An organic vegetable crop rotation aimed at self-sufficiency in nitrogen

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Summary

Nitrogen (N) limitation is a major problem in stock-less organic crop rotations, and is thus a hindrance for the development of organic vegetable production. To help develop methods for efficient N husbandry in stock-less organic crop rotations, we are working with a vegetable crop rotation designed to be self-sufficient in N. Although various vegetable crops are grown, 75% of the soil is plant-covered in the late autumn, and in these fields the risk of N leaching losses is kept very low.

During the first few years, all cash crops have shown reasonable yields, and more than half of the cash crops have produced yields on a level we would normally find in similar conventional crops. In the six-year crop rotation, including only one year with a grass clover ley grown as green manure, the cash crops have taken up on average 125 kg N ha^{-1}, and the N removal with harvested products across the whole rotation has been almost 70 kg N ha^{-1} $year^{-1}$.

The results show that methods for efficient N husbandry exists which can be used to design stock-less organic crop rotations without using a large part of the land for green manures, and with a limited risk of N leaching losses.

Introduction

Nitrogen supply is often a limiting factor in organic crop production. Organic farms with a high stocking rate of cattle, which dominate Danish organic farming at the moment, grow many legumes, and export relatively little N with their produce. Organic farms specializing in other products, especially vegetable production will have problems with the N supply, as their crop rotations include much less legumes, and especially farms which sell many plant products will export larger amounts of N.

We believe that limited nitrogen supply is one of the main factors limiting further development of organic vegetable production in Denmark. From the beginning, vegetable production was an important part of organic production, covering a much higher fraction of the organically farmed area than of the conventionally farmed area. Today approximately 7% of the vegetable area in Denmark is grown organically, this is still a higher fraction than for most other farm products, but during the last five years, the organic vegetable production has increased at a much lower rate than organic farming in general. The fraction of the area that is grown organically is very different for the vegetable crops, from less than 2% for some species to 15% or more for a few species. Half the organic vegetable area in Denmark is grown with carrots, and due to the high productivity of this crop, approximately 65% of the total amount of organic vegetables produced in Denmark are carrots. Carrots have a very small demand for nitrogen supply, and this may be one of the reasons why this crop has been much more successful in organic farming than most other vegetable crops. To increase organic vegetable production, and to increase the number of vegetable crops that are successfully grown in organic farming, better methods of nitrogen supply for the crops should be developed.

Thus we want to test and demonstrate some of the methods which can be used to optimize N husbandry in organic farming within a crop rotation. The results should help organic vegetable farmers to get enough N for their crops and to make them less dependent on external N supply from e.g. cattle farming. The crop rotation should allow the growing of the most common vegetable crops in Denmark. It should thus include years where the N supply is high enough for even the most demanding crops, and other years where the N supply is more moderate, to allow the growing of less N demanding crops without excess supply of N.

In the crop rotation we have attempted to achieve several goals: 1) The crop rotation should be self-sufficient in N. Though this is normally not necessary in practical farming, methods allowing less dependency on import of N from other sources will facilitate the spread of organic vegetable production. 2) The crop rotation should include fewer full year green manure crops than normally used in such crop rotations, but use autumn grown green manures and nitrogen catch crops to optimize N supply for the crops. A full year green manure is thus grown only once during the six course rotation. 3) The N leaching loss to the environment should be kept low.

In this paper the crop rotation and the ideas behind it will be described. Further, the results in terms of crop yield, soil N supply, crop N uptake, N removal from the crop rotation, and the level of N residues left in the soil in the late autumn.

Material and methods

The crop rotation is located at the Research Centre Aarslev (10°27'E, 55°18'N), on a Typic Agrudalf soil (Table 1). The crop rotation was initiated in the spring of 1996. Weather data are obtained from a weather station situated less than 500 m from the experimental site.

Table 1. Main characteristics of the soil used for the crop rotation.

	%C	%N	%Clay	%Silt	%Sand	pH
0-25 cm	2.0	0.15	14.6	27.3	55.2	7.0
25-50 cm	0.8	0.07	19.7	29.8	49.4	6.4
50-75 cm	0.3	0.04	21.7	29.0	48.8	5.1
75-100 cm	0.2	0.03	20.6	28.5	50.6	5.9

The crop rotation consists of six fields of approximately one hectare each. The crop rotation contains:

Field 1: A full year grass clover green manure (including red clover and lucerne). This crop is mown three times during its growth, but no plant material is removed from the field.

Field 2: The field is split to grow both white cabbage and leek. Before white cabbage the grass clover field is ploughed down in late November, but before leek it is ploughed down in late March. Leek and white cabbage are transplanted into the field in May. Two varieties of white cabbages are grown, which are harvested either in September or in November. After harvest the crop residues are left in the field and the cabbage stubble is growing on as a catch crop. Leek is harvested in November.

Field 3: The residues of white cabbage and leek are ploughed down in March, and in April a barley crop with undersown grass clover is sown. The legume component consists of white clover, black medic and birdsfoot-trefoil. At the harvest of barley the straw is chopped and left on the field. The undersown grass clover is left to grow in the autumn.

Field 4: The grass clover is ploughed down in late March. The field is split, and onions are sown in April and carrots in late May. Onions are harvested in late August and carrots in October. All crop residues are left in the field.

Field 5: The field is ploughed in March, and green peas are sown in April. The green peas are harvested in July, the crop residues left on the soil and ploughed down. As we do not have access to a pea harvester, also the peas are left in the field, but they contain only a small part of the biomass and N in this crop (see Table 2). The crop residues are ploughed down, and around 1 August a catch crop of fodder radish is sown.

Field 6: The fodder radish catch crop dies off during the winter, and in the spring the soil is only harrowed before the sowing of barley with undersown grass clover. The barley is harvested in August, and the straw chopped and left on the field. The grass clover is left to grow in the autumn, and in the next year as a green manure crop (field 1).

At the harvest of each crop the yield is measured in four subplots. Total yield, saleable yield, dry matter production and uptake of N, P and K in saleable products and crop residues are measured. Soil samples for the determination of nitrate- and ammonium-N is taken in late November as a measure of potential leaching risk after the different crops, and again in May as a measure of the effect of the crops on N supply for the succeeding crops. Soil samples are taken in five soil layers, 0-25, 25-50, 50-75, 75-100 and 100-150 cm.

Soil was sampled from two subplots after each crop, with nine samples combined into one bulk sample for analysis at each soil layer from each subplot. The soil samples were analysed for ammonium-N and nitrate-N after extraction for one hour in a 1 M KCl solution.

Results and discussion

The crop rotation was initiated in 1996 and by now the results from the first three years are available. Yield results from the first year are not related to the effects of green manures and other pre-crop effects, which are so important in the crop rotation. Thus the results presented here are from the second and third year only. These results can be used to evaluate the initial performance of the crop rotation, whether this performance can be kept up on the longer term cannot yet be judged.

The crop rotation

Field 1, Green manure: The full year green manure is grown as a mixture of grass, red clover and lucerne, established by undersowing in a barley crop of the previous year (field 6).

Field 2, N demanding vegetables, cabbage and leek: The very N demanding vegetable crops are grown after incorporation of the green manure. The two crops have very different root growth; leek is a shallow rooted crop (Burns, 1980; Smit *et al.*, 1996), whereas white cabbage is deep rooted as many cruciferous crops (Greenwood *et al.*, 1982; Thorup-Kristensen and Van den Boogaard, 1998). Thus, before white cabbage we incorporate the green manure in November, whereas before leek it is not incorporated until late March. By spring incorporation it is secured that the available N is present in the uppermost soil layers where it can be reached by the shallow root system of leek. This is not necessary before white cabbage with its deep root system.

After the harvest of these vegetables it is too late to establish a catch crop to prevent N leaching losses. After harvest of white cabbage, we leave the residues of the crop growing in the field as a catch crop. Such a strategy is not possible after leek, but we are testing a system where a catch crop is sown between the leek rows approximately two months after the planting of the leek crop (Thorup-Kristensen, 1997).

Field 3, Barley with undersown grass clover: In the third year a barley crop with undersown grass clover is grown. The N supply for the barley crop is the residual N effect from the vegetables in the previous year and from the green manure grown two years earlier. Thus, the barley crop is not highly supplied with N, and this allows vigorous growth of the undersown grass clover. After harvest the grass clover is allowed to grow as an autumn green manure until the next spring, when it is ploughed down.

Field 4, Less N demanding vegetables, onions and carrots: These two crops demand much less N than cabbage and leek. Carrots have a relatively deep root system, and can utilize the soil N reserves quite efficiently, and produce high yields on a low N supply. Onions demand more N and have a very shallow root system, and can thus only utilize N, which is available in the uppermost soil layers. It has been found that legumes undersown in barley and grown as green manure in the autumn can supply the equivalent of almost 100 kg fertilizer N ha^{-1} (Schröder *et al.*, 1997). Thus, after the autumn grass clover, the growth of the carrots should not be N limited (Greenwood *et al.* 1980; Sørensen, 1993), and onions should only be slightly N limited (Sørensen, 1996). The carrot and onion crops are harvested late (in September and October respectively), and we have no methods for establishing any catch crop to prevent leaching losses of the N left in the soil.

Field 5, Green peas followed by a fodder radish catch crop: After carrots and onions there may be very little available N in the soil, especially if the winter precipitation has been high. Thus we grow green peas, which are not dependent on a soil supply of available N. The green peas are harvested early, and only a small fraction of the crop matter is normally removed from the field (in the experiment none is removed). Thus there are substantial amounts of crop residues to incorporate, and there is time for an efficient catch crop of fodder radish. Fodder radish has a very fast growing and deep root system (Böhm, 1974; Thorup-Kristensen, 1993, 1997). Thus, fodder radish can take up N from deeper soil layers, which have not been reached by the more shallow rooted peas (Thorup-Kristensen, 1998), as well as N mineralized from the soil and from the pea residues after harvest. Previous results have shown that fodder radish is a very efficient catch crop, both in terms of soil N depletion in the autumn, and in terms of N delivery for the subsequent crop (Thorup-Kristensen, 1994).

Field 6, Barley with undersown grass clover: The fodder radish catch crop dies off during the winter, and in the spring a barley crop is sown with an undersown grass clover crop. The undersown grass clover is left to grow during the following year as the full year green manure crop (field 1).

Crop yields

Yield levels of vegetable crops are not easy to compare, as they vary strongly due to many factors. High yield is not always a primary goal, but it is attempted to obtain a specific quality or timing of the harvest even though this may lead to low yields. An attempt to compare the yields obtained in the crop rotation (Table 2) with yields obtained form “similar” vegetable crops grown in conventional experiments at our institute can be made, though even such a comparison can never be precise.

Table 2. Yield (fresh weight of saleable products, barley adjusted to 15% water content) dry matter production of whole crop incl. crop residues, total N uptake, and N removal by the crops (Average 1997 and 1998).

		t ha^{-1}		kg N ha^{-1}	
		Yield	Biomass, dry weight	N uptake	N removal from field
Field 2	**Cabbage**	69	12.1	173	106
	Leek	31	7.1	151	151
Field 3	**Barley after cabbage**	4.9	7.7	74	55
	Barley after leek	3.9	6.0	58	49
Field 4	**Carrot**	100	16.5	168	118
	Onion	42	7.1	127	127
Field 5	**Pea**	5.3	5.5	116	30
Field 6	**Barley after pea**	6.8	10.0	113	83

In an experiment with optimal N supply for vegetable crops (Sørensen, 1993), late harvested crops of leek, white cabbage and carrot were grown, which should be comparable to the similar crops in the crop rotation. The carrots in the organic crop rotation produced the same amount of dry matter as optimally fertilized conventional carrots, leek slightly less (7.1 t ha^{-1} vs. 7.5 t ha^{-1}) and white cabbage significantly less (12.1 t ha^{-1} vs. 18.4 t ha^{-1}).

The yield of onions in the crop rotation was somewhat lower than what was found with the same cultivar in a variety test (saleable yield of 41 t ha^{-1} vs. 57 t ha^{-1}, Bjørn (1998)). The yield of the green peas in the crop rotation has been the same as obtained with many of the relevant pea varieties in a variety test with green peas (Grevsen and Kidmose, 1992).

The yield of barley is easier to compare to conventional levels. Barley after peas in field 6 has produced a good yield even by conventional standards, whereas barley after cabbage and especially after leek has produced less than expected from a conventional crop.

Soil N dynamics

An important part of the strategy in the crop rotation is to keep the fields plant covered into the late autumn wherever possible. This is done by growing catch crops or green manure crops in the autumn and after the cabbage crop by leaving the stubble still growing in the field. Where the soil is assumed to be effectively N depleted at harvest, i.e. after the harvest of the two barley crops, an autumn cover including legumes is grown. Where higher amounts of N residues are present at the harvest of the main crop, a non-legume autumn cover is grown which can effectively deplete the soil of its inorganic N content. To summarize the results of this strategy, the fields/crops are split into three groups:

Group 1, where no living crop was present in the field at the time of soil sampling in November, i.e. after leek, onions and carrots

Group 2, where the field was plant covered at the time of soil sampling in November, but the plant cover was killed before the subsequent soil sampling in May.

Group 3, where the field was plant covered at the time of soil sampling in November, and was still covered at the subsequent soil sampling in May, i.e. where grass clover was established in one year and left as a green manure in the following year.

Comparing the N_{min} measurements in three groups shows very different N dynamics during the winter. In group 1, without plant cover in the late autumn, November N_{min} was quite high, and the N_{min} values were unchanged or reduced before the subsequent soil sampling in May (Table 3). As some mineralization must have occurred, a considerable loss of N from these fields must have occurred. This is in accordance with the high N_{min} values found even in the subsoil layers in these fields in November at the start of the leaching period (Table 4). In group 2 and 3 the fields were covered in the late autumn, and accordingly November N_{min} was very low, also in the deeper soil layers (Table 4). In group 3 N_{min} was kept low until May, as the grass clover was not ploughed under (Table 5), but in group 2 N_{min} increased strongly from November to May. In these fields an optimal combination of low N_{min} in the autumn before the main leaching period and high N_{min} in the spring before the main period of crop N uptake was achieved. Further, a larger fraction of the available N in May was found in the topsoil layers after group 2 crops than after group 1 crops (Table 5).

Table 3. Ranges of N_{min} (kg N ha^{-1}) in the 0-100 cm soil layer in November, in May and change from November until May within the three groups of crops (see text).

	N_{min}, kg N ha^{-1}		
	November	**May**	**Change over winter**
Group 1	36 to 149	51 to 91	-61 to 16
Group 2	9 to 26	60 to 138	41 to 114
Group 3	13 to 29	24 to 25	-4 to 13

Table 4. Ranges of N_{min} (kg N ha^{-1}) in three soil layers in November found within the three groups of crops (see text).

	N_{min} in November, kg N ha^{-1}		
	0-50 cm	**50-100 cm**	**100-150 cm**
Group 1	19 to 58	5 to 100	7 to 32
Group 2	9 to 40	1 to 7	1 to 5
Group 3	9 to 26	2 to 4	2 to 3

Table 5. Amounts and depth distribution of N_{min} in May after three crops from group 1 (onion, carrot and leek) and three crops from group 2 (barley, cabbage and pea). Data from May 1998 only.

	Group 1			Group 2		
	Onion	**Carrot**	**Leek**	**Barley**	**Cabbage**	**Pea**
0-150	81	109	70	105	68	91
0-50	31	46	35	88	41	50
50-100	18	27	18	11	19	29
100-150	32	36	17	6	8	12
% in 0-50	**38**	**42**	**50**	**84**	**60**	**55**

N balance

The average N uptake among the harvested crops was approx. 125 kg N ha^{-1}, of which 82 kg N ha^{-1} was removed with the crop at harvest. Across all six fields in the crop rotation this means that there was an N export of almost 70 kg N ha^{-1} $year^{-1}$. This amount must be added to the crop rotation by biological N fixation and atmospheric deposition, to make the crop rotation sustainable.

As the pea crop had an N uptake of only 115 kg N ha^{-1}, its N fixation must have been well below 100 kg N ha^{-1}. Eriksen *et al.* (1996) estimated a biological N fixation of 200 to 220 kg N ha^{-1} in ungrazed grass clover pasture. The two fields with an autumn cover of grass clover must be expected to have an N fixation well below that of a full year grass clover pasture. Based on these figures, the average biological N fixation across the six fields is unlikely to reach the 70 kg N ha^{-1} removed with the crops.

As some losses through N leaching, denitrification and ammonia volatilization must also occur, it seems that the crop rotation could have a substantial N deficit, and the soil should be gradually depleted of its N reserves. On the other hand, large amounts of plant material is added to the soil in the crop rotation, and the soil is plant covered most of the time, thus, significant depletion of the soil organic matter and its N content seems unlikely. The initial results show that the crop rotation has been able to supply the crops with enough N for reasonable yields. Whether the soil N is actually being depleted, maintained or even increased by this crop rotation, can only be answered by future measurements.

Conclusion

Though a precise comparison cannot be made, the results suggest that four of the seven cash crops have produced yields at a level which we would normally expect to find in similar conventional crops, and no crops have shown really low yields. Thus, the crop rotation has for the first few years shown that good yields could be obtained by the methods used, without adding any nitrogen from other sources.

The yearly N removal with the harvested crop parts has been approximately 70 kg N ha^{-1}, and there have been other N losses from the system. To avoid N depletion of the soil, this requires a high N fixation from the legumes in the crop rotation, and a very efficient use of the N, which is fixed. On the other hand, a build up of organic N could be expected due to the extensive crop cover, and the large amounts of plant matter returned to the soil. The results from the coming years will show whether the system is becoming N depleted, the yield level can be maintained, or build up of organic N, and an increased N export is found.

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