Facilitating reduced- and no-tillage organic grain legume production systems through integration of cover crop mulch for weed control

Final project report

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Summary

Aim of this research project was the development, testing and dissemination of weed management strategies for reduced- and no-tillage organic grain legume production. This was achieved by the strategic and combined use of biological characteristics of cover crops and associated ecological mechanisms facilitating soil nitrogen management and weed suppression. Early flowering cultivars of green rye were used as cover crop, providing rapid biomass production and hence strong competition for light, water and nutrients, suppressing weeds during autumn and early spring. Roller crimping was used for terminating and mulching the rye in spring. The mulch cover was expected to provide a physical barrier and source for allelopathic substances, suppressing weed emergence throughout the grain legume cropping season. The high C:N ratio of the rye mulch might also lead to a nitrogen deficiency, giving the grain legume a further growth advantage over perennial and annual weeds. This project was seeking to understand the mechanisms and consequences of this management system on weed-crop competition in general and to provide a holistic view on the interplay of soil nitrogen availability, weed population dynamics and crop performance.

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1. Project background

Reduced- and no-tillage practices are aiming for minimal soil aggregate disruption and leaving at least 30% of the soil covered with crop residues. While no-tillage practice is leaving the soil completely undisturbed, reduced tillage practice is allowing non-inversion tillage measures with e.g. tines or discs[1]. Both, reduced- or no-tillage practice can provide numerous benefits for agro-ecosystems, such as **reduction in soil erosion, enhanced storage or retention of soil organic matter, improvement of soil quality and reductions of energy consumption for crop production**[2]. Weeds are the major yield-limiting factor in organic agriculture in general and in grain legume production in particular[3]. Grain legumes such as field bean, soybean and lupine are particularly susceptible for weed competition, due to row cultivation with wide row spacing and their slow youth development[4]. P**erennial weed** species like *Cirsium arvense, Sonchus arvensis* or *Elymus repens* are in particular difficult to control in grain legume crop stands, why continuous no-till organic farming is regarded as impossible so far. Inversion tillage is still the main pillar of current weed control strategies due to a lack of effective and feasible alternatives, leaving organic farmers with a dependence on the plough which is preventing them to utilize the afore mentioned ecosystem services and agronomic benefits. Innovative approaches for the application of reduced- and no-tillage practice in grain legumes are needed and require a thorough scientific and practical assessment.

Previous research has demonstrated that a combination of autumn sown cover crops combined with direct seeding of grain legumes in spring can provide adequate control of annual weeds in agricultural and horticultural crops[5]. In organic no-till grain legume production, winter rye (Secale cereale L.) has shown the greatest potential as cover crop for weed suppression[6–8]. The effect of rye cultivar choice[9], sowing time, seed rate, timing and method of termination[10–12] was subject of thorough scientific studies in recent years. The effect of weed suppression through rye is based on physical as well as chemical mechanisms. When kept on the soil surface, rye mulch is providing a physical barrier for weeds to emerge. Furthermore, rye biomass is containing a range of benzoxazinoid compounds and phenolic acids which are known to be allelochemicals with strong weed suppressive effect[13,14]. Previous research could show that soybean is not affected by the afore mentioned allelochemicals, for field bean and lupine this has to be shown. Two other effects of winter rye that directly can influence weed growth are related to nitrogen (N) dynamics: i) Winter rye acts as catch crop during winter, accumulating available soil N, and thus pre-empting the plant available soil N pool in spring compared to winter fallow (pre-emptive competition)[15]. ii) The high C:N ratio of rye mulch can lead to N immobilization, further reducing plant available soil mineral N for periods of up to several months [16–18].

Ecosystem services of cover cropping systems beyond weed control

Cover crops help to protect surface- and groundwater quality by decreasing soil erosion, nitrogen leaching, and phosphorus runoff [19,2]. Using cover crops to improve N retention through scavenging and biological N fixation can lower fertilizer costs[21]. Increased N conservation and addition through nitrogen fixation through cover crops reduces the reliance of organic cropping systems on animal manure thereby reducing excessive P loading[22]. Furthermore, the cover crop–based organic rotational no-till system relies on terminating cover crops at anthesis, which can result in one to two orders of magnitude greater root and shoot biomass relative to cover crops grown in traditional organic or conventional cropping systems[22].

From theory to practice: Utilising ecological mechanisms for weed management

We are aiming to utilise the described biological and ecological characteristics of rye, for suppression of difficult to control perennial weed species. After mulching in spring, rye straw will provide a physical barrier and light deprivation as well as a source for allelochemicals preventing the emergence and growth of both annual and perennial weeds. The combined effect of pre-emptive competition by rye for soil N and the high C:N ratio of rye that cause surface N immobilisation during the legume growing season will induce a N-deficit environment for weeds, hampering their growth and development. Pre-emption of soil N and N immobilisation will not affect the grain legume crop as long as a sufficient infection with Rhizobia can be achieved.

Hypotheses and aims

In the proposed experimental approach, we are testing five main hypotheses:

1) Depending on cover crop management strategy in spring, cover crops are slowing down soil warming in spring, which delays germination and emergence of direct sown grain legumes.
2) The use of rye mulch is supressing the emergence and growth of perennial and annual weed species significantly.
3) The use of rye mulch for weed control does have an impact on crop and weed phenology as well as on weed-crop competitive dynamics.
4) The proposed cover crop – direct seeding systems are reducing mineral N availability after spring and throughout the legume growing season while increasing mineral N availability in the subsequent cereal crop.
5) The proposed cover crop – direct seeding systems increase the profitability of organic grain legume production.

2. Methods

Field experiments were set up in two regions located in central Sweden with contrasting soil texture. Field bean and lupine were compared as the main grain legume crop. A non-leguminous reference crop (buckwheat) was included to account for N effects. The experiments were comprising four main treatment combinations for testing the raised hypotheses:

I. no cover crop, ploughing before grain legume/reference crop sowing in spring, weed control with up to three hoeing passes (**inversion tillage/standard farmers practice**)
II. **ultra-shallow tillage** of cover crops in spring followed by direct seeding of grain legumes/reference crop, mechanical weed control with up to three hoeing passes (**reduced tillage strategy with hoeing**)
III. **roller crimping** of cover crop at anthesis in spring followed by direct seeding of grain legumes/reference crop, no additional mechanical weed control (**no-till strategy with roller crimping, late sowing**)
IV. **interseeding** of grain legumes/reference crop into standing cover crop followed by roller crimping shortly after emergence of the interseeded grain legume (**no-till interseeding strategy with roller crimping, early sowing**)

Green rye in treatment II-IV was sown in beginning of September and terminated in spring. The resulting 16 treatment combinations were arranged in a randomised block design with four replicates per treatment. Plots had a width of 9 m and a minimum length of 25 m. The experiments were repeated over two years.

Data collection

Biomass and C:N ratio of the cover crop was measured in spring after termination. Soil temperature and soil moisture was monitored in all treatments and throughout the experimental phase including winter fallow between grain legumes and subsequent spring cereals. Soil total N and mineral N content was determined after termination of winter rye and after grain legume harvest. Nitrogen fixation based on the natural abundance of 15N and N harvest index of the legumes was measured to allow N budget calculations of the legumes under different management strategies[2].

Weed and crop density and biomass accumulation was assessed at crop flowering. Crops were harvested for yield, yield parameter and quality determination.

3. Results summary

3.1 Soil mineral N availability after rye termination at grain legume seeding

Hypotheses I) was confirmed by the experiements as the treatments including rye as a service crop before seeding of grain legumes in spring has significantly decreased the soil minral nitrogen content in spring compared to the treatment without rye. The decomposition of rye mulch during the grain legume growing season has resulted in an increased soil mineral nitrogen content at harvest.
The increase in soil mineral nitrogen content after harvest will either require a winter annual crop as following crop or a winter hardy catch crop until the following spring in order to prevent nitrogen losses through leaching.

3.2 Absolute yield, protein yield and nitrogen fixation

Lupine growth and development was severely impeded by the rye mulch evn in treatment II) where the rye bimass was incorporated into the top soil layers. Therefore it was not possible to collect meaningful yield and quality data for this crop.
Faba bean yield was highest in treatment II) and lowest in treatment III) when compared to the standard treatment I). The significant difference between treatment II) and III) can be explained by the delayed seeding in treatnment III) and the resulting shortened vegetative and generative groth period.
The analysis of grain protein content as well as the 15N isotope analysis for determination of nitrogen derived from air has just been completed and the statistical analysis is in progress.

3.3 Effects on weed control

The effect of rye mulch on weed biomass accumulation and weed species diversity differed significantly between treatments but also between sites. When terminated with a roller crimper, rye mulch has significantly reduced the accumulation of weed biomass during the grain legume growing season and irrespective of site and year. Mulching rye with ultra shallow tillage tools has resulted in less weed biomas in only one of the two experimental sites.

Treatment strategy III) and IV) have significantly reduced the weed species diversity irrespective of site and year.

4. Conclusions

The experiments could demonstrate that reduced tillage grain legume production systems greatly benefit from rye mulch for weed suppression and management of soil mineral nitrogen. As shown in the case of lupin, the system does apparaently not work for all grain legume species. This is most likely because of differneces in sensitivity against allelopathic substances emmited by rye plants and rye mulch. The system is suitable for both, organic and conventional production systems, and can be combined with different within-season weed management methods.

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