N supply in stockless organic cereal production under northern temperate conditions. Undersown legumes, or whole-season green manure?

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Abstract

Two systems for nitrogen (N) supply to organic spring cereals were compared under Norwegian conditions. Repeated undersowing of clover in the cereals in four growing seasons was compared to a whole-season green manure in the second year. Cereal yields were higher in the treatments with clover than in the controls. The yield increasing effect of undersown clover was residual. One year of whole-season green manure increased subsequent cereal yields significantly, but not enough to compensate for the loss of yield over the total four-year period. If phytopathological problems can be avoided, repeated undersowing of legumes seems to be more profitable than green manure each fourth year in stockless organic cereal production systems. The soil mineral N decreased during the study, demonstrating a negative N balance. Hence, additional N sources should be found for stockless organic cereal systems under Norwegian conditions.

Introduction

In northern temperate regions, cereal yields in stockless organic crop production systems are limited by nitrogen (N) availability, and legumes are commonly grown to supply N. Pulses such as peas and lupins are difficult to grow successfully due to short and cold growing seasons. The most common option is undersowing of clover, where clover seed is applied shortly after cereal seeding. After cereal harvest the clover acts as a combined cash crop and N accumulator. Further, it will reduce the establishment of perennial weeds and protect the soil from erosion. However, continuous growing of legumes may be questionable due to phytopathological problems. To avoid this, a whole-season green manure may be grown e.g. each fourth year of the rotation. The green manure may be undersown in cereals the previous season. In the main season it is chopped and left to decompose in the field 2-3 times to favour N accumulation and control weeds. With both methods, the clover canopy is ploughed down before a new cereal crop is established. It may be useful to mix the clover with a grass species to ensure the presence of N conserving plants in the catch crop. Mixed with grass seed, the amount of expensive legume seed per ha may be reduced.

A project was carried out in 2002-06 to reveal the effects of repeated undersowing of clover on N supply and cereal yields under Norwegian conditions, and to assess the

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applicability of this method on stockless organic cereal production farms. Repeated undersowing in four years was compared to a whole–season green manure in the second year, but no legumes in other years. The effect of mixing the clover seed with a grass species was also studied. In this paper we present results of yield levels and N accumulation in biomass and soil.

Materials and methods

A field experiment comparing six treatments (Table 1) with four replicates was conducted at two experimental sites during 2002-06.

Tab. 1: Overview of treatments in the field experiments.

Treatment	2002	2003	2004	2005	2006
1, Cereals with no undersowing	Oats	Spring wheat	Oats	Spring wheat	Barley
2, Cereals undersown with ryegrass	Oats + ryegrass	Spring wheat + ryegrass	Oats + ryegrass	Spring wheat + ryegrass	Barley
3, Cereals undersown with clover	Oats + red clover	Spring wheat + white clover	Oats + red clover	Spring wheat + white clover	Barley
4, Cereals undersown with clover and ryegrass	Oats + red clover and ryegrass	Spring wheat + white clover and ryegrass	Oats + red clover and ryegrass	Spring wheat + white clover and ryegrass	Barley
5, Cereals with green manure, red clover and timothy	Oats + red clover and timothy	Red clover and timothy	Oats	Spring wheat	Barley
6, Cereals with green manure, red clover	Oats + red clover	Red clover	Oats	Spring wheat	Barley

No fertilisers were applied during the experiment. The amounts of seed used were 200 kg ha^{-1} of grain, 10 of ryegrass, 15 of red clover, 5 of white clover and 22 of timothy. For red clover, the amount was reduced to 7 kg ha^{-1} when mixed with ryegrass, and to 3 kg when mixed with timothy.

The experimental sites were Bioforsk Arable Crops Division, Apelsvoll (60°42'N, 10°51'E) and Kise (60°46'N, 10°49'E). There is only a short distance between the two sites, and the climatic conditions are comparable except from somewhat higher precipitation at Apelsvoll; annual average 609 vs. 526 mm during 2002-05. The experimental field was irrigated when required at Apelsvoll, but not at Kise. The main soil differences were a higher soil P-concentration at Apelsvoll (ammonium-acetate lactate soluble P 59 vs. 26 mg kg^{-1}) whereas the Kise soil contained slightly more clay (26 vs. 17%) and soil organic matter (organic C 2.9 vs. 1.7 %). The soil P concentration at Kise was very low due to several years of no other fertilisation than green manure.

Aboveground biomass of cereals, undersown crops and weeds was recorded in late April just before ploughing, in early July when the cereals were heading (Zadoks 49), in early September before cereal harvest, and at the end of the growing season in late October. The biomass of undersown crops was fractionated into grass and legumes. The N concentration in the dry matter (DM) of the fractionated plant material was measured. Soil mineral N (0-25 cm) was measured in late April and late October (extraction by 1M KCl). Statistically significant differences between treatments were analysed by variance analysis, and interesting relationships by regression analysis (Minitab software).

Results and discussion

There was a considerable variation in cereal yields between sites and over years, and the variation between years was different at the two sites (Figure 1). In 2002, the establishment of the field at Apelsvoll was hampered by wet soil in spring, causing a heavy soil crust. The yield differences between Kise and Apelsvoll was larger with spring wheat in 2003 and 2005 than with oats in 2004, which may be explained by the less fertile soil at Kise. It is a common experience in Norway that oats generally perform better than wheat with lower nutrient availability. In 2006, the field at Kise suffered from drought.

The yield differences between treatments were roughly as could be expected. There was a tendency of reduced yields in undersown treatments in 2002 (not statistically significant). In later years, yields were increased by the residual effect of the undersown legumes and the 2003 green manure.

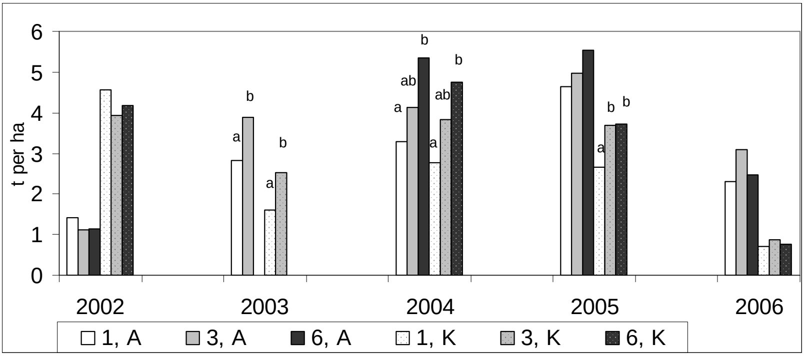

Figure 1: Cereal yields (15% water) in treatments 1, 3 and 6 (see Table 1) at Apelsvoll (A) and Kise (K) during the experiment. The cereals were oats in 2002 and 2004, spring wheat in 2003 and 2005, and barley in the residual effect year, 2006. Statistically significant differences between treatments within each year and site (when found) are shown by letters a and b.

The residual effect of undersown clover was a yield increase of about 30% in the subsequent cereal crop. The effect was not less when the clover seed was mixed with ryegrass (Table 2). For the whole-season green manure in 2003, the residual effect was considerable in 2004 and 2005. On both these years, the average yield for treatments 5 and 6 at both sites was 4.8 t ha^{-1}. However, in 2006 the residual effect of the green manure had disappeared, and over four years, the total yield increases were not large enough to compensate for the year without cereal yields.

Tab. 2: Average cereal yields at Apelsvoll and Kise, absolute values (Abs.), t grains ha^{-1}, 15% water and relative (Rel.) numbers. Treatments explained in Table 1.

Treatment	First year, 2002		Average 2003-05		After-effect, 2006	
	Abs.	Rel.	Abs.	Rel.	Abs.	Rel.
1	2.98	100	2.96	100	1.51	100
2	2.83	95	3.06	103	1.71	113
3	2.53	85	3.86	129	1.99	132
4	2.69	90	3.76	127	1.99	132
5	2.68	90	3.17	107	1.73	114
6	2.65	89	3.23	109	1.62	107

There was a large variation from year to year in the amount of N in aboveground biomass of the undersown crops (Fig. 2). The accumulation of N in aboveground biomass was considerable in treatments 3 and 4 (with undersown clover) during the autumn of 2002 and 2003. In 2004, the amount of N in biomass was only slightly higher in the treatments with undersown legumes than in treatment 2 with undersown ryegrass. It could be speculated if the declining N accumulation was an indication of phytopathological problems. However, in 2005 the amount of accumulated N increased again and the level in the autumn of 2005 was comparable to 2003. Hence, a general decline can not be stated. As no fertilisers were added except the N fixed by legumes, the N amount in treatment 2 reflects N mineralised from soil organic matter. There was no less N accumulated when some red clover seed was replaced by ryegrass (treatment 3 as compared to 4, Fig. 2).

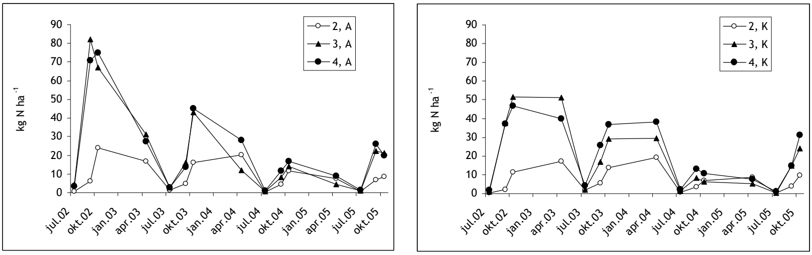

Figure 2: Amount of N in aboveground biomass of the undersown crops in treatments 2, 3 and 4 (see Table 1), from July 2002 to October 2005 at Apelsvoll (A) and Kise (K).

There was a significant and negative relationship between the amount of N in aboveground biomass of undersown plants in late autumn and the cereal yield in that growing season (r^2= 0.32 for treatment 3, 0.42 for treatment 4). This reflects the competition between the cereals and the undersown crops for light, water and nutrients. No relationship was found between the amount of N in aboveground biomass in late autumn or in spring and the cereal yields in the subsequent growing season. This is surprising, as a considerable residual effect of clover was found, increasing the cereal yields.

The amount of soil mineral N (N_{min}) was relatively high at the start of the experiment, on average for treatments 1-4, 20.3 kg N ha^{-1}. In the spring of 2005, this value had decreased to 11.5 kg, and the average value for tr. 3 and 4 was only slightly higher than for the controls; 12.5 vs. 10.5 kg ha^{-1}. Hence, repeated undersowing did not increase the N_{min} with time. At both sites, the N_{min} values in treatment 2 were generally lower than in treatment 1, which shows the capacity of the soil to mineralise some N, and the ryegrass to catch it. In spite of more organic C in the soil at Kise, the N_{min} levels were not higher at that site. Values between 25 and 30 kg N ha^{-1} were achieved in a few plots in treatments 5 and 6 in the spring of 2004. However, the average level was only 17.1 kg N ha^{-1} in late autumn 2003, and 22.1 in spring 2004. The value in spring 2004 was not much above the starting value measured in treatments 1-4. The preceding crop on both sites was spring cereals with no undersowing and no fertilisation. Hence, a larger effect on the N_{min} value was expected. As the residual effect was considerable, this result demonstrates that the N_{min} value is not necessarily a good characteristic of the soil's ability to supply crops with N. There was a weak, but significant positive relation between N_{min} in late autumn and the cereal yield in the next season (r^2= 0.06), as well as between N_{min} in spring and the following cereal yield (r^2= 0.05). A positive relationship was also found between the amount of N in aboveground biomass in spring and N_{min} in spring (r^2= 0.22), and between the same characteristics in late autumn (r^2= 0.08). These results are not surprising, and they demonstrate that legumes are important for the N supply of the cereals even if there is no straightforward relationship between the N in the green legume canopy and the later cereal yields.

Conclusions

The use of clover, undersown in cereals or as a whole-season green manure, significantly increased the subsequent cereal yields in an organic production system with no fertilisers applied. The average cereal yield over four years was larger with repeated undersowing than with green manure in the second year of the period. Hence, in organic stockless cereal production systems it seems to be a better option to harvest cereals each year with undersown clover, than to use a whole growing season to accumulate nutrients for subsequent cereals each fourth year. However, when legumes are included in most years of the crop rotation, there is a risk that phytopathological problems may arise (e.g clover nematodes, fungi). In all treatments, the soil mineral N was significantly decreased during the study, demonstrating a negative N balance. Neither repeated undersowing of clover nor one out of four years with a whole-season green manure did accumulate enough N to compensate for the N removed in cereals. Hence, there is a need for additional N sources to supply organic cereal production systems under northern temperate conditions.

Acknowledgments

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