

This paper is a 15 ECTs bachelor project. The final project for the bachelor: Natural Resources here under Environmental Science at Copenhagen University.

This study is done in cooperation with Thi Thuy Hong Phan who is a PhD student at Copenhagen University with base on the experimental farm at Tåstrup. The experiments described in this paper is a part of her PhD that focuses on constructing a cover crop system for organic agriculture not only in regard to termination, but also N-effect, competition with the cash crop, growth rate in autumn, root depth, winter hardiness etc. Some of the decisions regarding the experiments are made to fit her overall objective and not the objective of this paper alone.

Contents

Abstract

In the last few years EU and the Danish Government have put organic agriculture and the conservation of soil on the agenda. To be able to reach their goals it is necessary to focus research on how to combine organic agriculture with conservation tillage. One of many questions this raises, is how to terminate cover-crops when conventional ploughing and pesticides are not allowed. Cover-crops are a very important tool for organic farmers to improve the fertility of the soil. Reduced tillage methods have also proven to benefit the soil in many ways. It is therefore desirable to create a system where both cover-crops and reduced tillage methods are used. This study examines how 17 cover-crops react to rotovation tillage done in three depths; 4cm, 8cm and 15cm. The regrowth is measured as the dry biomass harvested from the field. To examine the cover-crops' regenerative mechanisms 10 of the 17 species are damaged and buried under a soil cover in pots in a greenhouse. The damage is done by cutting the root off at 0cm, 1cm and 3cm. The damaged plants and the cut off root pieces are covered with 2cm or 5cm soil. The rotovation tillage at 4cm is not adequate to terminate the investigated cover-crops. Lucerne, red clover, kidney vetch, persian clover, winter radish and hairy vetch can be terminated with rotovation tillage at, at least 8cm depth. White clover, winter rape, dyer's woad and chicory might be possible to control, but need more than one tillage treatment. Generally the grasses are only sensitive toward the soil cover and not the damage of the root. They are thereby not suitable for a reduced tillage system. Winter rye and stuaderug however show a lower tolerance than the other grass species and new trials may determine whether they are suitable for a reduced tillage system. Plantain, timothy, orchard grass and to a degree white clover are the most aggressive species and it is not recommendable to use these species in an organic reduced tillage system. More trials and knowledge are needed to construct a reduced tillage system suitable for organic agriculture.

1. Introduction and theory

The aim of this project is to study the possibilities of combining the use of cover-crops with reduced tillage in organic agriculture. A number of problems have to be solved before it is possible to construct a sustainable organic agricultural system which combines methods as reduced tillage and cover-crops. One of them is *how to kill off the cover-crops* in the spring when it is not possible to plough or use pesticides. The aim of this study is therefore to investigate how different cover-crops regenerate after damage and the intensity of the tillage needed to terminate the cover-crops. This will form a base for further study and hopefully lead to a more sustainable agricultural system in the future. To put the subject of this study into a societal context it is relevant to stress how these two management methods could be tools to achieve some of the goals that lie within organic agriculture and which are formulated by governments. In the following the focus will be on statements made by the EU and the Danish Government since it is in this context the study is made.

IFOAM (International Federation of Organic Agriculture Movements) is an international umbrella organization for the organic agriculture movement. They try to standardize organic agriculture worldwide and have formulated standards and principles which shall lead organic institutions and farmers globally. In their principles they stress that "*the health of individuals and communities cannot be separated from the health of ecosystems*" (IFOAM 2012, p. 9) and that "*production … should be managed in a way that … should be held in trust for future generations*" (IFOAM 2012, p. 11). To secure the health of ecosystems and production systems now and in the future, the health of soil is an important factor. Without a healthy soil to sustain plants, a sustainable agricultural system is non-existing. In the same way the organic principles stress that it is important to minimize input and use resources as efficient and cautious as possible (IFOAM 2012). Here techniques as cover-crops and reduced tillage can be useful.

The EU Commission and Parliament put soil conservation on the agenda in 2002. In the Decision 1600/2002/EC the European Parliament laid down "the Sixth Community Environment Action Program" where soil for the first time was addressed alongside water and air as an environmental media and a non-renewable resource. At the same time they committed to develop a "Thematic Strategy" for the protection of soil (European Commission 2005). In 2005 the European Commission presented a proposal for a directive of the European Parliament and of the council establishing a "framework for the protection of soil" (European Commission 2005). The aim of this proposed directive is: *"… protecting soil and the preservation of the capacity of soil to perform its environmental, economic, social and cultural functions"* (COM(2006) 232 final, p. 3). The proposed "framework for the protection of soil" was withdrawn because of a blocking minority with the opinion that soil is not a cross-border problem and should therefore be topic for the national legislation. After the withdrawal the European Commission stated that they would continue to work on better and uniform protection of the soil in the European Union (Miljøministeriet 2015).

In Denmark, drinking water and most of the water used in production are coming from ground water. As a result of this, the ground water is carefully monitored and protected by Danish law (Thorling et al. 2015). One of the actions is to use cover-crops to avoid nitrate leaching. According to Danish law; *BEK nr. 903 of 29/07/2014,* it is mandatory for farmers to plant cover-crops on 10% of their land. Thus the Danish law is promoting the use of cover-crops.

In 2012 The Danish Government released a plan for promoting organic agriculture in Denmark. 400 million Danish kr. was among other things allocated to doubling the area of organic production in Denmark by 2020 (Ministeriet for Fødevarer, Landbrug og Fiskeri 2012). Recently a new plan was released where it was stressed that it is essential to keep developing organic agriculture towards being more sustainable. The plan gives an example of a more climate friendly organic system (Ministeriet for Fødevarer, Landbrug og Fiskeri 2015). Here reduced tillage might be a key.

It is a wish from governmental institutions to protect soil in general and to promote and improve organic agriculture, especially in Denmark. In Denmark it is also an objective from the state to minimize nitrate leaching to the ground water. In the following it will be examined whether reduced tillage and cover-crops could be tools to gain these goals.

1.1 Reduced soil tillage

To be able to discuss if reduced tillage will benefit soil fertility it is important to understand what soil fertility is and how we can measure it. According to Stockdale et al. (2002) soil fertility is defined as the ability of a soil to provide the conditions that are needed for plant growth. A measure that is often used to determine a soils ability to support plant growth is yield or biomass. Doran et al. (1994) broadens the definitions and defines soil fertility as: "*The ability of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.*" (Doran et al. 1994, s. 7).

According to Doran et al. (1994) soil is more than a media for plant growth. It is also a reservoir for water storage, a buffer for the filtration, transformation and neutralization of pollutants and a habitat for plants and animals (Wilson & Maliszewska-Kordybach 2000).

Both Stockdale et al. (2002) and Doran et al. (1994) finds it difficult to determine specific factors to measure soil fertility. The different contexts in which the soil is found affects which factors that determine the soil fertility. It has however, because of the benefits of having specific measurements to determine soil fertility, been tried to identify the most important factors for soil fertility. Examples of measurable soil fertility parameters are shown in table 1.1.

Since the seventies there has been a wide range of research regarding reduced tillage, conservation tillage and no-tillage systems and the ability of these systems to improve soil fertility. In the following, an overview of the most important results in tillage research with the main focus on European conditions will be made. The different terms are defined as followed (Carter 1994, Rasmussen 1999):

- **Conventional till:** Mouldboard ploughing to a depth of 18cm to 30cm.
- **Reduced till**: Tillage done by any other non-inversion method to a maximum depth of 15cm.
- **Conservation-till:** Covers a range of tillage practices that reduce soil and water loss relative to conventional tillage in the specific region and leaves a mulch layer on the surface of the soil.
- **No-till/direct drilling:** The crops are sown directly without any tillage.

Table 1.1: Soil fertility parameters divided into physical, chemical and biological parameters (Wilson & Maliszewska-Kordybach 2000).

Parameter group	Parameters
Physical	- Soil depth - Water holding capacity - Aggregate stability - Bulk density - Infiltration rate - Hydraulic conductivity
Chemical	- pH - Base saturation - CEC (cation exchange capacity) - Nutrient availability (major and minor) - Electrical conductivity - Potentially toxic elements or compounds
Biological	- Soil organic matter content - Soil respiration - Microbial biomass carbon - Nitrification - Enzyme assays - Soil microorganisms (population/community) - Soil invertebrates

Overall different reduced or conservation tillage methods affect the soil parameters in the same way (Rasmussen 1999). It is generally showed that reduced till and no-till increase the organic carbon content. This Increases the available nitrogen, potassium and phosphorous in the upper soil layer and by time decreases the pH of the top soil (Rasmussen 1999, Carter 1994, Cannell & Hawes 1994, Mäder & Berner 2011). Changes in the distribution of nutrients within the top soil have not been shown to make any difference in crop uptake (Carter 1994). The higher organic carbon content in the near surface of the soil, increases the aggregate stability (Vakali et al. 2011). This leads to a lower risk of crust formation, it allows a better germination and seedling establishment of the crop and allows air and water to enter the soil. It also increases the water content, lowers the evapotranspiration and temperature and increases the cation exchange capacity (CEC) (Rasmussen 1999, Carter 1994, Idowu et al. 2009, Plagliai et al. 2004, Cannell & Hawes 1994). The lower temperature can delay germination of the seed. Due to the higher aggregate stability and infiltration rate conservation tillage and reduced tillage protect the soil from erosion of soil particles and nutrients (Rasmussen 1999, Carter 1994, Peigné et al. 2007).

No-till and reduced till enhance the number and activity of earthworms and the diversity of earthworm species (Rasmussen 1999, Francis & Knight 1993, Cannell & Hawes 1994, Peigné et al. 2007). Capowiez et al. (2009) found that the earthworm type *Anecic* was more abundant where reduced tillage was performed. This earthworm type is important for macro porosity and water infiltration since it makes large, vertical burrows close to the surface. It is important to have a healthy population of earthworms in the soil because they have the ability to counteract compaction by making burrows (Capowiez et al. 2012).

Reduced tillage increases the bulk density and decreases the porosity, especially just under the depth of tillage (10cm to 15cm) compared to conventional tillage (Rasmussen 1999). This leads to a higher penetration resistance, lower air-filled porosity and gaseous exchange and sometimes a higher water-holding capacity (Carter 1994, Vakali et al. 2011). Most Scandinavian studies show that reduced tillage decreases the volume of macropores (drainable pores) and micropores (containing non-available water) and increases the volume of medium pores (water-holding pores) (Rasmussen 1999). There is not a consistency in the effect of reduced till and no-till on hydraulic conductivity. There are a number of studies that show an increase (Carter 1994, Plagliai et al. 2004, Cannell & Hawes 1994), but some either show the opposite or do not show any difference between reduced tillage and conventional tillage on hydraulic conductivity (Rasmussen 1999, Cannell & Hawes 1994). Rasmussen (1999) concludes in his review that reduced tillage reduces the nitrate leaching compared with conventional tillage.

As mentioned earlier some studies show that reduced tillage can lead to a more compact soil and a higher penetration resistance (Vakali et al. 2011). This can influence the root development of the crop. However this relationship is not found to be significant (Rasmussen 1999). Cannell & Hawes (1994) found a general tendency of a higher root density in the upper part of the soil and in some cases also deeper into the soil especially in well drained soils.

When we look at grain yields they are generally the same or just 5% to 10% lower for reduced-till and no-till than for conventional-till. In some cases the yields are higher, all depending on the soil type and climatic conditions. It is mainly well-drained soils with a high content of organic matter in a dry and warm climate that favors reduced-till, conservation-till and no-till practices (Carter 1994, Cannell & Hawes 1994, Rahman & aksoy 2014). Also the crop species affect the outcome of tillage trials. It is mainly winter cereals that benefit from reduced tillage and no-tillage since these kinds of tillage treatments result in a slower release of nutrients which suit autumn sown crops (Francis & Knight 1993, Peigné et al. 2007). There is a tendency to a higher weed pressure for reduced tillage treatments compared to conventional especially from perennial weeds and grass weeds. In some cases the higher weed pressure affects the yield, but not always (Peigné et al. 2007, Vakali et al. 2011, Mäder & Berner 2011).

It is important to mention that when the tillage practice is changed, the whole soil environment changes. It takes about 10 years before the soil environment is stable again (Carter 1994, Cannell & Haws 1994). The effects of changed tillage practices therefore change over time and some of the beneficial effects do not show immediately. An example is the lower mineralization rate that reduced tillage causes. In the first years of changing to reduced tillage the crop might need more fertilizer. Over the years this is outweighed by the higher content of organic matter in the soil (Carter 1994).

1.2 Cover-crops

Since it is not allowed to use inorganic fertilizer in organic agriculture, arable farms typically import manure from other farms. Manure is highly valuable to organic farmers, why it can be difficult for an organic arable farm to find manure from other organic farms. This puts the arable organic farmer in a situation where he is forced to import conventional manure (Goulding et al. 2000). In this context cover-crops can be an important tool in organic N-management. Managed properly it posses the ability to reduce N-leaching losses, reduce N-erosion losses, fix N in the soil, immobilize N and increase crop N-uptake. In addition it increases the input and cycling of C, N and other nutrients. In long term cover-crops will improve the physical and biological properties of the soil. This will enhance the growth of the cash crop and the water and nutrient use efficiency of the cash crop (Delgado & Follett 2010).

A study showed that it is possible to obtain the same yield in an organic crop rotation with the use of fertility building crops, compared to an organic rotation with import of fertilizer. The study also showed that the leaching of N was markedly reduced and the root exploitation of the soil was almost doubled (Thorup-Kristensen et al. 2012). This shows that by using cover-crops it is possible to make a cropping system that is more independent from imported fertilizer. Another benefit from using cover-crops is that by choosing species with deep root systems it is possible to recover previously leached N from depths deeper than the crop's root system (Thorup-Kristensen 2006).

To achieve these benefits from cover-crops it is important to manage them properly. Thorup-Kristensen & Nielsen (1998) simulated the effect of nitrogen catch crops on the nitrogen supply for the succeeding crop. The results show that it is important to adapt the strategy for growing cover-crops to the actual situation. Especially in accordance to the risk of leaching and the root depth of the succeeding crop. One tool to optimize the N-effect is incorporation time. It is important that the cover-crop has enough time to take up N to avoid leaching in the autumn. On the other hand it is important that the cover-crop do not take up N when there is no danger of leaching. If the cover-crop is allowed to grow in the spring it will result in pre-emptive competition and high C/N ratio in the cover-crop, which will lower the mineralization. When the conditions are wet and cool the incorporation date has to be late compared to warm and dry conditions (Thorup-Kristensen & Dresbøll 2010).

Mineralization of dead plant parts begin fast after shredding or incorporation even during the winter. This means that when using non-winter hardy cover-crops there is a risk of losing nitrogen during the winter through leaching (Thorup-Kristensen 1994). It can therefore be an advantage to use winter hardy cover-crops depending on precipitation and on the climate in general.

However there are some disadvantages of using cover-crops. Ramussen et al. (2006) studied a 4 year organic crop rotation's effect on weeds. They discovered that mechanical weed control is important to keep the weed density down. The problem is that it is often not possible to carry out any weed control before sowing the cover-crop. This increased the weed density. It is especially perennial weeds and grass-weeds that become a problem if no weed control is carried out in the autumn. Also some diseases can be an increased problem if there are left plant residues on the surface of the soil (Małecka & Blecharczyk 2008). However new research have suggested that it might will be possible to use cover-crops as a weed and disease suppressor (Mäder & Berner 2011). More knowledge is needed on this subject.

If these problems are overcome the benefits from cover-crops according to Delgado & Follett (2010) are maximized by conservation tillage. This allows the cover-crop residues to stay on the soil surface to improve water infiltration and other factors discussed in section 1.1.

1.3 Specifying the problem

In conclusion the soil fertility parameters that benefit from reduced tillage and cover-crops are; the soil organic matter content, number of soil invertebrates and soil microorganisms, nutrient availability, cation exchange capacity, water holding capacity and aggregate stability. In addition both reduced tillage and cover-crops leads to less erosion and less nitrate leaching. Neither reduced tillage nor cover-crops reduce the yield of the succeeding crop markedly. In some cases the use of cover-crops and reduced tillage increase the yield of the succeeding crop (Rasmussen 1999).

However there are some restraints in both methods. Reduced tillage can lead to a more compact soil and lower temperature and pH of the topsoil. This can lead to a slower germination of the seed. Both reduced tillage and cover-crops can lead to a higher weed pressure especially from perennial weeds and grass-weeds and a higher risk of diseases. Beside these problems; cover-crops requires some form of incorporation before the main crop is sown. This is to avoid that the cover-crop becomes a weed in the succeeding crop. Some difficulties relative to compaction risk are connected to spring incorporation. Especially if the soil is too wet in the early spring (which is often the situation in Denmark). Other problems evolve in relation to combining cover-crops with reduced tillage. As shortly mentioned in section 1.2 a combination of cover-crops and reduced tillage will maximize the benefits from both methods and contribute to some of the goals set by politicians and organic farming organizations (mentioned in the begging of this chapter).

Today reduced tillage and conservation tillage are almost not practiced in organic agriculture in Scandinavia because of risk of compaction, problems with residue management and especially weed control (Rasmussen 1999). As to cover-crops, which are more widely used in organic agriculture, the normal practice is to either undersow them in the main crop or to sow them after harvest of the main crop. This sets requirements for the cover-crops' competiveness and fast growth in the autumn. Often it can be beneficial to use winter hardy cover-crops. This requires some form of incorporation or killing of the cover-crop in the spring (Suhr et al. 2005). Today mouldboard ploughing is normally used (Rasmussen 1999). This raises several restraints that have to be overcome to make an agricultural system where both reduced tillage and cover-crops are used in a beneficial way. One of the questions that can be raised is if it is possible to kill off winter hardy cover-crops in the spring by using reduced tillage methods. This is to avoiding that the cover-crop becomes a weed in the succeeding crop.

When reviewing research about reduced-tillage, conservation-tillage and no-tillage farming, there have generally not been done much research on the specific problem of killing off cover-crops in organic agriculture in a European context. Historically conservation-till and no-till systems evolved after the “dust-ball” in the Midwest in the U.S in the 1930s. It became profitable because of the development of pesticides. Still today pesticides are an important tool for conservation-till and no-till farmers to control weeds and kill off cover-crops (Carr et al. 2012). In organic agriculture it is not allowed to use pesticides. Other methods are therefore needed to deal with these problems.

Generally the research in no-till agricultural systems is much further in North America compared to Europe. In North America the research focuses on no-till systems where cover-crop mulches are used to suppress weeds (Mäder & Berner 2011). The main method for killing cover-crops investigated in these trials is the roller-crimper method. To reach a high effectiveness of this method the cover-crop, if it is a grass-species, has to be through anthesis before killing (Ashford & Reeves 2003, Mirsky et al. 2009). The explanation for this is that the roller-crimper method kills the cover-crop by squashing the stem. The stem has to be stiff and lignified to achieve a high killing rate.

In Europe the research is focused on reduced tillage and not the total elimination of tillage as in the U.S. According to Mäder & Berner (2011) the reason is probably the difference in the pedo-climate between the two continents. The humid and cold conditions during the growth season in large areas of Europe limits the suitability of no-tillage practices. Even though the roller-crimper method has evoked some interest among researchers in Europe, it is not yet a suitable tool for European conditions (Mäder & Berner 2011). It is necessary to adjust the roller-crimper method to European conditions. It is only in the recent two years that there have been any trials with the roller-crimper method in Europe. In Europe so far the roller-crimper technology has only been tested on vegetable cropping systems. Canali et al. (2013) found under a study in Italy that it was possible to achieve a 69% higher yield for a roller-crimper system in a zucchini crop than in a traditional green manure system. The roller-crimper system also decreased the weed biomass, increased the N-system use efficiency (yield/N-ratio) and decreased the energy and labor costs compared to the green manure system. In a study in Italy made by Ciaccia et al. (2015) the roller-crimper technique also showed an ability to reduce weed biomass compared to a green manure system. The second year the experiment ran the climate was cooler than usual. This resulted in a lower Zucchini yield for the roller-crimper treatment than for the other treatments. It shows that there are potential limits for the roller-crimper system under cooler conditions as in Northern Europe. This again emphasizes the need for testing this technique under Northern European conditions. In March 2015 the International Society of Organic Agriculture Research (ISOFAR) began a project called SOILVEG mainly with the purpose of assessing the efficacy of the roller-crimper technique in European climatic conditions, both in the south and north of Europe (Canali & D’Oppido 2015).

A few other studies have dealt with the problem of killing off cover-crops with conservation tillage methods. One of the methods that has been investigated, is using a sweep plow undercutter which is a non-inversion technique leaving the plant residues on the surface of the soil. The study showed that by using the undercutter to terminate cover-crops, it was possible to increase the N-content of the soil, the soil moisture and the yield of the succeeding crop compared to termination with a field disk (Wortman et al. 2012). Krauss et al. (2010) tested a new method of removing grass-clover ley on a field in

Switzerland. The method comprised superficial incorporation of the ley by a stubble-cleaner followed by loosening of the soil with a chisel plow. The grass-clover mulch dried as expected and the field was afterwards sown with a winter pea cover-crop. This method successfully removed the grass-clover ley. A further analysis of the colonization of the succeeding crop's roots with arbuscular mycorrhizal fungi, suggested a similar disturbance of the top soil compared to traditional ploughing.

To avoid the removal of the cover crop it has also been tried to grow cash crops in living mulches. Romaneckas et al. (2012) studied the effect of maize grown in different living mulches in Lithuania. The results showed that the living mulches lowered the weed density. However the maize yields were also lower for all living mulch treatments because of competition between the cover-crop and the cash crop. Yet some of the mulches showed a lower competition with the cash-crop than others. This implicates that it could be possible to find suitable cover-crop species for a living mulch system. A novel innovation was made by Båth et al. (2008) to weaken the root competition between the cover-crop and the cash crop. They constructed a machine to root prune living mulches in vegetable row crops. They found that the root pruning increased the growth of the White Cabbage. Another possibility, that Köpke & Schulte (2008) investigated, is to leave the straw and stubble from the previous crop over the winter and in the spring sow directly into the stubble. In this case Faba Bean was sown directly into Oat stubble and compared to Faba Bean sown after mouldboard ploughing. The yields were the same for the two treatments and the weed density was significantly lower for the directly sown treatment.

Research in terminating cover-crops in a reduced tillage system is scattered and inadequate especially under North European conditions. To construct an organic reduced tillage system it is necessary to construct an effective termination method. To do this, knowledge about the intensity of the soil treatment needed to terminate different species of cover-crops and the different species' regeneration mechanisms are needed. To investigate this, we tested 17 different cover-crops grown in 9 different mixes (see figure 2.1) in a field experiment. 10 representative species (see annex 1) were chosen for a pot study. The pot study was constructed to study their regeneration mechanisms and regeneration rate after damage. The purpose of our study was to answer the following questions:

- What is the mode of survival and the regenerative mechanisms for the chosen cover-crops?
- Which part of the plants can regenerate after damage?
- Which cover-crop species can potentially be used for a reduced tillage system?
- Which depth of rotovation tillage should be used? - One of three tested depths or deeper ones?

2. Methods

2.1 The chosen cover-crops

The 17 cover-crop species were selected from experience of which plants that are suitable as cover-crops and historically are used as cover-crops. Some of the plants were also chosen because of interesting characteristics as a fast and high production of biomass in the autumn. This makes it possible to sow the cover-crops later and do the weed control between the rows in row sown crops. Other characteristics were the ability to fixate nitrogen from the air and to produce a deep and extensive root system. The cover-crop species and some of their characteristics are listed in annex 1.

2.2 The field experiment

Eight mixes of cover-crops containing two or three different species (see figure 2.1), were tested on a field just outside Tåstrup, Denmark. The cover-crops were undersown in a spring barley crop in three replicates. They were sown in rows of 24cm. A 9th block was left as a control. The spring barley was sown the 29th of April 2014 and the cover-crops were undersown the 22nd of May 2014. The barley was harvested the 6th of August. After harvest the cover-crops were left over the winter. Just before sowing the spring barley in the spring 2014 pig slurry containing 15 Kg/ha nitrogen was applied to the field. Each block was 2,5 m x 10 m and there were 3 x 9 blocks in total. The soil is an Agrudalf soil classified as a sandy loam according to the ISSS classification. The weather over the winter season 2014-2015 and March 2015 and April 2015 is shown in table 2.1.

Species	Seed rate (Kg/ha)
Hairy vetch/stauderug	40+50
Persian clover/winter rye	5+80
Winter radish/persian clover	5+5
Winter rape/white clover	5+5
Chicory/lucerne/orchard grass	4+4+4
Dyer's woad/kidney vetch/timothy	4+4+4
Plantain/ryegrass/medick	4+4+4
Stauderug/red clover	50+5
-	

Figure 2.1: Showing the cover-crop mixes and the seed rate (Kg/ha) of the different species.

The 13th of March 2015 rotovation tillage was done in three different depths; 4cm, 8cm and 15cm - each replicate with a different depth. The rotovator was of the label KUHN and the model was "Power Tiller" – EL 62 (see figure 2.2).

The 21st of April biomass was harvested from each block. In each block two squares each with an area of 0,5 m^2 was placed randomly and all above ground biomass was harvested within the square. The biomass was sorted in the different cover-crop species and in weeds. After drying the biomass in a drying cabinet for a week, the biomass was weighted.

Figure 2.2: The rotovator in action at 15cm depth.

Table 2.1: Showing the mean temperature, sum of precipitation and total hours of sun during the winter months 2014-2015 (December, January and February), April 2015 and March 2015 and the average from 1961-90 and 2001-10 (Cappelen 2015a, Cappelen 2015b, Scharling 2015).

Parameter	**Winter 2014-2015**	**Average 1961-90**	**Average 2001-10**
Mean temperature	2,8℃	0,5℃	1,9℃
Sum of precipitation	245 mm	161 mm	180 mm
Total hours of sun	153 h	155 h	159 h
Parameter	**March 2015**	**Average 1961-90**	**Average 2001-10**
Mean temperature	4,7℃	2,1℃	3,0℃
Sum of precipitation	66 mm	46 mm	43 mm
Total hours of sun	127 h	110 h	146 h
Parameter	**April 2015**	**Average 1961-90**	**Average 2001-10**
Mean temperature	7,0℃	5,7℃	7,5℃
Sum of precipitation	27 mm	41 mm	37 mm
Total hours of sun	198 h	162 h	198 h

2.3 The pot experiment

10 of the 17 cover-crop species were selected to be representative for different regeneration mechanisms. Four species from the *Fabaceae* family, two from the *Poaceae* family, two from the *Brassicaceae* family, one from the *Asteraceae* family and one from the *Plantaginaceae* family were chosen (see annex 1 – the ones marked with grey). On the 16th, 17th and 18th of March, plants were taken from the field. The roots of each species were cut at 0cm, 1cm or 3cm from the base of the plant (see figure 2.3). For white clover also the runners was cut in 1cm or 3cm length to investigate if the plant could regenerate from stem parts (runners). The grass species' shoots were also cut so it was possible to cover them with the soil. The shoots and the roots were

put into pots with a top diameter of 23,5cm, a bottom diameter of 16,5cm and a height of 16,5cm. Four plants were put in each pot. For each cutting length two pots were made – one with 2cm of soil cover and one with 5cm of soil cover. Two replicates were made of each treatment – hence 120 pots in total.

Figure 2.3: a) Chicory cut at 0cm (left), 1cm (middle) and 3cm (right). b) Shows how the top of Stauderug was cut off. c) White clover cut at 0cm (left), 1cm (middle) and 3cm (right) – also the runners were cut.

In the greenhouse the light was turned on from 7am to 11pm. The temperature varied depending on the weather outside, but the temperature in the daytime did not get under 15ºC and at nighttime under 13ºC. The soil used in the pots was Pindstrup Substrate (see table 2.2). The plants were watered every second day.

Table 2.2: The contents of the soil used in the pot experiment. From Pinstrup Mosebrug A/S.

DECLARATION	
Screening	0-20 mm (for pots less than ø13cm) 0-35 mm (for pots more than ø13cm)
pH	5,5 (if irrigation water has high content of bicarbonate or for plants which demand a low pH) 6,0 (for most crops or if irrigation water has a low content of bicarbonate)
Dry matter content	55-75 gram/liter
NPK fertilizer per m³	0,650 kg per m³
Micro fertilizer per m³	50 gram per m³
EC, Ducth standard	app. 1,0
Other additives	-
Wetting agent	100 ml per m³

Three assessments were done on the following dates: The 23rd of March, the 29th of March and the 3rd of April. At each assessment a picture of each pot was taken for green-pixel analysis and the number of shoots of each of the four plants in each pot was counted. Later the mean shoot number for each pot was calculated (the sum of shoots on the four plants divided by four). At a fourth assessment time, the 8th and 10th of April, the plants were dug up and a qualitative assessment of the regeneration mechanisms was done.

2.4 Data analysis

The pictures from the pot experiment were analyzed in an online image analyzing program called "IMAGING Crop Response Analyzer" available at: www.imaging-crops.dk. For each picture the ratio of green pixels compared to the total number of pixels was found. To be able to compare the pictures, all pictures were taken at the same height and had the same total number of pixels.

A statistical analysis of all the data – shoot number and green cover for the pot experiment and dry biomass for the field experiment – was done in SAS using the GLM procedure to do an ANOVA analysis of the data. To achieve a low deviation the data was log-transformed to fit the linear model. A 1% significance level was used. The total SAS procedure is listed in annex 2.

3. Results

3.1 The pot experiment

For the pot experiment three types of data were gathered: Qualitative observations of the regeneration mechanisms of the 10 cover-crops, the mean shoot number of each pot and the green cover of each pot. The results are described in the following section.

3.1.1 Qualitative data of the cover-crop's regeneration mechanisms

The regeneration mechanisms observed are described for each family of cover-crops.

***Fabaceae*:**

According to our observations white clover can regenerate shoots and roots from the base of the plant. In addition white clover, as the only one of the tested species from the *Fabaceae* family, can regenerate from stem parts (runners). Red clover regenerates new shoots from the base and new roots from the base and the existing tap root. Even though kidney vetch had a hard time recovering from the damage, we observed some regeneration from the base. Yet none of the plants survived. Unlike the three other species in the *Fabaceae* family, lucerne is able to regenerate shoots from the top of the tap root. This was observed on roots cut 0cm and 1cm from the base. Lucerne is not able to regenerate shoots from all root parts, hence it can be concluded that Lucerne only regenerates from the part of the root closest to the base. Lucerne was dependent on having a part of the taproot to regenerate. This could be due to the tap roots role as a nutrient storage. See figure 3.1 for pictures of the described observations.

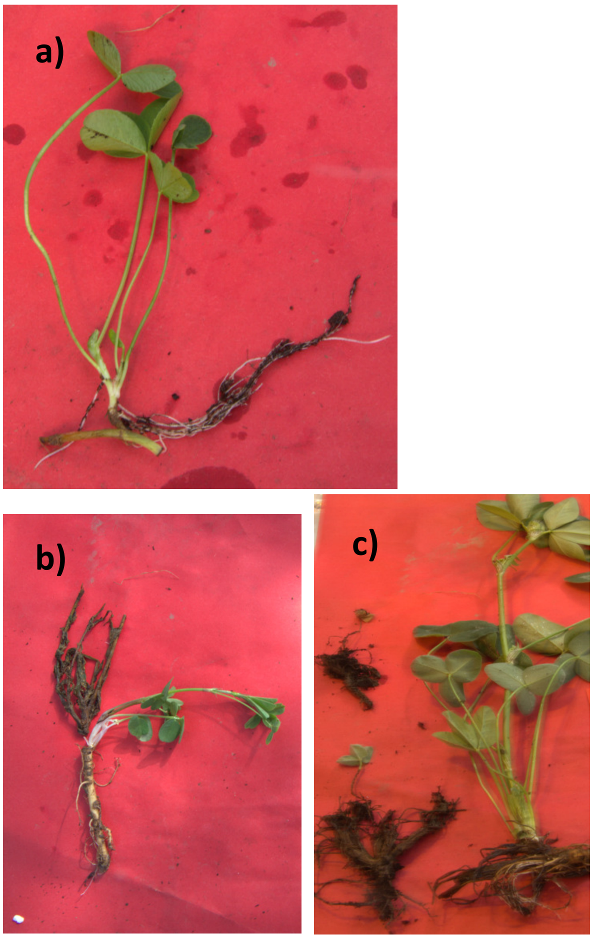


Figure 3.1: a) White clover (D: 2, L: 3) regenerating from a stem piece (runner), b) Lucerne (D: 2, L: 0) regenerating from the top of the tap root – old shoot is also represented, c) Red clover (D: 2, L: 3) regenerating from the base.

Poaceae:

Ryegrass and stauderug are able to regenerate from the base of the plant. Furthermore both species also produce rhizomes. See figure 3.2.

Figure 3.2: a) Ryegrass (D: 5, L: 1) producing rhizomes. b) Stauderug (D: 5, L: 0) Regenerating from the base.

Brassicaceae:

Dyer's woad and winter rape show the same regeneration mechanisms. They regenerate new shoots from the base and from root parts. The old shoots are not able to regenerate new shoots without a part of the tap root attached. The observations show that the cutting of the roots triggers a survival mechanism and the root parts produce a number of new shoots. See figure 3.3.

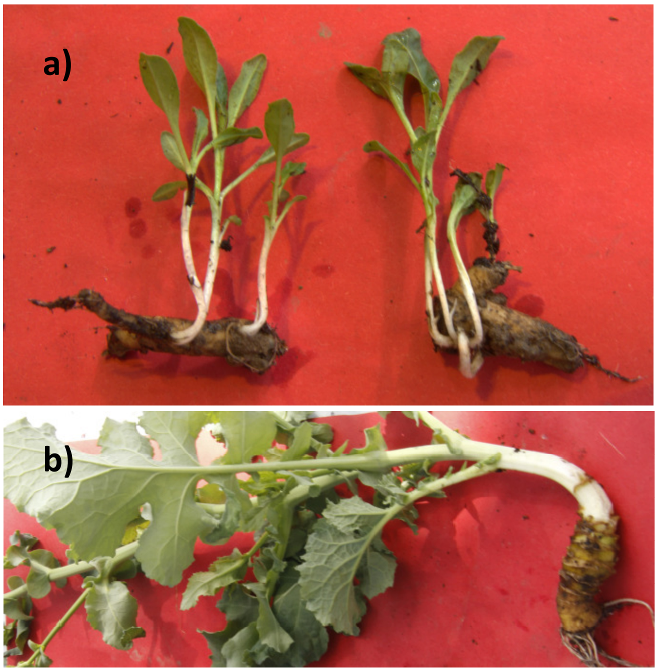


Figure 3.3: a) Dyer's woad (D: 2, L: 3) regenerating from root parts, b) Winter rape (D: 5, L: 1) regenerating from the base.

Asteraceae:

The regeneration mechanism of Chicory is similar to the ones of the species from the *Brassicaceae* family. According to our observations Chicory can regenerate from the base and from the cutting face of the root parts. There were also observed few examples of regeneration from wounds on the surface of the root. See figure 3.4.

Figure 3.4: Chicory (D: 2, L: 3) regenerating from the base, the cutting face and a wound on the side of the root.

Plantaginaceae:

Our observations show that Plantain is able to regenerate from the base, the tap root and the lateral roots (see figure 3.5). Plantain shows an aggressive regeneration mechanism where it produces a lot of new shoots from all parts of the plants except the old shoots.

Figure 3.5: Plantain (D: 5, L: 0) regenerating from the base, the tap root and the lateral roots.

3.1.2 Green cover and shoot number

When we look at the green cover and the shoot number of the pots the overall picture is the same for both parameters. For both shoot number and green cover we had four variables: Species, length of root cut, depth of soil cover and assessment time. We found a significant difference between the three lengths (0cm, 1cm and 3cm) and also between the two soil-cover depths (2cm and 5cm) for both green cover and shoot number data. For green cover there was also a significant difference between the three assessment times. The difference between assessment times for the shoot number data differed from this. There was a significant difference between the first and second assessment time, but the third assessment time did not significantly differ from either the first or the second assessment time.

There was also a significant difference between the species in shoot number and green cover. However the species that were significantly different were not the same for shoot number and green cover (See figure 3.6). However it was possible on the basis of both shoot number and green cover data to divide the species into two groups:

1) White clover, lucerne, red clover, chicory and kidney vetch.
2) Ryegrass, dyer's woad, plantain, staude-rug and winter rape.

Group 1) was more adverse affected by the damage than group 2) (see figure 3.7).

This gives us an idea of which cover crops that is more resistant than others. If we only look at the results for the green cover, kidney vetch is the species that is most vulnerable to the damage. Plantain, ryegrass and winter rape show the highest tolerance to damage. According to the results from the shoot counting the most vulnerable species are chicory and kidney vetch and the most tolerant are ryegrass and dyer's woad.

a)

Means with the same letter are not significantly different.				
Tukey Grouping		Mean	N	Species
	A	0.6436	36	10
	A			
B	A	0.4578	36	5
B	A			
B	A	0.2571	36	7
B				
B		0.2159	36	8
	C	-0.2213	36	6
	D	-1.2044	36	1
	D			
	D	-1.2329	36	4
	D			
	D	-1.4490	36	2
	D			
	D	-1.5918	36	9
	E	-2.1449	36	3

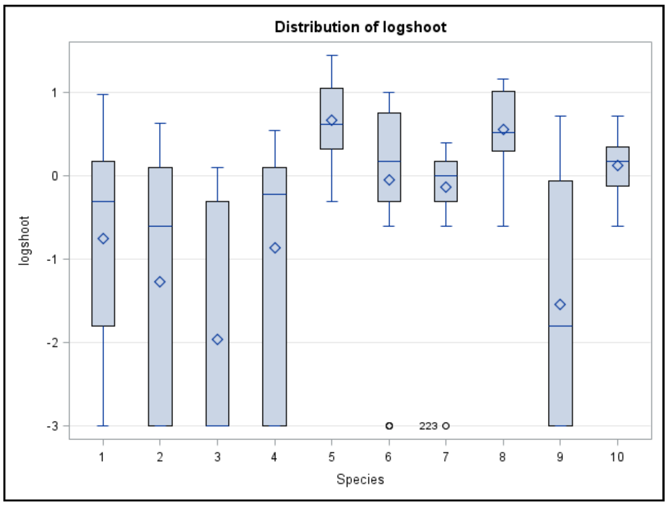
b)

Means with the same letter are not significantly different.				
Tukey Grouping		**Mean**	**N**	**Species**
	A	0.6704	36	5
	A			
B	A	0.5648	36	8
B				
B	C	0.1318	36	10
	C			
	C	-0.0390	36	6
	C			
	C	-0.1315	36	7
	D	-0.7471	36	1
	D			
E	D	-0.8591	36	4
E				
E	F	-1.2625	36	2
	F			
G	F	-1.5399	36	9
G				
G		-1.9574	36	3

Figure 3.6: The significant difference between the species for a) green cover and b) shoot number. Species with the same letter are not significantly different. 1: White clover, 2: Red clover, 3: Kidney vetch, 4: Lucerne, 5: Ryegrass, 6: Stauderug, 7: Winter rape, 8: Dyer's woad, 9: Chicory, 10: Plantain.

Interactions between all variables were tested (see annex 3). There was found a significant interaction between species & length, species & depth and species & time for both shoot number and green cover. For the green cover results there were also a significant interaction between species & length & depth which was not present for the shoot number results with a significance level on 1%. There was however a significant interaction if the level was on 5% (see annex 3).

a)



b)

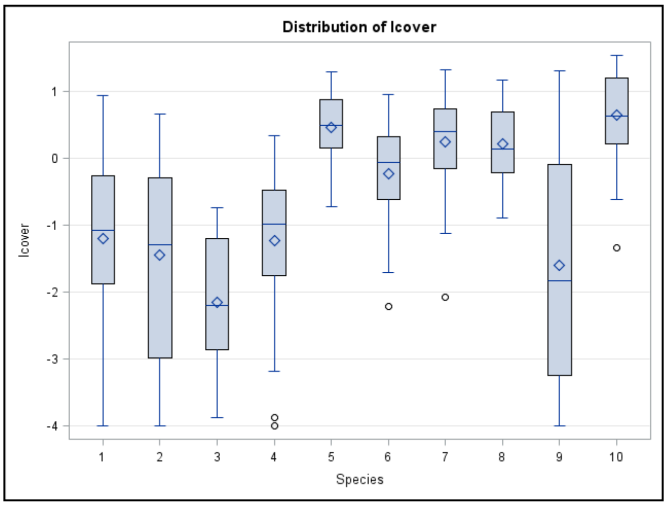
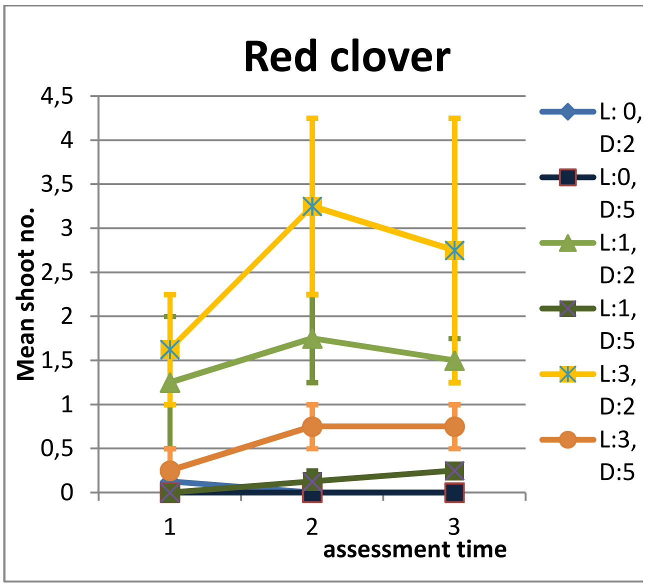


Figure 3.7: The distribution of a) shoot number and b) green cover for the different species (for species number see figure 3.6).

The results showed that white clover, red clover and lucerne reacted in a similar way to the treatments. The shoot count showed a tendency of an increase in shoot number between assessment one and two. The shoot number either stagnated or decreased between assessment two and three. Both the length of the root cut and the depth of the soil cover seemed to influence the regeneration. Figure 3.8 shows the results for red clover as an example of the three species regeneration. The treatment with the highest green cover was the treatment with the longest length (3cm) and the shallowest depth (2cm) for all three species. White clover achieved the highest green cover and shoot number and lucerne the lowest. However the range was between 0 and 6 shoots for the shoot number data and between 0% and 5% green cover for the green cover data which is low compared to some of the other species.

a)



b)

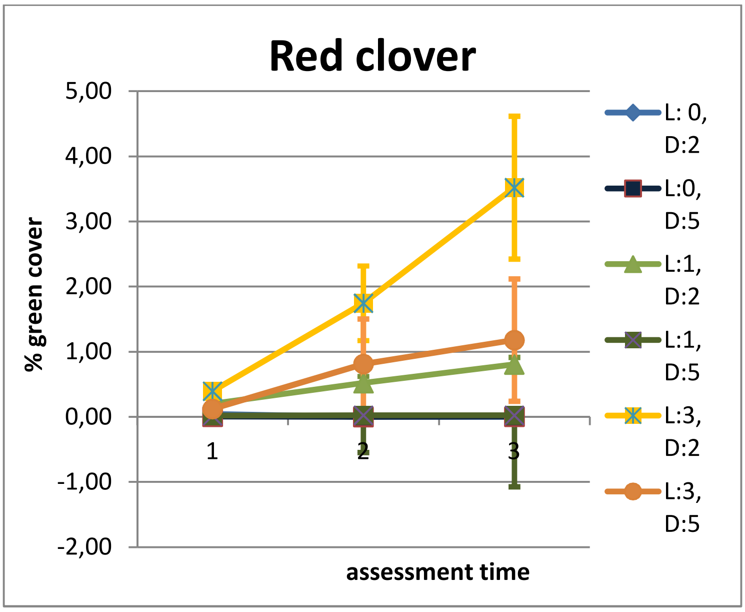
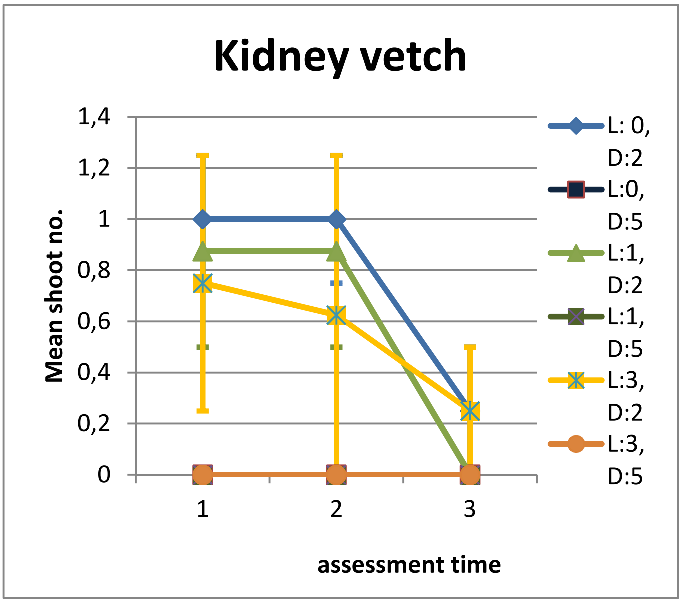


Figure 3.8: a) mean shoot number and b)% green cover as a function of assessment time shown for red clover. L = Length of root cut, D = Depth of soil cover.

Kidney vetch showed the lowest tolerance towards the damage of all the species. Only the treatments with the lowest depth of soil cover managed to regenerate new shoots even though they died at the end of the experiment (see figure 3.9).

a)



b)

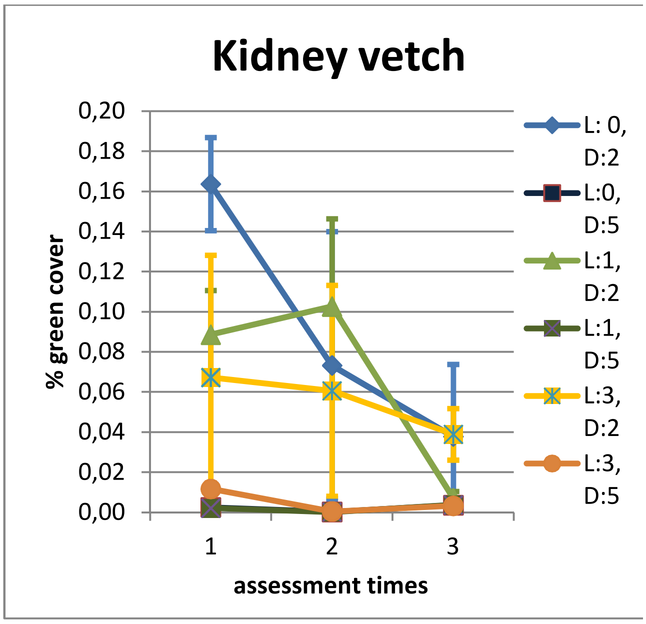
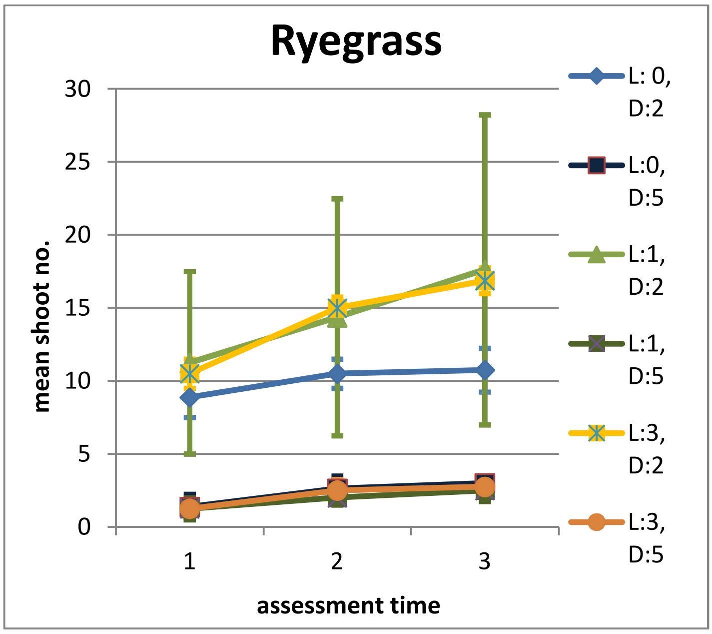


Figure 3.9: a) mean shoot number and b)% green cover as a function of assessment time shown for kidney vetch. L = Length of root cut, D = Depth of soil cover.

Ryegrass and stauderug showed a tendency of high sensitivity towards the depth of the soil cover, but not towards the length of the root cut (see figure 3.10 – shows the results for ryegrass as an example of this). According to the shoot data ryegrass had produced almost all the shoots before the first assessment. The data for stauderug showed the same tendency, even though almost half of the shoots died between second and third assessment. For ryegrass the green cover ranged between 0% and 16% and the shoot number between 0 and 17 shoots. For stauderug the values was much lower. The green cover ranged between 0% and 6% and the shoot number between 0 and 7 shoots. It is clear from these results that ryegrass is more tolerant to damage than stauderug.

a)



b)

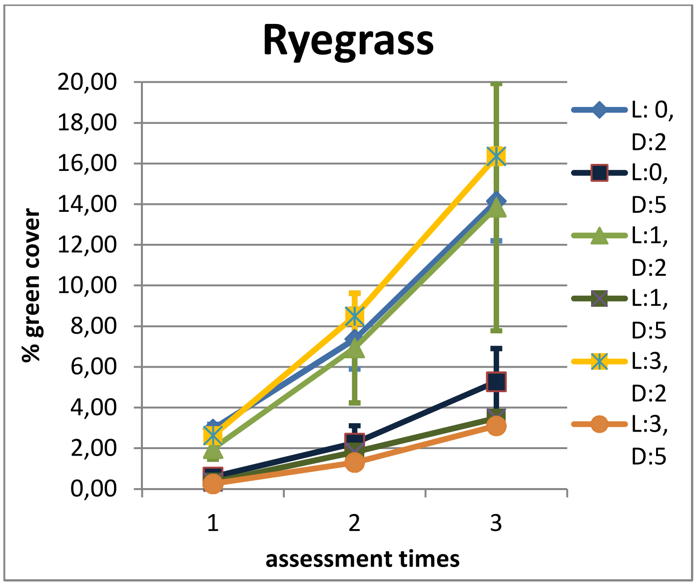
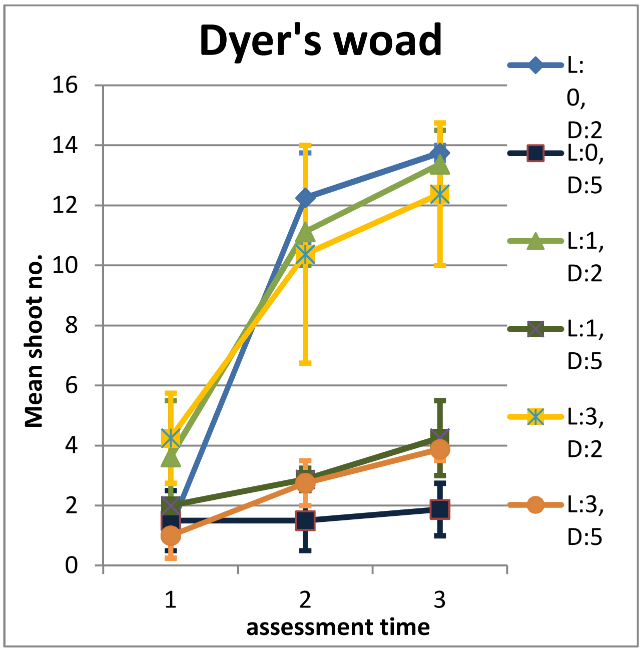


Figure 3.10: a) mean shoot number and b)% green cover as a function of assessment time shown for ryegrass. L = Length of root cut, D = Depth of soil cover.

Dyer's woad and winter rape seemed to regenerate in the same pattern. Both depth of soil cover and length of root cut seemed to affect them. Dyer's woad and winter rape regenerated for all treatments unless the one with length: 0cm and depth: 5cm. According to the shoot counting data, winter rape produced very few shoots after the first assessment. Dyer's woad took a bit longer time to regenerate. This was seen as a rapid increase in shoot numbers between first and second assessment, for the treatments with the lowest depth of soil cover (see figure 3.11). For winter rape the mean green cover ranged between 0% and 19% and the mean shoot number between 0,5 and 2 shoots. For dyer's woad the mean green cover ranged between 0% and 12% and the mean shoot number ranged between 1 and 14 shoots. It is noteworthy that winter rape produced very few shoots compared to the relatively high green cover value.

a)



b)

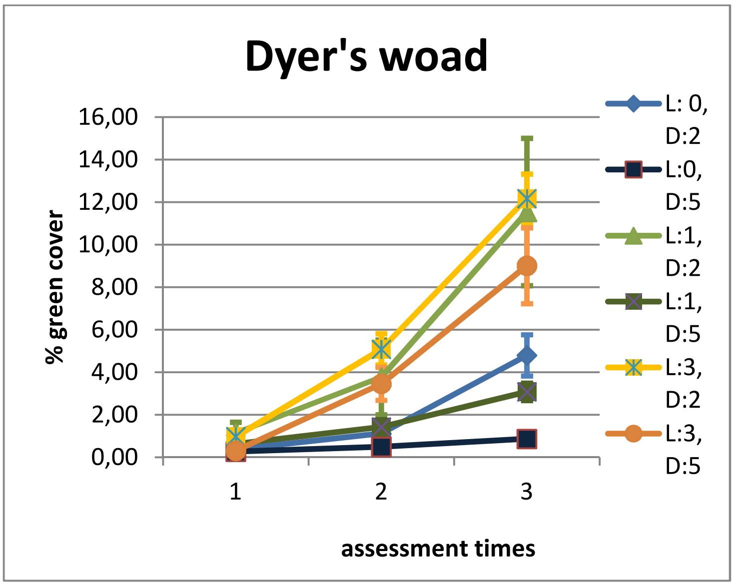
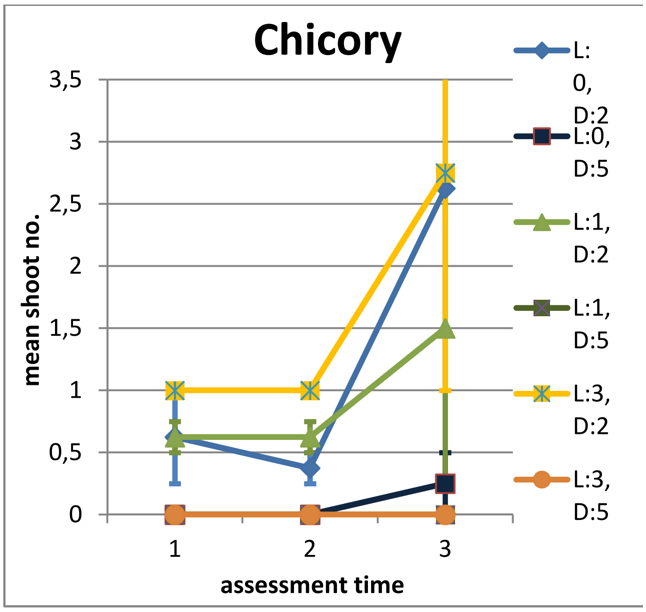


Figure 3.11: a) mean shoot number and b)% green cover as a function of assessmenttime shown for dyer's woad. L = Length of root cut, D = Depth of soil cover.

Chicory showed a high sensitivity to length of root cut and depth of soil cover. Chicory only succeeded in regenerating from two treatments: Length: 3cm & depth: 2cm and length: 1cm & depth: 2cm. Only for the treatment with length: 3cm and depth: 2cm, the growth was vigorous enough, estimating that the plant would survive in the long term. The shoot counting data showed a clear tendency to a slower recovery from the damage than for the other species (see figure 3.12).

a)



b)

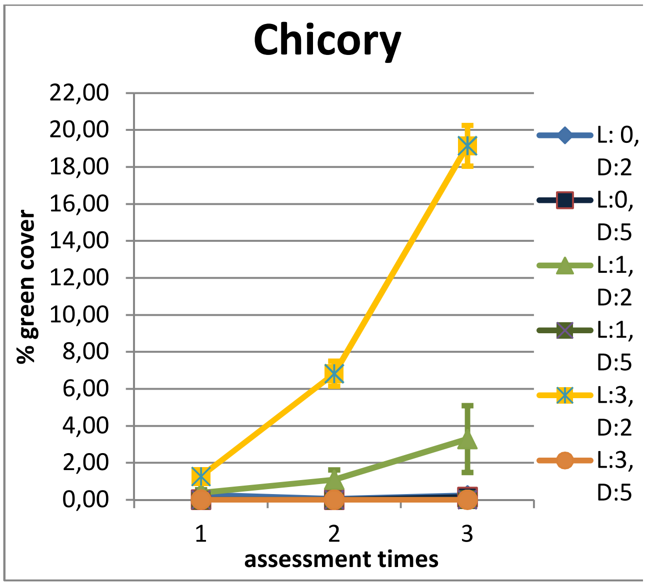
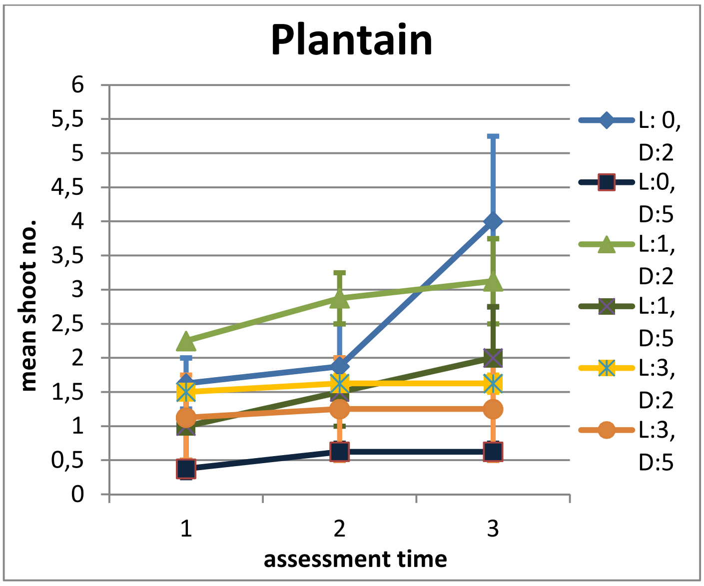


Figure 3.12: a) mean shoot number and b)% green cover as a function of assessment time shown for chicory. L = Length of root cut, D = Depth of soil cover.

Plantain showed a high recovery from the damage. All treatments regenerated new surviving shoots (see figure 3.13). However treatments where the root was cut at 0cm from the base, achieved the lowest values for both shoot number and green cover. The deepest depths slowed the regeneration of the plants. Also for plantain most of the shoots seemed to have been produced before the first assessment. Plantain reached the highest values for green cover among the 10 species.

a)



b)

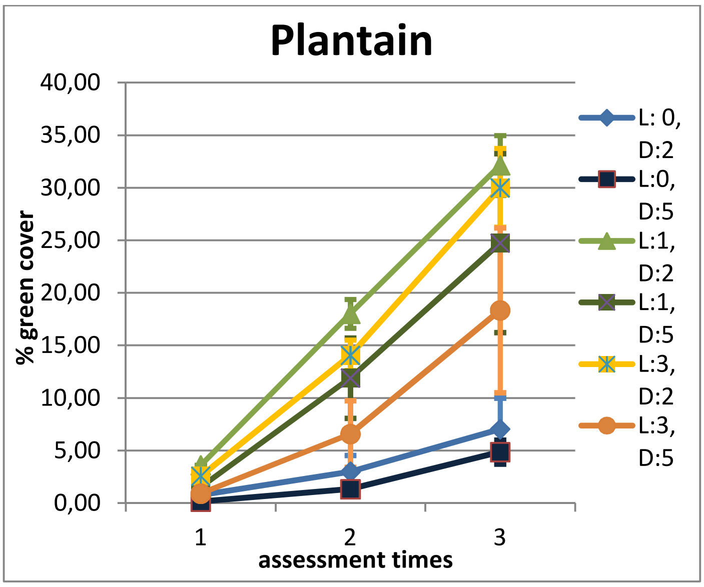


Figure 3.13: a) mean shoot number and b)% green cover as a function of assessment time shown for plantain. L = Length of root cut, D = Depth of soil cover.

Table 3.1: The overall mean growth rate calculated for each species between assessment 1 and 2 (by dividing the mean value for assessment 2 with the mean value for assessment 1) and assessment 2 and 3 (done in the same way as for assessment 1 and 2). The mean difference between the two growth rates is also calculated (negative = the growth is highest between assessment 1 and 2, positive = the growth is highest between assessment 2 and 3).

Species	Mean growth rate between ass. 1 and 2	Mean growth rate between ass. 2 and 3	Mean difference between growth rates
White clover	10,8	1,8	-8,9
Red clover	3,7	2,0	-1,7
Kidney vetch	0,6	2,2	1,6
Lucerne	2,8	1,4	-1,4
Ryegrass	3,9	2,2	-1,8
Stauderug	1,5	1,3	-0,2
Winter rape	11,1	3,5	-7,6
Dyer's woad	5,2	2,8	-2,4
Chicory	1,7	26,8	25,2
Plantain	7,3	2,5	-4,8

To be able to assess how fast the different species regenerate we calculated a growth rate. This was done from the green cover results. Since most of the shoots in many cases already was produced before first assessment, it made more sense to use the green cover results. This is because it gave a more accurate picture of the growth rate. In table 3.1 the mean growth rates of all the treatments were calculated for each of the species. It is important to note that this does not say anything about the treatments and how successful the species was in surviving them. It is merely an expression of the difference of how fast the species regenerate. All of the species, except kidney vetch and chicory, had the highest growth between assessment one and two. It is important to remember that kidney vetch barely had any growth at all and that the growth in average was decreasing between assessment one and two. The species with the highest growth rate was white clover, winter rape and chicory. Plantain and dyer's woad had also a relatively high growth rate. Kidney vetch and stuaderug was the species with the lowest growth rate in the three assessments.

3.2 The field experiment

To assess the three rotovation tillage depth's (4cm, 8cm and 15cm) effectiveness in killing off the 17 cover-crops (see figure 2.1), the dry biomass of each species and weeds in each block were measured.

According to the statistical test soil treatment 3 (4cm depth) was significantly different from soil treatment 1 and 2 (15cm and 8cm depth). Soil treatment 1 and 2 was not significantly different (see figure 3.14). According to figure 3.14, all three soil treatments showed the same pattern for the different species, which enabled us to conclude that some species were more resistant to rotovation tillage than others. Some of the species had a significantly different in biomass production than others. This enabled us to group them (see figure 3.14):

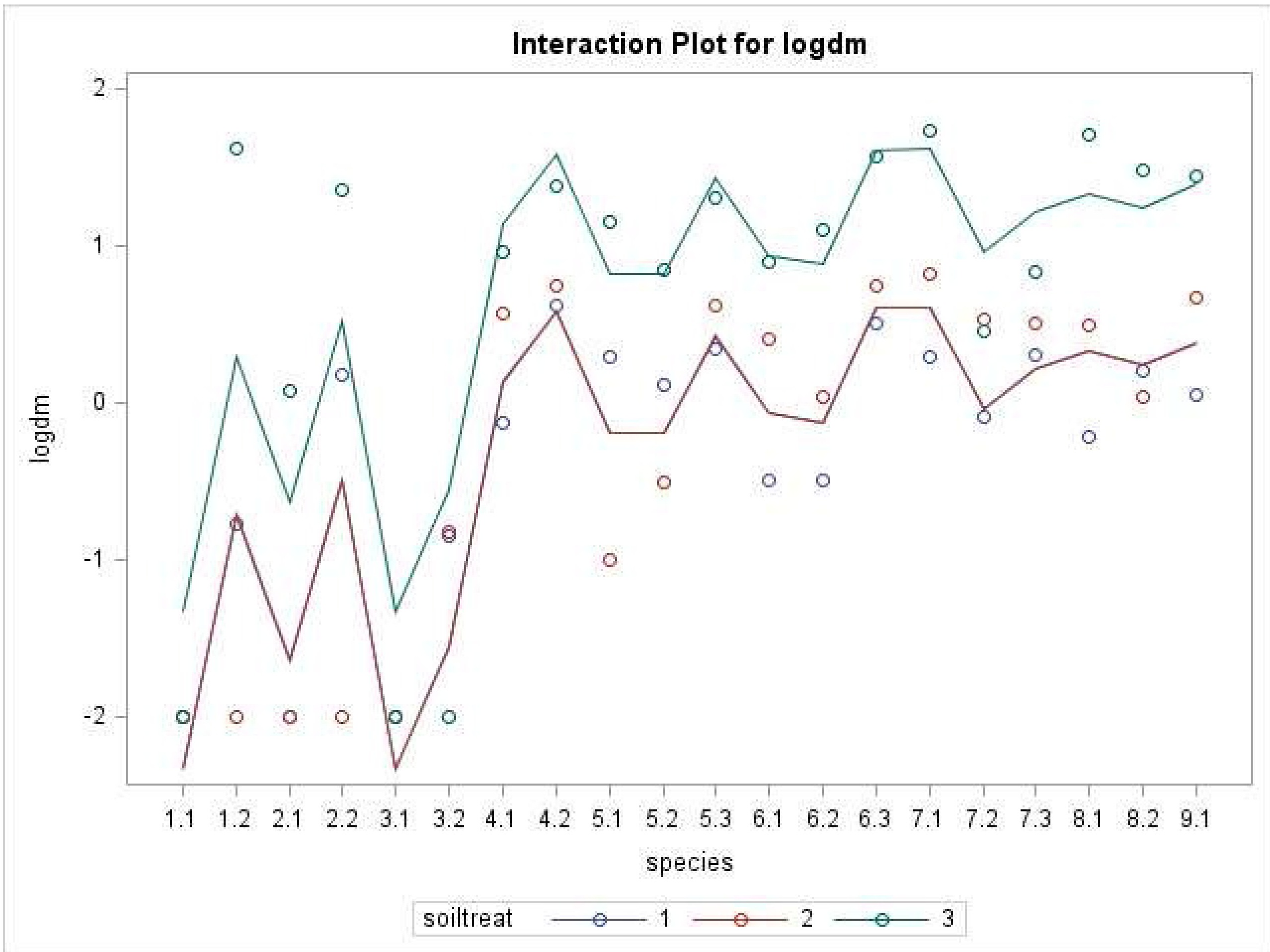


Figure 3.14: log transferred dry biomass data as a function of species. Showing the three soil treatments (1 = 15cm, 2 = 8cm, 3 = 4cm). Cover crop mix.species: 1.1: Hairy vetch, 1.2: Stauderug, 2.1: Persian clover, 2.2: Winter rye, 3.1: Winter radish, 3.2: Persian clover, 4.1: Winter rape, 4.2: White clover, 5.1: Chicory, 5.2: Lucerne, 5.3: Orchard grass, 6.1: Dyer's woad, 6.2: Kidney vetch, 6.3: Timothy, 7.1: Plantain, 7.2: Ryegrass, 7.3: Medick, 8.1 Stauderug, 8.2: Red clover, 9.1: Control.

1) Persian clover (treatment 3), persian clover (treatment 2), winter radish and hairy vetch.
2) Winter rye and stauderug (treatment 1).
3) Stauderug (treatment 8), red clover, medick, winter rape, ryegrass, dyer's woad, kidney vetch, chicory and lucerne.
4) Plantain, timothy, white clover and orchard Grass.

The cover-crops in group 1) did almost not recover. Winter radish and Hairy vetch did not produce any biomass in any of the blocks. Persian clover did only produce very little to none (not more than 1 g/m^2) (see figure 3.15 a).

The species in group 2) did very well in the blocks with soil treatment 3 (4cm). In the blocks with soil treatment 1 and 2 (15cm and 8cm) the species did not produce more than 1,5 g/m^2 dry biomass (see figure 3.15 a). Group 3) did generally produce more over-ground biomass for soil treatment 1 and 2 than the species in group 2) did (see figure 3.15 b, c). Group 4) covers the species that produced the highest value of over-ground biomass in general for all three soil treatments (see figure 3.15 b, c).

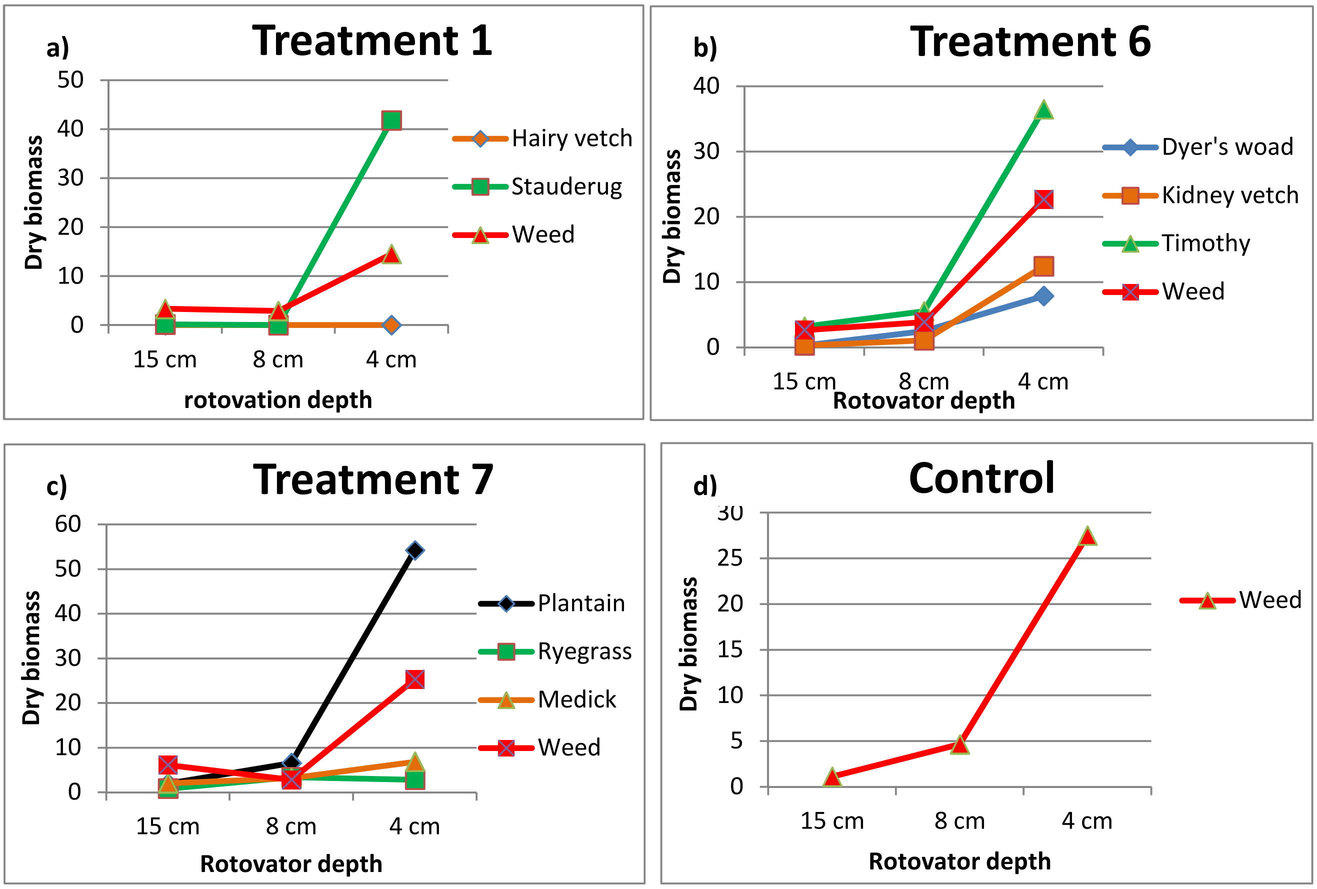


Figure 3.15: The dry biomass as a function of rotovator depth for a) treatment 1, b) treatment 6, c) treatment 7 and d) the control treatment.

In general the rotovation tillage at 4cm depth was not successful in killing either cover-crops or weeds (see figure 3.15). The rotovation tillage at depth 8cm and 15cm were almost equally as effective in terminating the cover-crops and weeds.

4. Discussion

4.1 Results

To get the full picture of the results it is necessary to combine them. In the pot experiment both qualitative and quantitative data was collected. Species from the *Fabaceae* family are only able to regenerate from the base of the plant except white clover which is also able to produce new shoots from stem parts. This is in contrast to the species which root system is based on a big tap root (*Brassicaceae* species, chicory and plantain). They are all able to regenerate from root pieces. By cutting these specie's roots into smaller pieces a number of new plants are created. This is reflected on the quantitative data where it is these species that show the highest survival rates compared to the *Fabaceae* species, except chicory. Chicory had a longer recovery period than the other species before it began producing new shoots. When we terminated the experiment and dug all the species out of the pots, there were a lot of small, new shoots beginning to grow from the root parts of chicory. This suggests that chicory is capable of recovery from damage, but takes a longer time to recover than the other species. Species from the *Poaceae* family have fibrous roots and regenerate new shoots from the base or subterranean stems called rhizomes. This makes them less dependent on their root system and able to fast regeneration of new shoots. According to our data it is only the depth that hinders the regeneration of the *Poaceae* species. This also makes them quite successful in surviving the damage even though stauderug lies on a level comparable with white clover.

The differences discussed above are supported by the fact that the statistical analysis found a significant interaction between species & depth, species & length and species & time and in the case of green cover also between species & depth & length. The species are affected differently by depth, length, time and depth & length.

From our data it is clear that different tillage methods are needed to kill the different cover-crops. To kill off lucerne, red clover and kidney vetch it is enough according to our data to rotovate at 8cm depth. White clover, winter rape, dyer's woad, chicory and plantain presumably need more than one tillage treatment to deplete the storage in the tap root and for white clover in the runners. For the grass-species depth is the most important variable in preventing their recovery hence a tillage method which is burrowing them at a deep depth is necessary.

The significance of time is not the same for the shoot count data and the green cover data. Time is highly significant for the green cover data; hence the green cover keeps increasing for each assessment for most of the species. Only assessment 1 and 2 is significantly different for the shoot count data which suggests that the plants produce a lot of shoots in the beginning and then after some time some of them die off and the rest are increased in size.

The above discussion stresses how the shoot count data and the green cover data do not show exactly the same results. The reason is that the mechanism for shoot production and green cover are not the same. Our results show that the majority of the tested plants early on produce the total number of shoots. The energy is then used on expanding the produced shoots and some shoots will die off in favor of the remaining shoots. This is why it is argued that green cover is a better indicator of the survival and growth of the plants. Only a plant that has enough energy to not only produce shoots but also expand them and thereby become a competitor against other plants will survive the damage in long term.

When comparing the results from the pot experiment and the field experiment it is not the same species that show a high or low recovery from the damage. The species that had the lowest recovery in the field experiment; persian clover, winter radish and hairy vetch, are species which were not included in the pot experiment. Kidney vetch had the lowest recovery in the pot experiment opposite the field experiment where kidney vetch showed a medium recovery. The other species included in the pot experiment except plantain and white clover showed a medium recovery in the field experiment. Plantain showed a high recovery both in the pot experiment and in the field experiment. In the pot experiment white clover was in the low recovery category opposite the field experiment where White clover showed some of the highest recovery. White clover did show the highest recovery in the low recovery category. In the greenhouse the conditions were optimal for the plants relative to water, temperature and nutrients and there were a low competition with other plants hence they were in separate pots. In the field there were competition from the other cover-crops and weeds. According to the weather data (see table 2.1) the winter months and March were wetter and warmer than usual and April was dryer than usual. Shortly after the rotovation tillage the weather was quite dry which possibly have affected some species more than others. Another factor is the damage. In the pot experiment we made sure that all species were damaged in the same way. In the field the rotovation tillage might not have been equally distributed which can lead to bigger parts of the plants surviving. In addition some species survived the winter better than others and therefore had a better starting point.

In this study we have chosen mainly to use winter hardy species under Danish conditions. It is important to mention that persian clover, winter radish and hairy vetch, which did not recover at all or had a very little recovery rate, are not winter hardy or partly winter hardy (see annex 1). To overcome the problem of terminating cover-crops in the spring in a reduced tillage system it is also possible to use cover-crops which are not able to survive the winter. As mentioned earlier, in wet winters the mineralization during the winter may counteract the effect of the cover-crop. A possibility would be to find cover-crops which die in late winter. Some species are known and it should be possible to find others.

4.2 Methods

For the pot experiment we chose the parameters; shoot number and green cover. These parameters enabled us to follow the cover-crop's development. Were other parameters as for instance biomass chosen, it would only have been possible to harvest the biomass once. This would only have given us knowledge about which species survived and which did not. By following the development we can say something about the growth rate and the degree of recovery. As already mentioned in the above section green cover and shoot number do not tell us the same. It is very different how many shoots different species produce. For instance grass species produce many shoots compared to species from the cabbage family. Therefore it can be difficult to compare between species and especially families. An example is winter rape which only produced two shoots but scored a high green cover value and therefore did recover from the damage. The conclusion is that shoot number can only tell us something about whether the plant survived or not and how fast after damage the shoots are produced. It cannot tell us about the rate of survival, especially not when there is compared between plant families. Another point is that the results have shown that shoot number do not necessarily increase (but can actually decrease), even though the plant is growing in size. Green cover tells us how much the plant covers the soil. Some plants are more upright and others produce big leaves to cover the ground. The biomass might be the same for these two types of plants, but they will not get the same green cover value. The main problem we want to solve in this study, is to avoid that the cover-crops compete with the newly sown cash crop in the spring. In this context green cover is a suitable parameter to use, since the amount of soil a plant covers can be used as a parameter for the plants competitive ability.

As mentioned in section 4.1 the pot study and the field study did not give us the same results relative to the species recovery rate. It is important to be aware, that in the field experiment we used dry biomass as a parameter for recovery and in the pot experiment we mainly used green cover as a parameter. As mentioned above, there can be some discrepancy between the two assessment methods.

Originally we also wanted to count the shoot number and do green cover assessment for the field experiment. The shoot counting showed to be too time consuming and imprecise. The pictures we took for the green cover assessment showed to deviate too much from each other because of changing height and angle. It was therefore decided to omit these results from this paper.

In the field we did not have any replicates. This is a drawback for the experiment since it is not possible to calculate the deviation and to test for any interactions between; the species and the depth of the rotovator. The decision not to include replicate-blocks was mainly made because of practical reasons and the fact that the experiment is the first screening in a series of experiments. In the pot study only two replicates were made. This was mainly because of space in the green house and time considerations. If we had had three replicates the deviation would properly have been lower. Especially on the treatments where there was a large recovery – Here the deviation in some cases was quite large.

In the statistical analysis we did not test for interactions between individual species and length, depth and time. Instead the conclusions of how length, depth and time affect the species differently are done from graphs and from calculated growth rates. The conclusions had been more validated if the mentioned statistical test had been done. However because of a large amount of data and short time to process it, it was not done. It should be done in a future study.

It can be questioned whether the representative species chosen to the pot study really were representative for the species used in the field experiment. However the qualitative data do show some consistency towards the regenerative mechanisms in each plant family. Yet winter radish showed a really low recovery rate in the field experiment compared to the other species in the *Brassicaceae* family. The low recovery rate might be due to the fact that winter radish only is partially winter hardy and not the damage caused by the rotovator. The same can be said about persian clover and hairy vetch.

The choice of the rotovator as a reduced tillage method is mainly because of the ability to adjust the depth and the fact that it was at hand. The main objective of this study was to investigate different cover-crops' resistance to different tillage intensities. The tillage method was there not the main focus. However this study might be used as a base to construct a study for further investigation of the combination of reduced tillage and cover-crops where different tillage methods also can be investigated.

4.3 Reduced tillage in organic agriculture

In section 1 it was found that the main problems hindering the introduction of reduced tillage to organic agriculture in northern Europe are:

- Management of weeds and diseases.
- Slower N mineralization.
- Risk of compaction.
- Residue management and the lower temperature and pH a mulch layer can cause on the soil surface.
- Termination of the cover-crop.

The question is whether these restraints can be overcome, so organic agriculture can achieve the benefits (mentioned in section 1) of conservation tillage.

An option could be to introduce a hybrid system were conventional tillage is used occasionally when necessary. It could be used for instance to incorporate winter hardy cover-crops or when weed infestation is too great (Rahmann & Aksoy 2014). A drawback is that occasional mouldboard ploughing may destroy the fertility that was build up during the reduced tillage period. It is necessary to investigate, the effect of conventional tillage on a soil that has been under reduced tillage or conservation tillage for a longer period.

Another way is novel equipment. An example is the stubble cleaner. It undercuts weeds and cover-crops and thereby kill them with little soil disturbance (Rahmann & Aksoy 2014). The roller-crimper technique is another example (see section 1.3). However these techniques need more investigations and present a cost to the farmer. A system where traditional farming equipment can be used will be much more attractive to the farmer.

Peigné et al. (2007) also suggested a kind of rotational tillage were tillage method is matched with crop type in combination with compaction control. The same problems with a possible loss of built fertility as mentioned above have to be investigated before applying this method.

A key factor in solving the problems hindering introduction of conservation tillage to organic agriculture is a proper crop rotation. A proper managed crop rotation should be able to solve nutrient shortage, weed and disease problems (Peigné et al. 2007). To be able to design such a crop rotation, more knowledge about the subject is required. Especially because it will differ from the climate, soil type, crop type, management history and so on.

Novel methods mentioned in section 1, such as living perennial mulches, mechanical control of cover-crops and the use of cover-crops and mulches as weed suppressor are all possibilities. The methods do however need more investigation before it is possible to use these methods in organic farming in Europe.

As to the question about killing off the cover-crops, our study might be a step on the way in finding suitable cover-crops for a conservation tillage system. The results have shown that there are differences between the species and it will probably be possible to find a range of cover-crops suitable for reduced tillage system.

Mäder & Berner (2011) stress how the success of a reduced tillage system relies on proper adjustment of tillage timing, the planting of green manures and the use of new equipment to optimize the system.

5. Conclusion

By studying the regenerative mechanisms of the cover-crops, it has been possible to observe differences between species and to group the investigated cover-crops. Lucerne, red clover and kidney vetch can be controlled by rotovation tillage at, at least 8cm depth. Persian clover, winter radish and hairy vetch can also be controlled at a low rotovation depth. It is important to be aware that the low tolerance might be due to low winter hardiness more than the rotovation tillage. White clover, winter rape, dyer's woad and chicory might be possible to control but will need more than one tillage treatment. The grasses showed to be tolerant towards the cutting of their roots. They were however not tolerant towards being covered under more than 5cm of soil. It is therefore concluded that the grasses are not suitable for a reduced tillage system, hence they need a deep coverage of soil to be controlled. Yet winter rye and stauderug showed a lower tolerance towards damage done by the rotovator than the other grass species. Generally there should be done further studies on how the mentioned species react toward reduced tillage methods. I do not recommend plantain, timothy, orchard grass and to a degree white clover, since they showed a high tolerance in the field.

As to the depth of the rotovator, 4cm did not have the wanted effect and should therefore not be used. 8cm and 15cm depth were not significantly different and did control the most of the cover-crop species. To be able to conclude on a fitting depth for reduced tillage, a new trial is needed. Here 8cm, 15cm and deeper ones could be tested both on their efficacy in killing cover-crops and weeds but also on what they do to the soil structure and the fertility factors mentioned earlier. Other tillage methods could also be included.

It is clear that the conversion of conservation tillage to organic agriculture is not yet around the corner. It is however not impossible and should be pursued hence the many benefits that lies within conservation tillage (see section 1.2). The solution does not lie within one method, but as the combination of methods and require clever and proper management. Knowledge is still needed to be able to design and manage such a system on validated ground. Further investigations in suitable cover-crops and living mulches that focus on competition with the cash crop, termination, the ability to suppress weeds and diseases and benefits as a greater nutrient availability are needed. In addition knowledge about what different tillage methods do to the soil structure and the soil fertility, knowledge about how all the mentioned factors differ from region and climate and how they play together are also needed to move towards a beneficial conservation tillage system in organic farming.

6. Perspectives

In a time where focus politically is on resource scarcity and sustainable development the production of food is under pressure from politicians and consumers to produce environmentally friendly and healthy food to an affordable price. This increases the demand for knowledge about sustainable production methods. As more knowledge is achieved a better understanding of the mechanisms of nature also seems to be achieved. It has been recognized that soil plays an important role in the health of ecosystems. To treat soil not just as a media of growth, but as an important non-renewable resource, new agricultural practices are needed. Conservation tillage is one approach which is more widely used in conventional agriculture than in organic agriculture. Historically organic agriculture has been seen as more environmentally friendly than conventional agriculture. This is mostly due to no use of pesticides and inorganic fertilizer and better animal welfare. Today the debate about climate change plays a grand role. Organic production is very machine heavy and thereby emits a high amount of CO_2. Conventional tillage is also found to lead to a higher release of CO_2 from the soil (Carbonell-Bojollo et al. 2011). Conservation tillage would therefore be a tool for organic production to regain the title as the most environmental friendly food production method. I personally think that we in the next decades are going to see a revolution in agriculture towards a more sustainable production. Here integrated methods are going to play a huge role and conservation agriculture is one of them.

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Annex 1

Characteristics of the cover-crops sorted after family. The species used in the pot experiment are marked with grey (Mossberg & Stenberg 2007, Suhr et al. 2005).

Family	Species	Characteristics
Fabaceae	*Vicia villosa,* Hairy vetch	**Height:** 50-150cm **Growth:** Strong, crawling **Soil cover:** Good **Duration:** Annual **Winter hardy:** Yes **Depth of root:** Medium **N fixating:** Yes
	Trifolium resupinatum, Persian clover	**Height:** 30-50cm **Growth:** Fast, first upright then crawling **Soil cover:** Good **Duration:** Annual **Winter hardy:** No **Depth of root:** Medium **N fixating:** Yes
	Trifolium repens, White clover	**Height:** 10-20cm, with up to 50cm runner **Growth:** Crawling with rooting runners, slow **Soil cover:** Good **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** Superficial **N fixating:** Yes
	Medicago sativa ssp. Sativa, Lucerne	**Height:** 40-90cm **Growth:** Upright, slow in cold soil **Soil cover:** Medium 1. Year, good 2. year **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** Yes
	Anthyllis vulneraria, Kidney vetch	**Height:** 30-40cm **Growth:** Weak, crawling **Soil cover:** Bad 1. Year, good 2. year **Duration:** Biennial/perennial **Winter hardy:** Yes **Depth of root:** Medium **N fixating:** Yes

	Medicago lupulina, Black medick	**Height:** 10-15cm **Growth:** Fast, first upright the crawling **Soil cover:** Good **Duration:** Annual/biennial **Winter hardy:** Yes **Depth of root:** Superficial **N fixating**: Yes
	Trifolium pretense, Red clover	**Height:** 15-50cm **Growth:** Good when growing conditions are optimal, upright **Soil cover:** Good **Duration:** Biennial/perennial **Winter hardy:** Yes **Depth of root:** Medium **N fixating:** Yes
Poaceae	*Secale cereal var. multicaule,* Stauderug	**Height:** 80-130cm **Growth:** Fast, upright **Soil cover:** Medium **Duration:** Annual **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** No
	Secale cereal, Winter rye	**Height:** 50-150cm **Growth:** Fast, upright **Soil cover:** Medium **Duration:** Annual **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** No
	Dactyllis glomerata, Orchard grass	**Height:** 60-100cm **Growth:** Fast germination, slow establishment **Soil cover:** Medium **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** No
	Phleum pratense, Timothy grass	**Height:** 30-120cm **Growth:** Upright **Soil cover:** ? **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** ? **N fixating:** No

	Lolium perenne, Ryegrass	**Height:** 25-70cm **Growth:** Fast, tussock-forming **Soil cover:** Good **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** Superficial to medium **N fixating:** No
Brassicaceae	*Raphanus sativus,* Winter radish	**Height:** 40-60cm **Growth:** Fast, leafs at base **Soil cover:** Good **Duration:** Annual/biennial **Winter hardy:** In mild winters **Depth of root:** Deep **N fixating:** No
	Brassica napus, Winter rape	**Height:** 40-80cm **Growth:** Good, rosette **Soil cover:** Good **Duration:** Biennial **Winter hardy:** Yes **Depth of root:** Medium, in loose soil deep **N fixating:** No
	Isatis tinctoria, Dyer's woad	**Height:** 40-100cm **Growth:** Strong, rosette with stiff stem **Soil cover:** Good **Duration:** Biennial/perennial **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** No
Asteraceae	*Cicorium intybus,* Chicory	**Height:** 50-100cm **Growth:** Slow to medium, upright with a stiff stem **Soil cover:** Good after mowing **Duration:** Biennial/perennial **Winter hardy:** Yes **Depth of root:** Deep **N fixating:** No
Plantaginaceae	*Plantago lanceolata,* Plantain	**Height:** 10-50cm **Growth:** rosette, leafs from base **Soil cover:** ? **Duration:** Perennial **Winter hardy:** Yes **Depth of root:** ? **N fixating:** No

Annex 2

SAS process:

1. Pot experiment – Shoot number

```
libname potdata '\\a00143.science.domain\~\Documents\Pictures\pot
study\Picture analysis';run;

PROC IMPORT OUT= potdata.shootpotdata
            DATAFILE= "\\a00143.science.domain\~\Documents\Pictures\pot
study\Picture analysis\shootpotdata.xlsx"
            DBMS=EXCELCS REPLACE;
                                 run;
                   /*          Mean_shoot_no*/
proc contents data=potdata.shootpotdata;

run;
proc print data=potdata.shootpotdata;
run;
proc glm data=potdata.shootpotdata;
class species length depth time  ;
model logshoot= species |length| depth |time ;
run;

proc glm data=potdata.shootpotdata;
class species length depth time  ;
model logshoot= species length depth time Species*length Species*depth
Species*length*depth Species*time depth*time Species*depth*time;
run;

proc glm data=potdata.shootpotdata;
class species length depth time  ;
model logshoot= species length depth time Species*length Species*depth
Species*length*depth Species*time depth*time Species*depth*time;
means species/tukey;
means length/tukey;
means depth/tukey;
means time/tukey;run;
```

2. Pot experiment – Green cover

```
libname potdata '\\a00143.science.domain\~\Documents\Pictures\pot
study\Picture analysis';run;
PROC IMPORT OUT= potdata.finaldata
            DATAFILE= "\\a00143.science.domain\~\Documents\Pictures\pot
study\Picture analysis\finaldata.xlsx"
            DBMS=EXCELCS REPLACE;
                                 run;
proc contents data=potdata.finaldata;

run;
proc print data=potdata.finaldata;
```

```
run;

proc tabulate data=potdata.finaldata ;
class species length depth time; /* no rep */
var cover lcover;
table species*length*depth*time,(cover*mean cover*stderr lcover*mean
lcover*stderr)*f=6.1;
run;

proc glm data=potdata.finaldata;
class species length depth time;
model lcover= species |length| depth |time ;
run;

proc glm data=potdata.finaldata;
class species length depth time;
model lcover=species depth length time species*depth Species*Length
Length*Depth Species*Length*Depth Species*time Length*time Depth*time
Species*Depth*time Length*Depth*time /solution;
run;

proc glm data=potdata.finaldata;
class species length depth time;
model lcover=species depth length time species*depth Species*Length
Length*Depth Species*Length*Depth Species*time Length*time Depth*time
Species*Depth*time Length*Depth*time /solution;
means species/tukey;
means Length/tukey;
means depth/=tukey;
means time/=tukey;
   run;
```

3. Field Experiment - Dry biomass

```
libname field '\\a00143.science.domain\~\Documents\Pictures\EXP3 Field
assessment\Field picture analysis';run;

PROC IMPORT OUT= field.fieldbiomass
            DATAFILE= "\\a00143.science.domain\~\Documents\Pictures\EXP3
Field assessment\Field picture analysis\fieldbiomass.xlsx"
            DBMS=EXCELCS REPLACE;
            run;
proc print data=field.fieldbiomass;run;
proc contents data=field.fieldbiomass;run;



proc glm data=field.fieldbiomass;
class species soiltreat;
model logdm =species soiltreat ;
means species/LSD;
means soiltreat/LSD;
run;

proc tabulate data=field.fieldbiomass;
class species soiltreat;
var DM logdm;
table species, soiltreat*(dm logdm)*f=6.2/rts=15;run
```

Annex 3

Statistical results for the green cover data:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Species	9	326.1188839	36.2354315	116.82	<.0001
Depth	1	101.7035195	101.7035195	327.89	<.0001
Length	2	26.6135060	13.3067530	42.90	<.0001
time	2	20.2815149	10.1407575	32.69	<.0001
Species*Depth	9	43.7776571	4.8641841	15.68	<.0001
Species*Length	18	36.5943566	2.0330198	6.55	<.0001
Length*Depth	2	0.6786874	0.3393437	1.09	0.3364
Species*Length*Depth	18	23.9760577	1.3320032	4.29	<.0001
Species*time	18	22.3113183	1.2395177	4.00	<.0001
Length*time	4	2.0234312	0.5058578	1.63	0.1669
Depth*time	2	0.9742242	0.4871121	1.57	0.2100
Species*Depth*time	18	8.7246778	0.4847043	1.56	0.0701
Length*Depth*time	4	2.3363490	0.5840873	1.88	0.1139

Statistical results for the shoot number data:

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Species	9	260.1016059	28.9001784	65.77	<.0001
length	2	12.6515330	6.3257665	14.40	<.0001
depth	1	145.6468883	145.6468883	331.47	<.0001
time	2	4.6360416	2.3180208	5.28	0.0057
Species*length	18	49.1867434	2.7325969	6.22	<.0001
Species*depth	9	44.2979143	4.9219905	11.20	<.0001
Species*length*depth	20	15.7559162	0.7877958	1.79	0.0216
Species*time	18	24.5371199	1.3631733	3.10	<.0001
depth*time	2	4.3914173	2.1957087	5.00	0.0074
Species*depth*time	18	15.1768392	0.8431577	1.92	0.0149