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Faculty of Landscape Architecture, Horticulture and Crop Production Science

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Sommarmellangrödor etablerade efter färskpotatis kontrollerar fröogräs

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"Friskt vågat, hälften vunnet" – "Fortune favours the bold"

Abstract

To reduce pesticides and find greener alternatives for weed management in crop production has been a big issue worldwide. In Sweden, the Board of Agriculture has developed grants for farmers who use e.g. cover crops and new and greener strategies (e.g. using other crops to suppress weeds to reduce the use of chemical pesticides) to add to their weed management. Cover crops are usually fast-growing crops which can cover the ground quickly to prevent weed growth. Cover crops can also have different qualities and abilities which can benefit the other crops in the crop rotation, e.g. prevent nutrient leakage, increase soil structure and suppressing weeds. The aim of this study was to investigate the cover crop's ability to suppress and minimize the number and biomass of annual weeds and see if there are any differences between the cover crops species ability to suppress weeds. Also, to investigate in literature the benefits cover crops can give the next main crop. A field experiment was set in the northwest of Scania, Sweden, with different cover crops. The cover crops used were buckwheat (*Fagopyrum esculentum*) in pure stock and mixed with crimson clover (*Trifolium incarnatum*), Persian clover (*Trifolium resupinatum*), Sudangrass (*Sorghum x sudanense*), Westerwoldisch ryegrass (*Lolium multiflorum var. westerwoldicum*), oat (*Avena sativa*) and black oat (*Avena strigosa*). Other cover crop mixes with lacy phacelia (*Phacelia tanacetifolia*) and Persian clover, hairy vetch (*Vicia villosa ssp. Villosa*) and winter rye (*Secale cerale*), and marigold (*Tagetes patula*) were tested. Due to a warm, dry and rain-free season this year, 2018 in Sweden, some cover crops didn't establish well, and they were oat, black oat, lacy phacelia, hairy vetch, Persian clover, crimson clover and winter rye. The results showed a significant difference in weeds biomass between the control and the cover crops tested and this means that the cover crops tested suppress seed weeds. The cover crops had weeds biomass of 1-54 g/m^2 the first sampling date and 4-47 g/m^2 the second sampling date, compared to the control which had 150 g/m^2 the first date and 192 g/m^2 the second date. This means that the cover crops had 64-91% (first sampling) and 76-93% (second sampling) lesser weeds biomass than the control, which means that the cover crops suppressed the seed weeds well. Thou the results is good further studies need to be done in order to see if the effects and abilities are the same in different places.

Sammanfattning

Pesticider har blivit ett allt mer omtalat problem över hela världen, hur man kan reducera användningen av dem och hur man hittar grönare miljövänligare och mer hållbarare alternativ till att odla. I Sverige har Jordbruksverket ett förgroningsstöd för ekologiska fokusarealer som odlare kan ansöka om, som gör att odlare kan applicera mer grönare strategier, ex. mellangrödor som konkurrerar med ogräs och undantrycker dem. Mellangrödor är ett samlingsnamn för olika sorters grödor som odlas mellan två huvudgrödor. Exempel på andra namn är fånggröda, täckgröda och bottengröda. Dessa mellangrödor kan ha olika egenskaper som ex. vara snabbväxande, allelopatisk mot ogräs, konkurrerar och undertrycker ogräs, minska läckage av näringsämnen, öka jordstrukturen m.m. Målet med denna studie är att se mellangrödornas egenskap att hålla undan ogräs och om det är någon skillnad mellan de olika blandningarna. Även utreda i litteraturen vilka fördelar en mellangröda kan ge den nästkommande grödan i växtföljden. För att få svar på dessa frågor så gjordes en litteraturstudie och ett fältförsök. Fältförsök testades olika blandningar av mellangrödor genomfördes i nordvästra Skåne. De mellangrödor som användes i försöket var bovete (*Fagopyrum esculentum*) i renbestånd och i blandningar med blodklöver (*Trifolium incarnatum*), persisk klöver (*Trifolium resupinatum*), sudangräs (*Sorghum x sudanense*), Westerwoldiskt rajgräs (*Lolium multiflorum var. westerwoldicum*), havre (*Avena sativa*) och purrhavre (*Avena strigosa*). I försöket testades även andra blandningar med honungsört (*Phacelia tanacetifolia*) och persisk klöver, luddvicker (*Vicia villosa ssp. Villosa*) och höstråg (*Secale cerale*), och tagetes (*Tagetes patula*). På grund av den varma, torra och regnfria säsongen 2018 så grodde och eTablerade sig inte alla mellangrödor så bra. De som eTablerade sig bra var bovete, blodklöver, persisk klöver, sudangräs, westerwodliskt rajgräs och tagetes. Resultaten från denna studie visade en signifikant skillnad mellan kontrollen och mellangrödorna, vilket innebär att de undersökta grödorna undantrycker ogräs och minskar fröogräsen. Den ogräsbiomassa som var i mellangrödorna var mellan 1–54 g/m^2 den första provtagningen och 4–47 g/m^2 den andra provtagningen och i jämförelse med kontrollen som hade en ogräsbiomassa på 150 g/m^2 den första provtagningen och 192 g/m^2 den andra provtagningen. Mellangrödornas effekt mot fröogräs var 91–93 % mindre ogräs i mellangrödorna än i kontrollen. Resultaten visade på en bra ogräseffekt av mellangrödorna, men mer forskning bör göras för att undersöka om effekten är samma på andra platser i Sverige.

Content

1. Introduction

Cover, catch and intermediate crops are used in Sweden and they are usually used as green manure or feed to cattle or livestock (Official Statistics of Sweden; Board of Agricultural of Sweden, 2018). There are no statistics on the use of cover crops in Sweden, but the species used are mostly included in other categories (ibid.). In Sweden an umbrella term for cover-, catch- and intermediate crops are "Mellangrödor" and the term used in this study is cover crops because the features we will investigate are the crops ability to make a cover and to suppress weeds.

The information about the different cover crop varieties and the function they have in Swedish crop rotations and environment, tend to be more requested by farmers and government, to develop a more sustainable crop production due to the increasing climate change (Sveriges miljömål, 2018; United Nations, 2018). In the recent years, there have been some field experiments using cover crops set in Scania (Andersson, et al., 2014; Ögren & Hansson, 2016; Hansson, et al., 2017; Hansson, et al., 2018). The studies showed results of cover crops ability to suppress weeds and some of the field experiments provided other information about the cover crops which became a basis for the pros and cons of the different cover crops and how they can be used. Ögren & Hansson (2016) have composed a list of appropriate cover crops to be used in a vegetable crop rotation which helps farmers that cultivate vegetables to select suitable cover crops for their crop rotation.

The board of agriculture in Sweden is the administrative authority which offers different grants enabling farmers to have more possibilities to grow vegetables and cereals. One grant is about cover crops and the use of them and is named EFA, ecological focus areas (Ekofokusarealer) and goes under Greening measures (Förgröningsstödet) (Jordbruksverket, 2018). This grant will give the farmers more possibilities to change their crop rotation and weed management and the grant will help the farmer to minimize the economic risk (ibid.). Another view of the use of cover crops is, e.g. as fodder to cattle, livestock or as green manure for the field (Thorup-Kristensen, et al., 2003). Harvesting the cover crops can lead to a decrease in the input of nutrients for the following crop (Baumgärtner, et al., 1998; Thorup-Kristensen, et al., 2003; Constantin, et al., 2010; Aronsson, et al., 2012; Balzewicz-Wozniak & Wach, 2012; Fogelfors, 2015). These aspects highlight how different (but not necessarily all) cover crops can be a source of additional income and therefore give an incentive for growing cover crops. An example of the use of cover crops is for feed and this year 2018 was an extremely dry, warm and sunny, which lead to a shortage of animal feed due to decreased harvest yield (SMHI, 2018; TT nyhetsbyrån, 2018; MSB, 2018), and cover crops can be a good addition to a higher demand for feed to animals.

1.1 Aims and research question

This study investigated different cover crops abilities and qualities known from other studies and literature. The study investigated if the cover crops tested can suppress seed sown weeds in a field experiment. This will help farmers to choose the right cover crop for their farm and crop rotation. It can help advisors to get more information about cover crops. The hypotheses are that cover crops will suppress seed weeds and that the mixes would be more effective than the cover crops in pure stock.

The aim of this study was to investigate the cover crops ability to suppress and minimize seed sown weeds and see if there are any differences in suppressing weeds between the cover crops species. Also, to investigate the benefits and effects cover crops can give a crop rotation. The research questions are:

- Can the cover crops (singular or mixes of species) reduce the growth of seed weeds on the field?

- Are there any differences in reducing seed weeds between the different cover crops species?

- Are there any differences in the number of seed weeds between the cover crops and control (only mechanic weed control once)?

1.2 Delimitation

This study will not investigate if the nitrogen level in the soil will increase or decrease as an effect of the cover crops, but this will be discussed in the literature. Other limitations; if the root systems of the cover crops will improve the soil structure, soil fertility, carbon in the soil and control nematodes, for example, will only be investigated the literature as well.

2. Background

Cover crops qualities and abilities

Cover crops are usually fast-growing crops which are grown between two main crops and can also be grown in a relay cropping system (University of Nebraska-Lincoln, 2003; Lockhart & Wiseman, 2014). The idea behind cover cropping is like a succession planting were the cover crops are cultivated between the main crops and is grown when the field otherwise would be in black fallow (Dabney, et al., 2001).

Figure 1: Buckwheat and sudangrass, they grow fast and cover the soil which suppresses weeds by shadowing. Photo: Ahlqvist, A (2018)

Cover crops can reduce mineral nutrient leakage from the soil (Lockhart & Wiseman, 2014), and can then also be called a catch crop because of its "catches" the nutrients. Some crops can work as both a catch crop and cover crop. Catch crops are a type of cover crops (Dabney, et al., 2010). A good quality a cover crop can have are that it can establish well and can cover the soil and can then give coverage over the soil. Cover crops have been proven to e.g. benefit the soil structure by having a deep root system and suppress weed growth by growing and establish fast, but these effects differ between species (Zhang, et al., 2007; Balzewicz-Wozniak & Wach, 2012). Cover crops can also decrease soil erosion, and they can balance the nutrients in the soil by binding the nutrients and this can lead to reduced nutrient leakage. They can also pass over the nutrients to the next main crop, as green manure and digestion by the microflora in the soil (Richards, et al., 1996; Thorup-Kristensen, et al., 2003; Gaskell & Smith, 2007; Zhang, et al., 2007; Balzewicz-Wozniak, et al., 2008). Constantin, et al. (2010) have proved that implementing cover crops in the crop rotation are the most efficient technique for decreasing nitrogen leakage. The organic matter in the soil will also increase by introducing cover crops in the rotation, e.g. cover crops grown after vegetables proved to be a rich source of nutrients for the following main crop and organic matter (Balzewicz-Wozniak & Wach, 2012).

There are economic aspects of adding cover crops in the cropping system. Cover crops can give an extra harvest of biomass that the farmer can sell as feed, food or biogas feedstock (Szerencsits, et al., 2015; Biogas Syd, 2015; Maier, et al., 2017).

While the cover crops are growing, they harvest solar energy for the photosynthesis and that provides energy in the form of sugar for the plants all mechanisms, e.g. via the tricarboxylic acid cycle. These mechanisms will increase the carbon flux from the plant to the soil, which provides food for the soil's macro and microorganisms (Dabney, et al., 2001). Cover crops also reduce soil particle runoff which reduces sedimentation on the cropland by taking the kinetic energy from rainfalls, which can then reduce the soil and water runoff from the field and minimize mini floods on the field (Dabney, et al., 2001). Other advantages and disadvantages of cover crops are listed in Table 1. These can vary for different species and only give a general overview.

Table 1: Advantages and disadvantages of using cover crops in a cropping system. Source: Wyland, et al., 1996; Dabney, et al., 2001; Thorup-Kristensen, et al., 2003; Jodanugiene, et al., 2006; Weston &Inderjit, 2007; Stoklosa, et al., 2008; Blazewicz-Wozniak & Konopinski, 2009; Lithourgidis, et al., 2011; Szerencsits, et al., 2015; Maier, et al., 2017.

Advantages and disadvantages of using cover crops:

Advantages	Disadvantages
Reduce soil erosion	Additional costs (seeds, cultivation, harvest)
Increase residue cover	Reduce soil moisture
Increase water infiltration into soil	May increase pest population
Increase soil organic carbon	Cover crop can become a weed
Improve soil physical properties	May increase risks of diseases
Improve field trafficability	Difficult to incorporate with tillage
Recycle nutrients	Allelopathy for the main crop
Legumes fix nitrogen	
Weed control	
Allelopathy against weeds	
Increase populations of beneficial insects	
Reduce diseases	
Increase mycorrhizal infection of crops	
Potential forage harvest	
Improve landscape aesthetics	
Potential feedstock harvest for biogas	
Green manure	
Biodiversity	
Increase soil structure	

Results from a study made by Vos & van der Putten (1997) show that leaf expansion is a key process in determining the performance of the cover crop species and how well they can have an impact on weeds and their establishment. A cover crop, in the vegetative stage of the development, binds a lot of nitrogen in the plant (Aronsson, et al., 2012). In the vegetative phase, the cover crop is focused on growing roots and shoots. For that, the plant needs and takes up nitrogen for these processes. The plant can then absorb most nitrogen when the roots and shoots are growing. When the cover crop starts to bloom the biomass does not increase and the focus is to set flowers and then seeds, therefore the nitrogen uptake decreases(ibid.).

Cover crops can increase biodiversity of insects (beneficial insects which can decrease pests) and plants cropped on the field and can also limit the occurrence of pests and diseases by adding other plants to the crop rotation (Wyland, et al., 1996; Jodanugiene, et al., 2006; Stoklosa, et al., 2008; Blazewicz-Wozniak & Konopinski, 2009; Lithourgidis, et al., 2011)

Results from a study made by Robak (1994), showed that no clubroot disease, *Plasmodiophora brassicae*, was observed when cover crops were grown. The main source of infestation tends to be the infected transplants that are left in the soil after harvest. To further reduce infestation is to have a crop rotation with fewer brassicas preferable. In order to avoid the clubroot disease, the cover crops should not belong to the plant family *Brassicaceae* (Robak, 1994). By adding different cover crops in a crop rotation mainly consisting plants from the same plant family, can prevent plant diseases and pest, by adding different species from different families to prevent further spread (Fogelfors, 2015).

Figure 2: Cover crops with buckwheat and crimcon clover. Photo: Amanda Ahlqvist (2018).

Weeds and weed management

The European Union (EU) has different directives and one of them is directive 2009/128/EC "Sustainable use of pesticides". The aim is to achieve sustainable use of pesticides in the EU by reducing the risks and impacts of pesticide use on human health, the environment and to promote the use of IPM- Integrated Pest Management (European Union (EU), 2009). This means that different types of methods need to be used to minimize the use of pesticides and that is one part of the IPM strategies which farmers shall work by (Fogelfors, 2015).

IPM- integrated pest management is composed of four major factors, which are to prevent or set action thresholds, monitor and identify pests, prevention, and control (Fogelfors, 2015). These factors should be used to see when and how the fields should be managed and use different methods at the right time. IPM is also a method were different strategies for weed management are used to reduce the pesticides (ibid.).

Weeds are plants which occur in unwanted places (Fogelfors, 2015). Weeds can be wild species and flora which is not wanted on the fields, which can cause yield losses and pests (ibid.). The frequency and the establishment of the weeds can depend on:

- The species adaptability for the cropping system
- The environmental conditions (e.g. Temperature, precipitation, etc.)
- Condition of soil
- Spreading capacity (e.g. wind transport, passive spread)
- Biological activity
- Crop rotation

Even the crops cultivated on the field can become a volunteer if a different crop is grown the next year and the previous one persists (Fogelfors, 2015). The different species of weeds have different adaptation to the cropping systems, which means that different weeds develop different due to crop rotation. A monoculture will increase the number of weed species, compared with a cropping system with different species from many plant families (Fogelfors, 2015).

Figure 3: Potatoes, Solanum tuberosum (Potatis). Photo: Amanda Ahlqvist (2017).

Potatoes, *Solanum tuberosum,* aren't that competitive to annual weeds and they can establish faster than in other cultivated crops (Fogelfors, 2015).

In general, the annual weeds have stronger competitiveness to agricultural crops and vegetables (ibid.). In a study made by Håkansson, S. (1995), which is illustrated in Fogelfors (2015), a Table on how the weeds grow after or under the potato establishment, which tells us that the weeds found in the field have a higher ability to grow and compete with potatoes (Håkansson, 1995; Fogelfors, 2015). The same results are found under the establishment of salat and brassicas, which is the case at Stefan's farm (Håkansson, 1995; Fogelfors, 2015; Grönsaksmästarna, 2018).

Weed management is a concept of how the farmer uses different tools to decrease and prevent weed growth (Upadhyaya & Blackshaw, 2007). There are different strategies that can be used to prevent weed growth, some example of these techniques is:

- Use of mechanical machines and tools, e.g. Tillage, cutting and mowing, pulling, etc.
- Use of herbicides
- Allelopathy, from other plants which leads to weeds suppression
- Cover crops
- Crop rotation

Mechanical weed management

The use of mechanical weed management has been the historical way for farmers to manage their weed problems (Cloutier, et al., 2007). But that changed when the appearance of herbicides introduced in the mid- 20th century which contributed to decreased reliance on mechanical weed techniques (ibid.). There are different or combined mechanical techniques farmers can use (Cloutier, et al., 2007). The mechanical weed management consists of three main techniques: the use of tillage, cutting weeds and pulling weeds (Cloutier, et al., 2007; Fogelfors, 2015).

Tillage is generally referred to as the changing of soil conditions to enhance crop production (Cloutier, et al., 2007). There are different techniques of tillage and some of them are harrowing, inter-row cultivator, ploughing, etc (Fogelfors, 2015). The different techniques can be divided into primary and secondary tillage (Cloutier, et al., 2007). Primary tillage is the first soil preparation before the seeding or transplantation and the primary tillage techniques are then always aggressive and usually carried out at considerable depth (ibid.). Secondary tillage is when the soil is not worked as aggressively as primary and the purpose of secondary tillage is to further pulverize the soil. Mix various materials such as fertilizers, manure into the soil, but also weed control by cultivators or harrows (Cloutier, et al., 2007).

Another secondary tillage is a method named false seedbeds. False seedbeds are a method where the soil is cultivated after harvest but are left to stimulate weeds to merge (Cloutier, et al., 2007; Sanbagavallis, et al., 2016). After one or two weeks the field is cultivated again to kill the weeds before seeding. Then the weeds are decreasing from the real seedbeds. Tillage is the most important technique in mechanical weed management (Cloutier, et al., 2007; Sanbagavallis, et al., 2016).

Cover crops as one measure against weeds

Cover crops as weed management are the most "natural way" of suppressing weeds (by competing between crops or allelopathy) and have multiple influences on an agroecosystem and as weed management (Teasdale, et al., 2007). Cover crops can prevent weed growth either in the form of living plants or as plant residue remaining after the cover crop is harvested or killed (ibid.). Different weed life stages will be affected by different mechanisms and are depending on whether the cover crop influences the weeds during its living phase or as residue (Teasdale, et al., 2007). Sowing cover crops after early-harvested crops, like early potatoes and vegetables, is possible at locations with short growing season and short growing cultivars (Teasdale, et al., 2007).

Generally, living cover crops will suppress weeds completely and in every stage of the weed's life cycle (Teasdale, et al., 2007). Dead cover crop residue does not suppress weeds as consistently as live cover crops do. A living cover crop absorbs red light and will reduce the red: far-red ratio sufficiently to inhibit seed germination, whereas cover crop residue has a minimal effect on the red: far-red ratio (Teasdale, et al., 2007). In Table 2 a potential impact of the cover crop as residue or as living.

Table 2: This Table shows the potential impact of typical cover crop residue or living cover crops on inhibition of weeds at the various life cycle stages. Modified from: Teasdale, et al., 2007.

Weed life cycle stage	*Cover crop residue*	*Live Cover crop*
Germination	Moderate	High
Emergence/establishment	Moderate	High
Growth	Low	High
Seed production	Low	Moderate
Seed survival	None? (a)	Moderate? (a)
Perennial structure survival	None? (a)	Low-moderate? (a)

(a) More research is needed to provide definitive estimates of cover crop influences on these processes.

Though the effect of cover crops is good and is a greener alternative to manage weeds, the high-intensity weed harrowing gave better weed control than cover cropping (Teasdale, et al., 2007). But the agronomic goal would be to replace unmanageable weed populations with a more manageable cover crop population.

Allelopathy

According to Weston & Inderjit (2007) is allelopathy a phenomenon were chemicals from plants which suppress other plants and could be exploited for the development of non-chemical weed management by using:

1. Allelopathic cover crops,
2. allelochemicals as natural herbicides,
3. allelopathic crop cultivars.

Allelopathic is a systematic approach to weed management in agronomic cropping systems and is often needed in order to address both the economic and environmental consequences of weeds and invasive weeds (Weston & Inderjit, 2007). Example of crops which is allelopathic are buckwheat, sudangrass, oat and rye (Ibid.). These crops suppress annual weed species and they are also suppressing weeds in a variety of cropping systems (Weston & Inderjit, 2007). These types of allelopathy will undoubtedly be of interest to future organic producers, also farming in general, with an interest in minimizing herbicidal inputs over time (ibid.). Additional systematic studies will be needed to find and conduct how allelopathy will contribute over time in different soil settings and to long-term weed or pest suppression in the soil rhizosphere (Weston & Inderjit, 2007).

The future in weed management will need options to make more sustainable crop production (Upadhyaya & Blackshaw, 2007). These options will be better crop rotations, increasing the competitive ability of a crop, delayed or early seeding, inclusion of cover crops, green manure and intercropping (Upadhyaya & Blackshaw, 2007). In Figure 8 a timeline of weed management is illustrated and is a model which can be used on a farm with early potatoes and summer cover crops. The model is made of literature from Upadhyaya & Blackshaw (2007) and Fogelfors (2015).

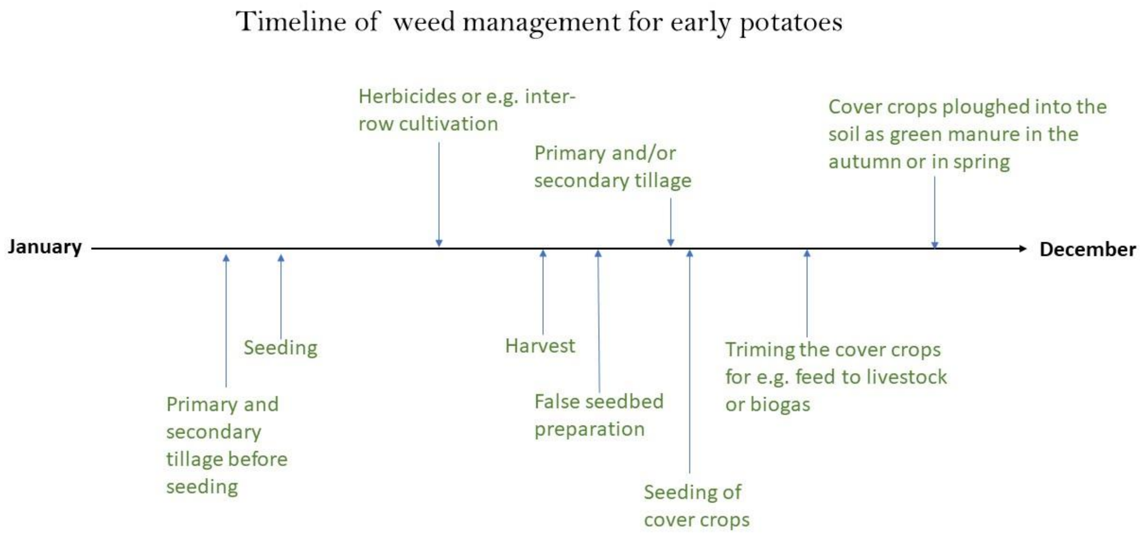

Figure 4: A timeline of how weed management can be applied in early potatoes. By Amanda Ahlqvist, Modified from: (Upadhyaya & Blackshaw, 2007; Fogelfors, 2015).

3. Material and Methods

The literature study is based on information found in books and using google scholar to find scientific studies and articles about cover crops, covering their abilities and qualities. Some of the search words used were i.e. the English crop names and search words like cover crops, cover crops qualities, use of cover crops. The literature study examines what cover crops are and how they can be used, qualities and abilities, also other types of weed management which can be used in agriculture cropping systems. The literature also covering the species which were chosen for the field experiment. Other studies in Sweden would also be used as a comparison.

On a farm in Grevie, northwest of Scania, a farmer named Stefan Olsson grows early potatoes, brassicas, and salat of different cultivars (Grönsaksmästarna, 2018). He already uses cover crops in his crop rotation and the species he uses is Westerwoldisch ryegrass and Persian clover (Olsson, 2018). The cover crops on the farm are cultivated separately and not in a mix. Our field experiment was cultivated on one of Stefan's fields early potatoes were grown in the spring 2018 and harvested in late June (23-25th of June). After the harvest, the field was ploughed and then left in black fallow until the field experiment was sown.

The field experiment was sown on the 20th of July 2018. The experiment was set after early potatoes which were the preceding crop and the early potatoes were harvest on the 23-25th of June. The cover crop experiment started after the field had a black fallow for 3 weeks after the harvest of early potatoes. The field was ploughed after the harvest. Before the cover crops were sown the field was ploughed, harrowed and irrigated. The seeds were sown with a trial- seeder which was approximately 2 meters wide and sowed the seed with a drilling depth of 5 cm. The field was then rolled to get a better establishment as possible. The field was then irrigated again after sowing. Under the crop's germination and growing state, the field was irrigated again, because of the drought and high temperatures.

3.1 Field experiment

The field experiment, where mixes of cover crops were cultivated to see if there are any differences between them and their ability to suppress weeds. The field experiment was designed as a block experiment with 3 blocks and 11 different cover crop mixes are cultivated. The experiment was fully randomized and in Table 4 the full randomized map of the blocks is illustrated and in Table 3 the different codes for each cover crop mix. The area used for this experiment is 1056 m^2. One plot corresponded to an area 24 m x 4 m. Table 3 shows the seed rate (kg/ha), which was used in the experiment.

Table 3: The seed rate in kg/ha which was used in this field experiment (Olssons frö, 2018).

Parcel:	**Cover crop 1:**	**Cover crop 2:**	**Cover crop 1:**	**Cover crop 2:**
K1	-	-	0	0
K2	Phacelia	Persian clover	6	7
1	Buckwheat	-	60	0
2	Buckwheat	Persian clover	30	7
3	Buckwheat	Crimson clover	30	9
4	Buckwheat	Westerwoldisch ryegrass	30	15
5	Buckwheat	Black oat	30	45
6	Buckwheat	Sudangrass	30	11
7	Buckwheat	Oat	30	100
T1	Winter rye	Hairy vetch	90	23
T2	Marigold	-	5	0

Table 4: The schematic illustration of the field experiment that was used on the field. Check Table 4 for explanation of the numbers.

Parcel:	*Block 1:*	*Block 2:*	*Block 3:*
1	6	T2	7
2	K2	5	K1
3	7	T1	4
4	2	2	5
5	5	6	K2
6	4	1	1
7	T1	3	3
8	K1	K1	T1
9	1	7	T2
10	T2	4	2
11	3	K2	6

The cover crop mixes which were used in this field experiment have been chosen to be a good complement to a crop rotation with only salat, brassicas, and potatoes. In Figure 5, the different cover crops used are illustrated and their good qualities. The different mixes of cover crop species shown in Table 4 and are the species that were included in the experiments. The crop that is used in the experiment is buckwheat, which was picked for its many advantages (Figure 5) and one of them is its economic potential as a crop that gives a yield to either food or feed (Angus, et al., 1982; Aufhammar & Kübler, 1991; Baumgärtner, et al., 1998; Käbler, et al., 2011). Marigold was chosen as a test to see its potential to establish in this part of Sweden. Marigold has also an effect on nematodes in the soil (Hooks, et al., 2010). This ability is good in a crop rotation with potatoes because there it can be nematodes which is an important pest in potatoes. Since Stefan's crop rotation mainly contains brassicas, we wanted to use cover crops from other plant families to prevent further risk of getting clubroot of cabbages (Robak, 1994). Sudangrass has shown to tend to reduce and decontamination of clubroot of cabbage (Robak, 1994) and after Sudangrass have been ploughed down in the soil it can reduce other pathogens like Common scab on potatoes (*Streptomyces* and *Rhizoctonia*) (Ögren & Hansson, 2016). Clover was chosen for its ability to nitro-fixate nitrogen from the air and prevent nitrogen leakage (Fogelfors, 2015).

Lacy phacelia in a mix with Persian clover, is a commonly used mix, which is recommended by advisors (Hansson, 2018) and was then a test to see the establishment differences between them and the other cover crops. Another mix that was chosen was the mix of winter rye and hairy vetch, this mix was also mentioned as a good pre-crop for vegetables (Hansson, 2018).

Cover crop	Plant family	Green manure	Allelopathy	Biogas	Food (humans)	Feed (animals)	Nitrogen fixating	Soil structure	Soil erosion	Organic matter	Inhibit soilborne pests	Increase microflora	Pollinators
Buckwheat	Polygonaceae	√	√	√	√	√				√			√
Crimson clover	Fabaceae	√		√		√	√						√
Persian clover	Fabaceae	√		√		√	√						√
Westerwoldisch ryegrass	Poaceae	√	√	√		√						√	
Sudangrass	Poaceae	√	√	√		√ *				√	√	√	
Marigold	Asteraceae	√		√ ?							√	√	
Lacy Phacelia	Boraginaceae	√	√	√		√							√
Hairy vetch	Fabaceae	√	√	√		√	√	√					
Black oat	Poaceae	√	√	√		√							
Oat	Poaceae	√	√	√	√	√		√	√			√	
Winter rye	Poaceae	√	√	√	√			√	√	√		√	

*Due to high cyanide levels sudangrass can be bad to use as feed to cattle and livestock.

Figure 5: Different cover crop species qualities and abilities, information from Appendix 2.

3.2 Sampling and sample preparation

Under the experiment, there were samples taken on two different dates. The first samples were taken on the 6th of September and the second samples were taken on the 12th of October 2018. The samples were taken from plots K1, 1, 2, 3, 4, 6 and T1 because they were best established on the first sample taking and in the other plots K2, 5, 7 and T2 the crops were approximately only 5-8cm or hadn't even germinated. In each plot, 3 squares of 0,25 m^2 were cut down to 5 cm stubble height in the 3 squares in ever plot were also weeds cut. The different cover crops were not divided and where but in the same bag, the weeds were separated from the cover crops and were put in paper bags. This procedure was carried out in the same way as the first sampling. The second sampling was carried out on the 12th of October. On both sampling dates, the mid-height of the cover crops (in K1 was the weeds measured) per plot was measured and there were 9 measurements per plot to see the differences in the plots and between the blocks. Field observations were done between the two dates of taking samples. The weeds were observed before and under the sampling. There were three species that was recurring. Under the field experiment, half of the plots were cut down to investigate if the crops grown/intercropped with buckwheat would grow better.

Figure 6: The equipment used to cut cover crops and weeds. Photo: Amanda Ahlqvist (2018).

The difference between cover crops was observed by photos which were taken under the field experiment. The photos show the cover crops height and how they were established.

The samples were then dried in a drying cabinet for 3 days at 60˚C. After drying, the dry weight of weeds and cover crops was registered. The dry weight from biomass of cover crops and weeds were converted into 1m^2 instead of 0,75m^2, by divide the total dry weight into 3 (because we want to find out how much it was per 0,25 m^2) then multiply it with 4. See equation below:

$$\frac{Dry\ weight\ \left({}^{g}/_{0{,}75m^2}\right)}{3} * 4 = dry\ weight\ ({}^{g}/_{m^2})$$

3.3 Statistics

The statistic programme Minitab 18 was used to make an ANOVA test and the other test included in ANOVA is the Tukey, Fisher's test and Dunnett’s test which also were made to see the significant difference between the plots and the sheets from this test are illustrated in Appendix 1. Microsoft Excel was used for the mathematic calculations and to help plot diagrams and Tables used in this study.

4. Results

The summer of 2018 was tough and difficult due to the severe drought conditions that effected negatively the entire Swedish agricultural sector. The weak establishment in plot K2, 5, 7 and T2, which is lacy phacelia with Persian clover, oat with buckwheat, black oat with buckwheat and winter rye with hairy vetch, was due to drought and the high temperatures this summer 2018.

4.1 Weeds found on the field

There were mainly three species of weed that was found in the fields in Grevie after the harvest of early potatoes. The weeds found on the field was dog nettle (*Urtica urens),* groundsel (*Senecio vulgaris*) and common chickweed (*Stellaria media*). Other weeds that occurred was also some potatoes (*Solanum tuberosum*) and some solitarily fat- hen weed (*Chenopodium album).*

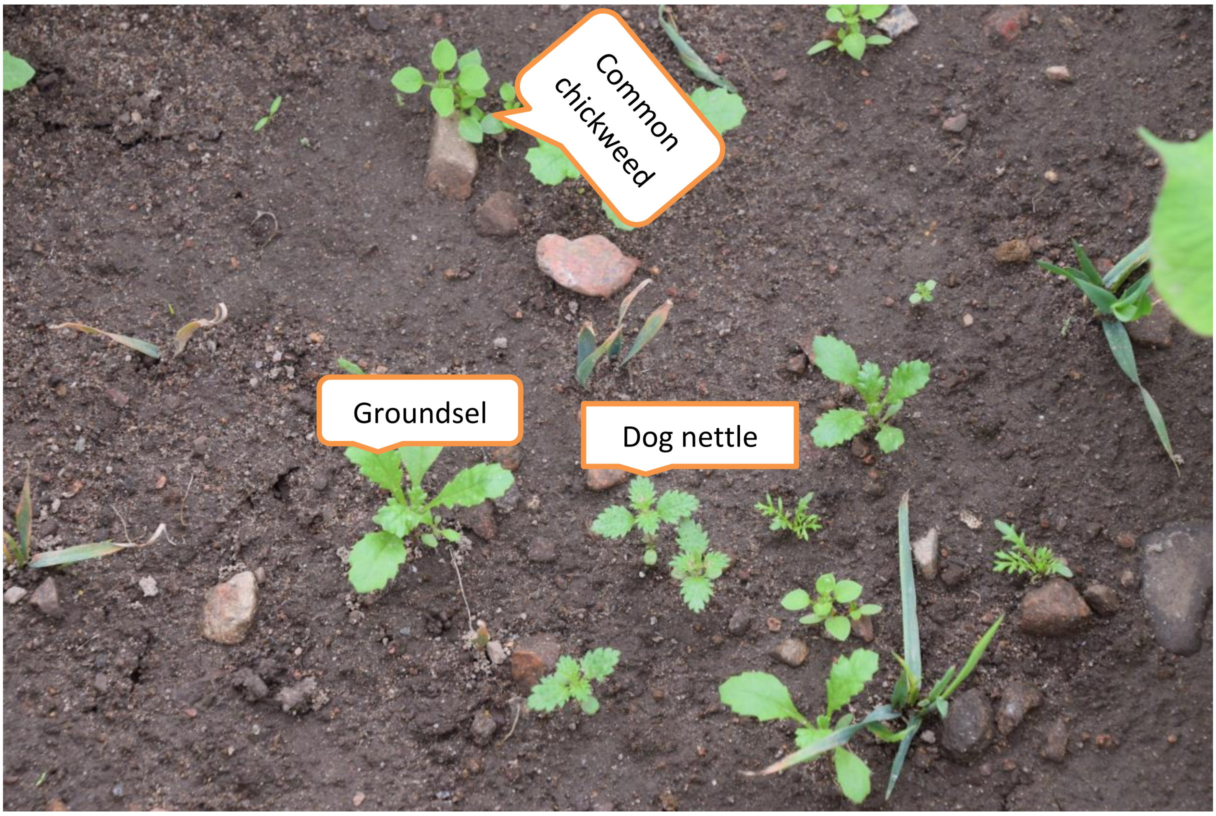

Figure 7: The three mostly found weeds species. Photo: Amanda Ahlqvist (2018).

4.2 Weed biomass

The data from the first sampling date is illustrated in Figure 8. The main result from the first sampling, which was taken on the 6th of September, is the significant difference between the control and the other cover crops. That the cover crops had a significantly lower amount of weed biomass compared to the control. Cover crops can suppress weeds, which highlights their competitive nature. There is a significant difference between marigold and the other cover crops and the control. This means that marigold can suppress weeds, but had significantly higher weed biomass than the other cover crops.

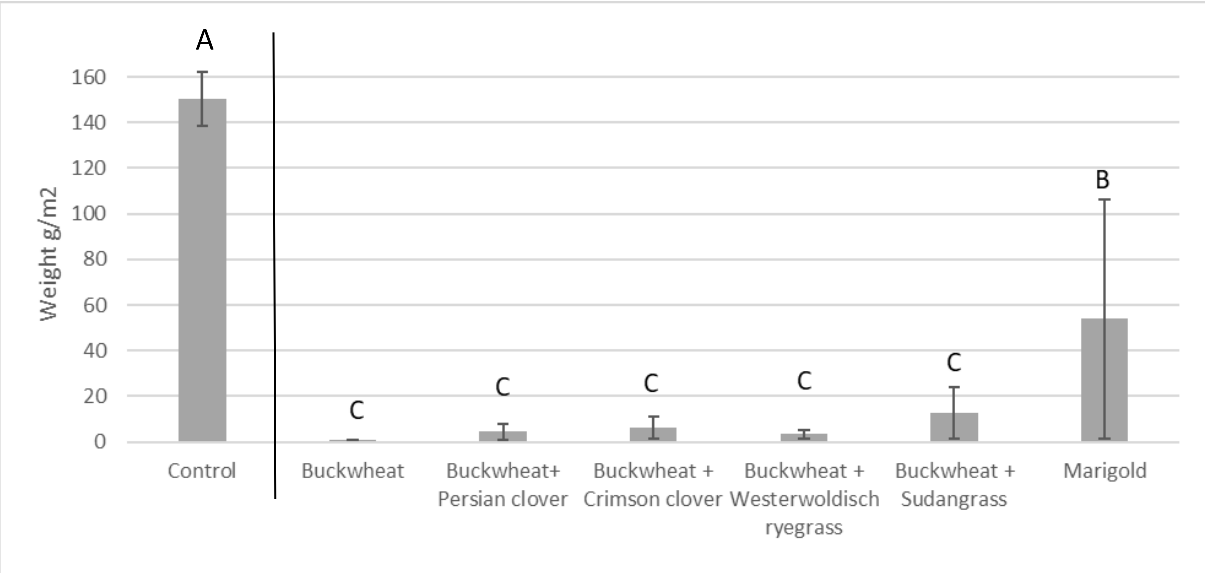

Figure 8: Shows the result from sample 1, the 6th of September. The average of the total dry weight from the weeds is showed. The letters show the significant difference between the different cover crop treatments and control. The error bars show the standard deviation.

The data from the second sampling date is illustrated in Figure 9. The main result from the second sampling is the significant differences between the control and the cover crops. This means that the cover crops suppress weeds well and had a significantly lower amount of weed biomass compared to the control. Marigold has a little higher weed biomass than the other cover crops but are **not** significantly different from the other cover crops and has the same effect against weeds.

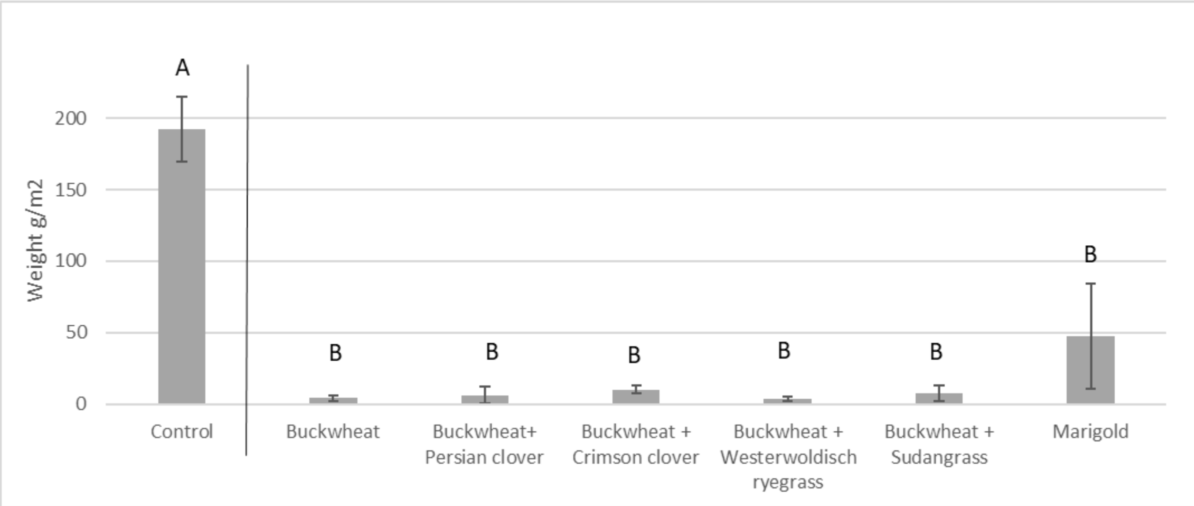

Figure 9: Shows the result from sample 2, the 12th of October. The average of the total dry weight from the weeds is showed. The letters show the significant difference between the different cover crop treatments and control. The error bars show the standard deviation.

4.3 The cover crops biomass

The data from the first sampling date is illustrated in Figure 10. Buckwheat in pure stock and buckwheat with crimson clover have significantly higher biomass yields compared with marigold. The other cover crops treatments with buckwheat and Persian clover, buckwheat and Westerwoldisch ryegrass, and buckwheat and sudangrass were not significantly different from the others and is as good as the others when it comes to producing biomass.

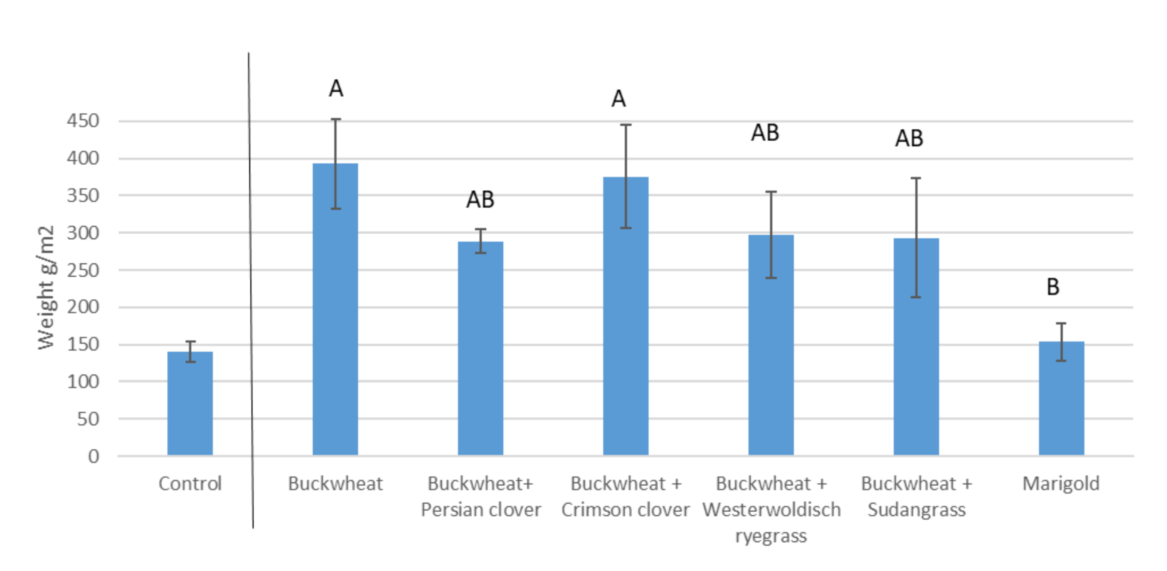

Figure 10: The average dry weight (g/m^2) of the cover crops biomass and Control (K1) shows the biomass from the weeds. The letters show the significant difference between the different cover crop treatments. The error bars show the standard deviation.

The data from the second sampling date is illustrated in Figure 11. The second sampling has significant differences between buckwheat in pure stock and buckwheat with crimson clover compared with buckwheat with Westerwoldisch ryegrass. Marigold, buckwheat with Persian clover and buckwheat with sudangrass were not significantly different from the other cover crops in biomass.

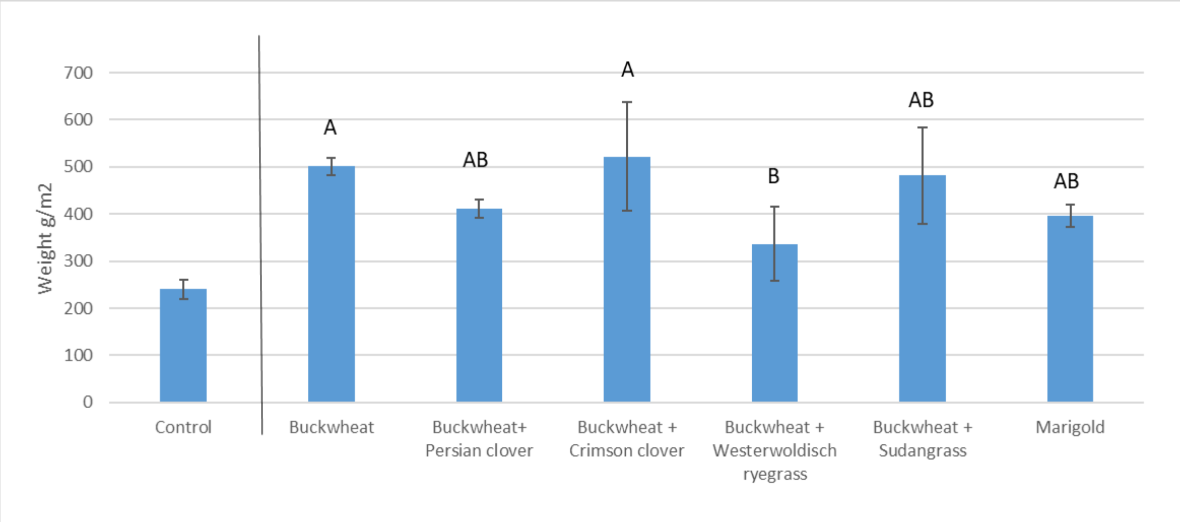

Figure 11: The average dry weight (g/m^2) of the cover crops biomass and Control (K1) shows the biomass from the weeds. The letters show the significant difference between the different cover crop treatments. The error bars show the standard deviation.

4.4 Altimetry of the cover crops

The height from the first measuring of the cover crop is not significantly different which is illustrated in Figure 12. Even if the height is almost the same between the buckwheat mixes, the biomass dry weight differs, as mentioned above.

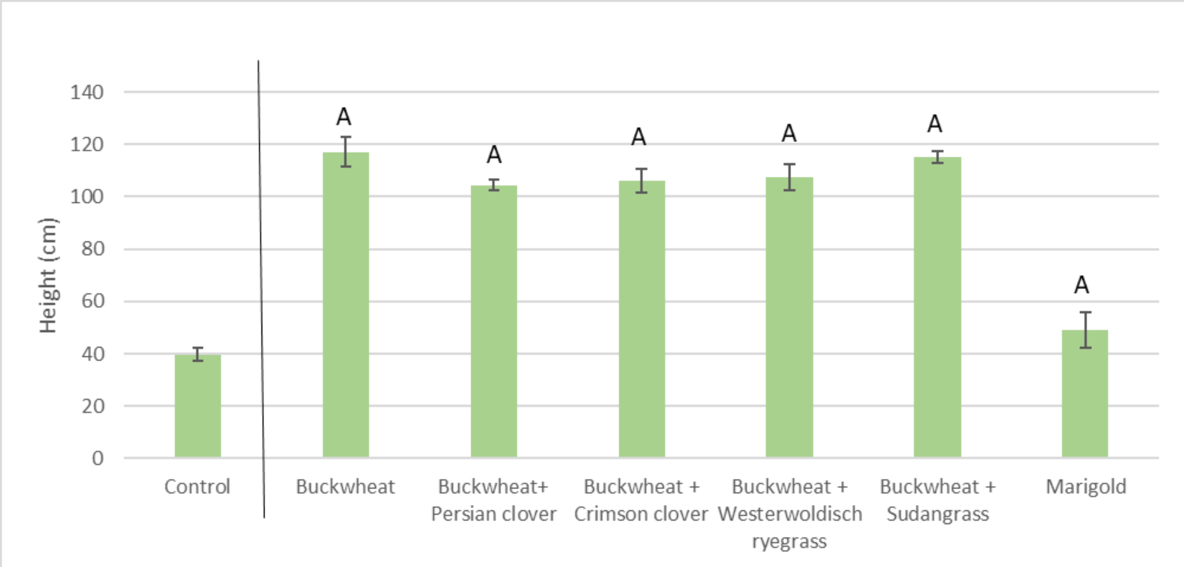

Figure 12: The cover crops and weeds average height (cm). The error bars show the standard deviation. The letters show the significant difference between the different cover crop treatments. The error bars show the standard deviation.

The height at the second measuring of the cover crop isn't significantly different from each other and has almost the same height, Figure 13.

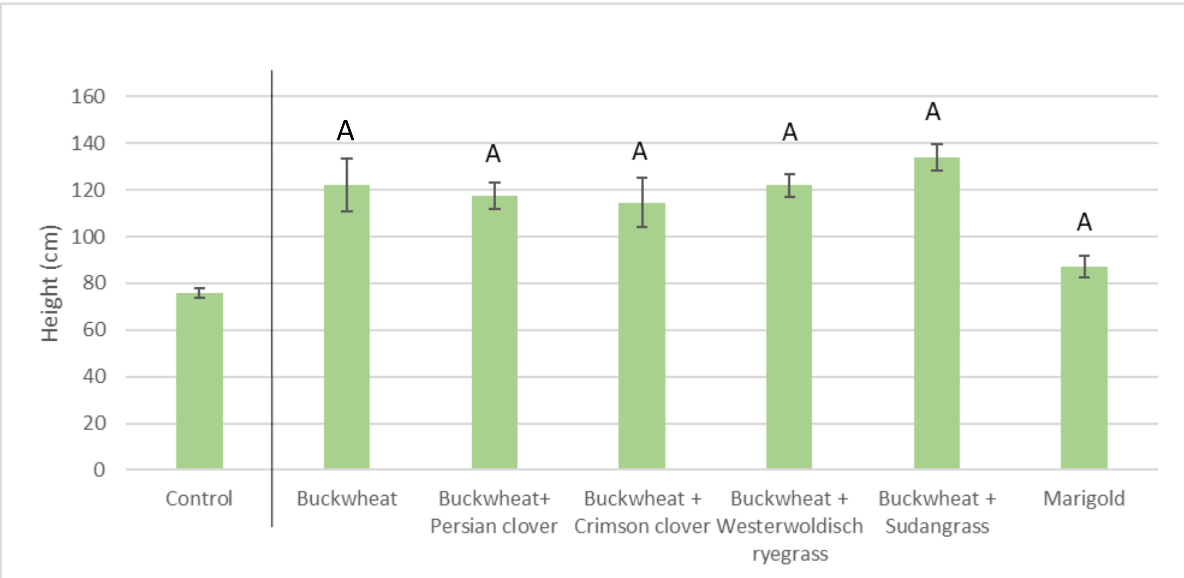

Figure 13: The cover crops and weeds average height (cm). The error bars show the standard deviation. The letters show the significant difference between the different cover crop treatments. The error bars show the standard deviation.

5. Discussion

The results showed that the cover crops had the ability to reduce the seed weeds in a crop rotation with early potatoes, by covering the soil and competing with the weeds. The cover crops suppressed 64- 91% (6th of September 2018) and 76-93% (12th of October 2018) of the seed weeds compared with the control. This indicates that the cover crop reduced the growth of weeds. This can then lead to and decrease of seeds that fall onto the soil surface. This reduces the seeds that can be a part of the soils seed bank. A seed can either germinate or persist on the surface or in the soil for a shorter or longer time and goes into dormancy (Thompson, 2000). Then if the soil gets ploughed the seeds can go from dormancy to germination (ibid.).

If the experiment weren't performed, Stefan would have grown Westerwoldisch ryegrass on the whole field and could give a good weed control. Cover crops are a good implement in a crop rotation to reduce the weeds and is a greener way to manage the weeds (Teasdale, et al., 2007). In an IPM point of view, the cover crops can be a measure to minimize the use of mechanical and chemical control of weeds (EU, 2009; Fogelfors, 2015).

Though all the cover crops tested suppressed weeds well, marigold (*T. patula*) did not suppress weeds as much as the other cover crops. This can be due to the sowing of marigold, which was little tricky, because of the seeds of marigold has a pappus (Mossberg & Stenberg, 2010) which very easy can tangled with each other. This makes it hard to sow it evenly and in block 2 the marigold plot was sown best and had the best establishment. In block 2 the marigold had the best weed suppression of all the marigold plots. On the second sampling date the 12th of October 2018, the result shows almost the same result that cover crops can suppress weeds well, and here has marigold the same effect against the weeds as the other cover crops in this study. Marigold overcame the bad establishment and once growing, it suppressed weeds well and had the same effect as the other cover crops tested.

Other field experiments made in Scania, Sweden have shown similar results of cover crops ability to suppress weeds and according to Hansson, et al. (2018), unfertilized cover crops grown in combination with hairy vetch, reduced weeds best. They also showed tendencies (non-statistical) that cover crops in mixes has lower weed biomass (g/m^2) than cover crops in pure stock on the cover crops tested, e.g. buckwheat, lacy phacelia and hairy vetch (Hansson, et al., 2018). Teasdale, et. al. (2007) found that cover crops abilities to suppress weeds are effective but can't control weeds throughout the growing season and can be effective both when growing, but can also be effective when cut and left as biomass cover and can, therefore, be applied as an alternative to herbicides or mechanical control (Teasdale, et al., 2007). When the cover crop residue is used as weed control, some cover crops may release allelopathic substances which also can be effective, even after the crop is dead. Some examples of allelopathic cover crops are sudangrass (Einhellig & Rasmussen, 1989), buckwheat, phacelia, winter rye, Westerwoldisch ryegrass, black oat and oat (Weston & Inderjit, 2007; Price, et al., 2008; Didon, et al., 2014; UCDAVIS Agricultural Sustainability Institute, 2017). To use allelopathic plants to suppress weeds can be a good strategy for weed management instead of using herbicides or take the active substance which causes allelopathy and use as a biologically made herbicides (Upadhyaya & Blackshaw, 2007; Weston & Inderjit, 2007). This can lead to a more sustainable method for weed management.

Teasdale, et al. (2007) presented data which showed that living cover crops have a high impact on the weed germination, establishment, and growth. However, the effect of cover crops are good, but not as good as the mechanical alternative of high- intensity harrowing which gave a better weed control than cover cropping (Teasdale, et al., 2007). But cover cropping is the more environmentally friendly, greener and more sustainable (more ecological and ecosystem friendly, more beneficial insects, etc.) alternative to manage weeds and has also many other advantages (ibid.). Example of positive factors with cover crops are that they can be used as green manure, fodder or feed to livestock, sold to biogas production and prevent nutrient leakage, see Figure 5 (Zhang, et al., 2007; Constantin, et al., 2010; Aronsson, et al., 2012; Balzewicz-Wozniak & Wach, 2012). Also, the biodiversity on the fields has been shown to increase by adding cover crops and also limiting the occurrence of pests and diseases (Wyland, et al., 1996; Jodanugiene, et al., 2006; Stoklosa, et al., 2008; Lithourgidis, et al., 2011). Cover crops can attract beneficial insects which can reduce pests or pollinate the cultivated crops. Cover crops can reduce the pest by diversifying the crop rotation and thereby decreasing risk for further infestation (ibid.). On the other hand, if the cover crops belong to the same family as one of the main crops, soilborne diseases have been showed to increase e.g. when attracting the same diseases, e.g. clubroot for

Brassicaceae or aphids that can host on other crops in the same family (Robak, 1994; Dabney, et al., 2001; Kilian, 2016). That requires the farmer to know which cover crops he/she shall use and which ones are suitable for his/her farm and crop rotation.

Weed management is maybe best if different techniques can be applied and not only rely on one factor and technique. This can lead to a more IPM way of thinking and farming in a sustainable way, e.g. by using mechanical, cover crops, biological herbicides to implement in a crop rotation, but also have more knowledge of your own crop rotation (Fogelfors, 2015).

Phacelia, Persian clover, crimson clover, oat, black oat, and rye are sensitive to high soil temperatures (UCDAVIS Agricultural Sustainability Institute, 2017). The cover crops in the plots with buckwheat intercropped with black oat, buckwheat with oat, lacy phacelia with Persian clover and winter rye with hairy vetch, didn't establish well. During the field experiment, due to drought and higher temperatures than usually were observed at the end of July (SMHI, 2018). This could explain why they didn't grow as well as the others, but on the second sampling date the seeds had germinated, and the crops were growing. These cover crops can, however, be used when grown in the autumn, when the temperatures are lower. Buckwheat, marigold, sudangrass and Westerwoldisch ryegrass can germinate even in soils with higher temperatures (USDA, 2014; UCDAVIS Agricultural Sustainability Institute, 2017). A theory would be that the seeds were in dormancy when the temperatures weren't beneficial and then started to germinate when the temperatures were lower. Soil temperatures might, therefore, be important when choosing the right cover crop. If the cover crops are to be cultivated in the summer, the farmer maybe needs to choose a cover crop that can germinate in higher soil temperatures. Or intercrop one cover crop e.g. marigold and then have a crop which germinates when the marigold has been trimmed, e.g. black oat.

Buckwheat or buckwheat intercropped with grasses did not only suppresses seed weeds well but also yielded a high amount of biomass which can be used in different ways, e.g. as feed or for biogas production (Aronsson, et al., 2012; Szerencsits, et al., 2015; Maier, et al., 2017). Harvesting the biomass can give the farmer a second yield and additional income.

Why buckwheat in pure stock resulted in less weed biomass compared to the other cover crop mixes can depend on the seed rate. The seed rate for buckwheat was twice as much as buckwheat with another cover crop, see Table 4. A lower seed rate on the cover crop mixes can be a result of lower ability to compete and suppress the weeds. If the seed rate wouldn't have been halved the cover crop mixes could have shown even better results.

Despite their ability to suppress weeds, cover crops can become a weed themselves the next year (Teasdale, et al., 2007). It is important to trim the cover crop in the right time, otherwise, if the crop grows too long and starts to produce seeds, the seeds can fall on the surface and germinate or contribute to the seed bank (Teasdale, et al., 2007).

Figure 14 shows the clear difference between using cover crops (to the right) and without cover crops (to the left). In the right part of the photo, the buckwheat has been trimmed and it had begun to die, but the intensity of the weeds is lesser than in the trimmed control, to the left in the photo. This could indicate an allelopathic effect of buckwheat against weeds (Weston & Inderjit, 2007). Further research is needed to confirm this effect.

Figure 14: This is the control (K1) to the left and buckwheat pure stock (1) to the right, which was cut down after the first sampling 6th of September. The intensity of weeds differs from the left and the right which can illustrate the difference between having cover crops and not. This can also indicate buckwheat's allelopathic effect against weeds (Weston & Inderjit, 2007). Photo: Amanda Ahlqvist.

Conclusion

The study showed that summer cover crops can suppress weeds in a crop rotation with early potatoes. In this study, there was no difference between cover crops in pure stock or in mixes when it comes to suppressing weeds. Thou in the future, further studies and field experiments in other locations in Sweden, could be studied to know the cover crops effect against weeds in different environments.

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Appendix 1

Here are all the Tables used to make the graphs from Excel, and the statistical test sheets from Minitab 18.

Samples from 6th of September:

Total dry weight from weed samples 6th sep: g/m2

Parcel:	Block 1:	Block 2:	Block 3:
K1	134	162	155
1	1	1	1
2	2	2	9
3	3	3	13
4	1	3	6
6	9	1	28
T1	37	0	125

Fisher Pairwise Comparisons: Behandling:
Grouping Information Using Fisher LSD Method and 95% Confidence

Behandling:	N	Mean	Grouping		
K1	3	150,333	A		
T1	2	80,500		B	
6	3	12,667			C
3	3	6,333			C
2	3	4,333			C
4	3	3,333			C
1	3	1,000			C

Means that do not share a letter are significantly different.

Dry Weight from biomass samples 6th sep: g/m2

Parcel:	Crop:	Block 1:	Block 2:	Block 3:
K1	Control = Weeds	124	157	141
1	Buckwheat	433	308	437
2	Buckwheat, Persian clover *	311	277	277
3	Buckwheat, Crimson clover *	399	447	281
4	Buckwheat, Westerwoldisch ryegrass *	376	237	277
6	Buckwheat, Sudan grass	320	375	184
T1	Marigold	183	155	123

Fisher Pairwise Comparisons: BBehadling:
Grouping Information Using Fisher LSD Method and 95% Confidence

BBehadling:	N	Mean	Grouping
1	3	392,778	A
3	3	375,556	A
4	3	296,667	A
6	3	293,000	A
2	3	288,222	A
T1	3	153,667	B

Means that do not share a letter are significantly different.

Samples from 12th of October:

The total dry weight from weed samples 12th oct: g/m2

Ruta:	Block 1:	Block 2:	Block 3:
K1	218	195	163
1	3	3	7
2	1	4	15
3	7	11	13
4	2	6	4
6	1	8	15
T1	24	19	99

Comparisons for Ogräs
Tukey Pairwise Comparisons: Behandling
Grouping Information Using the Tukey Method and 95% Confidence

Behandling	N	Mean	Grouping
K1	3	192,200	A
T1	3	47,233	B
3	3	10,167	B
6	3	7,700	B
2	3	6,433	B
1	3	4,233	B
4	3	3,900	B

Means that do not share a letter are significantly different.

Fisher Pairwise Comparisons: Behandling
Grouping Information Using Fisher LSD Method and 95% Confidence

Behandling	N	Mean	Grouping
K1	3	192,200	A
T1	3	47,233	B
3	3	10,167	B C
6	3	7,700	C
2	3	6,433	C
1	3	4,233	C
4	3	3,900	C

Means that do not share a letter are significantly different.

Dry Weight from biomass samples 12th oct: g/m2				
Parcel:	**Crop:**	**Block 1:**	**Block 2:**	**Block 3:**
K1	Control= weeds	259	251	211
1	Buckwheat	525	499	480
2	Buckwheat, Persian clover	384	429	421
3	Buckwheat, Crimson clover	578	626	361
4	Buckwheat, Westerwoldisch ryegrass	227	400	384
6	Buckwheat, Sudan grass	584	520	341
T1	Marigold	368	427	392

Fisher Pairwise Comparisons: BBehandling:

Grouping Information Using Fisher LSD Method and 95% Confidence

BBehandling:	N	Mean	Grouping	
3	3	521,511	A	
1	3	501,333	A	
6	3	481,778	A	B
2	3	411,467	A	B
T1	3	395,556	A	B
4	3	336,889		B

Means that do not share a letter are significantly different.

Altimetry of the cover crops, first and second sampling:

Table 2: The height (cm) of the cover crops and weeds in the different blocks, from the first sampling.

Ruta	*Block 1*	*Block 2*	*Block 3*
K1	37	39	43
1	112	114	125
2	107	104	102
3	101	105	112
4	101	108	113
6	113	118	114
T1	47	42	58

Comparisons for Block

Dunnett Multiple Comparisons with a Control: Behandling

Grouping Information Using the Dunnett Method and 95% Confidence

Behandling	N	Mean	Grouping

K1 (Control)	3	2	A
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means not labeled with the letter A are significantly different from the control level mean.

Tukey Pairwise Comparisons: Behandling 1

Grouping Information Using the Tukey Method and 95% Confidence

Behandling 1	N	Mean	Grouping
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means that do not share a letter are significantly different.

Fisher Pairwise Comparisons: Behandling 1

Grouping Information Using Fisher LSD Method and 95% Confidence

Behandling 1	N	Mean	Grouping
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means that do not share a letter are significantly different.

Table 3: The height (cm) of the cover crops and weeds in the different blocks, on the second sampling.

Ruta	Block 1	Block 2	Block 3
K1	74	79	75
1	106	129	131
2	111	125	117
3	100	120	124
4	115	126	125
6	142	128	132
T1	81	89	92

Dunnett Multiple Comparisons with a Control: 2: Behanlding

Grouping Information Using the Dunnett Method and 95% Confidence

2: Behanlding	N	Mean	Grouping
K1 (Control)	3	2	A
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means not labeled with the letter A are significantly different from the control level mean.

Tukey Pairwise Comparisons: 2: Behanlding_1

Grouping Information Using the Tukey Method and 95% Confidence

2: Behanlding_1	N	Mean	Grouping
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means that do not share a letter are significantly different.

Fisher Pairwise Comparisons: 2: Behanlding_1

Grouping Information Using Fisher LSD Method and 95% Confidence

2: Behanlding_1	N	Mean	Grouping
1	3	2	A
2	3	2	A
3	3	2	A
4	3	2	A
T1	3	2	A
6	3	2	A

Means that do not share a letter are significantly different.

Appendix 2

Fagopyrum esculentum (Buckwheat)

Buckwheat, *Fagopyrum esculentum* (Bovete), is an annual herb (Fogelfors, 2015) in the plant family *Polygonaceae* (Krok, et al., 2016). The name *Fagopyrum* refers to the resemblance of it to the beech trees nuts and the older Swedish name for buckwheat was beech- wheat (Fogelfors, 2015). Buckwheat has a shallow and weak root system and has a long flowering period (ibid.). Traditionally grains from buckwheat have been used for food to humans or as feed to livestock and cattle (Baumgärtner, et al., 1998; Käbler, et al., 2011).

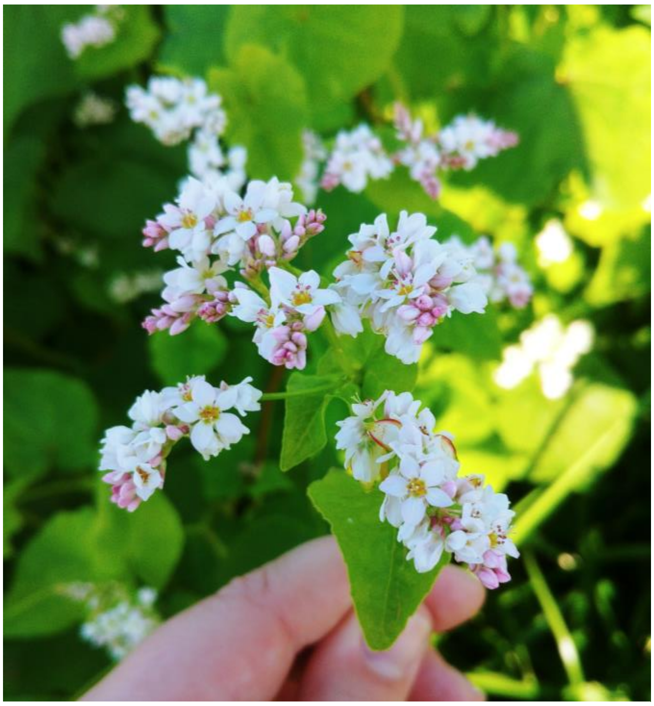

Figure 15: Buckwheat, Fagopyrum esculentum (Bovete). Photo: Amanda Ahlqvist (2018).

As a cover crop, buckwheat is a rich source of nutrients and organic matter for the coming crop (Balzewicz-Wozniak & Wach, 2012). Buckwheat can also be a supplement in a cereal dominated crop rotation and prevents transmission of diseases which can reduce the yields in the cereal cultivations (Baumgärtner, et al., 1998). One disadvantage with buckwheat is its sensitivity to lower temperatures and frost (ibid.). Buckwheat can't grow under 2-5 ̊C and will most likely die (Baumgärtner, et al., 1998).

On the other hand, one advantage is that the seeds can germinate in warm conditions and temperatures (Baumgärtner, et al., 1998). Buckwheat can adapt to poor growing conditions and has a high-temperature tolerance. Buckwheat has additional advantages from an economic aspect, because of the agricultural potential to be used as the main crop and to use as feed to livestock or cattle (Angus, et al., 1982; Aufhammar & Kübler, 1991; Baumgärtner, et al., 1998).

Phacelia tanacetifolia (Lacy phacelia or blue tansy)

Figure 16: Lacy phacelia, Phacelia tanacetifolia (Honungsört). Photo: Amanda Ahlqvist (2018).

Lacy phacelia, *Phacelia tanacetifolia* (Honungsört), is an annual herb in the plant subfamily *Hydrophyllaceae*, which belongs to the family *Boraginaceae* (Fogelfors, 2015; Krok, et al., 2016). Phacelia is a fast-growing crop with a shallow and weak root system (Fogelfors, 2015). The flower is violet- blue and lasts for a long time. Phacelia can be trimmed once and let to regrow, but the trimming needs to be done prior to flowering, otherwise, it will die (ibid.). It can be cultivated on several types of soils and is drought tolerant (Kilian, 2016), but not when germinating, it requires moist soil (Fogelfors, 2015). Phacelia should be sown early in the autumn and is usually grown for green manure, by ploughing down after the flowers have overblomed.

As a cover crop phacelia is a rich source of organic matter and nutrients for the coming crop (Balzewicz-Wozniak & Wach, 2012). It's also a crop which attracts pollinators like bees and insects (Kilian, 2016; The Royal Horticultural Society, 2018). When cultivated as a cover crop, Lacy phacelia is a winter hardy robust annual, which can grow between 20-120 cm high and is a fastgrowing crop (The Royal Horticultural Society, 2018). Phacelia can also be used as feed to livestock and is considered non-toxic (Kilian, 2016). It can also be used as a crop for bio-control, because it hosts hoverflies which feed on nectar and then lay their eggs on the plant. The hoverflies larvae is a predator of leaf aphids (Kilian, 2016).

Trifolium resupinatum (Persian clover)

Persian clover, *Trifolium resupinatum* (Persisk klöver), is an annual nitrogen-fixating herb in the plant family *Fabaceae* (Mossberg & Stenberg, 2010). Clover is good to implement in a crop rotation with mainly brassicas, because it can increase the nitrogen available in the soil (Fogelfors, 2015). Persian clover is suitable for cool temperature conditions and this type of clover is usually cultivated in late summer (UCDAVIS Agricultural Sustainability Institute, 2017). Thou the Persian clover needs cooler temperatures, the seed needs warmth, sun and moist soil to germinate (ibid.). The root system is heavy and contains a simple taproot, which improves the soil tilth. It increases the microorganism's life and increase the water- holding capacity in the soil (UCDAVIS Agricultural Sustainability Institute, 2017).

As a cover crop, Persian clover can be used as green manure or feed to livestock (Fogelfors, 2015). It's also a source of nutrients and primarily contains nitrogen. The nitrogen will become available through a symbiosis with nitrogen fixating bacteria and the clover roots (Fogelfors, 2015). The flowers of Persian clover can also attract pollinators to feed nectar (UCDAVIS Agricultural Sustainability Institute, 2017).

Trifolium incarnatum (Crimson clover or Italian clover)

Crimson clover, *Trifolium incarnatum* (Blodklöver), is an annual nitrogen-fixating herb in the plant family *Fabaceae* (Mossberg & Stenberg, 2010). Crimson clover grows and germinates faster than Persian clover (Fogelfors, 2015), but crimson clover needs much more water to establish (UCDAVIS Agricultural Sustainability Institute, 2017). Crimson clover grows fast but doesn't get longer than 40 cm (Naturhistoriska Riksmuseet , 2000). This clover is tolerant for cool temperatures and the ultimate temperature is between 6-21˚C and can't grow in extreme cold or warm weather (UCDAVIS Agricultural Sustainability Institute, 2017). Crimson clover has a simple root system and is dominated by a taproot, it is often well nodulated and the root depth is 31-55 cm (ibid.). Crimson clover tolerates a wide range of soil conditions. The flower of crimson clover produces much nectar and attract many bee varieties (UCDAVIS Agricultural Sustainability Institute, 2017).

Figure 17: Crimson clover, Trifolium incarnatum (Blodklöver). Photo: Tigernente (2005).

As a cover crop can Crimson clover be used as green manure and give more nitrogen to the next crop in the crop rotation (Fogelfors, 2015). It can also be used as pasture and fodder to livestock and cattle (Naturhistoriska Riksmuseet, 2000; UCDAVIS Agricultural Sustainability Institute, 2017). Crimson clover can protect the soil from nitrogen leakage under the winter if it is left on the field to spring and is then ploughed into the soil (UCDAVIS Agricultural Sustainability Institute, 2017).

Vicia villosa ssp. villosa (Hairy vetch)

Figure 18: Hairy vetch, Vicia villosa spp. villosa (Luddvicker). Photo: Kristian Peters (2004).

Hairy vetch, *Vicia villosa ssp. Villosa* (Luddvicker), is a nitrogen-fixating herb in the plant family *Fabaceae* (Mossberg & Stenberg, 2010). It can grow to 1- 1,5 m high (Naturhistoriska Riksmuseet, 2000) and is a straggling and climbing crop. When grown in an intercropped system with other crops, hairy vetch can climb on the other crop (UCDAVIS Agricultural Sustainability Institute, 2017). It has a shallow root system which contains a taproot that extends to a depth of 30-85 cm (UCDAVIS Agricultural Sustainability Institute, 2017). Hairy vetch is a legume and therefore has a symbiosis between their roots and nitrogen fixating bacteria (Fogelfors, 2015). Hairy vetch is drought tolerant and suits for sandy or sandy loam soils (UCDAVIS Agricultural Sustainability Institute, 2017). The hairy vetch tolerance for temperature is between 4- 21℃ (ibid.), but some Swedish varieties are cold tolerant and can overwinter to spring (Olssons frö, 2018).

As a cover crop, hairy vetch can be used as green manure, silage, and fodder to livestock (UCDAVIS Agricultural Sustainability Institute, 2017). Hairy vetch can be cultivated to improve the structure of the soil and to get a higher percentage by weight of water-sTable aggregates (ibid.). Hairy vetch has also showed allelopathic abilities and can suppress weed well (Geddes, et al., 2015).

Lolium multiflorum var. westerwoldicum (Westerwoldisch rye-grass)

Westerwoldisch ryegrass (WW), *Lolium multiflorum var. westerwoldicum* (Westerwoldiskt rajgräs), is an annual grass in the plant family *Poaceae* (Mossberg & Stenberg, 2010). Westerwoldisch ryegrass can be up to 80 cm high and is commonly used as a cover crop (Naturhistoriska Riksmuseet, 2000). Westerwoldisch ryegrass has a very glabrous and fibrous root system which can be 20 cm deep (Beddows, 1973). WW can grow on many different types of soils but prefer loams or sandy loams (Beddows, 1973; UCDAVIS Agricultural Sustainability Institute, 2017). The seeds germinate quickly and grow rapidly. It establishes even during cold weather and cooler soils (UCDAVIS Agricultural Sustainability Institute, 2017). WW can tolerate temporary floods and drought (Beddows, 1973). Though WW can tolerate cooler temperatures and cold weather, it’s not winter hardy (UCDAVIS Agricultural Sustainability Institute, 2017).

When WW is grown as a cover crop the main purpose is to be used as green manure, temporary pasture and as a protection to reduce soil leakage (UCDAVIS Agricultural Sustainability Institute, 2017). It also allows the farmer to take several harvests for feed to livestock (ibid.). By adding under- sown ryegrass as a cover crop to a cropping system can effectively reduce N leaching in manured systems (Torstensson & Aronsson, 2000). WW is likely to die in the winter and the seeds don’t hibernate (Beddows, 1973). If the ear of ryegrass has been established the Westerwoldisch ryegrass can become a weed the next year (Ögren & Hansson, 2016). Different types of ryegrass have shown to have allelopathic abilities, which can be used to control weeds and contribute to reducing the use of herbicides in the cropping systems (Didon, et al., 2014).

Tagetes patula (Marigold)

Marigold, *Tagetes patula* (Sammetsblomster, Tagetes), is an annual aromatic herb in the plant family *Asteraceae* (Mossberg & Stenberg, 2010). Marigold can be around 50-100 cm high and has yellow or orange coloured flowers (ibid.). Marigold can grow on different well-drained soils like loam, clay or sandy soils (The Royal Horticultural Society, 2018). Marigold needs to be cultivated in sunny and in warmer temperatures, the ideal temperature is around 21°C (ibid.).

Marigold has a fibrous root system and is known to produce compounds which are toxic for nematodes, one example of these compounds is α-terthienyl, which is allelopathic to many plant-parasitic nematodes (Hooks, et al., 2010). Marigold has proved to be more effective than different fumigants and chemical nematicides (ibid.). One study made by Sturz & Kimpinski (2004) showed that endroot bacteria which comes from *Tagetes* spp. can play a big role in nematode suppression, through the attenuation of the nematode propagation. This bacteria is like a beneficial "residual" microflora, like microbial allelopathy, which can be transferred to the next crop in the rotation (Sturz & Kimpinski, 2004).

Figure 19: Marigold, Tagetes patula (Tagetes, sammetsblomster). Photo: Amanda Ahlqvist (2018).

Marigold can be used in a rotation, as a cover crop, intercropped with another crop or as a crop residue amendment (Hooks, et al., 2010). It can also be used as a poor host for the unwanted plant- parasitic nematodes, as a "dead end" crop or enhancing nematode-antagonistic microorganisms in the soil (Sturz & Kimpinski, 2004; Hooks, et al., 2010).

Avena strigosa (Black oat)

Black oat, *Avena strigosa* (Purrhavre), is an annual grass in the plant family *Poaceae* and is also called bristle oat or lopsided oat (Naturhistoriska Riksmuseet, 1998; Mossberg & Stenberg, 2010). Black oat can be 50- 90 cm high and is a tall grown grass (ibid.). Black oat does establish well on sandy or loamy soils, but can also be grown in heavy clay and soils with low nutrient value (USDA, 2014). This type of oat has similar root system as other grasses and has fibrous root system (ibid.). Black oat is not cold tolerant and tolerate temperatures over 2℃ (Ashford & Reeves, 2003). Black oat is not frost tolerant and will die in conditions with temperatures under 2℃. Thou its intolerance for temperature, black oat can tolerate drought and conditions with less water (USDA, 2014).

As a cover crop, black oat can be used for green manure (USDA, 2014). This thou to its ability to grow fast. The leaf tissues have been shown to have allelopathic effects that can inhibit small seeded weed species (Price, et al., 2008). Black oat is also used for feed to cattle/livestock, because of its nutrient values (USDA, 2014). Black oat has formerly been a weed on cultivated fields in Sweden (Mossberg & Stenberg, 2010), but is now used as a fastgrowing cover crop (USDA, 2014; Jordbruksverket, 2018).

Avens sativa (Oat)

Oat, *Avena sativa* (Havre), is an annual grass in the plant family *Poaceae* (Mossberg & Stenberg, 2010). Oat can grow 70-120 cm high (Mossberg & Stenberg, 2010) and has a fibrous root system, which can grow 84-195 cm deep (UCDAVIS Agricultural Sustainability Institute, 2017). Oat is moderate resistance to cold and can tolerate temperatures to -8 degree, therefore can it be grown on cooler seasons of the year (ibid.). Oat is very susceptible to stress and damage made by hot and dry weather (UCDAVIS Agricultural Sustainability Institute, 2017). Oat is tolerant to wet soil for germination and when establishment oat requires loamy or heavy soil type but is adaptive to many soil types (UCDAVIS Agricultural Sustainability Institute, 2017).

Oat can be used in many ways and is grown mostly for grain and hay but can be grown for pasture and green manure too (UCDAVIS Agricultural Sustainability Institute, 2017). As a cover crop, oat can provide erosion control, enhance soil life, add organic matter and suppress weeds (ibid.). Oat has also the ability to decrease N leakage from the soil and retain the nitrogen in the soil (UCDAVIS Agricultural Sustainability Institute, 2017).

Secale cereale (Winter rye)

Winter rye, *Secale cereale* (Höstråg), is an annual grass in the plant family *Poaceae* (Mossberg & Stenberg, 2010). Rye is also called cereal rye (UCDAVIS Agricultural Sustainability Institute, 2017) and can grow to a length of 70-180 cm (Mossberg & Stenberg, 2010). Rye has a fibrous root system which can grow 90-230 cm deep (UCDAVIS Agricultural Sustainability Institute, 2017). Rye is the most winter hardy and cold tolerant of the cereal species and can germinate from 20˚C to 3˚C. Once established, rye can withstand low temperatures up to -35℃ (ibid.). Rye has a well extensive root system, which makes the crop most drought tolerant of the cereal crops (UCDAVIS Agricultural Sustainability Institute, 2017). It grows best on moist soils, well-drained loam or clay loam soils. Rye can also grow on heavy clays, infertile or poorly drained soils and light sand (ibid.).

The use of rye is mostly as grains, but also as pasture, hay, as a cover crop and green manure (UCDAVIS Agricultural Sustainability Institute, 2017). As a cover crop, rye is grown for erosion control, to add organic matter, to enhance soil life and for weed suppression. Rye can also stabilize and prevent nitrogen leaching (ibid.). Rye has shown allelopathic characters. Because of ryes root system it can increase and improve soil structure (UCDAVIS Agricultural Sustainability Institute, 2017).

Sorghum x sudanense (Sudangrass)

Sudangrass, *Sorghum* x *sudanense* (Sudangräs), is an annual grass in the plant family *Poaceae* (Mossberg & Stenberg, 2010). Sudangrass is a crop which prefers warm and higher temperatures and is frost sensitive (UCDAVIS Agricultural Sustainability Institute, 2017). This type of grass is growing very high and can be around 0,45- 5 m high (Mossberg & Stenberg, 2010; UCDAVIS Agricultural Sustainability Institute, 2017). Sudangrass is fairly tolerant of drought, but drought can induce temporary dormancy, and sudangrass needs water to establish well (UCDAVIS Agricultural Sustainability Institute, 2017). Sudangrasses tolerate very high salinity, pH and it can be used to reclaim sodic soil (ibid.). Like most grasses, sudangrass has a fibrous root system, which can grow to a length of 124 cm (UCDAVIS Agricultural Sustainability Institute, 2017).

Figure 20: Sudangrass, Sorghum x sudanense (Sudangräs). Photo: Markus Hagenlocher (2007).

Sudangrass is a cover crop that is mainly used for green manure, organic matter, to enhance soil life and to suppress weeds (UCDAVIS Agricultural Sustainability Institute, 2017). Sudangrass is very competitive and allelopathic agianst weeds (Einhellig & Rasmussen, 1989). When this grass is grown it can also provide mulch and soil structural improvements, because of the root system (UCDAVIS Agricultural Sustainability Institute, 2017). It can also be used as forage or silage to livestock, but sudangrass can be toxic when harvesting early, or when it died due to frost. This because of high cyanide levels in the early stage of development. When the sudangrass is matured the cyanide levels decrease making it less toxic (UCDAVIS Agricultural Sustainability Institute, 2017).