No-till grain legume production in organic farming

– constraints, possibilities and potential agronomic practice

Direktsådd i ekologisk odling av trindsäd - begränsningar, möjligheter och potentiella odlingsåtgärder

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Abstract

Today's agriculture is often specialised, and relies on pesticides, synthetic fertiliser and tillage. Tillage, especially ploughing, has shown to have a negative impact on climate, soil health and -biodiversity. An alternative is no-tillage, a practice that leaves the soil almost undisturbed except for minimal impact during sowing. Implementing no-tillage into organic agriculture has potential to make it more sustainable. However, it is a challenge since tillage is the main method of weed control in organic agriculture, especially in row crops with low competitiveness against weeds like grain legumes. Cultivation of grain legumes generates significantly less greenhouse gas emissions compared to animal products and are beneficial for cropping systems.

The aim of this study is to explore agronomic options available for cultivating grain legumes using no-tillage in organic agriculture: cover crop mulch, crop residue retention and intercropping. This is done by reviewing literature and interviewing a crop production advisor. The transferability of the reviewed research results to Swedish pedoclimatic conditions is discussed. The results show that no-tillage is uncommon in organic farming in northern climates due to the lack of efficient alternative weed control methods. Using mulch is a common method of weed control in organic no-tillage. However, in Sweden the growing period is too short to achieve the amount of biomass needed for weed suppression through mulching. Intercropping has shown to be beneficial for controlling weeds and could be feasible in Sweden. More research in this area is needed to successfully implement no-tillage into organic grain legume farming in Sweden.

Keywords: no-till, conservation tillage, cover crops, intercropping, organic farming, grain legumes

Sammanfattning

Dagens lantbruk är ofta specialiserat, intensivt och beroende av bekämpningsmedel, konstgödsel och jordbearbetning. Jordbearbetning, speciellt plöjning, har visat sig ha en negativ inverkan på markhälsa, klimatet och markens biologiska mångfald. Ett alternativ till jordbearbetning är direktsådd där jorden inte störs förutom vid sådden. Införande av direktsådd i ekologiskt lantbruk skulle kunna göra det mer hållbart. Det är dock en utmaning eftersom jordbearbetning är den huvudsakliga metoden för ogräsbekämpning inom ekologiskt lantbruk, speciellt i radsådda grödor med dålig konkurrensförmåga mot ogräs som trindsäd. Odling av trindsäd ger upphov till betydligt mindre utsläpp av växthusgaser jämfört med animaliska produkter och har flera växtföljdsfördelar.

Denna litteraturstudie har som mål att utforska några av de odlingsåtgärder som kan användas i ekologisk odling av trindsäd med direktsådd: kompost av täckgrödor, bibehållande av skörderester och samodling. Detta görs genom en litteraturstudie samt en telefonintervju med en växtodlingsfådgivare. För- och nackdelarna av dessa metoder inom områden som markhälsa, orgäskontroll och ekonomi beskrivs. Det diskuteras även om direktsådd är lämpligt i Sverige. Resultaten visar att direktsådd är ovanligt inom ekologiskt lantbruk i kallare klimat på grund av brist på effektiva metoder för ogräsbekämpning. Att använda kompost som marktäckning är en vanlig metod för ogräsbekämpning i ekologisk odling med direktsådd. I Sverige är dock växtsäsongen för kort för att åstadkomma tillräckligt mycket biomassa för att bekämpa ogräs. Samodling har visat sig vara fördelaktigt för att kontrollera ogräs och kan vara genomförbart i Sverige. Mer forskning behövs inom området för att framgångsrikt kunna odla ekologisk trindsäd med direktsådd i Sverige.

Nyckelord: direktsådd, conservation tillage, täckgrödor, samodling, ekologisk odling, trindsäd

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1. Introduction

Soil tillage is an old practice which is still frequently used today. It is mainly used for changing the soil structure, incorporating crop residues and fertiliser, and weed control. The fine soil structure achieved by tilling creates good conditions for the germination and establishment of the crop (Carter 2005). However, tillage and especially ploughing, can lead to degradation of soils involving erosion, loss of soil biodiversity and decline in soil fertility (Carr 2017).

Conservation tillage is a term describing tillage systems that aim to reduce erosion and improve soil health. Other potential benefits are saving money, time and reducing greenhouse gas emissions. Conservation tillage can be different forms of tillage that leave more than 30% of the plant residue on the soil surface after planting. The most common types of conservation tillage are mulch tillage, ridge tillage, zone tillage, and no-tillage. Mulch tillage usually means shallowly disturbing the whole soil surface while zone tillage and ridge tillage only disturb one third or less of the soil. Reduced tillage and minimal tillage are also variants of conservation tillage, but they are not as clearly defined (Carter 2005).

No-tillage or zero tillage is the least invasive form of conservation tillage where the soil is left almost undisturbed. The aim is to always have a soil cover consisting of organic matter (Stichler *et al.* 2020). There is no seedbed preparation or ploughing after harvest. Instead, row cleaners or seed drills are used to place seeds and fertilizer in the soil and the plant residue is usually left on the surface (Baker *et al.* 2006). In conventional no-tillage, weeds and pests are usually controlled with pesticides. No ploughs, cultivators, disks or other such implements are used (Stichler *et al.* 2020).

No-tillage farming is uncommon in Sweden (SCB 2017) and not much research has been done about it. It could, however, be a potential method of reducing the environmental impact of agriculture and make it more sustainable.

Organic farming is another method of making agriculture more sustainable. Organic farms often have higher biodiversity than conventional farms which provides ecosystem services and benefits several plant- and animal species. Larger amounts of flowering plants and the absence of pesticides in the fields benefit pollinators and natural enemies to pests which leads to better pollination of some crops and decreased pest pressure (Winqvist 2012). Organic farming can also mitigate greenhouse gas emissions. One of the reasons is that synthetic fertiliser, which causes greenhouse gas emissions, is prohibited (Squalli & Adamkiewicz 2018).

Since pesticides are also prohibited in organic farming, weed control is solely achieved by soil tillage and tools for mechanical weed control like tine harrows and row hoes. However, these practices are inconsistent with the principle of no-tillage itself. Therefore, when implementing no-tillage in organic farming, weed control needs to be achieved by other means to prevent weeds from outcompeting the crop (Rühlemann & Schmidtke 2015).

Another issue is that the yield is usually lower for organic no-tillage farming compared to conventional farming (Halwani *et al.* 2019). Farmers also need more information, knowledge and resources about organic no-tillage farming. There is a lot of knowledge about no-tillage practices for conventional farming but little for organic farming (Beach *et al.* 2018).

A way of reducing the climate impact of agriculture and food is cultivation of grain legumes, such as beans, peas and lupines, for human consumption and using it to replace the animal protein in our diets. Production of animal products uses about 83% of the world's farmland and causes over 50% of agricultural greenhouse gas emissions while only providing 37% of the protein and 18% of the calories humans consume. Animals also require feed, such as soy and pasture, which contributes to about 67% of the world's deforestation. Much less farmland is required when cultivating grain legumes for human consumption instead of feeding it to animals. The greenhouse gas emissions are also reduced because of less transports and emissions from animal digestion (Poore & Nemecek 2018).

Legumes also benefit cropping systems in various ways. One advantage is biological nitrogen fixation which reduces the need for fertiliser and can also benefit the following crop. Legumes can also serve as break-crops that help to diversify the crop rotation and increase biodiversity in the field (Köpke & Nemecek 2010; Angus *et al.* 2015; Preissel *et al.* 2015).

Organic no-tillage farming is not common but exists in some parts of the world. In parts of North America and Southern- and Central Europe, organic soybean (*Glycine max*) is cultivated using no-tillage practice (Zikeli & Gruber 2017). In North America, organic corn (*Zea mays*) and wheat (*Triticum aestivum*) is cultivated using no-tillage (Beach *et al.* 2018). In Brazil, some farmers grow organic corn, beans and wheat using no-tillage (Altieri *et al.* 2008).

An increase in no-tillage practice in organic farming could be beneficial for soil biodiversity, climate change mitigation, soil health and hence contribute to improving the sustainability of cropping systems (Hanavan *et al.* 2010; Akbarnia & Farhani 2014; Wang *et al.* 2017; Beach *et al.* 2018; Thomas *et al.* 2019). Cultivation of grain legumes for food in these systems and using it to replace animal protein could reduce the amount of greenhouse gas emissions from food production (Poore & Nemecek 2018). Grain legumes also benefit cropping systems by fixating nitrogen from the atmosphere which decreases the need for fertilisers (Köpke & Nemecek 2010).

1.1. Aims and objectives

The aim of the study is to review the current knowledge about no-tillage practice in organic grain legume farming and to discuss the transferability of the research results to pedoclimatic conditions in Sweden. The following questions will be answered

1. What are the advantages and disadvantages of no-tillage practice?

2. What agronomic options are available for organic no-till grain legume production?

3. What are the advantages and disadvantages of these agronomic practices?

4. Under which pedoclimatic conditions are these agronomic practices feasible?

5. Which of those options could be implemented in Swedish cropping systems and what are the knowledge gaps to be answered for implementing such systems under Swedish pedoclimatic conditions?

Question 3 will be answered for each agronomic option in question 2. Questions 4 and 5 will be addressed in the discussion.

2. Material and methods

This literature review is based on information from scientific, peer reviewed articles. I have used SLU library's search tool Primo, Scopus and Google Scholar to find scientific articles and Google for popular scientific articles and other information. I think that scientific, peer reviewed articles are trustworthy and reliable.

I have also conducted a semi-structured phone interview with Marcus Willert at Hushållningssällskapet in Skåne about the prevalence of conservation tillage in Sweden. Marcus is a crop production advisor who has experience with reduced tillage in Swedish conditions. The initial questions were:

-What is the prevalence of no-tillage and reduced tillage in Sweden in conventional and organic systems?

-Why is it uncommon?

-Are grain legumes cultivated using no-tillage or reduced tillage in Sweden?

-Are agronomic options such as cover crop mulching used in no-tillage or reduced tillage in Sweden?

-What research and knowledge are required to successfully implement no-tillage in Sweden?

3. Results

3.1. Advantages and disadvantages of no-tillage practice

3.1.1. Greenhouse gas emissions

It is estimated that about 10-24% of the total greenhouse gas emissions come from agriculture. These emissions are mainly caused by livestock production, manure management and storage as well as soil management but also include practices like liming (US EPA 2015, 2016). Soil management practices such as crop residue management, application of organic and synthetic fertilizer as well as cultivation of organic soils have an impact on the emissions of greenhouse gases such as methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) (Tubiello *et al.* 2014).

According to a meta-analysis, the amount of average emitted CO_2 is about the same in conventional tillage and no-tillage systems across all soil types and climates . In arid climates though, no-tillage practice decreased the emissions by 9.9% (Huang *et al.* 2018). However, another meta-analysis found that the average CO_2 emissions were 21% higher in conventionally tilled systems and there was no significant difference between arid and humid climates (Chivenge *et al.* 2016).

N_2O emissions were generally about 10% higher in no-tillage systems compared to conventional tillage. In humid climates N_2O emissions were 12.3% higher under no-tillage practice. One possible cause is the increased microbial activity in undisturbed and moist soil. In fine textured soils the N_2O emissions were 32.2% higher in no-tillage systems than in conventional tillage systems. Such soils are usually poorly drained and therefore have a high rate of denitrification. (Huang *et al.* 2018)

In soils that have a net uptake of CH_4 there seems to be no significant difference between no-tillage and conventional tillage. In soils that have a net emission of CH_4, no-tillage reduced the emission by 15.5% on average compared to conventional tillage systems. In humid climates the emissions were decreased by 18.9% and the soil uptake increased by 47% in no-tillage systems compared to conventional tillage. (Huang *et al.* 2018)

3.1.2. Yield

Crop yield tends to be lower in no-tillage systems than in tilled systems although it can vary between different climates and conditions. A Swedish study found that crop yields in no-tillage were 5-20% lower compared to mouldboard ploughing (Arvidsson *et al.* 2014) while in another study, the yield was 21.6 % lower in no-tillage systems (Akbarnia & Farhani 2014). Comparable studies could show that yields decreased under no-tillage practice by 10.2% in arid climates and 7.5% in humid climates (Huang *et al.* 2018).

Across 47 European studies it was found that the crop yields in conventional reduced tillage were on average 4,5% lower than in conventional tillage while in conventional no-tillage yields were about 8,5% lower (Van den Putte *et al.* 2010). Another meta-analysis found that the yield reduction is even larger in organic reduced tillage. The results show that crop yield was on average 7,6% lower in organic reduced tillage systems compared to deep inversion tillage, more than 25 cm deep, across all climates and management practices (Cooper *et al.* 2016).

There are several causes for the yield reduction. One of the purposes of tilling is to create good conditions for sowing and crop emergence. Tilled soil is usually homogenous which enables planting all the seeds at the same depth leading to an even emergence and establishment. Tillage also breaks large aggregates and creates a fine structure which ensures good soil to seed contact (Van den Putte *et al.* 2010). In organic no-tillage farming, weed pressure often furtherly decreases the yield as the weeds take resources from the crop (Cooper *et al.* 2016).

3.1.3. Soil health

Soil health is a term describing the condition of a soil based on its physical, chemical and biological properties. A common definition is the “capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health” (Doran & Parkin 2015). Important aspects of soil health are soil carbon storage, organic matter, aggregate stability, water-holding capacity, biological activity and plant nutrients (Reeve *et al.* 2016).

The effects of no-tillage systems on soil health vary between different climates and other conditions. A study in a warm and humid climate showed that no-tillage systems have a higher biodiversity of soil microorganisms, such as fungi and bacteria, than conventional tillage systems. The combination of no-tillage and organic farming had an even higher biodiversity and biomass of microorganisms (Wang *et al.* 2017). No-tillage farming also benefits earthworms, fungi- and bacterial diversity and arbuscular mycorrhiza (Beach *et al.* 2018). This is important as these microorganisms and animals help to decompose plant residue and make nutrients available to the crops (Wang *et al.* 2017).

A study in a maritime climate with cool, wet winters and warm, dry summers also found that no-tillage is beneficial for the soil health. The stability of wet aggregates was greater in no-tillage systems than in ploughed systems, which makes the soil more resistant to erosion. During heavy rainfalls, aggregated soil structure helps prevent surface runoff and flooding (Thomas *et al.* 2019). No-tillage systems also have a smaller risk of soil compaction because of fewer tractor trips during the growing season, which contributes to a healthy soil structure (Akbarnia & Farhani 2014).

The available water capacity was shown to be 9% higher in no-till systems compared to conventional tillage. This is beneficial in regions where the summers are hot and dry. The amount of active carbon was found to be 24% higher in no-tillage than in conventional tillage systems which benefits the microorganisms is the soil (Thomas *et al.* 2019).

A meta-analysis about reduced tillage in organic systems showed that the soil carbon stocks were higher in reduced tillage and no-tillage systems compared to conventional tillage. On average, soil carbon stocks were 143 g/m^2 higher in reduced tillage systems (Cooper *et al.* 2016).

3.1.4. Agronomic practice

Implementing no-tillage requires new equipment, knowledge and a different farming approach. The farmer must learn how to handle problems that might appear and plan their crop rotation carefully. When switching from conventional tillage to no-tillage, new species of weeds and pests may appear while others disappear (Baker *et al.* 2006). For weed control, dead plant mulch can be used to suppress weeds in no-tillage systems (Teasdale & Mohler 2000). To control pests, new methods may also be required (Baker *et al.* 2006 s.9).

In some cases, no-tillage practice can help to control pests. An example is the pea leaf weevil (*Sitona lineatus*) which is a common pest in pea crops in North America and Europe (*ArtDatabanken SLU*; Hanavan *et al.* 2010). A study has shown that in early May there were significantly less adult pea weevils in no-tillage compared to conventionally tilled plots. In late May there was no significant difference. The number of larvae was significantly lower in no-tillage plots compared to conventionally tilled plots in late June. There was no significant difference between the tillage methods in early July. The cooler soil temperature and delayed crop emergence and development in the no-tillage plots are thought to have suppressed the pea weevil (Hanavan *et al.* 2010).

3.1.5. Economy

No-tillage systems are more time and labour efficient than conventionally tilled systems and therefore more profitable in the terms of worker costs (Triplett 2002). Since no-tillage systems require less machine trips than conventional tillage, the amount of fuel consumption is also smaller. No-tillage uses, in some cases, approximately ¼ of the amount of fuel required for a conventional tillage system. However, this varies between different types of soils but in most cases, no-tillage systems use significantly less fuel than conventionally tilled systems (Akbarnia & Farhani 2014).

If a farmer wants to switch from conventional tillage to no-tillage, they will probably need different machines and equipment than before. A seed drill that can drill into the untilled soil is essential and in some cases, a larger tractor might be required to operate the drill (Baker *et al.* 2006 s.7). New equipment can be a big investment and may represent a serious obstacle for some farmers to adopt no-tillage practices.

3.2. Prevalence of reduced- and no-tillage practice in Sweden

The prevalence of no-tillage farming in Sweden is very low (SCB 2017) with only about five conventional Swedish farms practicing it today. However, about 10-20 conventional farms are practicing reduced tillage and own direct seeding machines. These farms could start practicing no-tillage in the future. Practices such as strip tillage and reduced tillage are more common, especially in Skåne, southern Sweden. 20-30% of the farmers in Skåne do not use the plough at all, and about 90% practice reduced tillage (without ploughing) at some point in their crop rotation while only using the plough occasionally. One crop that is often sown without previous ploughing is winter canola (*Brassica napus*) following cereals. Sometimes, winter wheat is also sown without ploughing (Willert 2020).

There are, probably, no organic farmers who practice no-tillage in Sweden today. Managing weeds in organic no-tillage farming is difficult because of the lack of alternatives to herbicides that work under the pedoclimatic conditions. Therefore, the herbicide glyphosate is usually used when practicing reduced- or no-tillage in conventional agriculture Sweden. Another challenge is disease control without pesticides or ploughing (Willert 2020).

In conventional farming, faba bean (*Vicia faba*) has been successfully cultivated using strip tillage in southern Sweden. After a ley was terminated using glyphosate, faba bean was seeded without previous tillage. This strategy resulted in less weeds partly because of the ley's weed suppression but also that weed seeds in the soil were not exposed to sunlight by tillage and consequently not stimulated to germinate (Willert 2020).

3.3. Cover crop mulch based no-tillage

Cover crop mulch-based no-tillage is a method that uses mulched plant material as a soil cover. Typically, a cover crop is planted in the autumn and terminated in the spring. In organic farming, this is done using a roller crimper or a similar tool while in conventional farming herbicides can be used. Then the cash crop is planted into the cover crop mulch. The mulch suppresses weeds by blocking light, being a physical barrier and, depending on the cover crop species, by releasing allelochemicals. An example for a cover crop mulch based no-tillage system is the direct sowing of soybean into rye (*Secale cereale*) mulch, practiced in parts of the United States (Wallace *et al.* 2017)

3.3.1. Weed control

Cover crops are important for managing weeds in organic no-tillage systems. In a study from USA, organic soybean was grown under mulch-based no-tillage. Rye was planted in the autumn and terminated in spring; the biomass produced varied between the plots. Between 10 854 kg/ha and 4 450 kg/ha of rye biomass was produced during the experiment in different plots and years. After terminating the rye, soybean was planted into the mulch. The results showed that in plots with the highest rye biomass, 10 854 kg/ha and 9 526 kg/ha, the weed suppression was enough to maintain yield equivalent to the weed free plots (control). Rye residue also contains allelopathic substances which can furtherly suppress weeds (Smith *et al.* 2011).

Plants with allelopathic abilities such as rye release phytotoxic substances (allelochemicals) into the soil when decomposing. One of the most important allelochemicals in rye are benzoxazinoids. When seeds are exposed to benzoxazinoids their germination can be inhibited and if seedlings are exposed their growth may be slowed down. The main mechanism of benzoxazinoids is generation of Reactive Oxygen Species causing oxidative stress in plant cells. This damages cell membranes, causes lipid peroxidation and protein oxidation. Important processes in the plant such as photosynthesis, electron transport and protein synthesis are affected. Densities of ribosomes, mitochondria and dictyosomes decrease in the plant. Further, lignin accumulation and stability of the cell walls are increased which causes slower growth. A degradation product of benzoxazinoids, benzoxazolinone, can block the formation of lateral roots which inhibits plant development. If the plant is exposed to high concentrations of benzoxazinoids the effect is lethal (Schulz *et al.* 2013). Benzoxazinoids and similar substances released from plant residues usually reach to a soil depth of about 2-3 cm where about 90% of the weed seed bank is (Altieri *et al.* 2011).

The weed suppressive effect also depends on the cover crop biomass. Research has shown that the mulch biomass should be over 8000 kg/ha and over 10 cm thick to achieve a weed suppression of 75% or higher (Teasdale & Mohler 2000). Another study found that a 50% reduction of cover crop biomass resulted in three times more weeds in organic soybean plots (Zinati *et al.* 2017).

In an experiment in Brazil, different cover crop species and mixtures were examined for cultivation of common bean (*Phaseolus vulgaris L.*). The results showed that a mixture of rye, vetch (*Vicia villosa*) and fodder radish (*Raphanus sativus subsp. oleiferus*) produced a higher biomass compared to rye alone. This led to significantly higher weed suppression due to a thicker layer of mulch on the soil surface. A mix of species often uses the resources more efficiently since different species have different requirements which allows them to produce more biomass (Altieri *et al.* 2011).

3.3.2. Cash crop and cover crop establishment

A possible problem in this kind of system is planting of the cash crop seeds. The seeds must be placed in the soil under the mulch layer to achieve sufficient seed-to-soil contact for germination. Also, the transpiration of the cover crop may dry the soil so that the seeds cannot germinate even if they are placed correctly. In spring, the soil temperature under the mulch is usually lower than in uncovered and tilled soil which can delay the sowing date (Wallace *et al.* 2017).

The establishment of cover crops such as rye has shown to be better when a seedbed is prepared using tillage compared to direct seeding (Wallace *et al.* 2017). This is commonly practiced among organic farmers who plant cover crops. Tillage can help manage existing perennial weeds and preparation of a false seedbed kills emerging weeds and lowers the weed seedbank. This reduces competition between the cover crop and weeds (Vincent-Caboud *et al.* 2019). In no-tillage systems, the establishment might not be optimal. This can lead to less biomass production and a thinner soil cover after termination reducing the weed suppressive effect (Wallace *et al.* 2017).

Studies show that rye mulch does not interfere with the establishment of soybean crop even at sites with more than 10 000 kg biomass mulch per hectare when sowing with a no-till planter. The stand counts and plant heights were not affected by rye mulch (Smith *et al.* 2011). The establishment and plant density of organic soybean planted in rye mulch was not significantly different from where the mulch was tilled a few weeks before soybean planting (Bernstein *et al.* 2011).

3.3.3. Method of cover crop termination

There are different options available for terminating cover crops. Two examples are the roller crimper and the flail mower. The roller crimper crimps the stems of the cover crop so it forms a mat while the flail mower cuts the plants into small pieces (Creamer *et al.* 1995; Mirsky *et al.* 2009; Davis 2010). There is indication that the roller crimper may be more effective in terms of weed control than the flail mower when cover crop biomass is high, while their effect is similar at low cover crop biomass ((Smith *et al.* 2011).

3.3.4. Economy and yield

A study comparing the yield of organic soybean in different tillage and cover crop systems showed that the yield across years was 32% greater in plots tilled before planting than in no-tillage rye mulch plots. The tilled systems had 9% more variable costs than no-tillage systems but was 36% more profitable per hectare. This was mostly because of the greater yield in the tilled plots. The yield was not significantly affected by the method of rye termination in no-tillage systems (Bernstein et al. 2011).

3.3.5. Soil health

The carbon to nitrogen ratio (C:N ratio) describes the mass of carbon in proportion to the mass of nitrogen in organic matter, an important factor influencing the decomposition of organic material. Soil microorganisms have a C:N ratio of 8:1. To stay alive they need to consume material with a C:N ratio of about 24:1 where 16 parts of the carbon is used for energy and the rest for maintenance. If plant material with a high C:N ratio such as wheat straw (80:1) is added to the soil the microorganisms will not be able to break it down since there is a shortage of nitrogen. To balance the C:N ratio they will use nitrogen from the soil and therefore immobilise it. While the microorganisms are alive this nitrogen will not be available to plants. If a material with a low C:N ratio is added, the microorganisms will leave the excess nitrogen in the soil and make it available to plants. The lower the C:N ratio the faster the material will decompose, since it is easier for the microorganisms to leave excess nitrogen than to collect it from the soil (USDA 2011).

An experiment was conducted to study the immobilisation of nitrogen by rye residue and its effects on weeds and soybean crop. The results showed that rye terminated using a roller crimper resulted in a significantly lower amount of soil inorganic nitrogen and plant available nitrogen compared to conventionally tilled rye. The high C:N ratio, about 22:1-28:1 in roots and 60:1-80:1 in above ground biomass, causes nitrogen immobilisation and slow decomposition of the rye residue. The soybean yield was not significantly different between roller crimped rye and conventionally tilled rye which suggests that the early development of soybean was not negatively affected by the low nitrogen levels in the roller crimped rye plots. When the nitrogen fixation began in soybean at about 6 weeks after planting the crop could fixate enough nitrogen on its own (Wells *et al.* 2013).

One of the weed species studied was pigweed (*Amaranthus retroflexus*). The C:N ratio of pigweed in the experiment was affected by the method of rye termination. In two of three locations the C:N ratio was significantly higher in plots where rye was terminated using a roller crimper compared to plots where it was tilled. Generally, the number of weeds was lower in the roller crimped rye plots than the weedy check plots. However, the number of weeds was significantly higher in the roller crimped rye plots compared to conventional tillage plots. This suggests that an environment low in nitrogen can suppress weeds without suppressing the legume cash crop which can fixate its own nitrogen (Wells *et al.* 2013).

3.4. Crop residue based no-tillage

Crop residue based no-tillage is a method where large amounts of crop residue are left on the soil surface after harvest and used as a ground cover (Arvidsson *et al.* 2014).

3.4.1. Crop establishment

The cash crop establishment is sometimes affected by residue from the previous crop. A Swedish study found that in no-tillage systems with crop residue retention, crop emergence was poorer compared to reduced tillage and conventional tillage. This was especially noticeable in spring sown crops. Springs in Sweden are usually dry so without a prepared seedbed the soil-to-seed contact might be poor and impair emergence (Arvidsson *et al.* 2014). A large amount of crop residue can impair germination as it slows down the drying and warming of the soil in the spring (Morris *et al.* 2010).

3.4.2. Greenhouse gas emissions

In an experiment in plots under no-tillage and with plant residue, the emissions of N_2O were lower compared to conventional tillage. The emissions of CO_2 were lower in plots under no-tillage compared to conventional tillage. However, in plots with plant residue on the soil surface the emissions were higher than in plots where it had been removed. In plots with plant residue the total CO_2 emissions were higher than in plots without plant residue. This could be caused by the soil temperature being lower under the plant residue which slows down decomposition and other microbial processes that generate CO_2 (Langeroodi *et al.* 2019).

3.4.3. Economy and yield

Crop residue retention has shown to have a positive effect on crop yield in dry climates. A study showed that implementing no-tillage practice without crop residue retention and crop rotation reduced the crop yields with about 10% in all climates. However, when combining no-tillage with residue retention and crop rotation, a yield increase of almost 10% was observed in dry climates (Pittelkow *et al.* 2015). In colder climates, such as Sweden, the yield in no-tillage systems with crop residue retention was 5-20% lower than conventional tillage (Arvidsson *et al.* 2014).

3.4.4. Soil health

An experiment was conducted in Iran in a soybean and durum wheat (*Triticum durum*) rotation. The results showed that no-tillage and wheat residue both had a positive effect on soil moisture while growing soybean. Plots under no-tillage treatment had a 1.5%-3.1% higher soil moisture than those under 30 cm deep tillage. In plots where wheat residue was left on the surface, the soil moisture was 2%-3% higher than in plots without residue. The soybean yield was lower in plots with plant residue compared to plots without residue. A possible cause is the pedoclimate under the residue, where it is cooler and moister than on bare soil (Langeroodi *et al.* 2019).

3.4.5. Plant health

The survival of plant pathogens can be affected by the method of tillage. Pathogens that infect plant parts above soil survive less well when they are buried. The root pathogens survive and grow better when buried. When using no-tillage methods and leaving plant residue on the surface, the risk of disease spreading increases. Even in a crop rotation, some pathogens that infect many different crops such as *Fusarium spp.* can survive on soybean residue and infect maize and wheat (Almeida *et al.* 2001).

Swedish studies found that crop residue retention can cause a 5-20% reduction in yield in reduced tillage and no-tillage systems compared to conventional tillage. This is probably due to pathogens transferred from the residue to the crop, for example: *Septoria nodorum*, *Septoria tritici*, *Fusarium* species and eyespot (*Cercosporella herpotrichoides*) (Arvidsson *et al.* 2014).

3.5. Intercropping

Intercropping is a practice where two or more crops are grown together in the same field (Vandermeer 1992). It is believed that humans have practiced intercropping ever since the domestication of plants. However, it is rarely used in today's specialised agriculture. Instead, intercropping is often used by small scale farmers in the tropics and often involves at least one grain legume (Boudreau 2013). There is not much research combining intercropping and no-tillage practice. However, this combination has been tested with successful results (Narayan Khatri & Tika Bahadur Karki 2015).

3.5.1. Weed control

Grain legumes like peas are weak competitors to weed pressure. However, when they are intercropped with cereals competitiveness against weeds increases and reach similar competitiveness as a cereal crop. This is probably caused by more efficient use of resources by the intercropped plants. The space, water, light and nutrients in the field are used by the crops in different ways and less resources are available for the weeds (Bedoussac et al. 2015).

3.5.2. Economy and yield

A study was conducted in Nepal to examine how different tillage methods, plant residue management and intercropping affected soybean and maize yield and economics. The results showed that intercropping had a significant effect on both maize and soybean yield. In plots where maize was grown alone, the yield was 4,76 tonnes/ha while in plots where it was grown together with soybean the yield was 4,27 tonnes/ha. Intercropping reduced the maize yield with about 10%. The thousand-seed weight and yield of soybean were also significantly affected by intercropping (Narayan Khatri & Tika Bahadur Karki 2015).

The land equivalent ratio (LER) is a concept that describes the relative land area required for crops in monoculture to produce the same yield when intercropped. If the LER value is higher than 1 it means that the crops would require more land when grown alone compared to intercropping to produce the same yield (Mead & Willey 1980). In the earlier mentioned intercropping experiment, the LER was 1,38 which indicates that intercropping soybean and maize was more space-efficient than growing them by themselves. It was also shown to be more economic. The gross return, net return and Benefit: Cost-ratio (B: C-ratio) were higher in intercropping systems compared to crops grown alone. The highest B: C-ratio (2.77) was observed in an intercropping plot under no-tillage and with plant residue removed while the lowest B: C-ratio (2.01) was observed in a sole maize conventional tillage with residue left on the surface. This shows that no-tillage intercropping systems can be more profitable than conventional monoculture (Narayan Khatri & Tika Bahadur Karki 2015).

A review of organic grain legume and cereal intercropping experiments conducted in France and Denmark also showed positive effects of intercropping. However, it is worth to note that tillage was used in these experiments. The crops in these experiments were soft wheat, hard wheat (*Triticum turgidum*), barley (*Hordeum vulgare*), faba bean and pea (*Pisum sativum*). The LER-values in these experiments varied between 0.93 and 2.41 with an average of 1.27. 50% of the observed LER-values were between 1.06 and 1.36. The results also showed that intercropping in organic farming can increase the grain yield. The total grain yield of the intercrops, cereal + grain legume, were higher than the mean yield of these crops when grown alone. It also seems that intercropping is more beneficial in systems where the yield of one or both crops is relatively low when grown alone such as in organic farming. Generally, results showed that when nitrogen fertilizer is applied to grain legume-cereal intercrops the growth and yield of the legume crop were significantly reduced while those of the cereal crop increased only a little (Bedoussac *et al.* 2015).

3.5.3. Soil health

A study was conducted in Brazil to examine the effects of intercropping and minimal tillage (shallow ploughing and manual tools) on soil health compared to natural vegetation. Results showed that intercropping and minimum tillage increased biomass input with between 13.7 Mg/ha and 35.9 Mg/ha while in native vegetation it was about 3.7 Mg/ha. Intercropping combined with minimum tillage maintained, and in some cases increased, the soil organic carbon and soil organic matter. The annual carbon input was between 6.4 Mg/ha and 17.9 Mg/ha. This was probably caused by low disturbance of the soil and input of crop residue and manure (Maia *et al.* 2019).

3.5.4. Plant health

Intercropping has been shown to be beneficial for plant health by several studies (Boudreau 2013). Danish studies showed that barley benefits from intercropping with pea, lupin (*Lupinus spp.*) and faba bean (Naudin *et al.* 2009). Intercropping can also be beneficial for the legume crop. Lupin intercropped with barley had 78% to 87% less brown spot (*Pleiochaeta setosa*) compared to sole lupin crops. Intercropping pea and barley resulted in a 20% to 40% reduction of *Mycosphaerella pinodes* infection in the pea compared to sole pea (Hauggaard-Nielsen' *et al.* 2008). A study in China showed that wheat intercropped with faba bean resulted in a 26% to 49% reduction of wheat powdery mildew (*Blumeria graminis*) compared to wheat grown alone (Chen *et al.* 2007).

There are several factors that could possibly influence disease spreading in intercropping. One of them is wind, by which many fungi spread their spores (Boudreau & Mundt 1992). When one of the intercropped plants is not susceptible to a disease, it can intercept spores and protect the other plants. If the crops have different height or leaf density it can also cause wind turbulence and changes in velocity in the field which could lead to less disease spreading (Perrin 1977). Intercropping may also affect other factors such as raindrop dispersal, vector dispersal and microclimate. Research has, many times, shown the positive effects of intercropping on plant health but the mechanisms are not fully understood (Boudreau 2013).

3.6. Perennial grain legumes

All the grain legumes cultivated for food today are annual. However, the benefits of legumes in the crop rotation, such as nitrogen fixation, could be even larger if they were perennial. At The Land Institute in USA, there are ongoing trials exploring the possibilities of domesticating new perennial legume species that could be suitable for farming in temperate climates. Perennial grain legumes could decrease the need for nitrogen fertiliser while keeping the grain yield stable and reliable (The Land Institute 2020).

For the Swedish climate, lupins (*Lupinus subg. Platycarpos)* are especially interesting because of their cold-and drought tolerance, early emergence and adaptability to the short growing season of Sweden. However, the high alkaloid content could be an issue when breeding perennial grain legume species for human consumption (Isendahl 2019).

4. Discussion

Most of the articles cited in this study describe experiments that were conducted in areas where the climate is significantly different from Swedish conditions. Therefore, most of the results are not directly transferable. There is a need for more research about no-tillage farming in northern countries. There are, however, plans to conduct experiments about direct seeding, no-tillage and weed control without using glyphosate in southern- and middle Sweden (Willert 2020).

The low prevalence of no-tillage farmers in Sweden seems to be caused mainly by the climatic conditions. In Sweden, the early springs and autumns are usually cold and wet. Tillage can help to warm and dry the soil (Morris *et al.* 2010) so that the farmer can plant the seeds earlier and fully use the short growing season. Especially in middle Sweden, farmers rarely have time to wait with the sowing which could make no-tillage a risky strategy. In southern Sweden, the growing season is longer, and the farmer has more time to wait for the soil to warm up and dry when using no-tillage. A potential alternative is strip-tillage where the soil is warmed up in the tilled strips. Still, conservation tillage and no-tillage may require more planning and different crop rotations and strategies than conventional tillage. The risk of a lower yield caused by late seeding and increased disease- and weed pressure stops farmers from adopting no-tillage practice (Willert 2020).

Managing weeds in organic no-tillage farming systems requires ground cover, such as mulch from cover crops or high amounts of crop residue. In cover crop mulch based no-tillage, it is essential to produce enough biomass to suppress the weeds. The minimum for efficient suppression seems to be around 8000-9000 kg biomass/ha (Teasdale & Mohler 2000; Smith *et al.* 2011). Most of the experiments cited in the results were conducted in Brazil, USA and middle- and southern Europe where the growing season is longer than that of southern Sweden (FAO). In Sweden, especially in middle- and northern Sweden, the growing season is too short for the cover crops to produce the biomass needed for efficient weed suppression. (Willert 2020).

Another problem in organic no-tillage farming is controlling diseases. The crop residue left on the soil surface can spread diseases between crops in the rotation. In Sweden, plant pathogens such as *Fusarium*- and *Septoria* species can be spread this way (Almeida *et al.* 2001; Arvidsson *et al.* 2014). These can be difficult to manage without the use of conventional fungicides and tillage (Willert 2020).

In cover crop based no-tillage, the cover crop species can be chosen to fit the conditions. Some species and mixtures produce more biomass than others while some species have allelopathic abilities (Altieri *et al.* 2011; Schulz *et al.* 2013). Most of the research has been done about the physical weed suppression abilities of plant mulch and not much about chemical effects, such as allelopathy. Perhaps it could be a way of suppressing weeds in colder climates as in Sweden, where it is difficult to produce enough cover crop biomass.

There is also ongoing research about different cover crop species mixtures for Swedish conditions which could lead to creating better mixtures for the climate and making it easier to produce enough biomass to suppress weeds (Willert 2020).

Climate change could result in a longer growing period in Sweden. According to the Swedish Meteorological and Hydrological Institute, the growing period in southern Sweden could be between 30 and 90 days longer in year 2100 than it is today (SMHI 2020). If this is the case, it would become much easier to grow cover crops for mulch in Sweden and successfully practice cover crop based no-tillage.

Climate change could, however, have other effects on cropping systems during this century. It is expected that precipitation will increase during the winter and decrease during summer. The risk for extreme weather such as storms and flooding could increase. These conditions will probably affect agriculture negatively. A warmer climate allows cultivation of new species but also benefits invasive weeds, making them more difficult to control (Henriksson 2009).

No-tillage practice, especially where the soil is covered by plant residue, has shown to reduce the risk of flooding and soil erosion and retain more moisture during dry periods compared to conventionally tilled systems (Langeroodi *et al.* 2019; Thomas *et al.* 2019). Therefore, no-tillage could be important for reducing the negative impact of climate change on agriculture.

Conservation-and no-tillage are often described as climate friendly alternatives to conventional tillage. However, the effect of no-tillage practice on greenhouse gas emissions is not completely understood. Some studies show that no-tillage reduces greenhouse gas emissions, while other state that there is no difference between different practices or even that no-tillage increases greenhouse gas emissions. The greenhouse gas emissions seem to be highly affected by climatic conditions, soil types, crop rotation and microbial activity. It is therefore important to take these factors into consideration when comparing different tillage practices (Chivenge *et al.* 2016; Huang *et al.* 2018).

Intercropping of grain legumes and cereals has shown to be beneficial for weed control and plant health (Hauggaard-Nielsen *et al.* 2008; Naudin *et al.* 2009; Bedoussac *et al.* 2015), making it possible to avoid pesticides and ploughing without risking the yield. Depending on the choice of crops, intercropping can be less dependent on the length of the growing period compared to cover crop cultivation which could make it feasible in Sweden's cropping systems. Intercropping is also more space efficient and, in some cases, more economically feasible (Bedoussac *et al.* 2015; Narayan Khatri & Tika Bahadur Karki 2015) compared to cover crop mulch or crop residue based no-tillage (Bernstein *et al.* 2011; Arvidsson *et al.* 2014).

Another system that could work in Sweden is perennial intercropping. Species suitable for colder climates are being explored by scientists (The Land Institute 2020) which could make cultivation in Sweden possible. Perennial intercrops could be an interesting weed management strategy in organic no-tillage farming. Considering the weed- and pest suppression benefits annual intercropping can provide, perennial intercrops could be even more efficient.

4.1. Conclusion

Today, no-tillage is not practiced in organic farming in Sweden. This is mostly due to the lack of efficient weed- and disease control methods and shortness of the growing period. Cultivation of cover crops for mulch has not been successful so far because of the short growing period. However, further research and adaptation to Swedish conditions might make it possible in the future. Warmer temperatures and a longer growing period caused by climate change could create better conditions for cover crop cultivation in Sweden.

Intercropping could be a method of controlling weeds and diseases in organic no-tillage farming in Sweden. The intercrops can be chosen to fit the short growing season and cultivated in organic, no-tillage systems with a smaller risk of yield loss compared to cover crop mulch- and crop residue based no-tillage.

More research about no-tillage practice in organic farming is needed to be able to implement it in northern countries such as Sweden and to fully understand processes and mechanisms in the soil and plants. Cover crop mulch based no-tillage seems to be the most researched practice today. Crop residue based no-tillage is quite similar, but it has not been researched as much. For intercropping, there is only little research about combining it with no-tillage practice and little about no-tillage organic intercropping of grain legumes. Interesting areas for future research could be exploring allelopathy and its efficiency for weed control, finding new cover crop species for northern climates and furtherly exploring intercropping for no-tillage systems.

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