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The Effect of Nitrogen Catch Crops on the Nitrogen Nutrition of a Succeeding Crop

I. Effects through Mineralization and Pre-emptive Competition

Thorup-Kristensen, K. (Horticultural Research Centre, Department of Vegetables, DK-5792 Årslev, Denmark). The effect of catch crops on the nitrogen nutrition of a succeeding crop. I. Effects through mineralization and pre-emptive competition. Accepted January 20, 1993. Acta Agric. **Scand., Sect. B, Soil and Plant Sci. 43: 74–81, 1993.** © Acta Agric. Scand. 1993.

The effects of catch crops on the nitrogen nutrition of a succeeding carrot crop were investigated. An attempt was made to distinguish the effects of growth and nitrogen uptake by the catch crop from the effect of mineralization of its residues. It was found that growth and nitrogen uptake by catch crops could reduce the nitrogen supply to the succeeding carrot crop through pre-emptive competition, whereas mineralization of nitrogen from the catch crop residues increased the nitrogen supply to the carrot crop. Nitrogen uptake by the carrots was thus highest where catch crop residues were incorporated on plots where no catch crop had been grown. The effect of the mineralization was found mainly to influence topsoil mineral nitrogen contents and the early nitrogen uptake by carrots, whereas the effect of pre-emptive competition was to reduce subsoil mineral nitrogen content and the nitrogen uptake by carrots late in the growing season. The apparent recovery of catch crop nitrogen by carrots was between 8 and 33%.

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Key words: carrots, incorporation time, phacelia, Italian ryegrass, winter rye.

Introduction

In vegetable production the use of fertilizers is normally very intensive, and this often leads to high leaching losses of nitrogen to the environment. One of the possible ways to reduce these losses is to grow nitrogen catch crops (Sørensen, 1992). Growing catch crops offers the advantage that losses to the environment can be reduced without reducing the nitrogen supply to the crop.

Catch crops reduce the losses to the environment by retaining nitrogen within the plant soil system, and, apart from reducing leaching losses, this will influence the nitrogen supply to the succeeding crops.

Experiments have shown very different effects of catch crops on the succeeding crop, from highly positive (e.g. Elers & Hartmann, 1986) to many negative results (e.g. Jensen, 1991). Negative results have often been explained by immobilization of nitrogen by the catch crop residues, but have also been found where catch crops led to increased topsoil mineral nitrogen content (Jensen, 1991).

One effect of catch crops on the nitrogen nutrition of the succeeding crop is the mineralization or immobilization caused by the decomposition of the plant residues in the soil. This effect is in principle only an effect of incorporation of the catch crop material; it is similar to the effect of an organic fertilizer added to the soil, and has been studied by several authors (e.g. Ladd et al., 1983; Jensen, 1992). The effect of catch crops is, however, more complex than that, as they, in contrast to organic fertilizers, do not add nitrogen to the soil but first assimilate their nitrogen from the soil itself.

The catch crops assimilate their nitrogen from the autumn soil mineral nitrogen pool. If this nitrogen pool is not completely leached before spring, then the catch crops reduce a nitrogen pool which would otherwise have been, at least partly, available for the succeeding crop. In this situation the nitrogen uptake by the catch crops occurs in a type of competition (pre-emptive competition) with the succeeding crop. In contrast to the effects of mineralization, this pre-emptive competition has not been much investigated.

As the nitrogen uptake by the catch crops leads to both an increase in the organic nitrogen pool and a decrease in the soil mineral nitrogen pool, the total effect of catch crops on the nitrogen supply of the succeeding crop (N_{eff}) can be described by the following equation:

$$N_{eff} = N_{upt} \cdot m - N_{upt} \cdot r \quad (1)$$

where N_{upt} is the nitrogen uptake by the catch crop, m is the fraction of the catch crop nitrogen which is mineralized in time to be utilized by the succeeding crop, and r is the fraction of late autumn soil mineral nitrogen retained within the rooting zone of the succeeding crop after winter leaching. $N_{upt} \cdot m$ is the fertilizer effect of catch crop residues and is thus only dependent on the incorporation of the catch crops. $N_{upt} \cdot r$ is the competition effect from the nitrogen uptake by the catch crops, and is thus only dependent on their nitrogen uptake and not on their incorporation. If leaching is complete, ($r = 0$) then decomposition ($m \cdot N_{upt}$) alone will determine the nitrogen effect of the catch crops. If leaching is less intense ($r > 0$), the total effect of catch crops on nitrogen supply is reduced, and if $r > m$ then the effect will be negative.

Apart from influencing the total amount of available nitrogen, catch crops also influence its distribution in time and space. Often a higher fraction of the soil mineral nitrogen will be present in the topsoil after catch crops (Sørensen, 1992), and the mineralization continues through the growing season. The result is an altered time course of nitrogen supply to the crops.

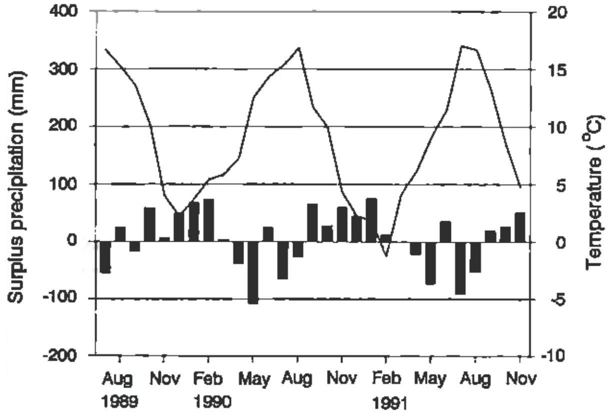

Fig. 1. Average monthly temperature and surplus precipitation during the experiment.

The purpose of the present work was to investigate separately the effects of mineralization and competition from catch crops, to investigate the effect of catch crops on the time course of nitrogen supply to a succeeding crop and to measure the effect of incorporation time on these nitrogen effects.

Materials and methods

The experiments were located at the Horticultural Research Centre, on a Typic Agrudalf soil. The upper 40 cm contains 2% organic matter, 11% clay, 14% silt and 73% sand. The 40–100 cm layer contains 0.2% organic matter, 19% clay, 13% silt and 67% sand.

The experiment was performed twice, in 1989/90 and 1990/91; the monthly average temperature and surplus precipitation are given in Fig. 1. The experiment included three catch crops each year: Italian ryegrass (*Lolium multiflorum*) and phacelia (*Phacelia tenacetifolia*) were included both years, and in the first year perennial ryegrass (*Lolium perenne*) and in the second year a winter rye with a strong growth in the autumn (*Secale cereale*, var. Multicaule) were included.

The experiment was made with a split-plot design, with ploughing time as the main plot factor and a plot size of 5 m × 10 m. The catch crop plots were rotavated just before ploughing, but in the spring-ploughed part autumn-rotavated plots were also included (Table 1). Before autumn incorporation the catch crops were harvested from some of the plots, and the harvested material was added to bare soil plots and incorporated. This treatment

Table 1. Treatments performed: A_a, autumn ploughing and rotavation; S_a, spring ploughing but autumn rotavation; S_s, spring ploughing and rotavation. It., Italian ryegrass; Phas., phacelia; per., perennial ryegrass; Rye, Winter rye; –, no catch crop. XX, performed each year; X ., performed first year; . X, performed second year and . ., combination not performed

Crop		Incorporation time		
Grown	Incorporated	A_a	S_a	S_s
–	–	XX	. .	XX
Phac.	Phac.	XX	XX	XX
It.	It.	XX	XX	XX
Rye	. X	. X	. X	
Per.	Per.	X .	X .	X .
Phac.	–	XX	. .	. .
It.	–	. X	. .	X .
Rye	–	. X	. .	. .
–	Phac.	XX	. .	. .
–	It.	. X	. .	X .
–	Rye	. X	. .	. .

was performed with phacelia both years and with all three crops in 1990/91. In 1989/90 it was performed with Italian ryegrass in the spring-ploughed part of the experiment, but the transfer of plant material was still performed in the autumn.

In order to simulate the situation after harvest of a vegetable crop, a crop of brussels sprouts was established in the spring of each of the two years. One to two weeks before sowing of the catch crops the brussels sprouts were cut at a height of 25–30 cm, the tops removed and the residues incorporated into the soil.

The catch crops were sown on August 1. In 1989 they were not fertilized, but in 1990 the brussels sprouts had left much less nitrogen and 50 kg N/ha were applied to all plots on September 8.

The autumn incorporation was done in the middle of November and the spring incorporation on March 20. Samples of the catch crops were taken before the autumn incorporation, and analyzed for dry matter production, nitrogen, nitrate nitrogen, carbon, and lignin content.

Carrots (*Daucus carota*) were sown about May 5 each of the years 1990 and 1991, and plant samples were taken four times during their growth including the final harvest (52, 80, 123, and 170 days after sowing in 1990, and 54, 94, 135 and 173 days after sowing in 1991). The crop was left unfertilized until after the first sampling date, when half of each plot was fertilized with 80 kg N/ha. In 1990 the carrots grown after perennial ryegrass were only sampled at the second and final dates, and only at the unfertilized plots.

Soil samples were taken in the autumn before incorporation of the catch crops (four soil layers 0–25, 25–50, 50–75 and 75–100 cm depth), about April 25 in the following spring and finally after harvest of the carrot crop. The soil samples were analyzed for content of mineral nitrogen (ammonium-N and nitrate-N). Soil sampling did not include the perennial ryegrass plots. The soil sampling after harvest of carrots did not include the S(a) treatments. In 1990 the four spring-ploughed Italian ryegrass plots were sampled at both fertilizer levels; the rest of the treatments were only sampled at the 0 N fertilizer level.

Results

The catch crops were quite effective in reducing autumn N_{min} both years, but as the nitrogen reserves were much higher in the autumn of 1989, the uptake was around twice as high as in the autumn of 1990 (Table 2).

The N_{min} (soil mineral nitrogen) left in the soil in November 1989 was leached to below 1 m before the spring of 1990, whereas after the winter of 1990/91 some of the autumn N_{min} was still present within the 50–100 cm soil layer in April 1991 (see below).

Table 2. Performance and composition of catch crops, legends as in Table 1

Catch crop	Dry matter, t/ha	N_{min} autumn	N uptake	NO_3-N content	C/N ratio	Lignin content, %
		kg N/ha				
1989						
Bare soil	–	260	–	–	–	–
Phac.	4.8	57	153	39	11.3	8
It.	5.3	57	168	23	12.7	2
Per.	3.8	66	130	17	11.8	2
1990						
Bare soil	–	115	–	–	–	–
Phac.	3.6	23	108	16	11.4	8
It.	2.7	24	76	2	14.7	2
Rye	1.9	19	69	1	11.0	3

The precipitation surplus between the time of autumn catch crop incorporation and the ending of the leaching period was 195 mm in 1989/90 and 165 in 1990/91. In 1990/91 more than 30 mm of this surplus occurred in the first week after ploughing, at a time when very little nitrogen from the incorporated catch crop residues could have been mineralized. Together these results indicate a more intense leaching in the first experimental year than in the second.

The utilization of added fertilizer nitrogen by the carrots was high both years, with addition of 80 kg N/ha leading to an increased uptake of about 60 kg N/ha on average over the bare soil plots (Table 3).

Soil mineral nitrogen content

Catch crops led to higher levels of total N_{min} in the spring, from 35–79 kg N/ha in 1990, and from −1 to 15 kg N/ha in 1991. In the spring of 1990 most catch crops had led to an increased subsoil N_{min} but in 1991 they led to reduced subsoil N_{min} (Table 4).

The more intense leaching in the first year meant that in 1989/90 autumn incorporated catch crops had a positive effect on both topsoil (0–50 cm) and subsoil (50–100 cm) N_{min}, and that the N_{min} in topsoil and subsoil showed a positive correlation (topsoil N = 50 kg N/ha + 0.43** × subsoil N, r^2 = 0.32). In 1990/1991 catch crops showed a positive effect only on topsoil N_{min}, but a negative effect on the subsoil, and the N_{min} in the topsoil and subsoil tended to be negatively correlated this year (topsoil N = 54 kg N/ha − 0.49* × subsoil N, r^2 = 0.21). In

Table 3. Nitrogen uptake by carrots on plots where catch crops were both grown and incorporated. The LSD value is for comparing treatments with the same ploughing time. Legends as in Table 1

	Nitrogen fertilization					
	0 kg N/ha			80 kg N/ha		
Catch crop	A_a	S_a	S_s	A_a	S_a	S_s
1990						
Bare soil	157	163		224	223	
Phac.	180	193	198	227	228	238
It.	201	195	194	240	244	242
Per.	194	218	199	.	.	.
$LSD_{0.05}$			15			
1991						
Bare soil	146	140		194	206	
Phac.	145	149	160	205	218	228
It.	151	153	149	209	231	215
Rye	173	158	163	218	226	226
$LSD_{0.05}$			14			

Table 4. Spring soil mineral nitrogen content where catch crops had both been grown and incorporated. Legends as in Table 1

		N_{min}, kg N/ha/soil layer			
		1990		1991	
Catch crop		0–50	50–100	0–50	50–100
Bare soil	A_a	42	23	33	22
Phac.	A_a	62	38	43	15
It.	A_a	66	55	49	10
Rye	A_a	–	–	56	15
Phac.	S_s	67	46	52	20
It.	S_s	82	20	61	6
Rye	S_s	–	–	73	10
Bare soil	S.	42	20	40	28
Phac.	S_a	62	45	50	22
It.	S_a	76	65	58	15
Rye	S_a	–	–	65	16
$LSD_{0.05}$		9	10	8	8

this season subsoil nitrogen content showed a close positive correlation to N_{min} in the previous autumn instead (subsoil N = 9 kg N/ha + 0.10*** × autumn N, $r^2 = 0.59$).

In the spring of 1990 the N_{min} was 40 and 68 kg N/ha higher after autumn incorporation (A_a and S_a) phacelia and Italian ryegrass, respectively, than after bare soil (Table 4), indicating that 26 and 40% of the nitrogen content in the incorporated catch crop material had already mineralized from the two crops. Similarly in 1991 the rise in topsoil N_{min} after catch crops was equivalent to 9, 22 and

Table 5. Nitrogen uptake and N_{min} as influenced by either growing or incorporation of autumn ploughed (A_a) catch crops. Legends as in Table 1

Catch crop		Nitrogen uptake, kg N/ha			Spring N_{min}, kg N/ha	
Grown	Incorporated	Early	Late	Total	0–50	50–100
1990						
–	–	52	102	154	42	23
–	Phac.	63	121	184	62	38
Phac.	–	58	106	164	49	21
Phac.	Phac.	64	112	176	62	38
$LSD_{0.05}$		11	23	21	9	10
1991						
–	–	82	88	170	33	22
–	Phac.	91	88	179	45	27
Phac.	–	84	77	160	36	13
Phac.	Phac.	91	84	175	43	15
–	It.	87	94	186	41	24
It.	–	85	88	174	35	10
It.	It.	98	82	180	49	10
–	Rye	84	102	186	35	23
Rye	–	85	86	171	47	13
Rye	Rye	96	100	196	56	15
$LSD_{0.05}$		10	14	14	8	8

35% of the nitrogen uptake by phacelia, Italian ryegrass and winter rye, respectively.

The nitrogen distribution in the soil after phacelia was unaffected by the time of incorporation (A_a and S_a vs. S_s), but after the grass catch crops (Italian ryegrass, perennial ryegrass and winter rye) spring incorporation led to reduced subsoil N_{min} and increased topsoil N_{min} as compared with autumn incorporation.

A separate effect of growing catch crops independently of whether they were incorporated on the plot or not was calculated as the average difference between (1) bare soil plots (–/–) and plots where catch crops were grown but not incorporated (+/–) and (2) bare soil plots where catch crop plant material was incorporated (–/+) and plots where catch crops were grown and incorporated (+/+). In the same way a separate effect of incorporating catch crops was calculated as the average difference between (1) –/– and –/+ and (2) +/– and +/+.

In both years the separate effect of incorporating a catch crop was to increase the topsoil N_{min} in the following spring. In 1989/90 it increased subsoil N_{min} too, an effect which was only weakly indicated in the 1990/91 results (Tables 5 and 6). A separate effect of growing a catch crop was only observed in 1990/91 when it led to a reduced subsoil N_{min} in the spring for phacelia, whereas topsoil N_{min} was only dependent on incorporation. For the grass

Table 6. Separate effects of growing or incorporation of autumn ploughed catch crops. Grass catch crops in 1991 is average over Italian ryegrass and winter rye

	Nitrogen uptake, kg N/ha			Spring N_{min}, kg N/ha	
	Early	Late	Total	0–50	50–100
1990					
Growing phacelia	+3	−3	0	+4	−1
Incorp. phacelia	+9	+13	+21	+17	+16
$LSD_{0.05}$		8	8	5	5
199					
Growing phacelia	+1	−8	−7	+1	−11
Incorp. phacelia	+8	+4	+12	+10	+4
Growing grass	+7	−3	+3	+12	−11
Incorp. grass	+8	+7	+16	+9	+2
$LSD_{0.05}$	9	9	8	4	3

catch crops the separate effect of growing was also a tendency to an increased topsoil N_{min}. This indicates that significant mineralization occurred from the roots and stubble left when the catch crops were harvested.

Nitrogen uptake

In both years the carrots showed a high nitrogen uptake and a high utilization of fertilizer nitrogen, and in both years the nitrogen uptake increased when the carrots were grown where catch crops had been grown and incorporated (Table 3). In 1990 this positive effect was only significant in the unfertilized plots, whereas in 1991 the positive effect of catch crops was unaffected by fertilizer level.

In 1990 the three catch crops of phacelia, Italian ryegrass and perennial ryegrass were on average able to increase the nitrogen uptake of the unfertilized carrots with 29, 39 and 43 kg N/ha, respectively, (Table 3) and in 1991 phacelia, Italian ryegrass and winter rye were on average able to increase this uptake with 12, 13 and 22 kg N/ha (average of both fertilizer levels). These effects on uptake were lower than the effect of the same catch crops on spring N_{min}.

The effect of different incorporation times on nitrogen uptake was very small, but the nitrogen uptake of carrots after phacelia seemed to show a positive effect of postponing the incorporation until spring (Table 3).

The separate effect of incorporating plant material was consistently an increased nitrogen uptake by the carrots, whereas a separate effect of growing catch crops was only found with phacelia in 1991, when it tended to reduce the nitrogen uptake (Tables 5 and 6).

Timing of nitrogen uptake

At the time of the first growth analysis the carrots had taken up between 2.5 and 5 kg N/ha, and the only clear result was that within the S_s plots carrots showed lower uptake after catch crops than after bare soil.

The uptake until the second analysis was generally increased where catch crops had both been grown and incorporated as compared to carrots after bare soil. The effect of growing and incorporating catch crops on the uptake late in the season, between second and fourth harvest, was less clear (Table 5). Postponing incorporation from autumn to spring made carrots following grasses take up an increased part of their nitrogen in the early part of the season, but it showed the opposite effect on carrots following phacelia.

The separate effect of incorporating plant material was an increased uptake throughout the season, whereas a separate effect of growing catch crops was only found in 1991, when it led to a reduced uptake by the carrots in the late part of the season with almost no effect on the early uptake (Table 6).

Correlations between soil mineral nitrogen and nitrogen uptake were insignificant in 1990, but in 1991 the early uptake (until second harvest) was correlated to topsoil N_{min} and the late uptake to the subsoil N_{min}. The equations (calculated on the A_a plots) were:

$$\text{Early uptake} = 51 + fN \cdot 0.32^{***} + tN \cdot 0.59^{***}$$

$$\text{Late uptake} = 63 + fN \cdot 0.35^{***} + tN \cdot 0.11^{NS} + sN \cdot 0.46^{*}$$

where fN, tN, and sN are fertilizer, topsoil and subsoil mineral nitrogen, respectively, in kg N/ha.

Nitrogen left in the soil

Especially in 1990, addition of organic material by catch crops led to higher nitrogen residues left in the soil after harvest of the carrots, and this effect was much stronger in the fertilized plots than in the unfertilized plots (Fig. 2). On the four spring-ploughed Italian ryegrass treatments of 1989/90 nitrogen residues were on average increased by 20 kg N/ha as a consequence of fertilization. A similar pattern was found in 1991, but the amount left in the soil was much smaller. The topsoil N_{min} was only slightly affected by the experimental treatments; almost all variation occurred in the subsoil.

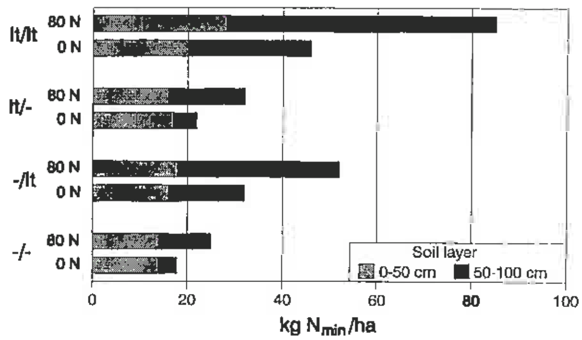

Fig. 2. Soil mineral nitrogen after harvest of carrots, effect of fertilization and Italian ryegrass treatments in 1990. Results from spring ploughed plots, It/It = ryegrass grown and incorporated, It/ − = grown but not incorporated, − /It = incorporated on bare soil plots, and − / − = bare soil.

Discussion

The different effects of catch crops on subsoil N_{min} in the two years indicate that leaching was more intense in 1989/90 than in 1990/91. This is supported by the climatic data and by the correlations relating spring subsoil N_{min} in 1990 to spring topsoil N_{min}, but relating spring subsoil N_{min} in 1991 to N_{min} in the previous autumn. This means that the 1990 results represent a situation with almost complete leaching, where pre-emptive competition from catch crops should be absent, and the 1991 results represent a situation with incomplete leaching, which may have led to competition from the catch crop.

The pre-emptive competition for nitrogen by catch crops was clearly demonstrated by the reduced subsoil N_{min} after catch crops in the spring of 1991, and the same effect is seen in the results of Sørensen & Thorup-Kristensen (1993). Further the pre-emptive competition was demonstrated in the reduced nitrogen uptake by carrots in the late part of the season. That the carrots assimilated nitrogen from the subsoil pool was indicated by their efficient depletion of this soil layer and by the correlation between subsoil N_{min} and late nitrogen uptake.

The retention (r) and mineralization (m) factors in eqn. (1) can be estimated for phacelia in the two seasons from the results on nitrogen uptake by carrots (Table 6), and the nitrogen uptake of phacelia (Table 2). For 1990 the estimates are $r=0.00$ and $m=0.14$ whereas for 1991 they are $r=0.06$ and $r=0.10$. In both cases m was found to be higher than r, so a positive effect of catch crops is indicated, but in 1991 the difference between m and r was small, and this was reflected in the low effect of phacelia found in the A_a and S_a plots.

The results on N_{min} after harvest of carrots indicate that the effective rooting depth for nitrogen utilization varied between the treatments (especially in 1990), and this must have made the correlations between subsoil N_{min} and nitrogen uptake less clear. It has been found that crops may show varying root depth as a consequence of an altered spatial distribution of nitrogen (Diggle & Bowden, 1990, Diggle et al., 1990), and as a consequence of preceding catch crops (Thorup-Kristensen, 1993).

The apparent nitrogen recovery by the carrots of between 8 and 33% of the nitrogen in the catch crops is in accordance with the results reported by Ladd et al. (1983) and Jensen (1992) on crop uptake of ^{15}N-labelled nitrogen mineralized from added plant material, and with Marstorp & Kirchmann (1991) and Sørensen & Thorup-Kristensen (1993) measuring the nitrogen effects by the difference method.

Spring soil N_{min} for both years indicated that in some situations at least 30% of the nitrogen content in incorporated catch crop material had already mineralized before spring, but the effect on nitrogen uptake by the carrots was generally lower than that. Part of the reason for this difference is that more nitrogen was left in the soil after harvest, at least in 1990 (Fig. 2).

Mineralization of 30% of the nitrogen content in the plant material during the winter and early spring is a high value compared to the 10–30% mineralized from several green plant materials over a whole year as reported by Ladd et al. (1983) and Jensen (1992). The high mineralization rate during the winter may be due to the high amounts of nitrogen-rich plant material added. In several experiments the nitrogen effect of catch crops, especially grasses, has been found to be negative (Jensen, 1991), but in the experiments in which grass catch crops were grown under nitrogen rich conditions they had a positive nitrogen effect (Elers & Hartmann, 1986; Sørensen, 1992; Sørensen & Thorup-Kristensen, 1993). Kirchmann & Marstorp (1991) predicted a mineralization of about 1/3 of the nitrogen content in clover green manure during the winter and early spring when their C/N ratios were around 13, as was the case in the plant materials used in the present experiment.

The relative mineralization rates presented are higher than the real values, as the root and stubble were not included in the measurements. This is probably a serious problem with the grasses, where root and stubble may contain a substantial part of the dry matter (Jensen, 1991; Breland, 1989), but for phacelia this was probably not much of a problem, as all stubble was easily harvested, and the crop is an annual crop which was in its seed-setting phase, a situation normally involving a low root mass.

Postponing incorporation from autumn to spring only influenced N_{min} after grass catch crops, not after phacelia, probably owing to the fact that phacelia died in the autumn, whereas for the grasses spring incorporation meant that nitrogen uptake continued until spring, and that the onset of mineralization was postponed. In spite of these results carrots after phacelia showed a positive yield and nitrogen uptake effect of postponing incorporation, whereas carrots after grass catch crops were unaffected. The reason for this discrepancy is not obvious from the results, but apart from its inability to survive the winter, phacelia also differed in that it contained more nitrate than the other catch crops. Nitrate nitrogen is available for leaching immediately after incorporation, but this leaching will be delayed by postponing the incorporation until spring. The reasons for the high N_{min} levels and low plant response after spring-incorporated grass catch crops are unclear, but the effect was present very early in the season, and is in accordance with the results of Sørensen & Thorup-Kristensen (1993).

The regressions found in the 1991 results show that in the early part of the season the carrots assimilated nitrogen only from the topsoil which the catch crops had enriched, whereas in the later part of the season the carrots assimilated nitrogen from the subsoil pool, which the catch crops had already reduced. That utilization of subsoil nitrogen will occur mainly in the later part of the growing season has been found by Strebel & Duynisveld (1989).

Apart from the altered spatial distribution of spring N_{min}, mineralization from the catch crop residues is likely to increase the nitrogen supply throughout the season. This is supported by the effect of adding plant material to bare soil plots. Growing and harvesting catch crops led to a low uptake in the late part of the season when mineralization was low, and when uptake at the same time occurred from the subsoil, which was depleted as a consequence of uptake by the catch crops.

The implications of the results on nitrogen left in the soil after harvest are that the carrots have only a limited ability to take up nitrogen, and that if this is fully supplied by other sources than mineralization from catch crops, then catch crops will lead to increased amounts of nitrogen left in the soil after harvest. This nitrogen is left in the subsoil, where it is most certain to be leached to below rooting depth of the next crop. If this is a general effect, catch crops must be followed by a reduced nitrogen fertilization, otherwise they will only reduce leaching the year they are grown and then lead to increased leaching in the following years, as shown by Jäggeli (1978).

Conclusion

Nitrogen uptake by the catch crops may occur in competition with the succeeding crop. The positive effect of a catch crop can therefore be expected to be highest when leaching is high. Leaching in this context means leaching to below the rooting zone of the succeeding crop, and is thus determined not only by soil and climate but also by the rooting depth of the succeeding crop. Situations with incomplete leaching demand more caution, as a positive result is less certain.

Catch crops also change the time course of the nitrogen supply, and will be of highest value to crops which are well able to benefit from a high early supply of nitrogen. To crops which benefit from a late supply of nitrogen [as has often been found for cereals, where too high an early supply may lead to high straw production and a low harvest index (e.g. Søegaard, 1986)], catch crops may lead to a negative response more due to the altered timing of nitrogen supply than to the total nitrogen supply.

After catch crops it may be advisable to change the fertilization strategy, so that apart from reducing the total amount of fertilizer used, a higher fraction of the fertilizer may have to be added later in the growing period.

Nitrogen from autumn-incorporated catch crops may be leached before spring, so spring incorporation of catch crops will, at least where mineralization and leaching during the winter is high, lead to a better environmental effect. Furthermore, overwintering catch crops may take up nitrogen during winter and early spring.

References

Breland, T.A. 1989. Soil organic carbon and nitrogen dynamics in grain cropping: Effects of undersown catch crops and green manuring. Ph.D. Thesis, Department of Microbiology, Agricultural University of Norway, Ås, 142 pp.

Elers, B. & Hartmann, H. D. 1986. Biologische Konservierung von Nitrat über Winter. VDLUFA-Schriftenreihe 20, 427–439.

Elers, B. & Hartmann, H. D. 1987. Biologische Konservierung von Nitrat. Gemüse 4, 210–214.

Diggle, A. J. & Bowden, J. W. 1990. The effect of water addition on the response of wheat roots to added nitrogen in a leaching environment. Aust. J. Soil Res. 28, 973–980.

Diggle, A. J., Bowden, J. W., & D'Antuono, M. F. 1990. A comparison of the effects of mineral and organic nitrogen sources on the distribution of wheat roots in a leaching environment. Aust. J. Soil Res. 28, 963–971.

Jäggli, F. 1978. Sickerverluste an mineralstoffen. Mitteilungen für die Schweizerische Landwirtschaft, 26, 130–136.

Jensen, E. S. 1991. Nitrogen accumulation and residual effects of nitrogen catch crops. Acta Agric. Scand. 41, 333–344.

Jensen, E. S. 1992. The release and fate of nitrogen from catch crop materials decomposing under field conditions. J. Soil. Sci. 43, 335–345.

Kirchmann, H. & Marstorp, H. 1991. Calculation of N mineralization from six green manure legumes under field conditions from autumn to spring. Acta Agric. Scand. 41, 253–258.

Ladd, J. N., Amato, M., Jackson, R. B. & Butler, H. A. 1983. Utilization by wheat crops of nitrogen from legume residues decomposing in soils in the field. Soil Biol. Biochem 15, 231–238.

Marstorp, H. & Kirchmann, H. 1991. Carbon and nitrogen mineralization and crop uptake of nitrogen from six green manure legumes decomposing in soil. Acta Agric. Scand. 41, 243–252.

Strebel, O. & Duynisveld, W. H. M. 1989. Nitrogen supply to cereals and sugar beet by mass flow and diffusion on a silty loam. Z. Pflanzenernär. Bodenk. 152, 135–141.

Søegaard, K. 1986. Deling af kvælstofgødning til vandet byg. Tidskr. Planteavl 90, 300. Beretning nr. S 1859.

Sørensen, J. N. 1992. Effect of catch crops on the content of soil mineral nitrogen before and after winter leaching. Z. Pflanzenernär. Bodenk. 155, 61–66.

Sørensen, J. N. & Thorup-Kristensen, K. 1993. Nitrogen effects of non legume catch crops. Z. Pflanzenernär. Bodenk. 156, 55–59.

Thorup-Kristensen, K. 1993. Root growth of catch crops and of a succeeding crop of broccoli. Acta Agric. Scand. Sect. B, 43, 58–64.