Effect of catch crops on the content of soil mineral nitrogen before and after winter leaching

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Summary - Zusammenfassung

Since large amounts of nitrogen may be lost by leaching during the winter period, investigations have been carried out to find suitable crops for catching nitrogen during the autumn. The plant species phacelia, common sunflower and italian ryegrass were sown at three times during the late summer. The soil was analysed for mineral nitrogen at the end of November just before incorporation of the catch crops and in the middle of April the following year.

The dry matter production and the uptake of nitrogen decreased as the establishment was postponed and the growth period thereby decreased. When sown in the middle of July or at the beginning of August phacelia and italian ryegrass accumulated 150 kg N per ha in the above ground plant parts.

The content of soil mineral nitrogen in November was reduced by growing catch crops during the autumn. The content of soil mineral nitrogen increased as the growth period of the catch crops decreased. The content of mineral nitrogen in the upper 50 cm soil layer in April was, irrespective of plant species, increased by catch crops.

When no crop was grown the difference between the content of soil mineral nitrogen measured before and after the winter period indicated a net loss of 144 kg of N per ha in 0-100 cm soil depth. When italian ryegrass was sown in the middle of July the previous year the content of soil mineral nitrogen found in April was 59 kg per ha higher compared to the content found in November.

Einfluß von Gründüngungspflanzen auf den Mineralstickstoffgehalt des Bodens vor und nach Nitratauswaschung über Winter

Da große Nitratmengen bei Auswaschung über Winter verloren gehen können, wurden Versuche über das Stickstoffentzugsvermögen von verschiedenen Gründüngungsarten durchgeführt. Die Pflanzenarten Phacelia, Sonnenblumen und Welsches Weidelgras wurden im Spätsommer zu drei verschiedenen Zeitpunkten ausgesät. Der Boden wurde Ende November, kurz vor der Einarbeitung, und Mitte April im folgenden Jahr auf Mineralstickstoff analysiert.

Je später die Aussaat erfolgte, um so geringer war der Trockenmasseertrag und der Stickstoffentzug. Wenn Phacelia und Welsches Weidelgras Mitte Juli oder Anfang August ausgesät wurde, konnten die oberirdischen Pflanzenteile dem Boden 150 kg N pro ha entziehen.

Im Vergleich zur unbewachsenen Fläche wurde der Mineralstickstoffgehalt des Bodens im November reduziert, wenn im Herbst Gründüngungspflanzen angebaut wurden. Wurde der Aussaatetermin verschoben, so nahm der Mineralstickstoffgehalt im Boden zu. Bei der Begrünung wurde der Mineralstickstoffgehalt bis zu 50 cm Tiefe im April unabhängig von der Pflanzenart vergrößert.

Über Winter zeigte sich ein Nettoverlust von 144 kg Mineralstickstoff pro ha in 0-100 cm Bodentiefe auf der unbewachsenen Fläche. Wenn Welsches Weidelgras Mitte Juli angebaut wurde, war der Gehalt von Mineralstickstoff im April 59 kg N pro ha größer als der Gehalt im November.

Introduction

After harvest of some vegetables a large loss of nitrogen by leaching during the winter period is possible. Firstly, high contents of residual nitrogen is found as some vegetables are not harvested at maturity, but in an active growth stage (Böhmer, 1980). Secondly, large amounts of nitrogen in easily decomposable plant residues are left in the field after harvest (Alt, 1987). Thirdly, many vegetables are harvested early in the season, in July and August. Since the soil temperature in this period is high, plant residues are going to be decomposed rapidly.

Growing catch crops during the autumn after harvest of a main crop has been conducted by Nielsen and Jensen (1985) and Elers and Hartmann (1986). In addition to yield and nitrogen uptake they measured the content of soil mineral nitrogen as affected by different catch crops.

A high catchment of nitrogen during the autumn is desir-

able to reduce the loss of soil mineral nitrogen by leaching during the period of water discharge, thereby protecting the environment. A high catchment of nitrogen during the autumn, however, is not necessarily a good predictor for a high content of soil mineral nitrogen in the spring and the following growth period of a main crop. This is influenced by the kinetic parameters of nitrogen mineralization as investigated by Frankenberger and Abdelmagid (1985), Gutscher and Vilsmeier (1985), and Müller et al. (1988).

The objective of this research was to investigate how loss of nitrogen during the winter period can be reduced or even prevented by growing catch crops, established at different times, during late summer. In the experiment only plant species, which are unrelated with the most commonly grown vegetables, were chosen for catching nitrogen.

To avoid nitrate leaching during the period of water discharge catch crops grown on light soils are normally overwintering and incorporated into the soil in the early spring.

However, in the present experiment the catch crops were incorporated into the soil just before the winter period. In Denmark the period of water discharge begins in November and last until April.

In addition to studying the effect of catch crops on soil mineral nitrogen before and after the period of nitrate leaching, the relationship between the chemical composition of the catch crops just before incorporation and the content of soil mineral nitrogen just after the winter period is discussed.

Materials and Methods

In four years, 1985-1988, the plant species phacelia (*Phacelia tanacetifolia* Benth.), common sunflower (*Helianthus annuus* L.), and italian ryegrass (*Lolium multiflorum* Lam.) were sown at 3 different times in the later summer. The first sowing time was in the middle of July, the second at the beginning of August and the third in the middle of August. The experiment was arranged in a split plot design with two replications. In this arrangement plots with no crop were included. The experimental area was changed each year.

Before sowing the experimental area was kept clear of weeds by harrowing. To simulate the amount of nitrogen, either unused fertilizer nitrogen or nitrogen mineralized from plant residues left in the field by a main crop, 150 kg N per ha was applied as calcium ammonium nitrate. The experiment was conducted on a sandy loam soil. The content of soil mineral nitrogen in June after application of nitrogen is given in table 1. The topsoil contained 15.1 mg K, 6.4 mg Mg, and 4.2 mg P per 100 g dry soil. Potassium and magnesium were extracted with ammonium acetate; phosphorus with sodium bicarbonate. The pH (0.01 M CaCl₂) was 6.4 and the bulk density 1.5 g per cm³ in the topsoil and 1.6 g per cm³ in the subsoil. The plants were neither irrigated nor sprayed against weeds or pests.

Table 1: Content of soil mineral nitrogen in June after application of fertilizer nitrogen. Average of four years.

Tabelle 1: Mineralstickstoffgehalt im Juni nach der Stickstoffdüngung. Mittelwert von vier Jahren.

Soil layer cm	Mineral nitrogen kg/ha
0 - 25	170
25 - 50	44
50 - 75	30
75 - 100	17

In the middle of November the above ground plant parts were sampled for yield determination. The plants were analysed for dry matter and chemical composition. The content of total nitrogen in plant dry matter was determined according to AOAC (1984). The content of carbon was determined after incineration to carbon dioxide (Tabatabai and Brenner, 1970) and the content of lignin was analysed according to Van Soest (1963).

At the end of November the experimental area was ploughed for incorporating the catch crops. Just before incorporation, and in the middle of April the following year, the soil was analysed for mineral nitrogen in 4 layers of 25 cm. Nitrate-nitrogen and ammonium-nitrogen was determined on an autoanalyzer according to slightly modified methods of Best (1976) and Crooke and Simpson (1971) respectively.

On the area with sunflower the soil was analysed only for the first sowing time in the experiment in 1985/86. The content of lignin was not determined in the experiments in 1985/86 and in 1986/87. Unless stated otherwise, all significant differences are at $P = 0.05$.

Results and Discussion

Dry matter yield and plant chemical composition

Decreasing growth period significantly reduced the dry matter production of the plant species. As can be seen in figure 1 the dry matter production of the catch crops was reduced by 30-70 % when sown in the middle of August compared to sowing one month earlier. This reduction is not only caused by reduced growth period but also by reduced day length and temperature in the late summer and autumn.

Figure 1: Production of dry matter in tons per ha and removal of N in kg per ha by catch crops sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3). Average of four years. Bars represent LSD_{0.05} for comparing means with different sowing times of the same species (a) and for comparing means with the same sowing time of different species (b).

Abbildung 1: Einfluß der drei Aussaattermine Mitte Juli (1), Anfang August (2) und Mitte August (3) auf den Ertrag in t Trockenmasse pro ha und den Stickstoffentzug in kg pro ha der drei Gründungsarten. Mittelwerte von vier Jahren. Um Mittelwerte derselben Pflanzenart mit verschiedenen Saatterminen zu vergleichen ist LSD_{0.05} (a), um Mittelwerte verschiedener Pflanzenarten mit gleichem Saattermin zu vergleichen LSD_{0.05} (b) angezeigt.

The contents of C and total N in the dry matter were significantly affected by the plant species and by the sowing time. The dry matter per cent and the C/N ratio was significantly affected by the sowing time whereas the content of lignin was significantly affected by the plant species only.

Italian ryegrass differ from the two other plant species in chemical composition. The percentage dry matter and the contents of C and total N in the dry matter of italian ryegrass was higher and less fluctuating compared to phacelia and sunflower (table 2). These differences influence the C/N ratio. The reduction in C/N ratio of italian ryegrass was not so pronounced as in the other species, especially sunflower. In an experiment with subterranean clover Müller et al. (1988) found an increased C/N ratio as the growth period increased. Contrary to Müller et al. (1988) Kirchmann and Bergqvist (1989) did not find any effect of growth period on the content of C and the C/N ratio in an experiment with white clover. However, both found an increased content of lignin as the growth period of clover increased.

In the present experiment the C/N ratio and the content of lignin in all plant species decreased as the growth period decreased (figure 2). The content of lignin in phacelia was

Table 2: Percentage dry matter and C and N as per cent in dry matter of catch crops sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3).

Tabelle 2: Trockenmasse, C und N in Prozent der Trockenmasse der Gründungspflanzen Mitte Juli (1), Anfang August (2) und Mitte August (3) ausgesät.

Species	Sowing	DM	C	N
Phacelia	1	14.4	38.9	2.60
	2	8.8	36.0	3.19
	3	8.1	33.9	3.38
Sunflower	1	15.3	39.9	2.43
	2	11.2	36.5	2.99
	3	11.8	35.6	3.88
Ryegrass	1	15.3	43.1	3.34
	2	14.0	41.8	3.66
	3	14.3	41.9	3.97
LSD _a		2.4	1.5	0.36
LSD _b		ns ^x	1.6	0.35
LSD _c		4.5	1.6	0.41

a) For comparing means with different sowing times of the same species.

b) For comparing means with the same sowing time of different species.

c) For comparing means with different sowing times of different species.

x) ns = nonsignificance.

more than halved in plants sown in the middle of August compared to plants sown a month earlier. The content of lignin in italian ryegrass was very low compared to the content in phacelia and sunflower. Italian ryegrass is a plant species, which is used for fodder. It is improved with the purpose of increasing the digestibility.

The content of total N in the present experiment increases with a decreasing growth period. This result is ascribed to a

Figure 2: C/N ratio and per cent of lignin in the dry matter of phacelia (Δ), sunflower (○) and italian ryegrass (□) sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3). Values for content of lignin are means of two years results. Bars represent LSD_{0.05} for comparing means with different sowing times of the same species (a), for comparing means with the same sowing time of different species (b) and for comparing means with different sowing times of different species (c). See text for further explanation.

Abbildung 2: C/N Verhältnis und Gehalte an Lignin in der Trockenmasse von Phacelia (Δ), Sonnenblume (○) und Welschem Weidelgras (□) mit den Aussaatterminen Mitte Juli (1), Anfang August (2) und Mitte August (3). Die Werte für die Konzentration von Lignin sind Mittelwerte von zwei Jahren. Um Mittelwerte derselben Pflanzenart mit verschiedenen Saatterminen zu vergleichen ist LSD_{0.05} (a), für Mittelwerte verschiedener Pflanzenarten mit gleichem Saattermin der LSD_{0.05} (b) und für Mittelwerte verschiedener Pflanzenarten mit verschiedenen Saatterminen der LSD_{0.05} (c) angezeigt.

dilution effect as plants get older. Although the nitrogen content increases as the growth period decreases the total nitrogen uptake generally decreases.

Nitrogen uptake by the catch crops

The uptake of N by sunflower was significantly lower than that by phacelia or italian ryegrass which accumulated 150 kg of N per ha when sown in the middle of July or at the beginning of August (figure 1). The uptake of N was significantly affected by the sowing time. When sown in the middle of August 120-130 kg of N per ha was taken up by phacelia or italian ryegrass.

In the present experiment 150 kg N per ha was supplied to simulate the amount of nitrogen, either residual nitrogen or nitrogen mineralized from plant residues, left in the field by a main crop. By supplying a commercial fertilizer the nitrogen is plant available soon after application. By supplying organic matter the nutrients have to be released by decomposition before they are plant available. Supplying nitrogen in plant residues would probably result in a lower yield and a lower nitrogen uptake by the catch crops. However, to simulate the content of residual nitrogen, which is high after growing several vegetable crops, an easily available nitrogen fertilizer has to be supplied.

Soil mineral nitrogen

Soil mineral nitrogen before winter leaching

The content of mineral nitrogen at different soil depths at the end of November was significantly affected by the plant

Table 3: Significance from analysis of variance for the content of mineral nitrogen in different soil depths at the end of November and in the middle of April the following year and for the difference between the two sampling times.

Tabelle 3: Signifikanzen nach Varianzanalysen der Mineralstickstoffgehalte in verschiedenen Bodentiefen zu den Zeitpunkten Ende November und Mitte April im folgenden Jahr, sowie der Differenzen zwischen den zwei Zeitpunkten.

Source of variation				
	Soil layer	Sowing time	Catch crop	Sowing time *Catch crop
November	0 - 25	ns	*	ns
	0 - 50	*	***	ns
	0 - 75	**	***	ns
	0 - 100	**	***	ns
April	0 - 25	ns	***	ns
	0 - 50	*	**	ns
	0 - 75	ns	**	ns
	0 - 100	ns	*	ns
Difference	0 - 25	*	**	ns
	0 - 50	**	***	ns
	0 - 75	**	***	ns
	0 - 100	**	***	ns

ns, *, **, *** designate nonsignificance, significance at 5 %, 1 % and 0.1 % level, respectively.

species and by the sowing time (table 3). No interactive effect was found. When no catch crop was grown 240 kg of mineral N per ha was found in 0-100 cm soil depth on average. This value ranged from 230 in 1985/86 and 1987/88 to 260 kg N per ha in the 1988/89 experiment. In addition to applied nitrogen fertilizer, nitrogen has been mineralized from soil organic matter. This mineralization has probably been promoted by affecting the soil moisture by several harrowings during the autumn (Sørensen, 1974).

The content of mineral nitrogen in the soil profile increased when the growth period of the catch crops decreased as seen in figure 3. When italian ryegrass was sown in the middle of July only 50 kg of mineral N per ha was found down to 1 m depth. When sown at the beginning of August or in the middle of August, 75 and 110 kg of soil mineral N per ha respectively was found.

Figure 3: Mineral nitrogen in kg per ha in soil layers of 25 cm measured at the end of November in bare soil and in soil grown with catch crops sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3).

Abbildung 3: Mineralstickstoffgehalt in kg pro ha in Bodenschichten von 25 cm Dicke Ende November für die Aussaattermine Mitte Juli (1), Anfang August (2) und Mitte August (3).

The main part of the mineral nitrogen in 0-100 cm soil depth at the end of November was found in the lower soil layers, when no catch crop was grown. On average 90 % of the mineral nitrogen found down to 1 m depth was located below 25 cm soil depth. When a catch crop was grown, in general most of the mineral nitrogen was found in the topsoil. On average 40-50 % of the mineral nitrogen found down to 1 m soil depth was located in the upper 25 cm when the catch crops were sown in the middle of July or at the beginning of August. Catch crops therefore have, by taking up nitrogen, reduced or even prevented the risk of nitrogen leaching to the subsoil during the period of water

content in bare soil, which contained 96 kg of mineral N per ha. Growing italian ryegrass the content was 10 % higher when sown in the middle of July, but decreased as the growth period decreased. These findings are in agreement with Elers and Hartmann (1986) who found that the content of nitrate-nitrogen in bare soil after the winter period was lower in soil grown with some catch crops but higher in soil grown with other catch crops, sown in the middle of August the previous year and incorporated into the soil in the spring.

The content of mineral nitrogen in the 0-50 cm layer in the middle of April was higher when a catch crop was

Figure 4: Mineral nitrogen in kg per ha in soil layers of 25 cm measured in the middle of April the year after leaving the soil bare or growing catch crops sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3). The catch crops were incorporated into the soil at the end of November.

Abbildung 4: Mineralstickstoffgehalt in kg pro ha in Bodenschichten von 25 cm Dicke Mitte April für die Aussaattermine Mitte Juli (1), Anfang August (2) und Mitte August (3). Die Gründungspflanzen wurden Ende November in den Boden eingearbeitet.

grown the previous year compared to bare soil as seen in figure 4. This result was found irrespective of plant species or sowing time. When phacelia, sunflower and italian ryegrass was sown in the middle of July the content of mineral nitrogen in the upper 50 cm was respectively 60, 30, and 120 % higher than the content in bare soil. The relative difference between crop-grown soils and bare soil decreased as the growth period decreased.

As can be seen in figure 4, the distribution of mineral nitrogen in the middle of April varied among the different treatments. When no catch crop was grown, 44 % of the mineral nitrogen in 0-100 cm soil depth was located in the 75-100 cm layer and only 30 % in the upper 50 cm on average of the four years. When italian ryegrass was grown in the period from July until November, 50-60 % of the mineral nitrogen down to 1 m depth was located in the upper 50 cm.

The content of ammonium-nitrogen was not affected by the treatments and the content found at the end of November was not different from that found in the middle of April the following year (figure 3 and 4). The content of ammonium-nitrogen decreased with an increased soil depth.

Net loss of nitrogen during the period of water discharge

The difference between the content of mineral nitrogen in the various soil depths found at the end of November and the content in the middle of April was significantly affected by both the sowing time and the plant species as seen in table 3. No interactive effect was found. Compared to the content at the end of November, the content in the middle of April was very low when no catch crop was grown. A difference of 115 and 190 kg of mineral N per ha in 0-100 cm soil depth was found in 1986/87 and in 1987/88 respectively. The amounts of nitrogen mentioned above was positively correlated to the water discharge. On average of the four years a net loss of 144 kg of mineral N per ha in 0-100 cm soil depth was found. In 0-50 cm soil depth the content of mineral nitrogen in the middle of

April was 25 % of the amount found at the end of November.

In the middle of April the content of mineral nitrogen was lower than at the end of November when phacelia and sunflower was grown. When italian ryegrass was sown in the middle of July and at the beginning of August, the content of mineral nitrogen in the 0-50 cm layer found in the middle of April was respectively 37 and 26 kg per ha higher than at the end of November (figure 5). Similar result was found by *Elers and Hartmann (1986)*.

Reasons for this difference between different catch crops has to be sought in differences in decomposition of the crops during the late autumn, winter and early spring. The rate of decomposition is not only influenced by the soil temperature and the soil moisture, but also by the chemical composition of the plant tissue.

Prediction of the soil mineral nitrogen in spring

The release of nitrogen during mineralization is influenced by the content of total N and the C/N ratio (*Frankenberger and Abdelmagid, 1985; Gutser and Vilsmeier, 1985*). The content of lignin as a predictor for the nitrogen release is proposed to be even better than the C/N ratio (*Müller et al., 1988*).

In the present experiment the content of mineral nitrogen in the upper 50 cm soil depth in April tended to be influenced by the contents of C, total N and lignin, the C/N ratio, and the nitrogen uptake, listed according to decreasing correlation coefficients. However, none of the correlations are significant. The correlations tended to be influenced by the sowing time more than the plant species. These results do not agree with the statements referred by *Frankenberger and Abdelmagid (1985)* and *Müller et al. (1988)*.

The nitrogen uptake by phacelia was equal to or even higher than the uptake by italian ryegrass. As this result does not reflect in the content of soil mineral nitrogen in April the nitrogen uptake during the autumn is not necessarily a good predictor for the content of soil mineral nitrogen in the following spring.

Figure 5: Difference between the mineral nitrogen in kg per ha in soil layers of 25 cm measured at the end of November and in the middle of April the year after leaving the soil bare or growing catch crops sown in the middle of July (1), at the beginning of August (2) and in the middle of August (3). The catch crops were incorporated into the soil at the end of November.

Abbildung 5: Differenzen der Mineralstickstoffgehalte in kg pro ha zwischen Ende November und Mitte April des folgenden Jahres nach Brache und nach Gründung. Werte für Bodenschichten von 25 cm Dicke und drei Aussaattermine Mitte Juli (1), Anfang August (2) und Mitte August (3). Die Gründungspflanzen wurden Ende November in den Boden eingearbeitet.

Conclusion

The dry matter yield of catch crops decreased as the growth period decreased. The plant species investigated differed widely in chemical composition. The different plant species showed large diversity in uptake of nitrogen: phacelia and italian ryegrass removed large amounts of N.

It can be confirmed that the content of soil mineral nitrogen in November can be reduced by growing a catch crop during the autumn. As catch crops phacelia and especially italian ryegrass were more efficient in depleting nitrogen from the soil than sunflower. When italian ryegrass was sown in the middle of July the content of mineral nitrogen in November in 0-100 cm soil depth was reduced to 37 % of the content in bare soil. The content of soil mineral nitrogen increases as the growth period of the catch crops decreases.

When a catch crop was sown in the middle of July or at the beginning of August the main part of the mineral nitrogen in November was located in the topsoil. If no crop was grown during the autumn the main part of the mineral nitrogen was found in the subsoil.

When a catch crop was grown during the previous autumn the content of mineral nitrogen in the upper 50 cm soil layer in April was higher than the content in bare soil.

During the winter period a net difference of 144 kg of N per ha in 0-100 cm soil depth was found when no crop was grown. When italian ryegrass was sown in the middle of July and at the beginning of August, the content of soil mineral nitrogen found in the middle of April was respectively 59 and 34 kg per ha higher than the content found at the end of November.

The content of mineral nitrogen in the upper 50 cm soil depth in April tended to be influenced by the contents of C, total N and lignin of the catch crops in November. The nitrogen uptake during the autumn was not a good predictor for the content of soil mineral nitrogen in the following spring.

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