Project outline

Repeated clover subcropping as a strategy for commercial organic grain production

There is a general consensus that organic agriculture should play a more prominent role in Norwegian food production in the years to come. According to The Norwegian Ministry of Agriculture (1999) there is an urgent need to increase the production and trade of organic grains. New EC regulations will exclude the use of conventionally grown fodder in organic animal husbandry from 2005. Shortage of organic grains on the trade marked will inflict the entire chain from farmers to consumers and cause a major set back for organic agriculture in Norway. Given the low trade of Norwegian organic grains today, our immediate action must be to develop organic production systems which ensures high and stable grain yields.

Only minimal acreage is available for grain production for trade on Norwegian organic husbandry farms and bulk production of organic grains for trade will mainly be a task for organic farms with few or no livestock. Grain nutrient demand must, therefore, be covered through mineralization of nutrients from soil, and different types of green manure. Green manure is the residues, both above and below ground, of crops (most often legumes) grown on the field in monoculture or as a subcrop through the entire, or parts of, the growing season in order to increase soil fertility and plant nutrient availability.
In an ongoing research programme (Eltun, 1998), we are working with nitrogen (N) effects of clover subcrops on subsequent grain growth. Preliminary results indicate that if clover subcrops are sown early and established successfully, they may gather up to 100 kg N per ha during the cropping season. This is approximately the same amount of N that is lost from the field through sales and leaching. Thus, our results indicate that repeated subcropping of clover may be used as a self-sufficient system in terms of N supply in commercial grain production on stockless organic farms. In this way the farmer avoids the costs of time and energy and lack of income related to cropping green manures in monoculture. However, we are working with short term effects of only N in the present programme and we need to look at more long term consequences on both N and other important plant nutrients such as phosphorous (P) and potassium (K) and also study weed infestation before advisory steps can be undertaken. If the nutrient deficiencies are large in the long run, or if weeds become an overriding problem, growing annual green manures as a main crop may be an alternative. The use of imported nutrients and animal manure is omitted from the proposed project to extract the direct effects of various green manure strategies. Thus, at a later stage, organic additives may be used when needed to further enhance grain yields.

Formatert: Engelsk (Storbritannia)

Objectives

Main objective:
Evaluate if repeated clover subcropping is a well functioning green manuring strategy to obtain high and stable grain yields on stockless organic farms.

Further goals:
Quantify effects of repeated clover subcropping on grain yields and:
1. Field N balance,
2. Mobilization of soil mineral P and K and
3. Weed infestation.

State of the art and development of hypotheses

On stockless organic farms, strategies for green manuring include the use of: 1) short-term, clover rich leys, 2) legume green manure monocultures, 3) cash legume crops and 4) subcropping clover in grains.

Leys are commonly included as forage and green manures in organic crop rotations (see e.g. Olesen *et al*., 1999; Eltun and Nordheim, 1999) but might not be the best way to supply nutrients on stockless organic farms. Clover-rich leys are capable of fixating huge amounts of atmospheric N (210 kg N ha^{-1}: Nesheim and Øyen, 1992; 450 kg N ha^{-1}: Loges *et al*., 1999), but it is difficult to retain this N within the soil-plant system (Loges *et al*., 1999). Moreover, if leys are grown merely for their green manure effect, no income can be expected. On the other hand, sale of clover-rich grass as fodder will lead to (underpayed) nutrient losses, especially of P and K, from the system. Much of the same goes for legumes if grown in monoculture. Seed costs are high for many species, their cultivation is time and energy consuming, no income from sales can be expected, losses of N from decomposing plant material may be considerable and the effect on subsequent grain crops may be disappointing (Wallgren and Lindén 1988; Solberg, 1993). Thus, it is important to develop new, rational, low cost green manuring strategies where the acreage withdrawn from sales production is kept low, nutrient losses are minimized and grain yields are maintained at satisfactory levels over time.

As a combined green manure and cash crop strategy, peas and beans may be cropped on the farm. However, N fixation by legume cash crops seems to be low as compared to the amount of N these crops remove from soil (Henriksen, 2001). An other alternative is to subcrop clovers in grains (see e.g. Breland, 1989). In this way grain yields can be taken simultaneously with N fixation. To keep the fixated N in soil through winter, ryegrass is sometimes mixed with clover in the subcrop. Results from our ongoing research programme (Eltun, 1998) indicate that approximately 100 kg N ha^{-1} may be gathered in plant biomass through a cropping season if the clover subcrop is successfully established (Henriksen, 2001). This is approximately the same amount of N that is lost from the field through sales of grains and leaching, and the main part of this N is most probably fixated from the atmosphere since the grain crops drain the soil for inorganic N. Thus, our results indicate that clover subcropping may be a self-sufficient system in terms of N nutrition.
<u>Central hypothesis:</u>
** Repeated subcropping of clover is a well functioning green manuring strategy to obtain high and stable grain yields on stockless organic farms.*
There are, however, some concerns which must be addressed before advisory steps can be undertaken: How does repeated clover subcropping affect 1) field N balance, 2) P and K mobilization and 3) weed infestation in the long run?

1. Effects of repeated clover subcropping on field N balance

Much effort has been spent on discussing whether the soil N content in the long run can be kept at the initial level on stockless organic farms. However, soil N content is to a large extent given from tillage intensity (Cambardella and Elliott, 1994) and historic land use (Thomsen *et al*., 2001). Maintaining field "N-balance" may thus be an irrelevant option if the cropping system is altered. In this project we are concerned about the levels at which soil N and grain yields eventually will stabilize in a continous subcropping system. However, fluctuation to a new stable soil N level takes decades and in the proposed project we will use N balance calculations to consider this.

Most experiments with clover subcropping have been performed on a short term basis and effects measured in subsequent grains. In some experiments extending over several years, grains have been strip-sown into permanent clover covers, a strategy which was abandoned due to heavy competition between clover and grains (Williams and Hayes, 1991; Jones and Clements, 1993). We have reached the same conclusion in experiments where cabbage was strip-planted into established clover covers (Riley and Brandsæter, in press). Hiitola and Eltun (1996) tested repeated clover subcropping in a seven year study in conventional farming and found that grain yields declined over the experimental period. However, they did not alter the crop sequence, which is considered to be important in organic farming, but repeatedly subcropped white clover in barley. N balances were not estimated, and repeated clover subcropping was not compared with other green manuring strategies.

In a study with clover grass and a mixture of vetch, peas, ryegrass and persian clover, Solberg (1993) found that removing aboveground plant material did not reduce oat yields the following year and he concluded that the "root effect" was considerable. Similarly, Poutala and Hannukkala (1995) found that the "root effect" of persian clover and hairy vetch resulted in approximately 20% higher wheat yields than did the aboveground biomass alone. This happened although roots of persian clover and hairy vetch comprised only 3.5 and 1.8% of total plant N respectively. An other indication of a significant "root effect" is that although there is a pronounced after-effect of having clover subcrops present, subsequent grain yields do not correlate with the amount of above ground clover biomass ploughed under the previous year (Henriksen, 2000). "Root effects" of green manures may comprise a number of mechanisms, but given the considerable size of the effect, and the low amount of N present in roots where these effects have been measured, we propose that:
<u>Hypotheses:</u>
* *Mineralization of rhizodeposited legume N contributes more to subsequent grain N nutrition than the legume roots themselves.*
* *N fixation is sufficiently high in a repeated clover subcropping system to account for N losses through sales of grains and leaching.*

2. Effects of repeated clover subcropping on P and K mobilization
Soils, especially in Europe and US, commonly contain ample amounts of both P and K that ought to be used for plant production. The bioavailability of nutrients to plants depends on soil properties and climatic conditions as well as various mechanisms of nutrient acquisition (Darrah, 1993). The most important mechanisms for increased acquisition of nutrients are increased root absorbing surface, and nutrient dissolving processes in the rhizosphere. An increased absorbing root surface can be achieved by thinner and longer roots, longer and denser root hairs and infection with AM (arbuscular mycorrhiza). The competitive ability of grasses as compared to dicotyledonous species to take up K was attributed to the longer, finer and denser root system of the grass species by Mengel and Steffens (1985), and confirmed by studies of Salomon (1999). Rhizosphere processes that increase soil weathering and uptake of nutrients comprise a decrease in pH close to the root surface (Hedley *et al*., 1983), exudation of organic acids (Hoffland *et al*., 1989), siderophores and enzymes such as phosphatase (Tarafdar and Jungk, 1987) and symbiosis with soil micro organisms (Berthelin and Leyval, 1982).

Many of these mechanisms have shown to differ considerably between plant species. White lupine (*Lupinus albus* L.) is a famous example, with proteoid roots that exude large amounts of citrate (Gardner *et al.,* 1983). Both Gardner and Boundy (1983) and Marschner *et al.* (1986)

found increased dry matter production and increased P uptake in wheat when it was mixed with white lupine.

Given the limited access to fertilizer in stockless organic farming, it is important to identify and include in the cropping system plant species that can mobilize nutrients from soil pools which are unavailable to less efficient crops. White lupine is an interesting species to study under Norwegian conditions. The subcrop species that will be used in the suggested study (red clover, white clover and ryegrass) are not known to have especially effective mechanisms for nutrient uptake except for the fine and dense root system of ryegrass. Still, these crops may take up nutrients from the soil that would have been unavailable for the grains because of a longer growing period, which means a longer period of nutrient uptake. The subcrop will continue to grow 1-2 months after the grains are harvested, and species such as white clover continue vegetative growth even after flowering has started.

After transfer to plant organic matter in the green manure crop, the nutrients will probably have become more easily available for the subsequent grain crop. But there is also a risk for losses by leaching or surface runoff. The time of ploughing should, therefore, be chosen carefully and in relation to winter climate. However, this topic is not included in the proposed project since it in part is dealt with in other projects.
<u>Hypotheses:</u>
** Subcropping of clover and ryegrass in grains will increase the P and K mobilization from soil as compared to grains grown alone.*
** The availability of P and K for subsequent grains will be higher if ryegrass is included in the clover subcrop, and the risk of nutrient losses will be reduced.*

3. Effects of repeated clover subcropping on weed infestation
In organic crop rotations dominated by grains, nutrient supply and weed control seems to be key factors. As already stated and refereed, much effort has been spent on green manure strategies in studies of stockless organic grain production systems and most of these studies have focused on nutrient supply. In fact, very few studies have been focused on weed control. Annual weeds should not be under-estimated in organic grain production, however, the management of the perennial weed species *Elymus repens* L., *Cirsium arvense* L. and *Sonchus arvensis* L. seems to be even more important for maintaining productivity. Studies in the Nordic countries (e.g. Jensen & Melander 2001; Salonen 2001) and also in other countries (e.g. Cormack 1999; Bacher *et. al* 1997) strongly indicate that these weed species may become serious problems in organic grain systems. A challenge in organic stockless grain production is that nutrient supply and weed control may contradict each other: While mechanical weed control is possible in systems without subcropping, it is impossible in systems with subcrops without severely affecting the growth or establishment of such crops (Rasmussen *et al.* 1999). On the other hand, we don't know how to take advantage of the potential suppressive effects of subcrops on perennial weeds. Only a few scientific papers are found on this subject. Dyke and Barnard (1976) found that red clover or Italian ryegrass undersown in barley reduced the growth of *Elymus repens* L. by a factor of two. Additionally, organic crop rotation experiments in Denmark have shown tendencies to less infestation of *Cirsium arvense* L. with subcropping in grains (Rasmussen 2000). Former studies on perennial weeds are very useful e.g. for *Elymus repens* L. (Håkansson 1974), but with increased focus on organic farming systems, we need even more basic knowledge to be able to control perennial weeds.
<u>Hypotheses:</u>

**If the field is not already infested by perennial weeds, the use of subcropping may prevent, or at least delay, infestation of perennial weeds.*
** If the growth of perennial weeds increase above economic threshold values, they could be controlled by soil cultivation and a subsequent competitive green manure crop.*

Scientific approach

Our central hypothesis can not be rigorously tested within a short project period. However, results brought forward through the testing of our working hypotheses will allow us to give a qualified evaluation of our central hypothesis.

Activity 1. Effects of repeated clover subcropping on field N balance

1.1. Field experiment 1. Experimental plan and measurements
Two four-year field experiments will be performed in Southeast Norway. One location will be on a poor sandy soil and one on a fertile moraine soil. The experimental plan is shown below, three replicates will be used for each treatment.

Treatment	2002	2003	2004	2005
1	Oat	Wheat	Oat	Wheat
2	Oat + ryegrass	Wheat + ryegrass	Oat + ryegrass	Wheat + ryegrass
3	Oat + red clover	Wheat + white clover	Oat + red clover	Wheat + white clover
4	Oat + red clover and ryegrass	Wheat + white clover and ryegrass	Oat + red clover and ryegrass	Wheat + white clover and ryegrass
5	Oat + red clover and timothy	Red clover and timothy	Oat	Wheat + white clover
6	Oat + red clover	White lupine	Oat	Wheat + white clover

1.1.1. Changes in mineralizable N during the field trial:
Mineralizable N will be determined in 2005 by incubation of soil from all plots, including frozen, plotwise samples from 2002.

1.1.2. N uptake in subcrops and grains and N leaching
On each plot, two 50 × 50 cm subplots will be sampled in late autumn and uptake of N in aboveground subcrop biomass will be determined. Twenty randomly chosen grain plants (aboveground biomass) will be sampled from each plot at four strategic development stages, and uptake of N determined. Grain yields and contents of N will be measured. Soil inorganic N concentrations will be measured in the topsoil (0-25cm) and subsoil (25-50cm) in spring and autumn. On the moraine soil, a common estimate of leaching losses will be taken from a comparable treatment in the Apelsvoll Field Lysimeter. On the sandy soil, leakage of nutrients will be measured by suction from ceramic cups placed at 90 cm depth on each plot and measurement of macro nutrients after incidents that leads to vertical water flow.

1.2. Quantification of N fixation, rhizodeposition, mineralization and uptake in grains.
We will perform a pot experiment in order to quantify N fixation and the relative importance of rhizodeposited, fixated N on grain N nutrition.

1.2.1. Quantification of N fixation and rhizodeposition

In the years 2002 and 2003, PVC cylinders will be placed close to field experiment 1 at one location, filled with soil from plots of selected treatments and sown with plants in accordance with the field experimental plan. ^{15}N enriched N gas will be injected into the cylinders at intervals, and at the end of each cropping season the cylinders will be dug out. Plant materials will be separated from soil and concentrations of ^{14}N and ^{15}N will be measured in plant biomass as well as in the belonging soil. N fixation will be calculated by the difference method with treatment 2 as the control. Rhizodeposited N will be calculated assuming a similar $^{14}N/^{15}N$ ratio in rhizodeposits as in the plant material.

1.2.2. Mineralization and grain uptake of fixated N

Plant material separated from soil (see 1.2.1.) will be split in eight. Four parts will be incorporated into soil from the treatment 1 plots (see field experimental plan) and grown with wheat under greenhouse conditions. The remaining soil (see above) will also be split in eight. Four parts will be grown with wheat as described for the plant material. Pots will be watered with a N-deficient nutrient solution and uptake of ^{15}N from subcrop plant material versus rhizodeposited N will be determined on four occasions during the pot experiment.

Activity 2. Effects of repeated clover subcropping on P and K mobilization

2.1. Field experiment and measurements

Field experiment 1 (described in 1.1.) will serve as arena for determination of P and K mobilization under field conditions.

2.1.1. Changes in soil properties during the field trial

Total content of P, organic P, P-AL, K-HNO_3, K-AL, and pH will be measured in topsoil (0-25cm) and subsoil (25-50 cm) in the spring of 2002 and 2005.

2.1.2. P and K uptake in subcrops and grains

Plotwise P and K uptake in aboveground subcrop biomass and in grain yields will be determined in autumn, while P and K uptake in grain biomass will be measured at four strategic development stages (see 1.1.2). Soil P and K concentrations (P-AL, K-AL) will be measured in the topsoil (0-25cm) and subsoil (25-50cm) in spring and autumn.

2.2. Quantification of subcrop effects on P and K availability in a pot experiment.

As for rhizodeposited N (see 1.2), we will perform a greenhouse pot experiment in order to quantify the subcrop effects on P and K mobilization and uptake in following grains under controlled conditions. The aim is to avoid the masking effect of increasing grain growth on P and K uptake, caused by green manure N, that will occur in the field experiment.

2.2.1. Mobilization of P and K and uptake in grains.

Pots amended with subcrop plant material and the belonging soil will be used in this experiment. See 1.2. for further description of methods. Wheat will be grown in the pots under greenhouse conditions and the plants will be watered with a N solution. Wheat uptake of P and K from subcrop plant material and belonging soil will be determined on four occasions during the pot experiment.

Activity 3. Effects of repeated clover subcropping on weed infestation

3.1. Weed infestation in field experiment 1

Weed infestation (species and biomass) in the field experiments (see 1.1) will be determined plotwise in late autumn on the two subplots (50 × 50 cm) described in 1.1.2.

3.2. Effects of clover subcropping and annual green manures on perennial weed infestation in grains

We will measure the effects of clover subcropping and annual green manures on perennial weed infestation in grains. Perennial weed species are often unevenly and spatially distributed in the field. To obtain homogeneous weed stands we will transplant the weeds in the field plots. Rhizomes of *Elymus repens* L. and roots of *Cirsium arvense* L. and *Sonchus arvensis* L. will be harvested from propagation areas (already established at Ås) and transplanted into the field plots the year before starting the experiment.

<u>3.2.1. Field experiment 2. Experimental plan and measurements</u>

The trial will be a randomised complete block trial, split split plot, 2 by 2 by 4 factorial, with three replicates. Naturally occurring weeds and transplanted perennial weeds compose the two main plots (whole plot). Oat with red clover subcropping and no subcropping, compose the 2 subplot treatments. The 4 sub-subplots treatments will be 1) Red clover continued from subcropping. 2) Autumn harrowing followed by hairy vetch as green manure (sown in spring). 3) Autumn harrowing followed by red clover as green manure (sown in spring). 4) Continued grain with sub cropping (wheat/white clover sown in spring). The autumn harrowing will be carried out according to organic farmers practice.

Observations: Grain yields (both years), clover biomass (autumn and spring) and soil nitrogen autumn and spring, number of aerial shoots from perennial weeds in autumn, in spring and early summer, perennial weed species dry weight in the second summer and number and weight of annual weeds in the first experimental year.

Project organization, research and reference group

The project is organized as an activity within the research field ”Organic Agriculture” run by The Norwegian Crop Research Institute. The Norwegian Centre for Ecological Agriculture will be the main cooperative partner.

Research group:

Project leader: *Dr. Trond M. Henriksen*, The Norwegian Crop Research Institute, (Appendix. 2) is a soil microbiologist and has specialized on microbial degradation of plant materials in soil. He is currently working on projects within the field of organic agriculture where C and N mineralization from various organic materials are quantified.

PhD student *Anne Kristin Løes*, (Appendix 3), The Norwegian Centre for Ecological Agriculture, has specialised in whole farm case studies, especially nutrient cycling and availability in organic farmings systems. In 1998 she started PhD-studies on P and K aquisition in organic farming systems with restricted access to animal manure, expected to be completed in 2002.

Dr. *Lars Olav Brandsæter*, The Norwegian Crop Research Institute (Appendix 4) covers research on weed control in organic farming. He is now in charge of several projects within this topic in close collaboration with projects on nutrient supply to develop practical production systems. He has also recently worked in projects on allelopathic effects in soil and plant residues.

Reference group:

To strengthen the competence of the research group, we will organize a reference group of three scandinavian scientists with long experience within fields of importance for this project (Appendix 5). The reference group will be involved in detail planning of the different experiments, informed on the development of the experiments and discussion partners on the evolving results. The research and reference groups will meet twice during the project.

Dr. *Sissel Hansen* is a senior scientist in soil and nutrient management at the Norwegian Centre for Ecological Agriculture (NORSØK). Her main topics are nutrient supply to organic farming systems, especially N and S and the bioavailability of organic manures.
AgrD *Börje Lindén* is docent in plant nutrition at The Agricultural University in Sweden. He has extensive experience in studies on N dynamics in different fertilization and cropping systems, the use of mineral and organic fertilizers, catch and cover crops, crop supply of mineralized N, N leaching, residual N effects in conventional and organic cultivation systems.
Prof. *Niels Erik Nielsen* at The Royal Veterinary and Agricultural University, Denmark has extensive experience from studies on soil as a source of nutrients, rhizosphere processes, kinetics for net uptake of nutrients by plants, causes to differences between crop plant genotypes in nutrient uptake efficiency (particularly phosphorus), turnover and movement of plant nutrients in the soil plant atmosphere system and modelling of crop production and carbon and nitrogen dynamics.

Environmental and social benefits and ethics

Organic agriculture is recognized as being an environmentally sound agricultural strategy and there is a general understanding that organic farming should expand in Norway through the years to come. This depends, however, on the development of well functioning strategies for the production of organic grains for trade. The proposed project is designed to deal precisely with this task.

We can not see that the project involves any ethical risks.

Publication plan

New knowledge brought forward through the project will be of interest not only in Norway or Scandinavia but of relevance internationally. We therefore plan to write three papers for publication in international journals.

Throughout the project, results will be presented on national and international conferences and in Norwegian magazines for farmers.

Project budget, milestones and time table

The proposed project will run from 2002 to 2005. The project will be financed through grants from The Norwegian Research Council. Total project costs are 800 000 NOK each year. Budget details and milestones are listed in the proposal scheme. The project time table is shown below.

Activity	2002				2003				2004				2005			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Detail planning	×	×														
Meetings, research and reference group		×											×			

Field experiment 1	(1.1 and 2.1)		×	×	×	×	×	×	×	×	×	×	×	×	×	×	
Pot experiment 1	(1.2 and 2.2)		×	×	×	×	×										
Pot experiment 2	(1.2 and 2.2)						×	×	×	×	×						
Field experiment 2	(3.2)		×	×	×	×	×	×	×	×	×	×					
Publication											×	×	×	×	×	×	×

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