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Published in: Landbauforschung Völkenrode 54(2004)1:7-12

Braunschweig
Federal Agricultural Research Centre (FAL)
2004

Influence of catch cropping on nitrate contents in soil and soil solution

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Abstract

The influence of catch cropping on the nitrate contents in soil and soil solution was investigated in a three-year field experiment conducted on the experimental research station Gross Luesewitz situated in the north-eastern part of Germany. The N uptake of catch crops was estimated as well as the N_{min} content of soil and the nitrate-N content in the corresponding soil solution. The highest N uptake was found for raphanobrassica and oil radish (> 240 kg ha^{-1} N). These two crops and phacelia led to the strongest reduction of the nitrate-N concentration in soil solution in 90 cm. A significant correlation between N uptake of crops and nitrate-N content in soil solution was found ($r = 0.87$, $p < 0.001$). There was also an association between the N uptake of crops and the N_{min} content in soil (0-90 cm) in autumn ($r = -0.69$, $p < 0.001$). However, the level of N uptake of plants failed to predict the N_{min} content in soil in spring of the following year. In spring soil did not show significant differences of N_{min} content between the tested variants. By far the highest nitrate-N concentration in the soil solution in 90 cm was found under fallow.

Keywords: catch crops, nitrate, nitrogen, N losses

Zusammenfassung

Der Einfluss des Zwischenfruchtanbaus auf den Nitratgehalt im Boden und in der Bodenlösung

Der Einfluss des Zwischenfruchtanbaus auf den mineralischen N-Gehalt im Boden (N_{min}) und dem Nitratgehalt in der Bodenlösung wurde in einem 3-jährigen Feldversuch in Nordostdeutschland (Gross Lüsewitz) untersucht. Die höchsten N-Aufnahmen hatten die Fruchtarten Raphanobrassica und Ölrettich (> 240 kg ha^{-1} N). Diese beiden Fruchtarten und Phacelia reduzierten den Nitrat-Gehalt in der Bodenlösung in 90 cm am stärksten. Es konnte ein enger Zusammenhang zwischen der N-Aufnahme der Fruchtarten und den Nitratgehalten in der Bodenlösung ermittelt werden ($r = 0{,}87$; $p < 0{,}001$). Ein gesicherter Zusammenhang bestand ebenfalls zwischen der N-Aufnahme der Pflanzen und dem N_{min}-Gehalt im Boden (0-90 cm) im Herbst ($r = -0{,}69$; $p < 0{,}001$). Jedoch kann die Höhe der aufgenommenen N-Menge der Zwischenfrüchte nicht zur Vorhersage des N_{min}-Gehaltes im darauffolgenden Frühjahr genutzt werden. Für März ergaben sich keine gesicherten Unterschiede hinsichtlich der N_{min}-Gehalte der untersuchten Varianten. Die höchsten Nitrat-Gehalte in der Bodenlösung in 90 cm wurden unter Brache gefunden.

Schlüsselwörter: Nitrat, N-Verluste, Stickstoff, Zwischenfrucht

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1 Introduction

Major parts of European agriculture operate on the basis of a net nitrogen (N) surplus and large amounts of the N content in surface and ground-waters derive from agricultural sources. Globally, regionally, and on a local basis agriculture is a main source of air (e. g. methanol, nitric oxide) and water pollution (e. g. nitrate, phosphate). High concentrations of phosphor and nitrogen in surface waters lead to an increased growth of algae which reduces oxygen concentration. Eventually this affects the aquatic fauna. This negative influence on the ecosystem may even expand to sea-waters, as LUND (2000) has mentioned for the Baltic area.

In Germany more than half of all phosphor and nitrogen input in surface waters derive from agriculture. The annual net surplus of 111 kg ha^{-1} N and 8-12 kg ha^{-1} P in Germany (Isermann 1998, Bach et al. 1997) is mainly due to high concentration of livestock in some regions leading to large amounts of organic fertilisers. This situation is comparable to other, mainly western European regions (Withers 1996, Brouwer and Hellegers 1997, Tunney et al. 1997, Schmid et al. 1999, Oenema 2000, Spiess 2000).

Nutrients are mainly lost from agricultural soils due to erosion and leaching especially, when the soil is not covered by plants. These losses also occur with crops that have a slow-growing juvenile phase.

Catch cropping may help to reduce nutrient losses, since erosion is significantly reduced when the soil is thoroughly covered by crops, and nutrients can be temporarily biologically fixed by catch crops and thereby be protected from leaching (Merbach et al. 1997 a, Merbach et al. 1997 b). Eichler et al. (2000) reported already that certain catch crops can significantly reduce P concentrations in soil solution in soil depth relevant for losses into the ground water. In addition to this previous work it was the objective of this study to verify the influence of different catch crops on this important parameters of the nitrogen dynamics of agroecosystems.

2 Material and Methods

In summer 1999 a three-year field-experiment on a high P supplied sandy loam in northern Germany (experimental station Gross Luesewitz, Institute for Land and Water Management) was started with 10 different treatments (fallow and 9 catch crops, see table 1). The plots were randomised in the field and tests were done as 4-fold repetition. Catch crops were planted annually in August and were kept on the field until the following spring, when the main crop (potato) was planted. The annual fertilisation consisted of 80 kg ha^{-1} N for the main crop.

Preceding the seeding of catch crops, after the vegetation period in autumn and before plowing in spring soil samples were taken from different depths (0-30 cm, 30-60 cm, 60-90 cm).

Soil solution was collected employing ceramic cups on 8 occasions in two depths (30 cm, 90 cm) during each winter period.

Pea could not be harvested in 2000 due to fungal infection. Measures for plant protection were not done for catch crops, since this is not applied in common practice.

The yields and N uptake of catch crops were estimated as well as the N_{min} content of soil and the nitrate-N content in soil solution (because the N contents in plant material were measured only in 1999 and 2000 the given values for N uptake are means from only this two years) . Statistics for the evaluation of variance, regression, and correlation were carried out using the SPSS program package.

3 Results and Discussion

For the N uptake only the shoots were evaluated. The root systems was not evaluated for N uptake, therefore the total N uptake is supposed to be higher than the uptake given in table 2.

The level of yield and the N-uptake were significantly different in different catch crops.

Table 1:
Catch crops tested in the trial at Gross Luesewitz, Germany

Catch crop	**Variety**	**Seed Density** kg ha^{-1}
Oil radish *(Raphanus sativus)*	Trick	10-12
Yellow Mustard *(Sinapis alba)*	Ascot	20-25
Buckwheat *(Fagopyrum esculentum)*	Lifago	60-80
Phacelia *(Phacelia tanacetifolia)*	Lisette	10-12
Common Ryegrass *(Lolium westerwoldicum)*	Liflora	40-50
Serradella *(Ornithopus sativus)*	Lippstädter Sorte	30-40
Pea *(Pisum sativum)*	Duel	130-150
Lupin *(Lupinus luteus)*	Schwako	160-180
Raphanobrassica *(Raphanus sativus x Brassica oleracea)*	Colano	10-12
Control (without catch crops)		

Table 2:
Yield and N uptake of different catch crops in the trial at Gross Luesewitz, Germany

Catch crop	**Yield** (dt ha^{-1} dry matter)	**N uptake** (kg ha^{-1} N)
Oil radish	54.6 b	255.5 e
Mustard	43.3 ab	146.9 bc
Phacelia	40.9 ab	155.3 cd
Buckwheat	28.7 ab	83.1 ab
Common Ryegrass	28.1 ab	85.9 b
Lupin	35.3 ab	126.4 bc
Pea	8.5 a	29.8 a
Serradella	37.5 ab	161.4 cd
Raphanobrassica	47.8 b	243.1 de

alphanumeric (a-e) indicate significant differences between the evaluated variants (Duncan, $p < 0.05$). Yields are means of the three years studied, N uptakes are given as means of the years 1999 and 2000.

Table 3:
Influence of catch cropping on N_{min} contents in soil in 0-90 cm in autumn (November) and spring (March) observed in the trial at Gross Luesewitz, Germany (means of 1999-2001).

Catch crop	**N_{min} in November** kg ha^{-1} N	**N_{min} in March** kg ha^{-1} N
Control (fallow)	119.5 d	42.5 a
Oil radish	59.8 ab	59.7 a
Mustard	63.0 ab	47.5 a
Phacelia	57.0 ab	50.4 a
Buckwheat	70.8 ab	57.1 a
Common Ryegrass	74.8 ab	47.6 a
Lupin	81.0 b	50.4 a
Pea	101.1 c	38.9 a
Serradella	70.1 ab	56.0 a
Raphanobrassica	49.3 a	53.7 a
mean	76.6	50.4

alphanumeric (a-c) indicate significant differences between the evaluated variants (Duncan, $p < 0.05$).

During the first year of the experiment a nutrient uptake of up to 350 kg ha^{-1} N was recorded for raphanobrassica. Oil radish had an uptake of 318 kg ha^{-1} N and mustard and phacelia both had an uptake of approximately 200 kg ha^{-1} N. These amounts distinctively exceed the average N uptake of main crops in the Land Mecklenburg-Vorpommern (Eichler and Leidel 2002).

But this data stress also the potential of catch crops for the biologically fixation of nutrients under suitable conditions. With this, catch crops may play a role in cleaning up of over-supplied soils, provided the yield of these catch crops is sufficiently high.

Results from the second and third year showed, that unfavourable growing conditions may lead to a significant reduction of nutrient uptake, in 2000 and 2001 average N uptake was below 100 kg ha^{-1} N.

Adequate use of catch crops is mainly a question of suitable seeding times. In northern Germany the typical crop rotation (winter oilseed rape, winter wheat and winter barley) may occasionally not permit the use of suitable catch crops. Short vegetation periods of crucifer catch crops and its low seeding costs are the main reasons for the use of these catch crops. Problems of crucifer catch crops are mainly due to phytosanitary reasons, when used in crop rotation with other crucifer main crops.

Previous results show that if seeding times of catch crops are as early as July crops like buckwheat or legume crops have a higher potency to fix nutrients than crucifer catch crops (Eichler 1997). This is due to the fact that in early dates of seeding crucifer catch crops develop their generative phase without having developed sufficient vegetative biomass.

With respects to N concentrations raphanobrassica had highest amounts in the dry matter (4 %) compared with the other examined catch crops.

If nutrients are fixed in catch crops, this does not mean they are lost for plant nutrition. Provided catch crops are not removed from the field the fixed nutrients can be utilised by the following main crops.

In autumn, after the vegetation period, the average N_{min} concentrations in the soil in 0-90 cm depth were significantly different between the treatments (table 3). There was a significant negative correlation between N_{min} in soil and the N uptake of plants ($r = -0.69$, $p < 0.001$). However, the level of N uptake in autumn failed to predict the N_{min} content in soil in spring of the following year. Evaluations in spring did not show significant differences between the tested variants. N_{min} contents of soil in spring were lower compared to autumn contents. This is mainly due to the high solubility of nitrate, leading to leaching during the winter months.

Especially the use of raphanobrassica or oil radish reduced the concentrations of mineral N in soil in each autumn. Both catch crops had the highest N uptake, highlighting the influence of plant N uptake on the N_{min} contents in soil. In the case of fallow, when no catch crops are used, N_{min} concentrations in November were extremely high and fell to concentrations comparable to the other examined treatments in March of the following year. This possibly indicates a high N loss during winter months. Comparable losses of N during the winter months were seen in pea, due to its low yields which has fixed only a small amount of N. The other legume catch crops only had small differences in N_{min} concentrations between autumn and spring since their bio mass was higher.

Sørensen (1991) found a net loss of 144 kg ha^{-1} N in a depth of 0-100 cm during the winter period in fallow fields. He was able to show, that these losses were significantly reduced when common ryegrass was used as catch crop, always taking into consideration an optimal seeding time.

Different authors were able to show the relation between the N balance on the N_{min} concentrations in soil (Herold et al. 1996, Albert and Lippold 1997, Kerschberger and Hess 1997), but others could not prove this fact (Haas et al. 1998). According to Isermann (1988) the N set free in spring from N conserved in organic material can lead to NO_3^- pollution of ground and surface waters if not used by a following crop. On the other hand high concentrations of N_{min} in soil may lead to gaseous N emissions (Augustin and Rogasik 1999, Leidel 2000), which can be prevented by binding N in organic material of catch crops.

The distribution of nitrate-N in soil solution from upper to lower soil levels was correlated with the amount of leaching water. The higher the amount of leaching water was, the more amount of nitrate-N could be detected at 90 cm soil level and the less nitrate-N could be detected at 30 cm soil level. Furthermore, the use of catch crops reduced the nitrate-N concentration in soil solution at 90 cm in comparison to fallow (table 4). In 90 cm soil depth highest nitrate-N concentrations were measured in fallow fields, but also when legume plants like lupin and pea were used as catch crops, these concentrations were comparatively high and not significantly different from those seen in fallow. On average catch crops had lower nitrate-N concentrations compared to fallow land (169.0 mg l^{-1} NO_3 -N vs. 120.8 mg l^{-1} NO_3-N). Lowest concentrations of nitrate-N could be detected in raphanobrassica as catch crop (47.0 mg NO_3-N l^{-1}).

Table 4:
Influence of catch crops and fallow on nitrate-N concentrations in soil solution sampled in 30 cm and 90 cm depth in the trial at Gross Luesewitz, Germany (means of 1999-2001).

Catch crop	**N in soil solution 30 cm** (mg l^{-1} NO_3)	**N in soil solution 90 cm** (mg l^{-1} NO_3)
Fallow	61.3 ab	169.0 c
Oil radish	78.3 ab	94.0 b
Mustard	72.7 ab	127.3 bc
Phacelia	78.0 ab	117.7 bc
Buckwheat	66.3 ab	139.7 bc
Common Ryegrass	52.0 ab	136.0 bc
Lupin	84.0 b	156.3 bc
Pea	70.0 ab	157.7 bc
Serradella	87.7 b	112.7 bc
Raphanobrassica	34.0 a	47.0 a
mean	68.4	125.7

alphanumeric (a-c) indicate significant differences between the evaluated variants (Duncan, $p < 0.05$).

The upper limit of N in drinking water in Germany is 50 mg NO_3-N l^{-1}. Only raphanobrassica as catch crop had nitrate-N concentrations in the soil solution at 90 cm that were below this limit.

The higher the N uptake of the analysed catch crops was, the lower the nitrate-N concentration of the soil solution was (figure 1). In 30 cm soil depth there were no significant differences of the nitrate-N concentrations in the soil solution within the examined variants (table 4).

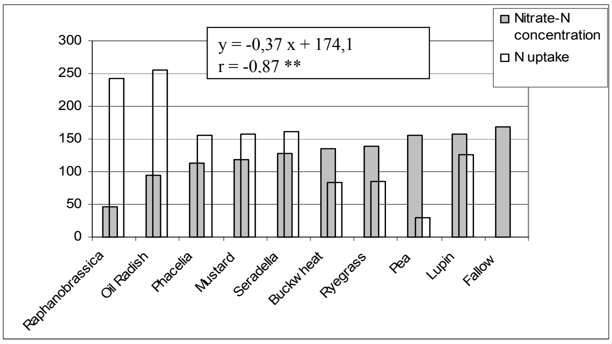

Fig. 1:
Relation between nitrate-N concentration in soil solution (y) (mg l^{-1} NO_3-N) at 90 cm depth and the N uptake (x) (kg ha^{-1} N) of different catch crops in the trial at Gross Luesewitz, Germany (means of 1999-2001).

In fallow land nitrate-N concentrations of the soil solution in 30 cm soil depth are lower compared to the other examined catch crops, possibly indicating that N is moved to lower soil levels. In accordance with the results presented here, Sørensen (1991) found higher concentrations of N_{min} in lower soil levels in fallow land.

In lysimeter experiments at the research centre Gross Luesewitz Zachow (1998) could show, that from 1991 to 1998 there was a average annual N leaching of 44 kg ha^{-1} N, but leaching strongly depended on the amount of percolating water and the yields obtained.

4 Conclusion

Under favourable cultivation conditions high amounts of nutrients can be biologically fixed by catch crops that develop large green mass. Yields of the catch crops are mainly dependent on the time of seeding, therefore available planting times are a major criterion for the selection of the catch crop used.

In 90 cm soil depth the nitrate-N concentration of the soil solution was significantly reduced by the cultivation of catch crops. The amount of N uptake of the catch crop had a strong influence on the nitrate-N concentration of the soil solution in this depth. Among the crops tested, raphanobrassica, oil radish, and phacelia are most suited for reducing nitrate-N concentration in the soil solution.

Although the N uptake of the catch crops in autumn failed to predict the N_{min} contents of soils in the following spring, it strongly influences the N_{min} contents of soil in autumn.

With the beginning of the vegetation period in spring the mineralisation of organic substance in soil is increased. Therefore the cultivation of the main crops should be started as early as possible to enable the utilisation of the nutrients set free from the organic material.

The results of the research work presented here strongly suggest that catch crops have a positive effect on ground- and surface-water quality and they may prevent nutrient losses, thereby improving soil quality. Due to this, catch cropping should be encouraged. Since economic engagement and man power is needed for catch cropping, political decisions have to support the wider employment of catch cropping.

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