Rheinische Friedrich-Wilhelms-Universität Bonn
Institut für Organischen Landbau
Prof. Dr. U. Köpke

Optimisation of nitrogen management after harvest of the main crop by growing turnips [*Brassica rapa* L. ssp. *rapifera* (Metzg.) Sinsk.] as a catch crop and field vegetable

Inaugural-Dissertation

zur

Erlangung des Grades

Doktor der Agrarwissenschaften

(Dr. agr.)

der

Hohen Landwirtschaftlichen Fakultät

der

Rheinische Friedrich-Wilhelms-Universität Bonn

zu Bonn

vorgelegt im Februar 2006

von

Dipl. Ing. Agr. **Tomaž Kotnik**

aus

Ratingen

Vorsitzender:	Prof. Dr. M. B. Piorkowsky
Berichterstatter:	Prof. Dr. U. Köpke
Berichterstatter:	Prof. Dr. A. Skowronek
Tag der mündlichen Prüfung:	28. Juni 2006
Gedruckt bei:	Verlag Dr. H. J. Köster, Berlin

ABSTRACT

The objective of the present study was to investigate whether the short growing season after the harvest of potatoes (PO) and faba beans (FB) enables to grow a marketable crop that can at the same time reduce soil nitrate concentration. For that reason turnips (*Brassica rapa* L. ssp. *rapifera* (Metzg.) Sinsk.) grown as field vegetables were investigated in order to determine their nitrogen sink capacity, nitrogen export with marketable roots and precrop effect on following wheat crop. A 2-years field experiment (1999-2001) was conducted on brown alluvial loamy-silty to sandy-silty soils of the organically managed experimental farm Wiesengut near Bonn, Germany (7 17' E, 50 48' N). The experimental design was a Latin Square with four replications. Single plot size was 6 x 12 m. The amount of soil nitrate after harvest of PO and FB reached up to 120 and 88 kg NO_3^--N ha^{-1} in the upper 90 cm soil depth respectively. Turnips cv. 'Market Express F1' (Me), 'Petrowski' (Pe) and reference crop white mustard cv. 'Zlata' (Wm), were sown immediately after harvesting the main crops. Bare fallow (F) was used as a control. In both years after PO and FB, 100 days after sowing, Me, Pe and Wm took up 57 - 101, 60 - 120 and 73 - 207 kg N ha^{-1} respectively, thus reducing soil nitrate content up to 105 kg NO_3^--N ha^{-1} compared with F. DM yield of turnip roots (1.13 - 1.66 t ha^{-1}) represented 40 to 65 % of total DM yield, containing between 32 and 60 % (34 - 53 kg N ha^{-1}) of all accumulated nitrogen. Catch crops decreased grain yield of following winter wheat between 6 - 17 % compared to F and the total N uptake of winter wheat grown after catch crops was reduced up to 29 kg N ha^{-1}. However decrease in total DM yield of wheat and corresponding N uptake were not influenced by N export of 34 - 53 kg N ha^{-1} from the field with turnip roots in autumn. When catch crops were left on the field over the winter and incorporated in spring at seed bed preparation an increase in spring wheat grain yield between 2 - 29 % and increase in total N uptake of 39.6 kg ha^{-1} compared to bare fallow were recorded. Export of nitrogen with roots of turnip Pe in spring ranging between 22 and 60 kg N ha^{-1} decreased DM grain yield of spring wheat by 1 - 17 % and reduced its total N uptake up to 26 kg ha^{-1}. Generally, the positive precrop effect of catch crops on spring wheat was in the following order Wm > Me > Pe. Catch crops significantly influenced mineralization-immobilisation processes in the soil. Thus in autumn up to 135 kg ha^{-1} more nitrogen was determined in the plant - soil system when brassica catch crops were grown compared to bare soil. These results demonstrate that in a short growing period, after harvest of PO and FB, turnips can be successfully grown as field vegetables and as catch crops. Turnips produce a notable amount of marketable roots and are able to significantly reduce the soil nitrate content.

KURZFASSUNG

Mit der vorliegenden Arbeit wurde untersucht, ob in der kurzen Vegetationszeit nach der Ernte von Kartoffeln (PO) und Ackerbohnen (FB) eine marktfähige Nachfrucht produziert und gleichzeitig die Bodennitratgehalte reduziert werden können. Dazu wurden Stoppelrüben (*Brassica rapa* L. ssp. *rapifera* (Metzg.) Sinsk.) als Feldgemüse angebaut und die Stickstoff-Aufnahmekapazität, der Stickstoff-Export über die marktfähigen Rüben und die Vorfruchteffekte zu Weizen in einem zweijährigen Feldexperiment (1999-2001) auf lehmig-schluffigen bis sandig-schluffigen Auensedimenten auf der organisch bewirtschafteten Lehr- und Forschungsstation Wiesengut in der Nähe von Bonn, Deutschland (7 17' E, 50 48' N) untersucht. Die Versuchsparzellen in der Größe von 6 x 12 m wurden als lateinisches Quadrat mit vier Wiederholungen angelegt. Der Nitratgehalt im Boden erreichte nach der Ernte in 0 - 90 cm Bodentiefe nach PO bis zu 120 kg NO_3^--N ha^{-1} und nach FB bis zu 88 kg NO_3^--N ha^{-1}. Als Vergleich wurden Stoppelrüben der Sorten 'Market Express F1' (Me), 'Petrowski' (Pe) und Weisser Senf der Sorte 'Zlata' (Wm) unmittelbar nach der Ernte der Hauptfrüchte gesät. Schwarzbrache (F) diente als Kontrollvariante. In beiden Jahren wurden nach PO und FB in den ersten 100 Tagen nach der Saat durch Me 57 - 101 kg N ha^{-1}, durch Pe 60 - 120 kg N ha^{-1} und durch Wm 73 - 207 kg N ha^{-1}aufgenommen, wodurch die Bodennitratgehalte auf 105 kg NO_3^--N ha^{-1} im Vergleich zu F reduziert wurden. Die Trockenmassenerträge der Stoppelrübenwurzeln (1.13 - 1.66 t ha^{-1}) repräsentierten 40 bis 65 % der gesamten Trockenmasse und enthielten 32 - 60 % (34 - 53 kg N ha^{-1}) des gesamten aufgenommenen Stickstoffs. Die Zwischenfrüchte reduzierten die Kornerträge des nachfolgenden Winterweizens zwischen 6 - 17 % verglichen mit F. Die N-Aufnahme von Winterweizen wurde nach den Zwischenfrüchten bis zu 29 kg N ha^{-1} reduziert. Allerdings war die Reduktion des Trockenmassenertrages und der entsprechenden N-Aufnahme nicht durch den N-Export durch die Rüben im Herbst (34 - 53 kg N ha^{-1}) beeinflusst. Verblieben die Zwischenfrüchte über Winter auf den Parzellen und wurden im Frühjahr bei der Saatbeetbereitung eingearbeitet, wurde eine Erhöhung der Sommerweizenerträge zwischen 2 - 29 % und ein Anstieg der Gesamtstickstoffaufnahme bis zu 39.6 kg ha^{-1} verglichen mit der Schwarzbrache festgestellt. Der Stickstoffexport im Frühjahr durch Rüben der Sorte Pe (22 - 60 kg N ha^{-1}) reduzierte den Ertrag von Sommerweizen zwischen 1 - 17 % und die gesamte N-Aufnahme bis zu 26 kg ha^{-1}. Generell nahm der positive Vorfruchteffekt der Zwischenfrüchte zu Sommerweizen in der Reihenfolge Wm > Me > Pe ab. Die Zwischenfrüchte zeigten signifikante Einflüsse auf Mineralisations- und Immobilisierungsprozesse im Boden. Dementsprechend war nach Brassiceen - Zwischenfrüchten im Vergleich zur Schwarzbrache im Herbst bis zu 135 kg ha^{-1} mehr N im System Pflanze-Boden. Somit können Stoppelrüben in der kurzen Wachstumsperiode nach der Ernte von PO und FB erfolgreich als Feldgemüse und Zwischenfrüchte angebaut werden. Dabei wird eine bemerkenswerte Menge an markfähigen Rüben produziert und gleichzeitig der Bodennitratgehalt im Vergleich zur Schwarzbrache signifikant reduziert.

FIGURES

TABLES

ABBREVIATIONS

C	carbon
C_t	total carbon
cv.	cultivar
DAS	days after sowing
DM	dry matter
F	fallow
FM	fresh matter
GSL	glucosinolate
Me	turnips cv. 'Market Express F1'
N	nitrogen
N_{min}	soil mineral nitrogen: NH_4^+ and NO_3^-
N_t	total nitrogen
NO_3^-- N	nitrate-N
Pe	turnips cv. 'Petrowski'
SCN^-	thiocyanate ion
SOM	soil organic matter
Wm	white mustard cv. 'Zlata'

CONTENTS

1 INTRODUCTION

Sustainable soil fertility in organic agriculture is mainly based on optimal and increased production of soil organic matter (SOM) which, after mineralization, supplies growing plants with essential nutrients. Cropping systems, which increase soil organic matter content, generally lead to greater mineralization of soil N (POWLSON et al. 1989). However, as a consequence of a higher proportion of SOM the extended soil nitrogen pool is potentially jeopardised because most of the mineralised nitrogen in agricultural soils is quickly transformed into nitrate, which is prone to leaching. Long-term applications of organic manure can pose a particularly large risk while there is often a lack of synchronisation between mineralization of N in soil and crop demand for N (GLENDINING et al. 1990, GOSS et al. 1998).

High concentration of soil nitrate occurs regularly after the harvest of potato and faba beans main crops and it is known that post-harvest mineralization of crop residues and soil organic matter can have a major effect on the quantity of nitrate at risk of leaching (POWLSON 1993).

After potato harvest, nitrate concentration in the soil rises rapidly as a consequence of often used grass-clover precrop, manure application and intensive soil aeration during the harvest procedures (NEETESON et al. 1989, REENTS & MÖLLER 1997, HAAS et al. 1998). Soil nitrate accumulates already during the growing period of faba beans as a result of a relatively low rooting density of pulses, their heterogeneous root distribution and an inefficient uptake of soil-borne nitrate (KÖPKE 1995, JUSTUS 1996). Harvest residues with a narrow C:N ratio can also stimulate rapid mineralization that increases soil nitrate concentration (MAIDL et al. 1991).

After potato and faba beans harvests, winter wheat as following crop does not represent an effective nitrogen sink (JUNG et al. 1989, GUIOT et al. 1990, KÖPKE 1996, REENTS et al. 1997). In the short growing period between the harvest of the previous crop and the beginning of winter period wheat does not develop adequate plant biomass to take up the available soil nitrate. Therefore, considerable amount of nitrate can be leached beneath the root zone during the winter and hence lost for the farming system. To avoid nitrate accumulation and leaching losses under winter wheat alternative crop rotation – growing a catch crop after the harvest of the main crop with postponed tillage and sowing date of winter wheat – has been suggested (HEß 1989).

Increased soil nitrate concentration in the late summer and beginning of autumn can be successfully controlled with catch crops. They counteract nutrient leaching directly by nutrient uptake and indirectly by decreasing soil water content. Strategies to use brassica catch crops as green manure or fodder are well known (BERENDONK 1985, ELERS & HARTMAN 1987, MEISINGER et al. 1991, BERENDONK 1992, JUSTUS & KÖPKE 1995, SHEPHERD 1999). However, they act merely temporary because the accumulated nitrogen is released in to the soil liquid phase after catch crop incorporation and rapid mineralization, and are sub-optimal if the soil nitrate pool is steadily increased (KÖPKE 1996).

Information about growing brassica vegetables in arable cropping systems late in the growing season, their efficiency in reducing soil nitrate, their nitrogen export and their precrop effect is seriously lacking. The objective of the present work was therefore to extend and optimise strategies for reducing nitrate leaching after the harvest of the main crop by growing brassicas as field vegetables. Understanding the effects of alternative management systems employing brassicas as field vegetables on N cycling in soil and associated precrop effect is essential for developing economical and environmental management systems that are sustainable in the near and distant future.

2 LITERATURE SURVEY

2.1 The problem of nitrate leaching

Nitrate leaching is a natural consequence of the soil N cycle, which occurs when the soil reaches field capacity (NEETESON et al. 1989). However, due to ecological and economical impacts N losses from the field have to be minimised. In well-drained and properly cultivated fields leaching represents the main loss of nitrogen (OOMEN 1995). The magnitude of nitrate leaching depends on the percolation rate of soil water and its nitrate concentration. Both vary strongly depending on climate conditions and location (JUNG et al. 1989, VAN DAM & LEFFELAAR 1998).

Post-harvest mineralization of crop residues and limited crop uptake of N during the growing season often result in excessive accumulation of soil nitrate (GUILLARD et al. 1995). After the harvest of a main crop in summer a large loss of nitrogen by leaching during winter period is therefore expected (SØRENSEN 1992). Studies have shown that high soil NO_3^- concentration after harvest is positively correlated with NO_3^- losses during the autumn to spring period (GUILLARD et al. 1995, JUSTES et al. 1999).

Most nitrate leaching in European humid climate occurs during autumn and winter (SHIPLEY et al. 1992). Furthermore the extent of leaching of mineralised N in autumn and winter depends on the tillage intensity, the time and amount of manure application, mineral uptake by the current crop and the applied crop rotation in general (ELTUN 1995, GOSS et al. 1998). Crop rotations that supply large amounts of organic matter in the long term lead to an increase in the basal mineralization rate of the soil (POWLSON et al. 1987). However, due to a greater potential for mineralization in autumn, higher soil organic matter contents are expected to increase the risk of N leaching from arable soils (CUTTLE & JARVIS 1995). Most of the mineralised nitrogen in agricultural soils is rapidly transformed into nitrate, which is prone to leaching (STANFORD et al. 1973).

A key factor in reducing nitrate leaching is therefore the reduction of the quantity of nitrate present in soil before and during the winter period. Sowing an autumn catch crop represents an important management strategy to take up nitrate, which can otherwise be lost by leaching (ELERS & HARTMANN 1986, HARRISON et al. 1996).

2.2 Residual nitrate after potatoes and faba beans

High content of soil nitrate that usually occur after potato harvest is the consequence of several factors: nitrogen rich precrop (grass-clover mixture), organic fertilisers (10-20 t ha^{-1} manure) and intensive soil aeration during the harvest (NEETESON et al. 1989, REENTS et al. 1997, HAAS et al. 1998). Mineralization of soil organic matter is additionally enhanced by high soil temperature at the time of harvest (SØRENSEN 1992). Besides potatoes are rather inefficient users of nitrogen (PRINS et al. 1988). They are considered as unable to absorb mineral nitrogen from the soil when its concentration drops to a critical level of 0.46 kg N ha^{-1} cm^{-1} soil depth, which corresponds to a level of 40 kg N ha^{-1} for a 0 - 90 cm soil profile (DILZ 1991). Nitrogen not taken up by the crop can already be leached in summer, or it can accumulate in the soil, and then be leached out of the rooting zone in autumn and winter when crop uptake is limited.

Compared with sugar beets, winter rye, spring barley and winter wheat potatoes have been shown to leach most nitrate SHEPHERD & LORD (1996). HOFMAN & VAN CLEEMPUT (1992) used potato as an example of a crop with a restricted rooting depth and rooting distribution with residual N amounts ranging between 60 and more than 100 kg N ha^{-1}. In Germany amounts of nitrate in the soil after potato of 97 kg NO_3^--N ha^{-1} were determined (HAAS et al. 1998). In long-term field trials where bio**d**ynamic, **o**rganic and **c**onventional managed fields have been compared, ALFÖLDI et al. (1992) reported residual nitrogen amounts, in the top 90 cm soil layer, up to 235 kg NO_3^--N ha^{-1}. In maritime conditions of England amounts between 64 - 132 and 154 - 284 kg NO_3^--N ha^{-1} (0 - 90 cm) for sandy soil and sandy clay soil were determined respectively (WIDDOWSON et al. 1987). Seventeen days after the harvest ALBLAS et al. (1992) found the mineral N content of the 0 - 60 cm soil layer to be 40, 73 and 219 kg ha^{-1} corresponding with a fertiliser N supply of 0, 180 and 300 kg ha^{-1} respectively. REENTS & MÖLLER (1997) determined on an organic cropped farm the amount of soil NO_3^--N after potatoes above 50 kg ha^{-1} at the end of September. ERREBHI et al. (1998) reported leaching losses from irrigated and fertilised (270 kg N ha^{-1}) plots up to 260 kg N ha^{-1}. In the worst-case scenario with high mineralization rate and surplus of precipitation at a fertilising rate of 300 kg N ha^{-1} NEETESON et al. (1989) calculated, for the Netherlands, potential losses of 288 kg N ha^{-1} already during the crop growth. They estimated that at the precipitation surplus of 300 mm, the maximum permissible nitrate concentration for drinking water of 50 mg NO_3^- l^{-1} (EEC 1980) is reached when 34 kg N ha^{-1} is leached.

Also during the growing period of faba beans the concentration of accumulated soil nitrate rises significantly, due to relatively low rooting density, inhomogeneous root distribution and low rooting depth (KÖPKE 1995). After the harvest rapid mineralization of roots and crop residues usually occur resulting in an increase of soil nitrate concentration in a soil milieu dominated by net N-mineralization (KAHNT 1985, HAUNZ et al. 1988).

MAIDL et al. (1991) reported of 100 - 150 kg N ha^{-1} in crop residues after faba beans raising the autumn soil nitrate content in the top 80 cm to 120 - 140 kg NO_3^--N ha^{-1}. HAUNZ et al. (1988) determined 140 kg N ha^{-1} in plant residues after the harvest and soil nitrate content of 119 kg NO_3^--N ha^{-1} (0 - 90 cm) in November. These authors presume that considerable amount of legume nitrogen was leached in deeper soil layers during the winter because only 39 kg NO_3^--N ha^{-1} were found in the soil in the following spring. Yearly average N loss of 58 kg N ha^{-1} from faba bean plots was recorded by JUNG et al. (1989) concluding, that leaching occurs during both, summer and winter. JENSEN (1995) found 94 and 9 kg of residual N ha^{-1} after faba beans harvest in straw and roots respectively. Residual N after faba beans of 125 - 225 kg ha^{-1} was reported by KÖPKE (1987).

2.3 Succeeding crop – winter wheat

The common practice of sowing winter wheat, as a following crop after potatoes and faba beans, was found not to be the most appropriate measure in order to save nitrate from leaching because the amount of soil mineralised N after harvest far exceeds the sink capacity of young wheat plants (HEß 1989, JUNG et al. 1989, KÖPKE 1996, SHEPHERD & LORD 1996, REENTS et al. 1997, FRANCIS et al. 1998).

The time during which winter wheat influences the evolution of mineral nitrogen in the soil can be divided into three periods (GUIOT et al. 1990). The first covers the time from the sowing to the end of winter, the second stretches from the end of winter to the harvest and the third begins after harvest until the establishment of the following crop. In the first period the evolution of nitrate in the profile is relatively independent from the grown crop since the uptake of mineral N is small. In the studies of JUNG et al. (1989) winter wheat grown after faba beans took up only 18 kg N ha^{-1} to the end of winter while values between 15 and 30 kg N ha^{-1} after potatoes were reported by RICHTER et al. (1996). Nitrogen uptake of 49.3 and 12.5 kg ha^{-1} for winter wheat sown in September and October respectively were measured by MILFORD et al. (1993). Unfavourable weather conditions during the first growing period can easily prevent winter wheat from making effective use of large amounts of N available to produce shoots, dry matter and leaf area. This is supported by results of MILFORD et al. (1993) where neither the difference in residual N nor an application of fertiliser N in winter affected the yield of the following September-sown wheat, since autumn growth and N uptake were restricted by adverse weather. Low uptake of residual N by subsequent winter wheat can be generally expected.

After a grass/clover mixture 40 kg N ha^{-1} were lost under following winter wheat in experiments carried out by HEß (1989). Due to a low nitrogen uptake of winter wheat during autumn and winter, the amount of mineral nitrogen leached under winter wheat from October until April represented approximately 95 % of leaching losses during the whole growing period in the lysimeter studies of MOUCHOVA et al. (1996).

2.4 Catch crops

Plants used as catch crops belong mainly to three botanical families *Brassicaceae*, *Poaceae* and *Fabaceae*. According to their soil nutrient uptake capacity they can be ranked as follows: *Brassicaceae* > *Poaceae* > *Fabaceae* (SMUKALSKI et al. 1991). With exception of legumes, they are usually grown to absorb nitrogen from the rooting zone during autumn and winter (THORUP-KRISTENSEN & NIELSEN 1998). Thus, at least in the short term, they can decrease nitrate leaching and therefore improve the quality of water leaving the root zone (VANDENDRIESSCHE et al. 1996, MARTINEZ & GUIRAUD 1990a).

The practice of growing a catch crop produces a pool of organic N that might otherwise be lost below the rooting-depth horizon and allows N to be recycled at a later date (HOYT & MIKKELSEN 1991). The ability of catch crops to serve as an effective source of nutrients for the following crops depends, to a large extent, on climate and growth stage of the catch crop, soil and cropping characteristics, as well as tillage management practises (DORAN & SMITH 1991).

Nutrient cycling, particularly N is an important aspect in the management of catch crops. Nitrogen release from catch crops depends on microbial immobilisation/mineralization of N (and C) as influenced by residue type, placement, degree of incorporation in soil, soil temperature and water/aeration regimes (AULAKH et al. 1991).

Timing of releasing N from plant residues is of crucial importance for a beneficial precrop effect of catch crops since positive precrop effects are mainly determined by available nitrogen (KÖPKE 1996). If catch crop decomposition and N mineralization are not synchronised with N demand by the subsequent crop released nitrate is again endangered to be leached to ground water (MEISINGER et al. 1991).

2.4.1 Brassica catch crops

The number of possible candidates for catch crops after potatoes and field beans is rather limited due to the relatively short growing season and often unfavourable weather conditions. A catch crop that establishes quickly and grows vigorously in the autumn is ideal for preventing leaching.

Brassicas are known for their rapid establishment and cool-season growth (MEISINGER et al. 1991). Their capacity to take up considerable amounts of nitrogen in a very short time is well known and has been several times confirmed (KAHNT 1985, MERBACH et al. 1993, THORUP-KRISTENSEN 1993, KÖPKE 1996). Brassicas have a wide range of adaptability as evidenced by their use from Scandinavia to Florida and from semiarid areas of California to the Mediterranean climate of France (MEISINGER et al. 1991).

Brasssicas grown as catch crops are mainly used as green manure (white mustard, oil radish) or as a forage crop (rape seed, bird rape). Both strategies can contribute, on the long run, to the enlargement of the N pool on the farm, which can be a potential burden for the environment. Green manure catch crops take up nitrate and they set it free again in the soil liquid phase after their incorporation and subsequent mineralization. In this case the nitrogen remains all the time on the same field. When catch crops are used as a fodder and fed in the stable, the nitrogen is transferred and temporarily stored in the solid phase as farmyard manure. After its incorporation in the soil, the nitrogen will be slowly released and again present in the soil solution. Mentioned strategies of using catch crops to prevent nitrate losses act therefore suboptimal if the pool of soil nitrogen is steadily increased. Thus KÖPKE (1996) suggested using brassica vegetables as catch and cash crops as a possible long term solution of nitrate losses. As efficient sinks for nitrogen brassica vegetables can reduce soil nitrate pool in the autumn and at the same time they can realise an export of nitrogen from the farm when sold.

2.4.2 Turnips (*Brassica rapa* L. ssp. *rapifera* (Metzg.) Sinsk.)

Turnips are known as a cool-season crop, which is heat tolerant as well as frost resistant. Therefore, growth and N accumulation can be expected even late in winter and also - in the case that it remains on the field and it is not destroyed by cold - at the beginning of growing period in the subsequent spring.

Turnip leaves generally survive temperatures between -6 and -10 ºC, while bulbs will tolerate temperatures between -9 to -13 ºC (PENROSE et al. 1996). Growth of turnip remains highly productive (2.2 and 6.3 t ha^{-1} of DM for roots and tops respectively) even when the air temperatures exceed 32 ºC (JUNG & SHAFFER 1993). In contrast, the occurrence of drought-induced dormancy is documented if drought occurred at sowing time resulting in a reduction of root yield for 65 % and significant reduction of mean root diameter (JUNG & SHAFFER 1993). Once established, turnips are tolerant for dry conditions (PENROSE et al. 1996).

Rooting depth of turnips up to 150 cm were reported by BUCHNER (1987). BURNS (1980) determined an effective rooting depth of turnips to be up to 94 cm and a critical root length (minimum length of root required for normal growth expressed as a percentage of the total root length) of 3.0 to 4.6 %.

In a serial of comparative experiments with *Brassica* species, GUILLARD & ALLINSON (1988) reported that species with edible roots produced the highest yields of dry matter with turnip root yields greater than either swede (*Brassica napus* L.) or *Brassica* hybrid Tyfon [*Brassica rapa* L. X *Brassica pekinensis* (Lour.) Rupr.]. In fertilisation experiments N uptake of turnips without N fertilisation was 30.6 and 26.4 kg N ha^{-1} and when 538 kg fertiliser N ha^{-1} was added turnips took up 210.0 and 53.3 kg N ha^{-1} with leaves and roots respectively (GREENWOOD et al. 1980).

3 HYPOTHESIS

The objective of the present work was to extend and optimise strategies for reducing nitrate leaching after the harvest of the main crop (potatoes and faba beans) by growing brassicas as field vegetables.

The present study investigated whether the short growing season after the harvest of the main crop allows to grow a marketable product that can reduce high soil nitrate concentration and thus enables nitrogen export from the farm when sold. For that reason turnips (*Brassica rapa* L. ssp. *rapifera* (Metzg.) Sinsk.), as the member of *Brassicaceae* family, grown as a field vegetable were investigated in order to determine its nitrogen sink capacity, nitrogen export with its marketable roots and precrop effect on following wheat crop.

To answer these questions following hypothesis were tested:

1 – Compared with bare soil nitrogen uptake of turnips reduces soil nitrate concentration significantly.

2 – Nitrogen sink capacity of turnips corresponds with the nitrogen sink capacity of white mustard commonly used as a catch crop.

3 – In a short growing season after the harvest of potatoes and faba beans turnips can accumulate considerable amounts of dry matter in marketable roots.

4 – Positive precrop effect of potatoes and faba beans on yields of following winter or spring wheat, respectively, is not reduced by growing turnip vegetables and subsequent nitrogen export from the field with marketable roots.

4 MATERIALS AND METHODS

4.1 Materials

4.1.1 Experimental site

Field experiments were established on the experimental station Wiesengut (7 17' eastern longitude, 50 48' northern latitude) that belongs to the Institute for Organic Agriculture at Rheinische Friedrich-Wilhelms-Universität Bonn, Germany. The experimental farm Wiesengut is characterised by brown alluvial sandy soils (loamy-silty to sandy-silty) and is located in the Sieg river valley, 65 m above sea level.

Table 1: Soil properties of the experimental fields (0 – 30 cm soil depth).

	1999		2000	
Soil property	**Potatoes**	**Faba beans**	**Potatoes**	**Faba beans**
pH	5.9	5.9	6.0	6.0
SOM (%)	1.65	1.87	1.76	1.70
C_t (%)	0.96	1.09	1.02	0.99
N_t (%)	0.11	0.12	0.11	0.11
P mg/100g soil	12.32	6.39	13.09	10.11
K mg/100g soil	22.26	17.17	26.10	21.53

Experiments were established on soils that had been in arable crops for many years and since 1987 under organic crop rotation: **1**-winter rye with undersown grass / red clover-ley, **2**-grass / red clover-ley, **3**-potatoes, **4**-winter / spring wheat (in case of spring wheat catch crop mustard or oil radish), **5**-faba beans (catch crop mustard, oil-radish or winter vetch), **6**-spring wheat.

4.1.2 Climatic conditions

Average annual precipitation of the experimental site is 768 mm with maximum rainfall between 80 and 90 mm month^{-1} in June, July and August and rather dry (50 to 60 mm month^{-1}) autumn and spring. Total precipitation in 1999 was approximately normal, though distribution was uneven. Summer rainfall in 2000 was considerably higher than the 30-year-average (Table 2). Therefore no irrigation of experimental plots was necessary as was the case in the first year.

Table 2: Monthly precipitation, deviations from 30 years average (Dev.), and cumulative precipitation totals (Cum.) for 3 years determined at Köln-Wahn*.

	Precipitation (mm)								
	1999			2000			2001		
Month	Monthly	Dev.	Cum.	Monthly	Dev.	Cum.	Monthly	Dev.	Cum.
Jan.	81	+25	81	58	+2	58	65	+9	65
Feb.	72	+26	153	87	+41	145	88	+42	153
Mar.	51	0	204	71	+20	216	75	+24	228
Apr.	75	+25	279	44	-6	260	87	+37	315
May	62	-5	341	34	-33	294	36	-31	351
June	77	-4	418	64	-17	358	87	+6	438
July	57	-32	475	205	+116	563	48	-41	486
Aug.	87	-1	562	103	+15	666	41	-47	527
Sept.	56	-3	618	122	+63	788	141	+82	668
Oct.	70	+18	688	55	+3	843	51	-1	719
Nov.	32	-32	720	29	-35	872	118	+54	837
Dec.	43	-22	763	66	+1	938	51	-14	888

* weather station is located 9 km northwest from experimental site 'Wiesengut'

Average annual air temperature of the experimental site is 9.5°C. Temperatures between November and March usually do not exceed 5°C. In both experimental years mean monthly temperatures were above the reported average values. In 2000 first frost occurred almost one month later than in 1999 (Figure. 1).

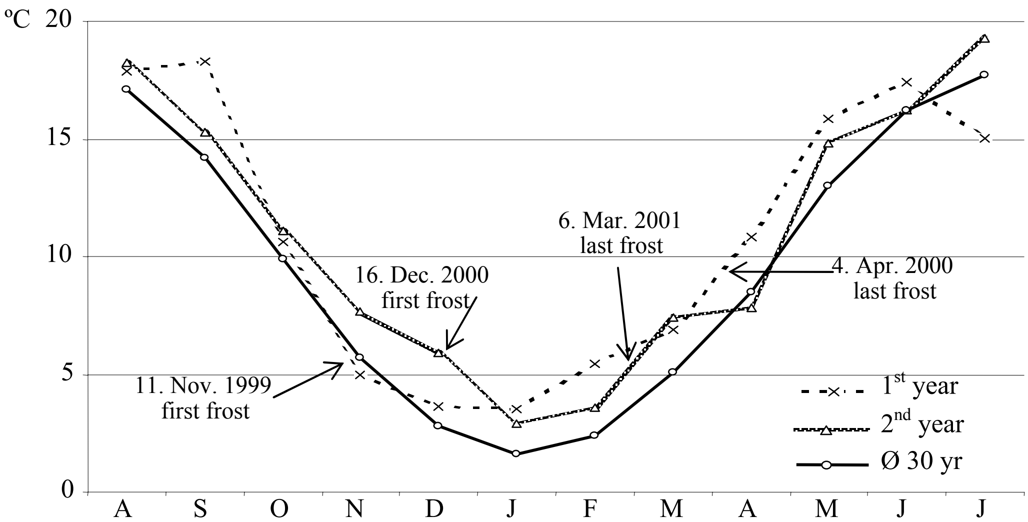

Figure 1: Mean monthly temperatures of the first (1999 – 2000) and the second (2000 – 2001) experimental year.

4.1.3 Field experiments

Over growing periods 1999/2000 and 2000/2001 turnips cv. "Petrowski" (Pe) and cv. "Market Express F1" (Me) were grown to evaluate their nitrogen sink capacity, marketable yields and their precrop effect on the following winter- and spring wheats. Commonly used catch crop white mustard (*Sinapis alba* L.) cv. "Zlata (Wm) was used as a reference crop and bare fallow (F) as a control treatment.

In each season two field experiments were established after the harvest of potatoes and faba beans, respectively. The experimental design was a Latin Square with four replications. Single plot size was 6 x 12 m. To evaluate the precrop effect of experimental treatments on following winter and spring wheat plots were divided into winter wheat (WW) and spring wheat (SW) subplots of 3 x 12 m size.

After the harvest of potatoes and faba beans (August 6 - 16) soil was ploughed (20 cm) and the seedbed prepared with a rotary harrow. Turnips and mustard were sown within two weeks after the harvest of the main crop. Seeding rates were 4 and 20 kg ha^{-1} with a row spacing of 30 and 10 cm for turnips and mustard respectively. Subsequently the experimental site was rolled with a continental Cambridge roller. At 10 cm height turnip plants were thinned to achieve a plant density of 30 to 40 plants m^{-2}. Turnip and fallow treatments were kept without weeds by shallow hoeing. Due to a drought at the beginning of growing season of catch crops in 1999 both experiments (all treatments) were irrigated twice with 15 - 20 mm.

At the time of the autumn harvest, on subplots prepared for following WW, turnip roots were exported from the field while turnip leaves remained on the soil surface of corresponding WW subplots. At the same time mustard treatments were mulched and residues were left on the plots. The soil was then prepared for the sowing of winter wheat (plough, rotary harrow). Winter wheat cv. "Pegassos" was sown at 450 germinative seeds m^{-2} in rows 17 cm apart. At the time of autumn turnip harvest crops and soil on SW subplots remained untreated; i.e. catch crops remained on the field over the winter.

At the time of the spring harvest of turnips, on subplots designed for SW at the end of March, only turnip Pe was harvested while turnip Me and Wm in both years did not survive the winter. Pe roots were removed from the field while leaves remained on corresponding SW subplots. Plant residues of Me and Wm were left on the field. Because they were almost completely decayed the assessment of DM and N_t in plant residues was not possible. Sowing of spring wheat on SW subplots was accomplished as soon as possible after Pe harvest according to weather conditions. Spring wheat cv. "Tasos" was sown at 440 germinative seeds m^{-2} in rows 17 cm apart and rolled with continental Cambridge roller. Because winter wheat after faba beans in the first experimental year failed due to bird damage, WW subplots were resown with spring wheat. In the second year all crops, after sowing, were covered with mesh to protect from birds feeding on the germinating plants.

Weeds in winter and spring wheat were controlled with inter row hoeing and harrow combing when necessary. Dates of the operations and associated agronomic practices are shown in table 1 of the appendix.

4.2 Methods

4.2.1 Plant material sampling and analysis

All plant samples were dried at 105°C to constant weight and ground to pass a 0.2 mm mesh. The exceptions were turnip root samples for ascorbic acid determination (fresh samples) as well as samples for the determination of glucosinolate (GSL) and nitrate in turnip roots. For the last two fresh samples were quickly frozen in liquid N and stored at -18°C. The frozen samples were then subject to freeze-drying.

To assess dry matter yield, N uptake and mineral composition of turnips samples were taken by bulking material from 2 times 4 m^2 rectangles from each subplot. Turnips were separated into leaf and root fraction. Each fraction was separately analysed on total nitrogen (N_t), total carbon (C_t) and total sulphur (S_t) using GC-Element analyser (Carlo-Erba Company, FALBE & REGITZ 1990). Additionally, ascorbic acid (BOEHRINGER MANNHEIM 1995), phosphorus (P) and potassium (K) (VDLUFA 1991), GSL content (palladium test, THIES 1982) were determined in turnip roots. GSL of both turnip cultivars were identified by using HPLC (BIO-DATA GmbH, Germany).

Shoot biomass of mustard was determined by taking two randomly located 1 m^2 quadrate from each WW subplot. N uptake in shoots of turnips and mustard was assessed by bulking two times

1 m central rows and two times 0.5 m^2 quadrate samples per plot respectively. N uptake in shoots of wheat was estimated by harvesting of 0.5 m^2 quadrate area from each plot.

To get an indication of the chlorophyll concentration in wheat leaves, light absorption at 650 nm and at 940 nm wavelength was measured for WW and SW after potatoes in the first year and after potatoes and faba beans in the second year by using SPAD-502 (Minolta Inc., Japan). Absorption values determined with this instrument has been shown to correlate strongly with the chlorophyll concentration of measured tissue and can therefore be used to estimate different green coloration of wheat leaves (FRITZ 2000). Ten measurements of flag leaf (EC 59) or upper two leaves (EC 45) per plot were accomplished for WW and SW respectively.

Immediately before wheat harvest, total shoot samples were taken by bulking two 1 m rows from each plot for determination of straw yield and N uptake. Finally, wheat was harvested by combine harvester and grain was weighed from a known area. Grain sub-samples were analysed for dry matter and nitrogen concentration.

4.2.2 Soil sampling and analysis

To determine the quantity and distribution of soil nitrate, soil samples were taken during the growing season of turnips, white mustard and succeeding winter and spring wheat (Table 2 in Appendix). Five soil cores per subplot (WW and SW) were taken, using a Pürckhauer soil probe (φ25 mm), to a depth of 90 cm in 30 cm increments and bulked on a depth basis. Additional five cores were taken from each subplot from the layer 0 - 30 cm to increase the accuracy of measurements in the top soil layer. A sub-sample was then taken from the bulked and homogenised sample and placed into an ice cooler for transfer to the laboratory. Soil samples were frozen at -18ºC until NO_3^- extraction occurred, and were thawed shortly at room temperature just before analysis.

Nitrate was determined in duplicate by extracting the soil in 1% K_2SO_4 (50 g of field-moist fresh soil / 200 ml K_2SO_4). Filtered extracts were analysed for concentration of NO_3^--N using a colorimetric procedure at 540 nm on a continuous-flow-analyser (SKALAR ANALYTICAL 1993, VDLUFA 1980). Soil moisture was monitored gravimetrically by 105ºC oven-drying to a constant weight.

4.3 Statistical analysis

Analysis of variance was carried out using SAS – statistical program version 6.12 for a latin square design with four replicates. The difference between means of various treatments was determined using Tukey's honestly significant difference (HSD) value at 5 % probability. In subsequent tables and figures significant differences are marked with different small letters.

5 RESULTS AND DISCUSSION

5.1 Soil nitrate dynamics, DM production and N uptake of catch crops after harvest of the main crop

5.1.1 Precrop potatoes

First year 1999

In the first experimental year (1999) two weeks after potato harvest soil NO_3^--N ranged between 21.7 and 25.4 kg ha^{-1} in the top 90 cm soil layer with 60 % of the soil nitrate in the upper 30 cm (Figure 2, Aug 28). This low content of soil NO_3^--N was due to the low precipitation in July and August (Table 2) and the well-established potato main crop.

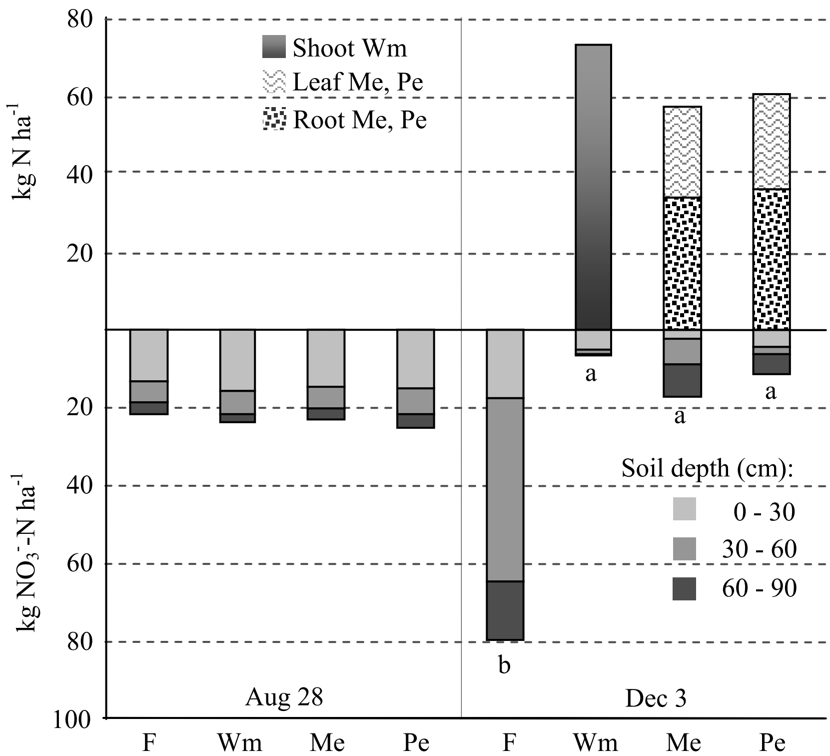

Figure 2: Soil nitrate after potato harvest 1999 and N uptake of catch crops. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Three months later (100 DAS) the distribution and the amount of soil nitrate were affected by catch crop sinks (Figure 2, Dec 3). In comparison to the fallow treatment with 79.7 kg NO_3^--N ha^{-1} in the top 90 cm soil layer (47.0 kg NO_3^--N ha^{-1} present in the layer between 30 and 60 cm) catch crops significantly reduced the content of soil nitrate. The reduction of soil nitrate under

Wm, Me and Pe was, compared with fallow treatment, 72.9, 62.6 and 68.3 kg NO_3^--N ha^{-1} respectively and thus corresponded well with nitrogen uptake of catch crops (Table 3).

100 DAS shoot DM production of Wm, Me and Pe was 3.45, 1.76 and 1.83 t ha^{-1} respectively (Table 3). Turnips accumulated more than 63 % of DM in their roots, which amounts 1.13 and 1.16 t ha^{-1} for Me and Pe, respectively. N_t concentration in DM of turnip roots was 3.01 % for both cultivars. Both turnip cultivars accumulated 59 % of total N uptake in their roots, i.e. 33.8 and 35.9 kg N ha^{-1} for Me and Pe respectively. N_t concentration in DM of leaves was 2.13, 3.73 and 3.63 % for Wm, Me and Pe respectively. Although N_t concentration in DM of Wm was significantly lower compared with turnips, as a consequence of significantly higher DM production, its N uptake was higher (73.2 kg ha^{-1}).

The amount of nitrogen in plant - soil system (kg N ha^{-1} in plant tissue + kg NO_3^--N ha^{-1} in soil) of all four treatments was similar; 79.7, 80.0, 74.2 and 71.7 kg ha^{-1} under F, Wm, Me and Pe respectively (Figure 2 and Table 3 in Appendix). These results indicate that the N sink of Wm and both turnips was adequate and well synchronised with N supply by organic matter mineralization.

Table 3: Dry matter yield, N_t concentration in DM and N uptake of catch crops after potato harvest 1999 (Nov 25, 100 DAS).

	DM yield (t ha^{-1})			N_t conc. (%)		N (kg N ha^{-1})		
Catch crop	Root	Leaf	∑	Root	Leaf	Root	Leaf	∑
W. mustard	-	3.45^b	3.45^b	-	2.13^a	-	73.2^b	73.2
M. Exp. F1	1.13	0.63^a	1.76^a	3.01	3.73^b	33.8	23.3^a	57.1
Petrowski	1.16	0.67^a	1.83^a	3.01	3.63^b	35.9	24.4^a	60.3

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Second year 2000

In the second experimental year (2000) the amount of soil nitrate after the potato harvest was higher for 100 kg NO_3^--N ha^{-1}than in the first year (compare figures 2 and 3). Under F, Me and Pe treatments 120 kg NO_3^--N ha^{-1} and under Wm treatment 98.9 kg NO_3^--N ha^{-1} were recorded in top 90 cm soil layer (Figure 3, Sep 14). The amount of nitrate-N under Wm was lower mainly in the upper soil layers 0 - 60 cm which indicates the possibility that already in the first three weeks after sowing Wm was representing an efficient nitrogen sink, taking up more than 20 kg N ha^{-1}.

At the next soil sampling (Oct 17) the amount of soil nitrate on F plots remained on the same level (121.0 kg NO_3^--N ha^{-1}). Substantial amount of nitrate was present in the deeper soil layers (65.6 kg NO_3^--N ha^{-1} in 30 - 60 cm and 39.0 kg NO_3^--N ha^{-1} in 60 - 90 cm; Figure 3). Compared to the fallow treatment the amount of soil nitrate was significantly reduced by growing catch crops. Figure 3 (Oct 17) illustrates also that Wm decreased soil nitrate-N content significantly more than both turnips. Soil nitrate-N contents of 15.9, 66.6 and 43.7 kg ha^{-1} were recorded under Wm, Me and Pe, respectively (Figure 3, Oct 17). Turnip Pe decreased the amount of soil nitrate significantly compared to turnip Me.

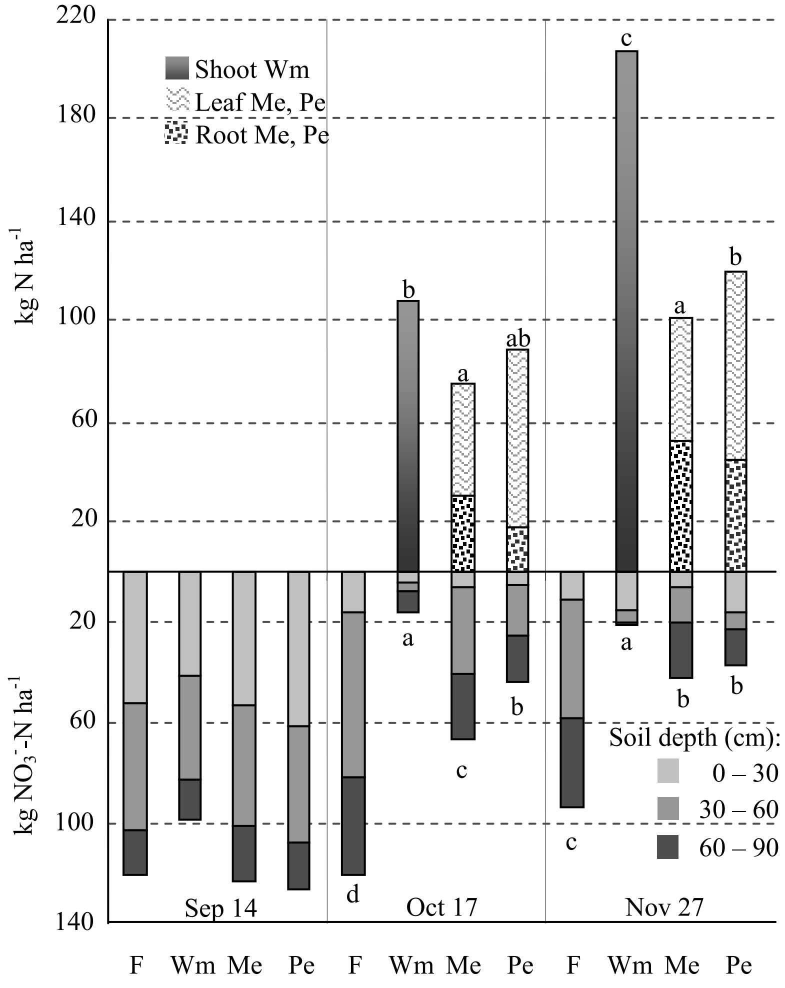

Figure 3: Soil nitrate after potato harvest 2000 and N uptake of catch crops. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

During the first 56 DAS (Oct 17) nitrogen uptake of Wm (108.0 kg ha^{-1}) was significantly higher compared with uptake of Me (75.1 kg ha^{-1}) but not significantly higher compared with Pe (88.4 kg ha^{-1}; Figure 3 and Table 4). Comparing the amount of soil nitrate N on F plots (121.0 kg ha^{-1})

with the total N in plant-soil systems on Wm plots (123.9 kg ha^{-1}) it can be seen that in the 56 DAS N uptake of Wm was well synchronised with N supply by organic matter mineralization. (Figure 3 and Table 3 in Appendix).

Table 4: Dry matter yield, N_t concentration in DM and N uptake of catch crops after potato harvest 2000. Growth analysis sampling (Oct 20, 56 DAS).

	DM yield (t ha^{-1})			**N_t conc. (%)**		**N (kg N ha^{-1})**		
Catch crop	Root	Leaf	Σ	Root	Leaf	Root	Leaf	Σ
W. mustard	-	2.47^{c}	2.47^{b}	-	4.38^{a}	-	108.0^{c}	108.0^{b}
M. Exp. F1	0.73^{b}	0.95^{a}	1.68^{a}	4.09^{a}	4.76^{b}	29.9^{b}	45.2^{a}	75.1^{a}
Petrowski	0.40^{a}	1.42^{b}	1.82^{ab}	4.46^{b}	5.01^{b}	17.6^{a}	70.8^{b}	88.4^{ab}

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

In 56 DAS turnips produced 1.68 and 1.82 t ha^{-1} of DM (Table 4) and were thus already on the same level as in the first year at final harvest (Table 3). The distribution of DM accumulation in turnips Me and Pe was quite the reverse. Me accumulated significantly more DM in roots on the other hand Pe accumulated significantly more DM in leaves. With Shoot DM production of Wm (2.47 t ha^{-1}) was significantly higher than total DM production of Me but did not differ significantly from total DM production of Pe (Table 4). High DM production as well as high N_t concentration in plant tissues of catch crops were responsible for high N uptakes. 56 DAS total N uptake of 108.0, 75.1 and 88.4 kg N ha^{-1} was recorded for Wm, Me and Pe respectively. The distribution of accumulated N in turnips followed the pattern of DM distribution. Thus turnip Me accumulated significantly higher amount of N in their roots and turnip Pe accumulated significantly more N in their leaves (Table 4).

At soil sampling on Nov 27 (Figure 3) the amount of soil nitrate-N under fallow treatment was 93.5 kg ha^{-1} with 89 % located below 30 cm soil depth. The amount of soil nitrate-N on catch crop plots was significantly lower. The lowest quantity of 21.3 kg NO_3^--N ha^{-1} was measured under Wm which was significantly less than 42.3 and 36.9 kg NO_3^--N ha^{-1} found under turnips Me and Pe respectively (Figure 3).

At final harvest of catch crops in the second year (2000) significant differences in DM accumulation and N uptake for all three catch crops were determined. Total DM yield of 4.96, 2.62 and 2.98 t ha^{-1} with corresponding N uptake of 207.3, 101.0 and 119.5 kg ha^{-1} were recorded for Wm, Me and Pe respectively (Table 5). Turnips accumulated 52.5 and 45.0 kg N ha^{-1} in roots, i.e. 52 and 38 % of all accumulated N for Me and Pe respectively. There was no significant difference in N_t concentration in DM of turnip roots. However, N_t concentration in DM of Pe and Wm leaves was significantly higher than N_t concentration in leaves of turnip Me.

Table 5: Dry matter yield, N_t concentration in DM and N uptake of catch crops after potato harvest 2000 (Nov 21, 90 DAS).

	DM yield (t ha^{-1})			**N_t conc. (%)**		**N (kg N ha^{-1})**		
Catch crop	Root	Leaf	∑	Root	Leaf	Root	Leaf	∑
W. mustard	-	4.96^c	4.96^c	-	4.18^b	-	207.3^c	207.3^c
M. Exp. F1	1.38	1.24^a	2.62^a	3.76	3.95^a	52.5^b	48.5^a	101.0^a
Petrowski	1.18	1.80^b	2.98^b	3.88	4.12^b	45.0^a	74.5^b	119.5^b

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

At final harvest of catch crops in the second year (2000) plant-soil system on F plots contained 93.5 kg NO_3^--N ha^{-1} (soil nitrate-N only). This was significantly less than on catch crop plots (Table 3 in appendix). On Wm plots plant-soil system contained 228.6 kg N ha^{-1} (21.3 kg NO_3^--N ha^{-1} in soil + 207.3 kg N ha^{-1} in plant tissue). This was significantly more than under both turnips where 143.3 kg N ha^{-1} (42.3 kg NO_3^--N ha^{-1} in soil + 101.0 kg N ha^{-1} in plant tissue) and 156,4 kg N ha^{-1} (36.9 kg NO_3^--N ha^{-1} in soil + 119.5 kg N ha^{-1} in plant tissue) were determined on Me and Pe plots respectively (Figure 3 and Table 3 in appendix).

5.1.2 Precrop faba beans

First year 1999

On Aug 28 - 10 days after faba bean harvest - soil nitrate content in the top 90 cm soil layer ranged between 30.7 and 36.3 kg NO_3^--N ha^{-1} (Figure 4). Over 75 % of soil nitrate was present in the soil layer 0 - 30 cm.

On Dec 3 soil nitrate content under all four treatments varied between 4.1 to 105.5, 4.1 to 60.6, 12.6 to 23.8 and 9.7 to 64.7 kg NO_3^--N ha^{-1} under F, Wm, Me and Pe respectively. However figure 4 shows that the average amount of soil nitrate was to a large extent decreased by growing catch crops compared with F treatment where 52.1 kg NO_3^--N ha^{-1} were measured.

In 100 DAS Wm, Me and Pe took up 74.2, 77.3 and 74.0 kg N ha^{-1} with average nitrate content in the soil of 21.1, 18.1 and 26.9 kg NO_3^--N ha^{-1} under Wm, Me and Pe respectively. The plant-soil systems of catch crop treatments exhibited similar amounts of N, i.e. 95.3, 95,4 and 100.9 kg N ha^{-1} on Wm, Me and Pe plots (Figure 4 and Table 3 in Appendix). The plant-soil system on F plots contained only 52.1 kg N ha^{-1} which was significantly less than on Wm plots but not significantly less than on turnip plots (Table 3 in Appendix).

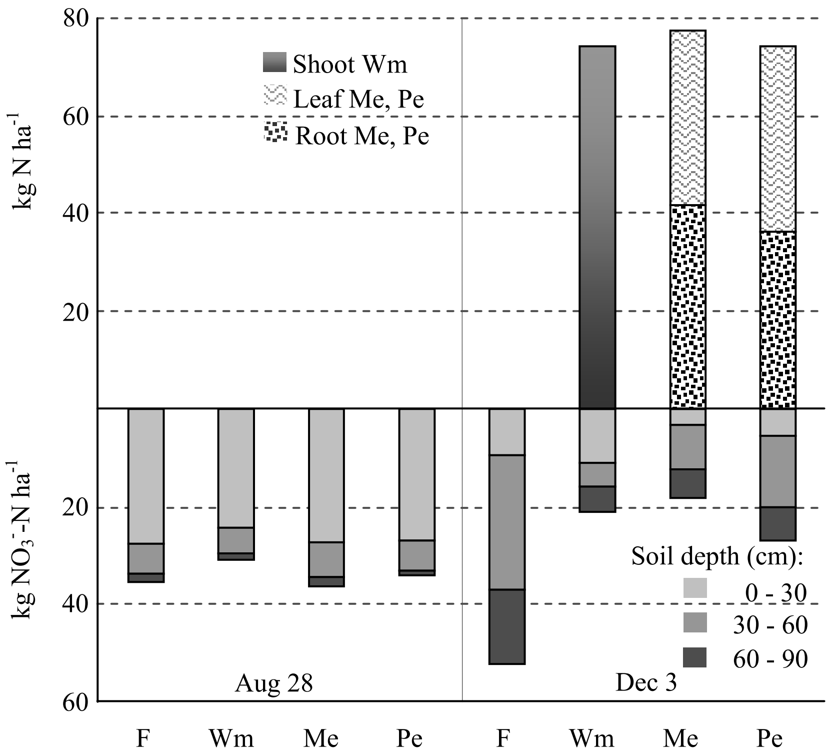

Figure 4: Soil nitrate after faba bean harvest 1999 and N uptake of catch crops. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

In the first experimental year the DM production of Wm after faba beans was 3.37 t ha^{-1}. This was significantly higher than the DM production of Me and Pe with 2.26 and 2.39 t ha^{-1} respectively (Table 6). Both turnip cultivars accumulated over 54 % of DM in roots corresponding to 1.32 and 1.31 t ha^{-1}. N_t concentration in DM of Me and Pe roots was 3.15 and 2.77 % resulting in storage of 49 % of total N uptake in the roots (corresponding with 41.6 and 36.3 kg N ha^{-1} for Me and Pe, respectively). N_t concentration in DM of Wm leaves (2.20 %) was significantly lower than N_t concentration in turnip leaves yet the total N uptake of all three catch crops did not differ considerably which was a consequence of the significantly higher DM production of Wm.

Table 6: Dry matter yield, N_t concentration in DM and N uptake of catch crops after faba bean harvest 1999 (Nov 25, 100 DAS).

	DM yield (t ha^{-1})			N_t conc. (%)		N (kg N ha^{-1})		
Catch crop	Root	Leaf	Σ	Root	Leaf	Root	Leaf	Σ
W. mustard	-	3.37^b	3.37^b	-	2.20^a	-	74.2^b	74.2
M. Exp. F1	1.32	0.94^a	$2,26^a$	3.15	3.79^b	41.6	35.7^a	77.3
Petrowski	1.31	1.08^a	2.39^a	2.77	3.50^b	36.3	37.7^a	74.0

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Second year 2000

In the second experimental year, 20 DAS (Figure 5, Sep 14) of catch crops, the amount of soil nitrate-N in 0 - 90 cm soil layer was 74.6, 66.0, 76.2 and 74.4 kg ha^{-1} on F, Wm, Me and Pe plots (Figure 5, Sep 14). Under Wm the amount of soil nitrate in top 30 cm was already lowered for 10 kg NO_3^--N ha^{-1} indicating an N uptake of young Wm plants.

At the next soil sampling 53 DAS (Figure 5, Oct 17) the amount of soil nitrate on F plots did not considerably differ from the amount measured on Sep 14. However, over 80 % of the nitrate was present in the soil layer 30 - 60 cm. The amount of soil nitrate under catch crops was significantly reduced compared to fallow treatment. The amounts of 6.2, 36.5 and 26.9 kg NO_3^--N ha^{-1} were recorded on Wm, Me and Pe plots respectively. The amount of soil nitrate under Wm was significantly lower than under both turnip cultivars and turnip Pe reduced soil nitrate significantly more than cultivar Me.

At growth analysis sampling on Oct 20 (56 DAS) DM production of Wm was 2.17 t ha^{-1}, which was significantly higher than the one of turnip Me with 1.47 t ha^{-1}. At this time turnip Pe produced 1.79 t ha^{-1} of DM (Table 7). The distribution of DM accumulation in both turnips was quite inverse: turnip Me accumulated significantly more DM in roots, whereas turnip Pe accumulated more DM in leaves. N_t concentration in root DM was 3.91 and 4.04 % for Me and Pe respectively. N_t concentration in DM of turnip leaves was higher compared with roots reaching 4.20 and 4.46 % for Me and Pe respectively. Both concentrations were significantly higher as in shoot DM of Wm that reached only 3.52 %.

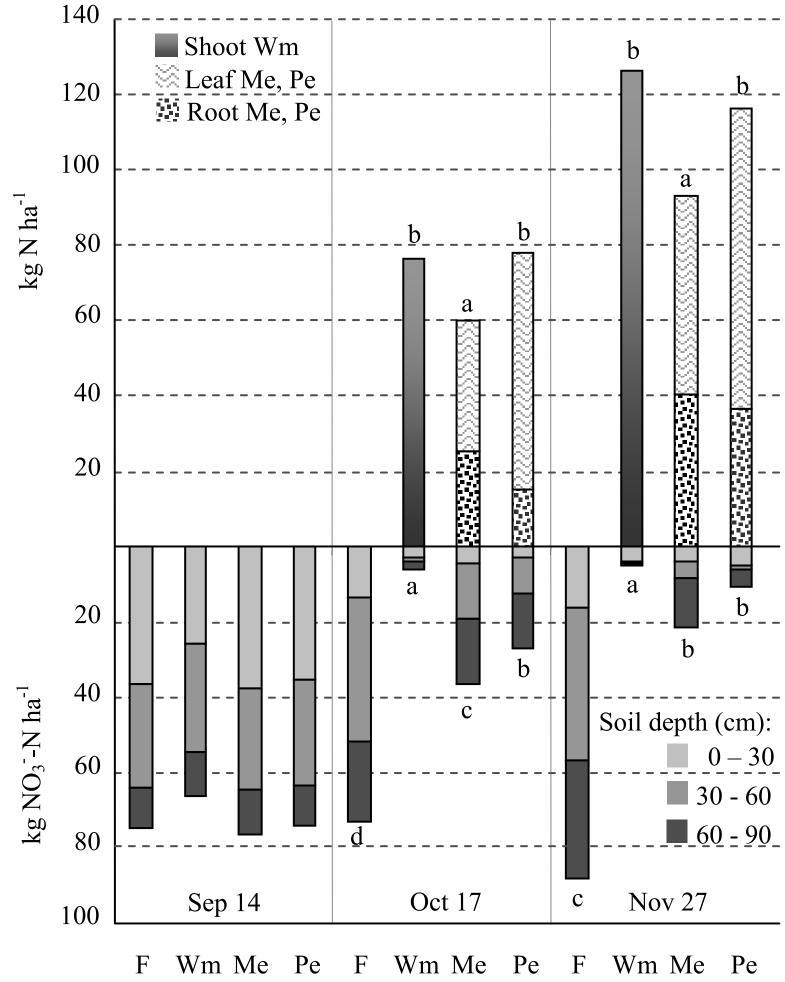

Figure 5: Soil nitrate after faba bean harvest 2000 and N uptake of catch crops. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Until Oct 20 Wm, Me and Pe took up 76.3, 60.0 and 78.4 kg N ha^{-1} (Table 7). The N uptake of turnip Me was significantly lower than N uptake of Wm and Pe. The distribution of accumulated N in turnips correlated with the pattern of DM accumulation: significantly more N was stored in Me than in Pe roots, whereas Pe leaves contained significantly more N as Me leaves. Because leaves of turnip Pe accumulated more DM with higher N_t concentration than Me, total accumulation of N (root + leaf) in turnip Pe was significantly higher than the total N accumulation of Me.

At growth analysis sampling on Oct 20 (56 DAS) plant-soil system of catch crops contained: Wm 82.5 kg N ha^{-1} (76.3 kg N ha^{-1} in plant tissue + 6.2 kg NO_3^--N ha^{-1} in soil), Me 96.5 kg N ha^{-1} (60.0 kg N ha^{-1} in plant tissue + 36.5 kg NO_3^--N ha^{-1} in soil) and Pe 105.3 kg N ha^{-1} (78.4 kg N ha^{-1} in plant tissue + 26.9 kg NO_3^--N ha^{-1} in soil). The amount of N in plant-soil system on turnip plots was significantly higher than the amount of soil nitrate-N on F plots, which was 73.0 kg NO_3^--N ha^{-1} (Figure 5 and Table 3 in Appendix).

Table 7: Dry matter yield, N_t concentration in DM and N uptake of catch crops after faba bean harvest 2000. Growth analysis sampling (Oct 20, 56 DAS).

	DM yield (t ha^{-1})			N_t conc. (%)		N (kg N ha^{-1})		
Catch crop	Root	Leaf	∑	Root	Leaf	Root	Leaf	∑
W. mustard	-	2.17^{c}	2.17^{b}	-	3.52^{a}	-	76.3^{c}	76.3^{b}
M. Exp. F1	0.65^{b}	0.82^{a}	1.47^{a}	3.91	4.20^{b}	25.4^{b}	34.6^{a}	60.0^{a}
Petrowski	0.38^{a}	1.41^{b}	1.79^{ab}	4.04	4.46^{b}	15.4^{a}	63.0^{b}	78.4^{b}

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Between Oct 17 and the following soil sampling on Nov 27 (Figure 5) the soil nitrate under F treatment raised to 88.1 kg NO_3^--N ha^{-1}. During the same period the amount of soil nitrate under catch crops decreased. Consequently under Me and Pe significantly lower amounts of 21.6 and 10.4 kg NO_3^--N ha^{-1} respectively were measured. With only 5.0 kg NO_3^--N ha^{-1} soil nitrate content under Wm was significantly lower than under both turnips.

At the final harvest on Nov 21 (Table 8) a catch crop DM accumulation of 3.75, 3.10 and 3.61 t ha^{-1} with corresponding total N uptake of 126.4, 93.2 and 116.4 kg N ha^{-1} for Wm, Me and Pe respectively was recorded. The significantly lowest DM accumulation and total N uptake were found for turnip Me. Similar as on Oct 20 also at final harvest both turnips differed significantly in respect to the distribution of accumulated DM and N (Table 8).

Table 8: Dry matter yield, N_t concentration in DM and N uptake of catch crops after faba bean harvest 2000 (Nov 21, 90 DAS).

	DM yield (t ha^{-1})			N_t conc. (%)		N (kg N ha^{-1})		
Catch crop	Root	Leaf	∑	Root	Leaf	Root	Leaf	∑
W. mustard	-	3.75^{c}	3.75^{b}	-	3.37^{a}	-	126.4^{c}	126.4^{b}
M. Exp. F1	1.66^{b}	1.44^{a}	3.10^{a}	2.52	3.73^{b}	40.5^{b}	52.7^{a}	93.2^{a}
Petrowski	1.52^{a}	2.09^{b}	3.61^{b}	2.46	3.81^{b}	36.8^{a}	79.6^{b}	116.4^{b}

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

At the end of the growing season of catch crops the plant-soil systems contained 88.1 kg NO_3^--N ha^{-1} on fallow, 131.4 kg N ha^{-1} on Wm treatment (5.0 kg NO_3^--N ha^{-1} in soil + 126.4 kg N ha^{-1} in plant tissue), 114.8 kg N ha^{-1} on Me treatment (21.6 kg NO_3^--N ha^{-1} in soil + 93.2 kg N ha^{-1} in plant tissue) and 126.8 kg N ha^{-1} on Pe treatment (10.4 kg NO_3^--N ha^{-1} in soil + 116.4 kg N ha^{-1} in plant tissue). Plant soil systems on Wm and Pe plots were thus containing significantly more N than on Me plots and Me plots contained significantly more N than fallowed plots (Table 3 in Appendix).

5.1.3 Discussion

Soil nitrate dynamics

After the harvest of the main crop, potatoes and faba beans, in summer the amount of soil nitrate varied strongly among the two years studied. Soil nitrate ranged between 20 - 130 kg NO_3^--N ha^{-1} after potato and 30 - 80 kg NO_3^--N ha^{-1} after faba bean harvest (Figures 2 and 3). This was in agreement with previous reports on soil nitrate by WIDDOWSON et al. (1987), HOFMAN & VAN CLEEMPUT (1992), ALFÖLDI et al. (1992), ALBLAS et al. (1992) and REENTS & MÖLLER (1997) after potatoes and KÖPKE (1987), HAUNZ et al. (1988), MAIDL et al. (1991) and JENSEN (1995) after faba beans.

High variation in post harvest soil nitrate content in both experimental years was mainly caused by the heterogeneity of experimental fields, higher summer precipitation in the second experimental year and a 50 % lower potato and faba bean yield in the second year. This resulted in a considerable accumulation of nitrate in the soil already during the growing season of both main crops.

Present data show that in both years Wm and both turnips significantly reduced the amount of soil nitrate compared to bare fallow. This way nitrate accumulation in deeper soil layers or even leaching under the rooting zone was diminished. Under fallow the amount of soil nitrate increased and a large amount of it was already present in deeper soil layers at the beginning of winter discharge (Figures 2,3,4 and 5).

In the autumn of the first experimental year (1999) there were no significant differences in depletion of soil nitrate between Wm and both turnips. On the other hand in the second experimental year (2000) significant differences between all three catch crops were observed.

When soil nitrate-N content was exceeding 120 kg ha^{-1} after potatoes (Figure 3) and 60 kg ha^{-1} after faba beans (Figure 5), white mustard depleted soil nitrate significantly better than both turnips.

Soil nitrate status under Wm and both turnip cultivars on Oct 17, 2000 (Figures 3 and 5) indicate that Wm, with its rapid growth, considerably depleted the soil layer 60 - 90 cm already during the first 56 DAS. This was not observed with turnips. It can thus be supposed that the root system of Wm reached deeper soil layers fast, resulting in high soil nitrate depletion. This observation corresponds with reports of THORUP-KRISTENSEN (1993) who found fodder radish roots at depth of 112 cm only 49 days after sowing and is consistent with findings of BURNS (1980), that roots of more closely-spaced plants tend to explore deeper regions of the soil in search of water or nutrients in response to competition from their neighbour plants.

Low nitrate content in upper soil layers (0 - 30 and 30 - 60 cm) and higher amounts of soil nitrate in 60 - 90 cm soil layer under turnips at the time of harvest, indicate that the root system of turnips at plant density between 30 to 40 plants m^{-2} successfully depleted soil nitrate from the upper soil layer but was rather inefficient (compared to Wm) when nitrate was already present under 60 cm.

DM production and N uptake

Dry matter yield of turnips recorded in this study (1.76 - 3.61 t ha^{-1}) was low, compared with some literature data. This was a consequence of a late sowing and low plant density, which is required when turnips are grown as vegetables. Other studies reported the DM production of turnips, grown as fodder with a higher plant density, to be between 5 to 10 t ha^{-1} (GREENWOOD et al. 1980, BERENDONK 1992, REID et al. 1994). Nevertheless also lower values between 1 and 5 t ha^{-1} were reported (JUNG et al. 1979, PERCIVAL et al. 1986, YOUNG 1998). See Appendix table 4 for detailed literature survey.

Although DM yields were rather low, total N uptake of turnips in this study was due to a high N_t concentration in DM high ranging between 57.1 and 119.5 kg N ha^{-1}. N uptake between 102.1 and 107.4 kg ha^{-1} for unfertilised turnips was reported by YOUNG (1998) which is in consistence with N uptake of turnips observed in the present study in the second year (Table 5 and 8). A higher N uptake of 142 - 205 kg N ha^{-1}was calculated by BERENDONK (1992) and GUILLARD & ALLINSON (1989) (182 - 193 kg N ha^{-1}) when turnips were fertilized with 100 and 140 kg N ha^{-1}

respectively. The extent of N uptake by turnips in this experiment was dominated mainly by the short growing season (100 days), lower plant density (30 to 40 plants m^{-2}) and available soil N and did not depend on the degree of success in crop establishment often reported as a factor limiting N uptake of catch crops (RICHARDS et al. 1996, SHEPHERD 1999).

N_t concentration in DM of turnip roots (2.46 to 3.88 %) and leaves (3.50 to 4.12 %) were on the upper range reported previously by RAO & HORN (1986), JUNG et al. (1986), GUILLARD & ALLINSON (1989) and PEARSON & THOMSON (1996) for field grown turnips (see Appendix table 12). In comparison with N_t concentration in DM reported for some other brassica vegetables (chinese cabbage 4.2 %, savoy cabbage 3.8 %, curly kale 4.1 % and kohlrabi 4.1 % (ALT & WIEMANN 1990), collard 3.82 - 5.61 % (DANGLER & WOOD 1993)) nitrogen concentration of turnips in this study nevertheless ranged within expected values.

White mustard DM yields of 3.37 - 4.96 t ha^{-1} found in this research correspond to 4.36 and 4 t ha^{-1} reported by YOUNG (1998) and ALLISON et al. (1998) and ranged between 2.2 and 5.4 t ha^{-1} reported for Germany by ELERS & HARTMANN (1987) and BERENDONK (1987) with N uptake of 66 and 83 kg N ha^{-1} respectively. N uptake of white mustard after potatoes in the second year exceeded 200 kg ha^{-1}. This high N uptake was a result of an extended time of root activity late in the autumn, which was a consequence of high soil nitrate content (Figure 3) and favourable weather conditions. In the second year, with high N uptake, white mustard - in contrast to first year- did not set any flowers. Because flowering is generally accompanied by reduced root activity and the beginning of senescence of non-reproductive plant parts (THORUP-KRISTENSEN 1994) this support the explanation that root activity of white mustard in the second year was considerably prolonged. NINANE et al. (1996) reported N uptake of white mustard up to 204 kg ha^{-1} when fertilised with 80 kg N ha^{-1}. N uptake over 200 kg ha^{-1} in shoots was also reported by JACKSON et al. (1993).

There were substantial differences between both turnip cultivars evaluated in this research. Turnips Me showed rapid DM and N accumulation in roots (Tables 4 and 7) whereas turnips Pe took advantage of the favourable growing conditions primarily to produce large leaf biomass accumulating therewith-higher amounts of total N in a short period of time. This feature was more transparent when growing conditions were favourable as was the case in the second experimental year of this study. Higher N export from the field was achieved with turnips Me since it accumulated higher amounts of N in harvested roots.

Differences in DM accumulation, corresponding N uptake, growth pattern and winter hardiness between both turnip cultivars used in this study showed that the selection of a cultivar is of great importance when explicit aims like reduction of soil nitrate, N export or production of marketable roots have to be achieved.

Plant - soil system

On Dec 3 in the first experimental year the plant - soil system after potatoes contained 79.7, 80.0, 74.2 and 71.7 kg N ha^{-1} under F, Wm, Me and Pe respectively (Table 3 in Appendix). These results demonstrate that the N uptake of white mustard and both turnips was well synchronised with N supply by organic matter mineralization.

After faba beans, the plant - soil system on Dec 3 in the first year contained 52.1, 95.3, 95.4 and 100.9 kg N ha^{-1} under F, Wm, Me and Pe respectively (Table 2 in Appendix). These large differences in N content of plant - soil system measured between F and catch crop treatments was a result of a high variability in soil nitrate on F plots that ranged between 4.1 and 105.5 kg NO_3^--N ha^{-1}. These data shows that on some F plots the amount of nitrate N was on the same level as plant - soil system on plots with catch crops while on other F plots nitrate N content was negligible. Whether these low nitrate contents on some F plots were a consequence of low mineralization of organic matter or a consequence of leaching below 90 cm is beyond this research.

In the second experimental year at final turnip harvest on Nov 27 the plant - soil system after potatoes contained 93.5, 228.6, 143.3 and 156.4 kg NO_3^--N ha^{-1} under F, Wm, Me and Pe respectively (Table 2 in Appendix). However, minor differences of about 20 kg N ha^{-1} are rather common in plant soil systems and can be attributed to immobilisation or denitrification processes (MARTINEZ & GUIRAUD 1990). Considerable differences of up to 135 kg N ha^{-1} between treatments in the present study (see above) indicate a substantial impact of the management regimes on the soil nitrogen transformations.

An assumption that these high difference in N content of plant - soil systems under different treatments could originate just from leaching is not very plausible. Under this assumption the amounts of 135.1, 85.3 and 72.2 kg NO_3^--N ha^{-1} under F, Me and Pe plots respectively had to be leached below 90 cm to be in a balance with a plant - soil system on Wm plots. The amount of precipitation during this time was 150 mm. If it is assumed that also the precipitation surplus was

150 mm, which is not possible because the soil was far from being saturated, the rough calculation for F plots shows that each mm of water should be responsible for 0.9 kg of leached N ha^{-1}, which means with other words that average concentration of N in leached water should be over 90 mg N l^{-1}. This is not in agreement with reported concentrations of nitrate in leached water under field conditions which usually range between 18 - 42 mg N l^{-1} (MARTINEZ & GUIRAUD 1990), 50 - 70 mg N l^{-1} (MACDUFF et al. 1990), 22.3 mg N l^{-1} (SHEPHERD & LORD 1996) and can under controlled conditions extraordinarily reach 136 mg N l^{-1} (VAN DAM & LEFFELAAR 1998).

Another option suggests that on F plots less N was mineralised from organic matter due to a lack of plant roots, which could stimulate mineralization of organic matter (JINGGUO & BAKKEN 1989, CORTEZ & CHERQUI 1991). CLARHOLM (1985) found that the plant growth profoundly influenced N transformations. In the presence of root-derived carbon, much more N was mineralised from the organic matter and immobilised mainly in plant biomass. HELAL & SAUERBECK (1986) also demonstrated that growing roots are a significant C-source for the microorganisms and render an additional fraction of soil-C available to microbial utilisation. Furthermore low molecular organic substances are able to stimulate soil microorganisms, thus intensifying the break down of soil organic matter (SCHELLER & VOGTMANN 1995).

Bacterial activities leading to N mineralization are often depressed because of a lack of suitable energy source, which is supplied by plant roots in the vegetated soil (CLARHOLM 1985). HAIDER et al. (1987) reported that at the termination of their pot experiment about 500 mg N from the soil organic matter in planted soil and only 150 mg N of that without plants was mineralised and concluded that the mineralization of organic N seems to be greatly enhanced by the presence of plants. According to HART et al. (1979) also continuous removal of soil nitrate depletes the equilibrium level of the soil inorganic N pool and may stimulate greater release of N from organic matter. Without root uptake, high amounts of inorganic N in the soil can be build up, possibly retarding further mineralization (CLARHOLM 1985).

Alternatively these large differences in N content of plant - soil systems (see above) may also be explained by the mineralised N being immediately immobilised by the microbial biomass (RECOUS & MARY 1990). Mineralised N was hence not entering the soil solution as nitrate at all and was thus not recorded by soil nitrate analysis. However this extreme variation in N content of plant - soil system recorded in the second year was most probably a combined effect of leaching, enhanced mineralization under catch crops as well as microbial immobilisation.

5.1.4 Resume

I Heterogeneity of experimental fields, high summer precipitation and lower potato and faba bean yields in the second experimental year caused high variations in post-harvest soil-nitrate content during the experiment (20 - 130 kg NO_3^--N ha^{-1} after potato and 30 - 80 kg NO_3^--N ha^{-1} after faba bean harvest).

II In both years white mustard and turnips significantly reduced soil nitrate compared to bare fallow. At lower soil nitrate content after the harvest (less than 60 NO_3^--N ha^{-1}) turnips reduced soil nitrate as good as white mustard. At higher soil nitrate content the reduction under turnips was lower compared to white mustard.

III As a consequence of a late sowing date and low plant density, which is required when turnips are grown as vegetables, dry matter yield of turnips was low (1.76 - 3.61 t ha^{-1}). However the total N uptake of turnips was high due to a high N content in DM (57.1 and 119.5 kg N ha^{-1}).

IV Variations of up to 135 kg N ha^{-1} in N content of plant - soil systems under different treatments recorded in the second experimental year indicate a substantial impact of the management regimes on the soil nitrogen transformations. These large differences in N content of plant - soil systems were most probably a combined effect of leaching, enhanced mineralization under catch crops as well as microbial immobilisation.

5.2 Soil nitrate after winter and N uptake of following winter wheat

5.2.1 Precrop potatoes

First year 2000

Catch crop treatments and winter wheat sowing in autumn 1999 did not significantly influence soil nitrate content in following spring (2000). On March 21, 2000 amounts of soil nitrate ranged between 19.1 and 26.8 kg NO_3^--N ha^{-1} (Figure 6). The amount of soil nitrate under fallow treatment decreased over the winter from 79.7 (Dec 3, 1999, Figure 2) to 26.8 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 6). After Me the amount of soil nitrate remained unchanged. An increase of 16.9 and 7.7 kg NO_3^--N ha^{-1} was measured after Wm and Pe respectively.

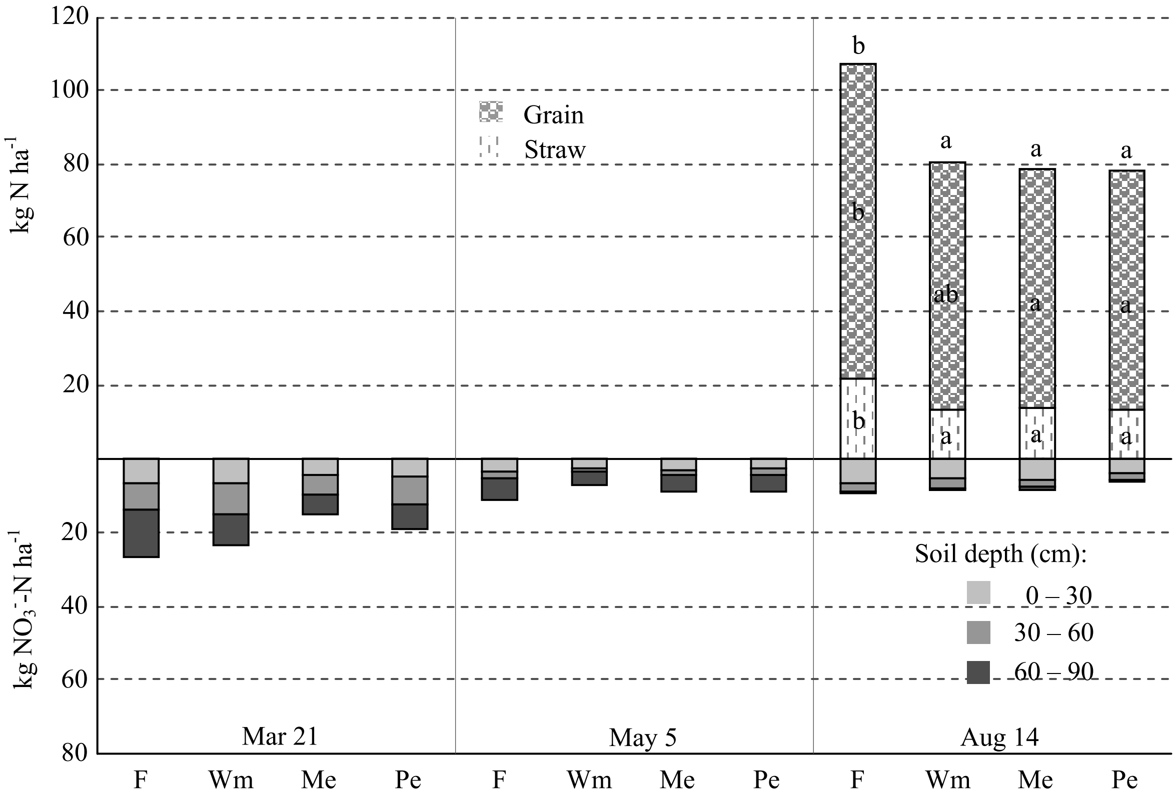

Figure 6: Effect of catch crop treatments on soil nitrate after winter and N uptake of winter wheat (2000). In 1999 precrop potato. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

At the next soil sampling date on May 5 between 7.0 and 11.1 kg NO_3^--N ha^{-1} were found in the soil under winter wheat. After winter wheat harvest the amount of soil nitrate under all four treatments was lower than 9.4 kg NO_3^--N ha^{-1} (Figure 6, Aug 14).

N uptake of winter wheat in 2000 was 107.1, 80.3, 78.5 and 78.2 kg N ha^{-1} after F, Wm, Me and Pe treatments respectively. Thus N uptake of winter wheat after fallow was significantly higher than after catch crops.

Second year 2001

In the second experimental year catch crops grown in autumn 2000 significantly influenced soil nitrate content in following February (2001). As a result 71.0, 36.4, 42.1 and 34.3 kg NO_3^--N ha^{-1} were recorded under F, Wm, Me and Pe respectively (Figure 7).

The difference between the amount of soil nitrate-N measured on Nov 27, 2000 (Figure 3) and on Feb 14, 2001 (Figure 7) shows that it decreased by 22.5 kg NO_3^--N ha^{-1} under F, increased by 15.1 kg NO_3^--N ha^{-1} after Wm and remained approximately at the same level after both turnip cultivars.

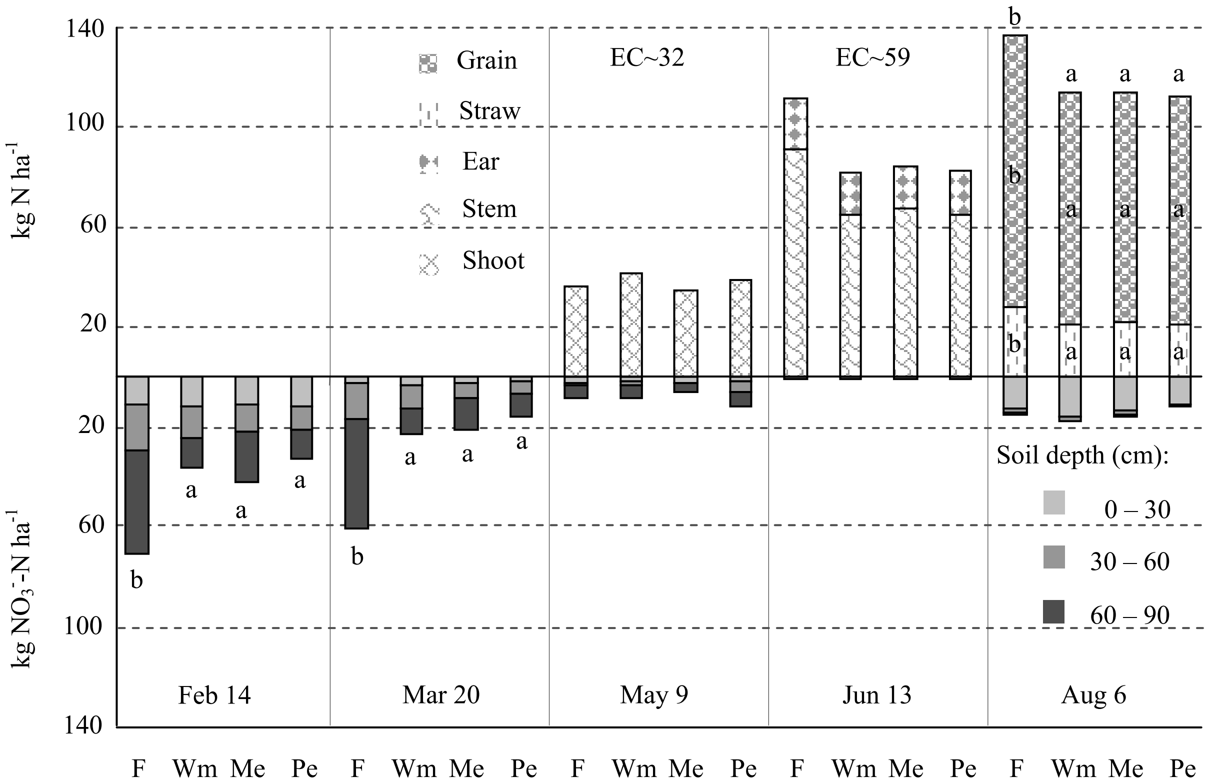

Figure 7: Effect of catch crop treatments on soil nitrate after winter and N uptake of winter wheat (2001). In 2000 precrop potato. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Five weeks later on Mar 20 a decrease of soil nitrate-N between 10.1 and 20.9 kg ha^{-1} was recorded on all plots (Figure 7). With exception of F plots where 60.9 kg NO_3^--N ha^{-1} were recorded the amount of soil nitrate was on the same level as in 2000 (see Figure 6).

Between March 20 and May 9 winter wheat functioned as an efficient nitrogen sink taking up 34.8 to 41.4 kg N ha^{-1}. Soil nitrate on all plots was thus reduced - ranging between 5.9 and 12.1 kg ha^{-1}. From May 9 until the end of the experimental observations the amount of soil nitrate did not differ significantly according to the different treatments in previous autumn (Figure 7).

Vigorous growth and N uptake of winter wheat during May and at the beginning of June 2001 depleted the soil nitrate. On June 13 less than 1 kg NO_3^--N ha^{-1} was found in the soil. Total N uptake of winter wheat was at that time 110.8, 81.6, 84.2 and 82.2 kg ha^{-1} after F, Wm, Me and Pe respectively. Though the variation in N uptake of winter wheat was high no significant differences among treatments existed.

After the harvest of winter wheat the amount of soil nitrate on Aug 6, 2001 was low on all plots - ranging between 12.2 and 18.2 kg NO_3^--N ha^{-1} (Figure 7). Total shoot N uptake of winter wheat at harvest was 136.6, 114.2, 114.0 and 112.4 kg N ha^{-1} after F, Wm, Me and Pe treatments respectively. Thus N uptake of winter wheat after fallow was significantly higher than after catch crops.

5.2.2 Precrop faba beans

First year 2000

After faba beans in 1999 catch crop treatments and winter wheat sowing in autumn did not significantly influence soil nitrate content in following spring (2000). On March 21 (2000) amounts of soil nitrate ranged between 32.7 and 40.8 kg NO_3^--N ha^{-1} (Figure 8). The amount of soil nitrate under fallow treatment decreased over the winter from 52.1 (Dec 3, 1999, Figure 4) to 38.3 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 8). On Wm, Me and Pe plots soil nitrate-N amounts of 34.1, 40.8 and 32.7 kg NO_3^--N ha^{-1} were recorded respectively (Figure 8). Thus soil nitrate in catch crop plots increased between 5.8 and 22.7 kg NO_3^--N ha^{-1} over the winter.

At the following sampling on May 5, 2000 soil nitrate on all plots ranged between 7.0 and 11.1 kg NO_3^--N ha^{-1} (Figure 8). This reduction in soil nitrate between March 21 and May 5 indicate N losses by leaching or immobilisation in the soil because on winter wheat plots there was no growing crop, which could represent such an effective nitrogen sink (*winter wheat failed during the winter and plots were re-sown with spring wheat in April).

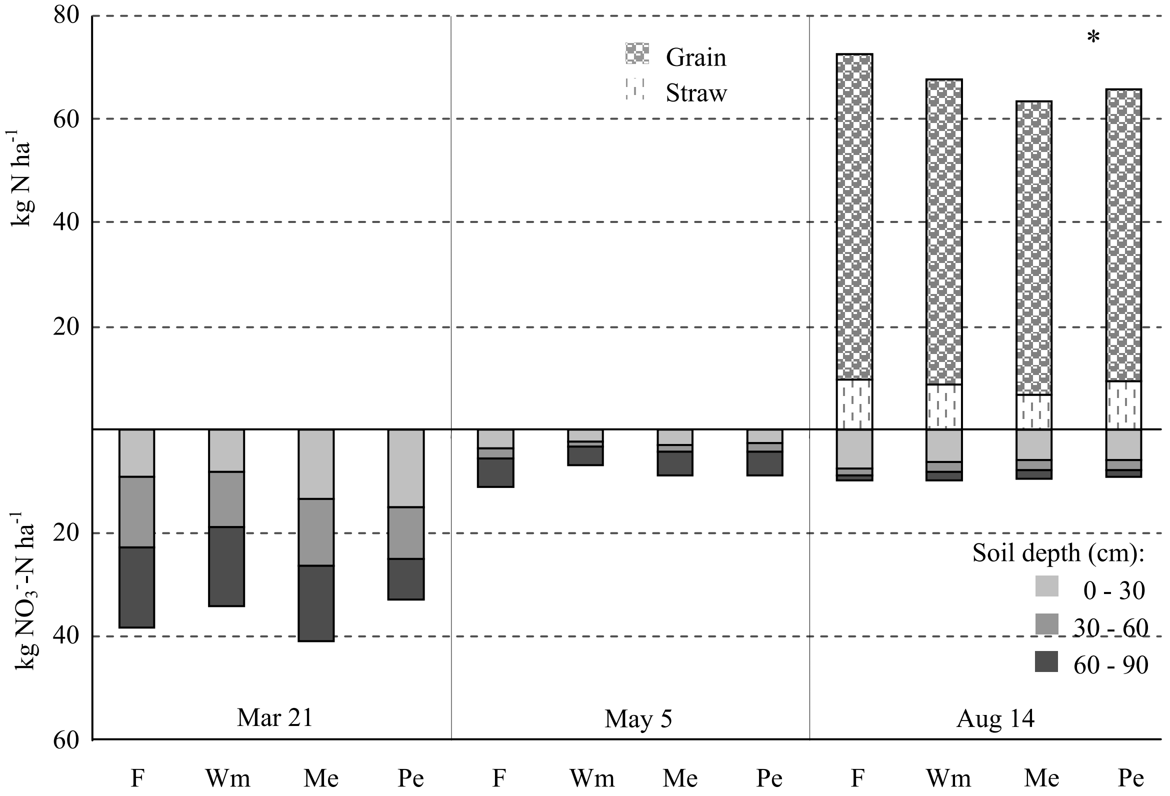

Figure 8: Effect of catch crop treatments on soil nitrate after winter and N uptake of spring wheat (2000) *winter wheat re-sown to spring wheat. In 1999 precrop faba beans. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

After the wheat harvest, the amount of soil nitrate on all plots was lower than 10 kg NO_3^--N ha^{-1} showing no differences according to different catch crop treatment in the previous autumn. The N uptake of re-sown spring wheat was the highest on F plots (72.4 kg N ha^{-1}) followed by the N uptake of 67.7, 63.5 and 65.7 kg N ha^{-1} on Wm, Me and Pe plots respectively.

Second year 2001

In the second experimental year catch crops grown in autumn 2000 significantly influenced soil nitrate content in following February 14 (2001). As a result 41.9, 19.4, 19.4 and 26.0 kg NO_3^--N ha^{-1} were recorded under F, Wm, Me and Pe respectively (Figure 9).

On Mar 20 (Figure 9) the soil nitrate content on F, Wm, Me and Pe plots plots was reduced compared to Feb 14 resulting in 33.3, 14.8, 13.8 and 13.3 kg NO_3^--N ha^{-1} respectively. Soil nitrate content on F plots was thus significantly higher as on plots previously grown with catch crops. On F plots 70 % of nitrate was present in the 60 - 90 cm soil layer.

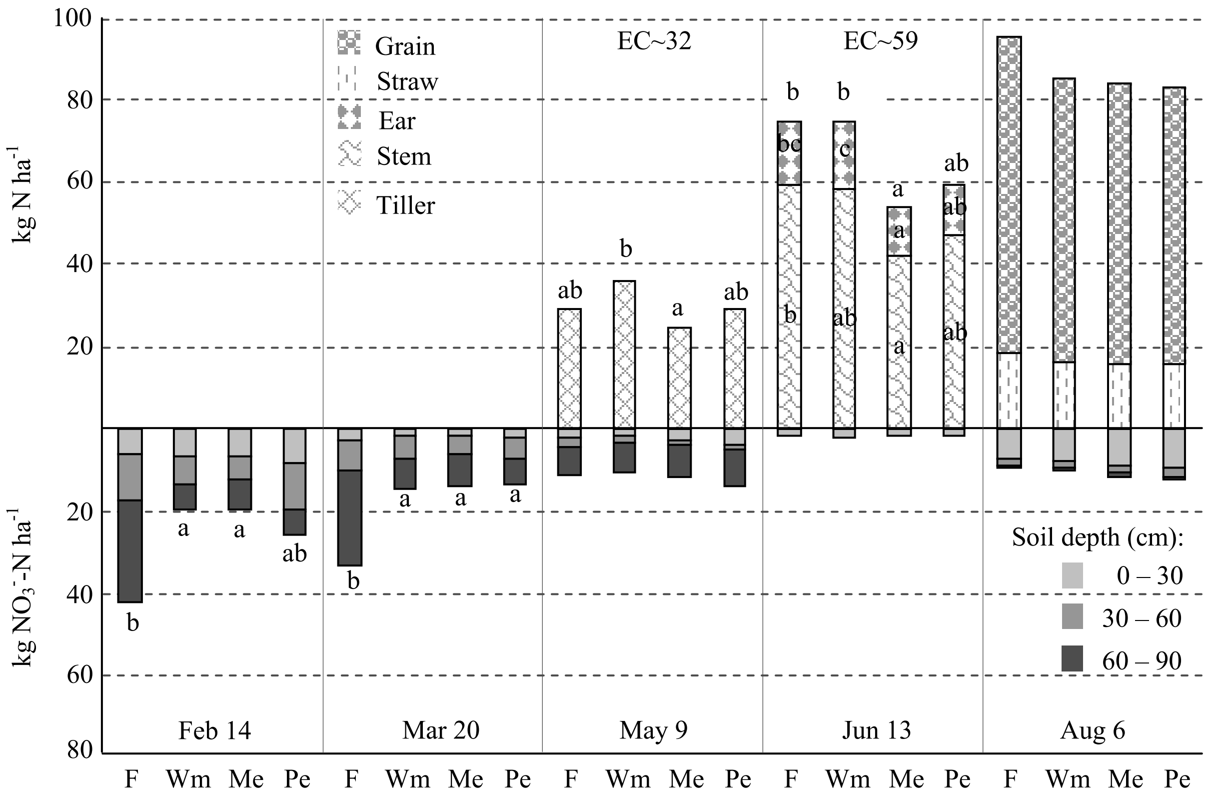

Figure 9: Effect of catch crop treatments on soil nitrate after winter and N uptake of winter wheat (2001). In 2000 precrop faba beans. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

In May winter wheat tillers contained between 24.8 and 36.0 kg N ha^{-1} (Figure 9). The soil nitrate content measured on May 9, 2001 ranged on all plots between 10.6 and 14.0 kg NO_3^--N ha^{-1} without any significant differences. Thus, between Mar 20 and May 9 winter wheat functioned as an efficient nitrogen sink. On June 13 between 1.4 and 2.4 kg NO_3^--N ha^{-1} were measured in the 0 - 90 cm soil layer (Figure 9). At this time between 54.0 and 74.9 kg N ha^{-1} were found in ears and stems of winter wheat.

After the harvest of winter wheat, the amount of soil nitrate did not significantly differ according to different catch crop treatments in previous year and ranged between 9.7 and 12.3 kg NO_3^--N ha^{-1} (Figure 9, Aug 6). Different catch crop treatments did not significantly influence N uptake of winter wheat. Though N uptake was the highest on F plots (95.8 kg N ha^{-1}) followed by N uptakes of 85.2, 84.1 and 83.3 kg N ha^{-1} on F, Wm, Me and Pe plots respectively.

5.2.3 Discussion

Soil nitrate dynamics after winter (winter wheat treatment)

When catch crop plant residues (white mustard and turnip leaves) were incorporated in autumn, and winter wheat was sown subsequently, the amount of soil nitrate in following March did not significantly differ according to incorporation of various catch crop residues with different amounts of residue N. Even the difference of 158 kg N ha^{-1} between incorporated residues of Wm and Me, after potatoes in the second year (Table 5), did not show any significant effect on the amount of soil nitrate in following spring. This suggests that incorporated biomass of Wm, Me and Pe retained a substantial part of the accumulated nitrogen in their tissues.

These findings differ from reports of MEISINGER et al. 1991, JENSEN 1992, and WAGGER et al. 1998 who found nitrogen from catch crops incorporated in autumn to be rapidly mineralised and leached out of the rooting zone already before spring. However in present experiments some factors could have suppressed rapid mineralization of catch crop residues: at the time of incorporation in late autumn, catch crops were still alive therefore availability for microbial attack could be under question since brassicas can contain high concentrations of secondary metabolites that can effectively depress soil micro-organisms and thus decomposition of incorporated plant material. Additionally, mineralization during the winter is substantially decreased by low temperatures (STANFORD et al. 1973) and soil moisture that reduce oxygen diffusion in the soil thus reducing oxygen supply of micro-organisms (THORUP-KRISTENSEN 1995). Present results are nevertheless consistent with findings of FRANZLUEBBERS et al. (1996) who found canola (*Brassica campestris* L.) residues to contain more N when incorporated than when surface placed.

Nitrogen export from the field of 33.8 - 52.5 kg ha^{-1} with turnip roots in the previous autumn did not significantly affect the amount of soil nitrate in the following spring because it was identical after both turnip cultivars and Wm where all plant biomass stayed on the field. This indicates that soil nitrate in spring was to a certain extent independent from the amount of N incorporated with catch crop residues in autumn.

The amount of soil nitrate in following March was reduced when the field was fallowed during the autumn. The reduction could either be due to a leaching of nitrate into the soil layer beneath 90 cm, the transfer of nitrogen into the soil organic nitrogen pool of microbial biomass or denitrification. However, both later processes presumably did not influence the N circle significantly, because due to the adverse weather condition during winter period denitrification and microbial N fixation should be negligible (THORUP-KRISTENSEN 1994).

In the first experimental year (1999 - 2000) the amount of soil nitrate after fallow and catch crop treatments in spring did not differ significantly (Figures 6 and 8). In contrast the soil nitrate content in the second experimental spring (2001) was significantly higher after fallow treatment than on the plots with incorporated catch crop residues (Figures 7 and 9). Presumably, this was a consequence of high soil nitrate content on fallow plots at the beginning of previous winter and only minor leaching leaving a considerable amount of nitrate within the 60 - 90 cm soil layer.

Between the end of March and the beginning of May in both years and after both precrops the reduction in soil nitrate was observed (Figures 6, 7, 8 and 9). Therefore it can be concluded, that winter wheat in that time already functioned as an effective N-sink. At the beginning of May 24.8 to 41.4 kg N ha^{-1} were thus determined in winter wheat shoots (Figures 7 and 9). However the reduction of soil nitrate between Mar 21 and May 5 in the first year after faba beans (Figure 8) indicate a reduction of soil nitrate which was not connected with N uptake of growing winter wheat. On winter wheat plots after faba beans there was no growing crop, which could represent a nitrogen sink (after faba beans in the first year winter wheat failed during the winter and plots were re-sown with spring wheat in April). This decrease of soil nitrate between March and May do not consist with a course of mineralisation during a year in typical agricultural soils under the climatic conditions of North West Europe (POWLSON 1993). However JENSEN (1992) found that the incorporation of catch crops in late autumn can significantly reduce the inorganic N content of the top soil in spring compared to soil with no catch crop incorporated. This is presumably because the incorporation of the catch crop increases the microbial biomass, which immobilises inorganic N during the decomposition of the incorporated plant material in spring (MARTINEZ & GUIRAUD 1990).

5.2.4 Resume

I When catch crop plant residues (white mustard and turnip leaves) were incorporated in autumn and winter wheat was sown subsequently, the amount of soil nitrate in following spring remained approximately on the same level as in previous autumn. On the other hand soil nitrate content on fallow treatments was reduced.

II The incorporation of various catch crop residues with different amounts of residue N in autumn did not show any significant effect on the amount of soil nitrate in following spring. This suggests that incorporated biomass of Wm, Me and Pe retained a substantial part of the accumulated nitrogen in their tissues.

III Nitrogen export from the field of 33.8 - 52.5 kg ha^{-1} with turnip roots in the previous autumn did not significantly affect the amount of soil nitrate in the following spring. This indicates that soil nitrate in spring was to a certain extent independent from the amount of N incorporated with catch crop residues in autumn.

IV Between the end of March and the beginning of May a reduction in soil nitrate under winter wheat was recorded. However the reduction cannot only be attributed to N uptake of growing winter wheat because the same tendency was observed also on the plots where winter wheat was lacking.

5.3 Soil nitrate dynamics after winter and N uptake of following spring wheat

5.3.1 Precrop potatoes

First year 2000

When experimental plots remained undisturbed over the winter the amount of soil nitrate on fallow plots decreased from 79.7 (Dec 3, 1999, Figure 2) to 9.9 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 10). The amount of soil-N under Wm increased during the winter from 6.8 (Dec 3, 1999, Figure 2) to 31.9 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 10) and was thus significantly higher than after fallow and both turnip treatments (Figure 10).

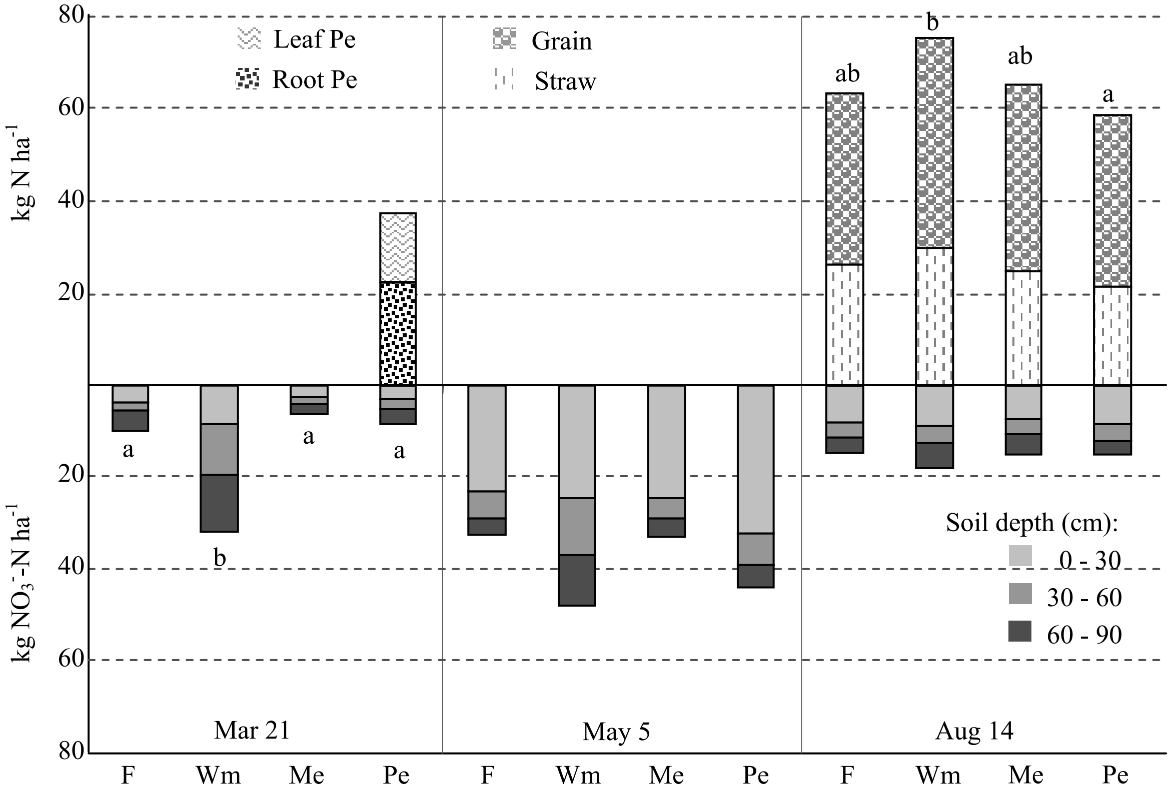

Figure 10: Effect of catch crop treatments on soil nitrate after winter and N uptake of spring wheat (2000). In 1999 precrop potato. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Turnip Me and Wm were destroyed by frost during the winter therefore on Mar 21 only the amount of N stored in plant tissue of turnip Pe was assessed (Figure 10). In roots and leaves 22.2 and 14.9 kg N ha^{-1} were stored respectively (Figure 10 and Table 7 in Appendix).

Until the following soil sampling on May 5, 2000 soil nitrate-N content under April-sown spring wheat increased for 22.8, 16.1, 26.8 and 35.3 kg NO_3^--N ha^{-1} after F, Wm, Me and Pe respectively and ranged between 32.7 and 48.0 kg ha^{-1} (Figure 10). Although 22.2 kg N ha^{-1} were removed from Pe plots by harvest of roots soil-N increase on these plots was the highest.

The amount of residual soil nitrate on Aug 14, 2000 (Figure 10), after the harvest of spring wheat, ranged between 14.8 and 18.0 kg NO_3^--N ha^{-1} showing no considerable differences according to different catch crop management in previous year.

Total N uptake of spring wheat was 63.3, 75.3, 65.0 and 58.6 kg N ha^{-1} on F, Wm, Me and Pe treatments respectively (Figure 10). N uptake of spring wheat after Wm was thus significantly higher than N uptake after turnip Pe but not significantly higher from N uptake on F and Me plots.

Second year 2001

In the second year soil nitrate-N on F plots decreased during the winter from 93.5 (Nov 27, 2000, Figure 3) to 44.4 kg ha^{-1} (Feb 14, 2001, Figure 11). On the other hand the amount of soil nitrate-N on Wm plots increased during the winter from 21.3 to 70.3 kg ha^{-1} and was thus significantly higher than under both turnip cultivars. The amount of soil NO_3^--N on turnip plots remained on the same level as before winter thus ranging between 32.7 and 34.3 kg ha^{-1}.

On the March 20 (Figure 11) soil nitrate content on Wm plots was 75.6 kg NO_3^--N ha^{-1} thus significantly higher than on all other plots where the content of soil nitrate ranged between 24.0 (F) and 36.6 (Pe) kg NO_3^--N ha^{-1}.

As in the first experimental year Wm and turnip Me were destroyed by frost during the winter. Thus, figure 11 shows only data for N stored in turnip Pe at the time of spring harvest (Mar 28, 2001). Total amount of N stored in turnip Pe was 81.6 kg N ha^{-1}. Compared with 119.5 kg N ha^{-1} stored in turnip Pe before winter (Nov 27, 2000, Figure 3).

On May 9 (Figure 11), soil nitrate content on all plots remained more or less on the same level as on March 20, with slight increase (4.3 to 10.7 kg NO_3^--N ha^{-1}) on Wm, Me and Pe plots.

Between May 9 and June 13 spring wheat functioned as an efficient nitrogen sink taking up 59.7, 86.8, 64.8 and 77.5 kg N ha^{-1} on F, Wm, Me and Pe plots. As a result no nitrate was found in the soil on June 13 (Figure 11).

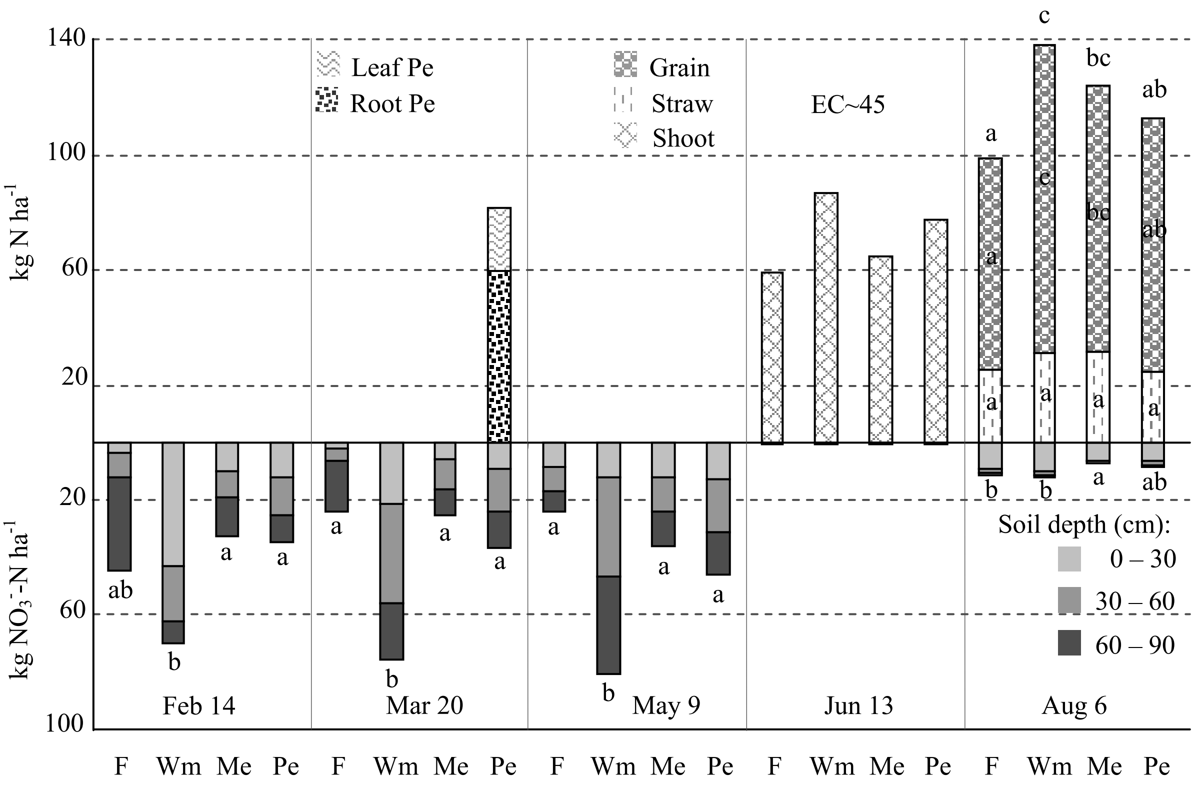

Figure 11: Effect of catch crop treatments on soil nitrate after winter and N uptake of spring wheat (2001). In 2000 precrop potato. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

At the time of grain harvest of spring wheat soil nitrate on all plots ranged between 12.1 and 6.9 kg NO_3^--N ha^{-1} (Figure 11). Total N uptake of spring wheat was 99.3, 138.9, 124.8 and 113.2 on F, Wm, Me and Pe treatments respectively. N uptake of spring wheat grown on Wm plots was thus significantly higher than on F and Pe plots but not significantly higher than N uptake of spring wheat on Me plots. There was no significant difference in N uptake of spring wheat grown on turnip plots (Me and Pe) however N uptake of spring wheat on Me plots was significantly higher than N uptake on F plots.

5.3.2 Precrop faba beans

First year

When soil was not tilled in previous autumn and catch crops were left on the field during the winter the amount of soil nitrate on fallow plots decreased from 52.1 (Dec 3, 1999, Figure 4) to 17.0 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 12). The amount of soil-N under Wm increased during the winter from 21.1 (Dec 3, 1999, Figure 4) to 31.5 kg NO_3^--N ha^{-1} (Mar 21, 2000, Figure 12). Under Me the amount of soil nitrate remained approximately on the same level whereas on Pe plots a decrease of 21.1 kg NO_3^--N ha^{-1} was recorded.

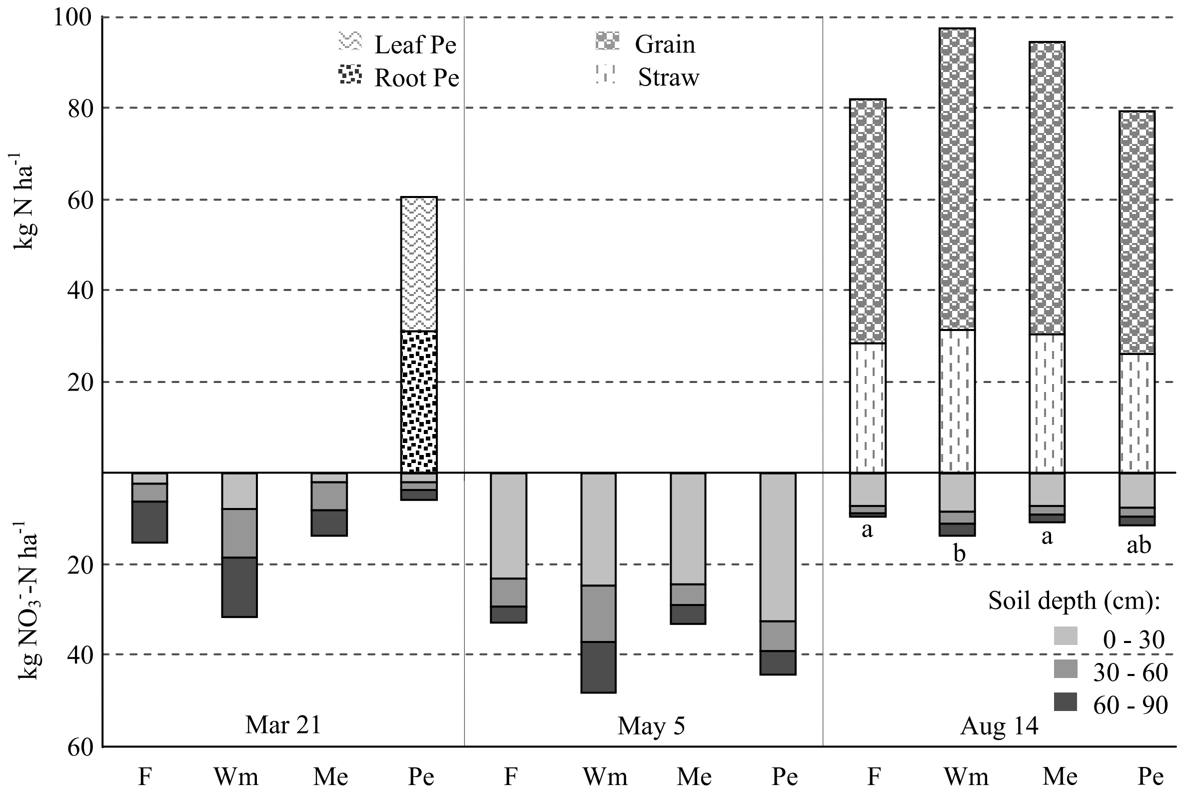

Figure 12: Effect of catch crop treatments on soil nitrate after winter and N uptake of spring wheat (2000). In 1999 precrop faba beans. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Wm and Me after faba beans were destroyed by frost during the winter. Thus figure 12 contains only the amount of stored N in turnip Pe. It shows that 30.9 and 29.5 kg N ha^{-1} were stored in roots and leaves respectively.

At the soil sampling on May 5 soil nitrate under April-sown spring wheat increased on all plots and ranged between 32.7 and 48.0 kg NO_3^--N ha^{-1}. These results indicate that nitrogen sink capacity of spring wheat at this time did not follow the mineralization of catch crop residues and soil organic matter. As a consequence between 50 and 70 % of soil nitrate were present in the upper 0 - 30 cm soil layer (Figure 12).

The highest total N uptake of spring wheat at final harvest was recorded on Wm plots 97.5 kg N ha^{-1} followed by N uptakes of 94.4, 81.9 and 79.4 kg N ha^{-1} on Me, F and Pe plots. Anyway these differences were not significant (Figure 12).

Soil nitrate content measured after the spring wheat harvest (Aug 14) was low ranging between 9.6 and 13.8 kg NO_3^--N ha^{-1}. However on Wm plots soil nitrate content was about 4 kg NO_3^--N ha^{-1} higher than on F and Me plots.

Second year

During the winter in the second year (2001) the amount of soil nitrate decreased on F plots, increased on Wm plots and remained approximately on the same level under both turnips. Consequently the amount of soil nitrate on F and Wm plots recorded on Feb 14 was 41.6 and 38.4 kg NO_3^--N ha^{-1} respectively thus significantly higher than under both turnips where 19.6 and 18.9 kg NO_3^--N ha^{-1} for Me and Pe were recorded respectively (Figure 13).

On Mar 20 a further reduction of soil nitrate for 19.4 kg NO_3^--N ha^{-1} was observed on F plots. Thus, the amount of soil nitrate on F, Me and Pe plots was on the same level ranging between 20.4 and 22.8 kg NO_3^--N ha^{-1}. The amount of soil nitrate on Wm plots was 45.3 kg NO_3^--N ha^{-1} thus significantly higher compared with other treatments.

Turnip Pe was not destroyed by frost as both other catch crops, thus on Mar 28, 2001 22.5 and 47.3 kg N ha^{-1} were assessed in leaves and roots respectively (Figure 13 and Table 7 in Appendix).

On May 9 an increase in soil nitrate was observed on all plots (Figure 13). On Wm plots the amount of soil nitrate reached 63.9 kg NO_3^--N ha^{-1} which was significantly higher than on F, Me and Pe plots with 33.3, 41.6 and 41.3 kg NO_3^--N ha^{-1} respectively. These data indicate that N uptake of spring wheat sown on April 3, 2001 was not able to follow a rapid mineralization of plant residues and soil organic matter. Because nitrate content under both turnips at this time was equal it would seem that N export of 47.3 kg N ha^{-1} from the field with spring harvest of Pe roots did not substantially influence the amount of soil nitrate available to the first following crop - spring wheat.

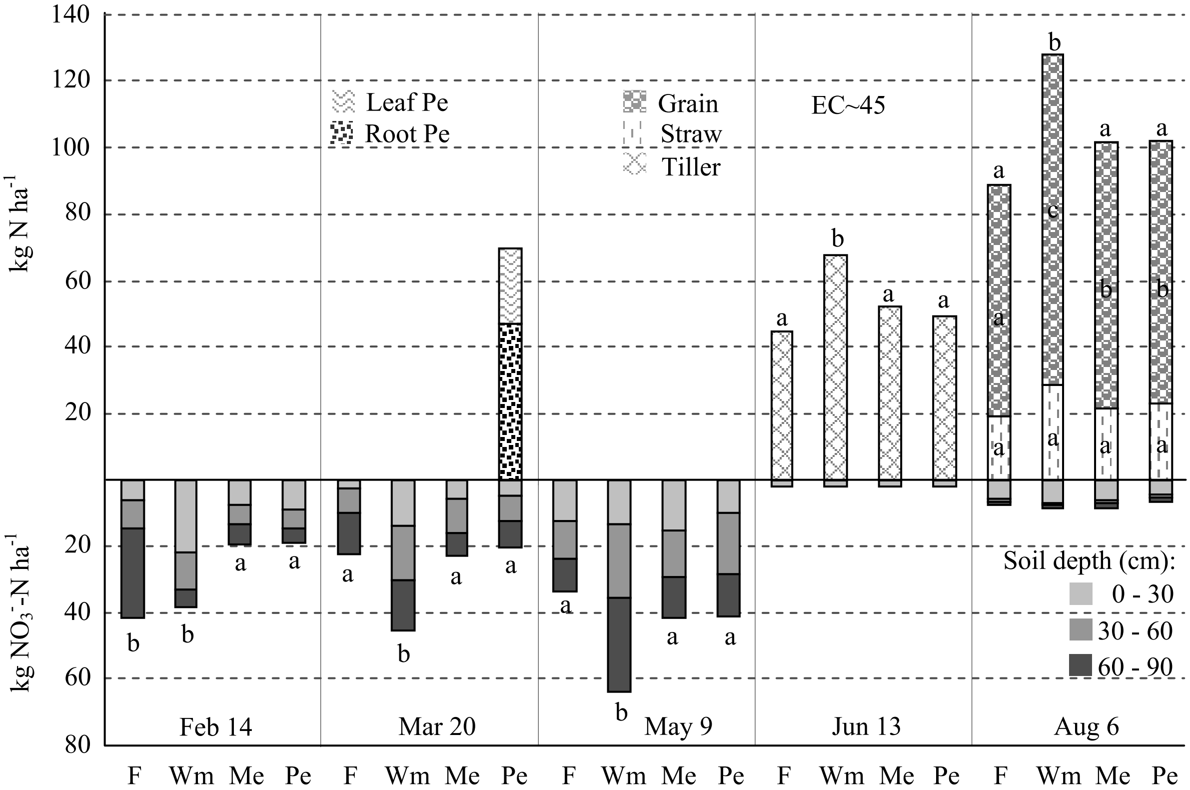

Figure 13: Effect of catch crop treatments on soil nitrate after winter and N uptake of spring wheat (2001). In 2000 precrop faba beans. **F**: fallow, **Wm**: white mustard, turnips **Me**: Market Express F1 and **Pe**: Petrowski; (Tukey; α=0.05).

Between May 9 and June 13 (Figure 13) spring wheat functioned as an effective nitrogen sink thus less than 2.0 kg NO_3^--N ha^{-1} was found in the soil layer 0 - 90 cm. At growth analysis sampling on June 12, 2001 spring wheat tillers contained 44.8, 68.0, 52.5 and 49.4 kg N ha^{-1} on F, Wm, Me and Pe plots respectively. N uptake of 68.0 kg N ha^{-1} on Wm plots was significantly higher compared to the other treatments. In this aspect N uptake of spring wheat corresponded well to the soil nitrate content determined on May 9, 2001.

After spring wheat harvest the amount of soil nitrate recorded on Aug 6 ranged between 6.7 and 8.6 kg NO_3^--N ha^{-1} without significant differences between different treatments in previous autumn (Figure 13). The significantly highest N uptake of spring wheat was found on Wm plots (128.3 kg N ha $^{-1}$) followed by the N uptake on turnip plots (102.0 kg N ha^{-1}) and F plots (89.3 kg N ha^{-1}).

5.3.3 Discussion

Soil nitrate dynamics after winter (spring wheat treatment)

When catch crops were left on the field over the winter and the soil remained untilled, the type of a catch crop significantly influenced the amount of soil nitrate in the following spring. Under both turnips, the soil nitrate status in spring did no differ considerably and remained approximately on the same level as before winter. Although the biomass of cv. Me was nearly decayed during both winters and up to 81.6 kg N ha^{-1} were stored in plant tissue of cv. Pe, this did not have a significant impact on the amount of soil nitrate in spring.

On contrary under Wm the amount of soil nitrate increased during the winter and was thus in spring significantly higher compared with soil nitrate content under both turnips. It can be thus supposed that the plant tissue of Wm left on the field was a subject of a rapid decomposition already during the winter thus releasing a substantial amount of nitrogen into the soil nitrate pool. However according to C:N ratio which was lower in turnip leaves compared with leaves of white mustard (Table 9 in Appendix) faster mineralization of turnips would be expected. It is namely generally accepted that residues with a high C:N ratio decompose more slowly (REINERTSEN et al. 1984, WAGGER 1989, VIGIL & KISSEL 1991, QUEMADA & CABRERA 1995). In the case of our study the persistency of a catch crop against frost had probably dominated the mineralization processes during the winter and spring thus non-persistent white mustard decayed faster than winter hardy turnips. Similar results were obtained by BERGER & KRETSCHMER (1991) who reported a loss of over 90 kg N ha^{-1} from Wm biomass left on the field and a corresponding increase in soil nitrate during and after the winter. Present data are also consistent with results of THORUP-KRISTENSEN (1994) who found soil mineral nitrogen content under Wm in spring of more than 80 kg ha^{-1} and more than 100 kg ha^{-1} under fodder radish, whereas the mineral nitrogen under persistent catch crops (winter rape) in spring was less than 40 kg ha^{-1}.

When the soil remained untilled the amount of soil nitrate under the fallow treatment decreased during the winter. Compared with plots that were tilled and sown with winter wheat in the autumn the amount of soil nitrate on untilled fallow plots was up to 36.9 kg NO_3^--N ha^{-1} lower. Higher soil nitrate content under winter wheat could be attributed to the additional N mineralization caused by a secondary tillage needed to create a seed bed for this crop (FRANCIS et al. 1998). By ploughing the soil organic matter is exposed to oxygen and thus the decomposition is stimulated resulting in an increased nitrogen release (GOSS et al. 1988).

Further on in the growing season no considerable differences in soil nitrate content in spring were found between both turnip cultivars and fallow treatment. These results suggest that plant residues of turnips did not largely contribute to mineralisation - immobilisation processes early in spring. Also the N export from the field between 22.2 and 59.6 kg ha^{-1} in the spring (Figures 10, 11, 12 and 13), with turnip roots of cv. Petrowski, did not largely affect the amount of soil nitrate. On the other hand Wm residues were subject to substantial decomposition. Thus the amount of soil nitrate at the beginning of May (up to 80 kg NO_3^--N ha^{-1}) was significantly higher compared to other treatments (F, Me and Pe in both years after both precrops) where 23.9 to 45.9 kg NO_3^--N ha^{-1} were recorded.

These results demonstrate that a nitrogen supply of spring wheat grown after Wm which decayed over the winter was to some extent better than after fallow and turnips. Indeed yield and N uptake of spring wheat, at the final harvest, after Wm were, in general, higher than after turnips and fallow. Because yield and N uptake of spring wheat after turnip Me were, in general, higher than after bare soil, it can be assumed that some additional N was released from turnip Me residues later in the growing season.

5.3.4 Resume

I When catch crops were left on the field over the winter the type of a catch crop influenced the amount of soil nitrate in the following spring. After turnips soil nitrate status in spring remained approximately on the same level as before winter. After Wm the amount of soil nitrate during the winter increased and after fallow soil nitrate content decreased.

II Incorporation of turnip plant residues and N export from the field with turnip roots in spring did not largely affect the soil nitrate content. On the other hand Wm residues were subject to a substantial decomposition. As a consequence the amount of soil nitrate after seed bed preparation on Wm plots increased and was thus significantly higher than after turnips or fallow.

III When catch crops were left intact on the field over the winter and were incorporated in spring at seed bed preparation increased N uptake of spring wheat was recorded in comparison with fallow treatment. The positive effect of catch crops on N uptake was in the following order Wm > Me > Pe ≥ F. Export of nitrogen with roots of turnip Pe in spring decreased N uptake of spring wheat.

5.4 Catch crop effects on following winter wheat

5.4.1 First experimental year 1999 / 2000

Precrop potatoes

In the first experimental year 1999 - 2000 DM yield of winter wheat grain and straw after potatoes did not show significant differences according to different catch crop treatments in previous autumn (Table 9). However grain and straw DM yields tended to be the highest on F plots followed by Wm, Me and Pe plots.

Nevertheless, previous cultivation had significantly influenced N_t concentration in DM and the corresponding N uptake of the following winter wheat. When grown after fallow N_t concentration in DM of grain and straw was significantly higher than after catch crop treatments.

Table 9: Yield parameters and N uptake of winter wheat following potatoes and different catch crop treatments. Harvest time August 1, 2000.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	4.80	4.16	4.00	3.97
Ears (m^{-2})	330^{b}	305^{ab}	297^{ab}	288^{a}
N_t (% DM)	1.78^{b}	1.62^{a}	1.61^{a}	1.63^{a}
$N_{upt.}$ (kg ha^{-1})	85.3^{b}	67.0^{ab}	64.5^{a}	64.8^{a}
STRAW				
DM yield (t ha^{-1})	4.39	3.68	3.64	3.51
N_t (% DM)	0.50^{b}	0.36^{a}	0.39^{a}	0.38^{a}
$N_{upt.}$ (kg ha^{-1})	21.9^{b}	13.3^{a}	14.0^{a}	13.4^{a}
TOTAL				
N upt. (kg ha^{-1})	107.1^{b}	80.3^{a}	78.5^{a}	78.2^{a}

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

As a consequence of a higher DM yield and higher N_t concentration in DM, winter wheat grown on previously fallowed plots had taken up significantly more N than after catch crops (Table 9, Figure 6). N uptake of grain and straw after fallow was 85.3 and 21.9 kg ha^{-1} respectively.

Precrop faba beans

Winter wheat sown after faba beans in the first year established so poorly (bird damage) that it was resown to spring wheat. Table 10 shows therefore spring wheat replacing failed winter wheat.

It can be seen that spring wheat developed low but very identical DM yields of grain and straw after all treatments. Nevertheless N_t concentration in grain DM of spring wheat grown after fallow was with 2.12 % significantly higher as in grain DM of spring wheat grown after catch crops. The highest N_t concentration in DM of straw was also found on F plots. With 0.65 % it was significantly higher as N_t concentration in DM of straw from Pe plots.

Table 10: Yield parameters and N uptake of winter wheat re-sown to spring wheat following faba beans and different catch crop treatments. Harvest time August 10, 2000.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	2.96	3.00	2.99	3.02
Ears (m^{-2})	422	417	407	395
N_t (% DM)	$2.12^{\mathbf{b}}$	$1.97^{\mathbf{a}}$	$1.90^{\mathbf{a}}$	$1.87^{\mathbf{a}}$
$N_{upt.}$ (kg ha^{-1})	62.8	59.0	56.7	56.4
STRAW				
DM yield (t ha^{-1})	2.06	2.03	2.11	2.16
N_t (% DM)	$0.65^{\mathbf{b}}$	$0.56^{\mathbf{ab}}$	$0.61^{\mathbf{ab}}$	$0.55^{\mathbf{a}}$
$N_{upt.}$ (kg ha^{-1})	9.6	8.7	6.8	9.3
TOTAL				
N upt. (kg ha^{-1})	72.4	67.7	63.5	65.7

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

5.4.2 Second experimental year 2000 / 2001

Precrop potatoes: first growth analysis sampling

At the first growth analysis sampling of winter wheat (May 11, 2001) no significant differences in DM yield, N_t concentration in DM and N uptake were determined. However the same tendency was observed at all three parameters with the highest values recorded on Wm plots followed by Pe, F, and Me plots (Table 11).

Table 11: Shoot dry matter yield and N uptake of winter wheat following potatoes and different catch crop treatments. First growth analysis sampling on May 11, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
SHOOT				
DM yield (t ha^{-1})	1.79	1.91	1.72	1.86
N_t (% DM)	2.03	2.16	2.02	2.08
$N_{upt.}$ (kg ha^{-1})	36.1	41.4	34.8	38.7

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Precrop faba beans: first growth analysis sampling

After faba beans DM yield of winter wheat at the first growth analysis sampling was not significantly influenced by different catch crop treatments in previous autumn. Nevertheless DM yield showed the same tendency as after potatoes with the highest yield of 1.69 t ha^{-1} on Wm plots followed by 1.59, 1.42 and 1.37 t ha^{-1} of DM on Pe, F and Me plots (Table 12).

Table 12: Shoot dry matter yield and N uptake of winter wheat following faba beans and different catch crop treatments. First growth analysis sampling on May 11, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
SHOOT				
DM yield (t ha^{-1})	1.42	1.69	1.37	1.59
N_t (% DM)	2.07$^{\mathbf{b}}$	2.11$^{\mathbf{b}}$	1.81$^{\mathbf{a}}$	1.84$^{\mathbf{a}}$
$N_{upt.}$ (kg ha^{-1})	29.5$^{\mathbf{ab}}$	36.0$^{\mathbf{b}}$	24.8$^{\mathbf{a}}$	29.4$^{\mathbf{ab}}$

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

N_t concentration in wheat DM on Wm and F plots was significantly higher than those after both turnips (Table 12). Consequently N uptake of winter wheat on Wm plots was significantly higher than after turnip Me but not significantly higher as N uptake of winter wheat on F and Pe plots..

Precrop potatoes: second growth analysis sampling

On June 7 DM yield, N_t in DM and corresponding N uptake of winter wheat grown after potatoes showed no significant differences according to different catch crop treatments (Table 13). However DM yield, N_t in DM and corresponding N uptake of winter wheat tended to be the highest on F plots. The most evident difference was observed by total N uptake where winter wheat grown on F plots took up almost 30 kg ha^{-1} more than on plots previously grown with catch crops.

Table 13: Yield parameters and N uptake of winter wheat following potatoes and different catch crop treatments. Second growth analysis sampling on June 7, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
EAR				
DM yield (t ha^{-1})	1.24	1.11	1.08	1.14
N_t (% DM)	1.59	1.52	1.54	1.54
$N_{upt.}$ (kg ha^{-1})	20.1	16.8	16.7	17.6
STEM				
DM yield (t ha^{-1})	6.52	5.96	5.46	5.71
N_t (% DM)	1.33	1.08	1.22	1.14
$N_{upt.}$ (kg ha^{-1})	90.8	64.8	67.5	64.6
TOTAL				
N upt. (kg ha^{-1})	110.8	81.6	84.2	82.2

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Precrop faba beans: second growth analysis sampling

On June 7 DM yield of winter wheat after faba beans was significantly higher on Wm plots as on turnip plots but not significantly higher as on F plots (Table 14). The same tendency was observed by N uptake. Accordingly N uptake of winter wheat grown on F and Wm plots was higher as on turnip plots.

Table 14: Yield parameters and N uptake of winter wheat following faba beans and different catch crop treatments. Second growth analysis sampling on June 7, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
EAR				
DM yield (t ha^{-1})	0.99^{bc}	1.04^{c}	0.81^{a}	0.84^{b}
N_t (% DM)	1.53	1.52	1.47	1.49
$N_{upt.}$ (kg ha^{-1})	15.1^{bc}	15.8^{c}	12.0^{a}	12.6^{ab}
STEM				
DM yield (t ha^{-1})	5.00^{ab}	5.87^{b}	4.20^{a}	4.51^{a}
N_t (% DM)	1.22	0.99	0.99	1.04
$N_{upt.}$ (kg ha^{-1})	59.7^{b}	58.7^{ab}	42.1^{a}	47.2^{ab}
TOTAL				
N upt. (kg ha^{-1})	74.9^{b}	74.5^{b}	54.0^{a}	59.7^{ab}

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Final harvest

At final harvest of winter wheat after potatoes and faba beans no significant differences in any of evaluated parameters were recorded between Wm, Me and Pe plots. On the contrary winter wheat grown on F plots after both precrops gave higher DM yields, higher N_t concentration in DM and higher N uptake. After potatoes these differences were mainly statistically significant whereas after faba beans none of the differences reached statistical significance (Table 15 and 16).

Final harvest (precrop potatoes)

After potatoes bare fallow significantly increased grain, straw and total N uptake of winter wheat compared with catch crop treatments. Thus total N uptake of winter wheat of 136.6 kg ha^{-1} was recorded on F plots. This was 22.4 - 24.2 kg N ha^{-1} more than on catch crop plots (Table 15).

Though 0.48 t ha^{-1} higher than on catch crop plots, DM yield on F plots (6.47 t ha^{-1}) failed to be statistically significant. N_t concentration in DM of grain and straw on F plots was significantly higher compared with Wm plots but not significantly higher compared with turnip plots (Table 15).

Table 15: Yield parameters and N uptake of winter wheat following potatoes and different catch crop treatments. Final harvest July 26, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	6.47	5.99	5.74	5.85
Ears (m^{-2})	486	449	427	443
N_t (% DM)	1.68$^{\mathbf{b}}$	1.53$^{\mathbf{a}}$	1.59$^{\mathbf{ab}}$	1.60$^{\mathbf{ab}}$
$N_{upt.}$ (kg ha^{-1})	109.1$^{\mathbf{b}}$	93.1$^{\mathbf{a}}$	92.5$^{\mathbf{a}}$	91.8$^{\mathbf{a}}$
STRAW				
DM yield (t ha^{-1})	6.43$^{\mathbf{b}}$	6.69$^{\mathbf{c}}$	5.88$^{\mathbf{a}}$	5.99$^{\mathbf{a}}$
N_t (% DM)	0.42$^{\mathbf{b}}$	0.31$^{\mathbf{a}}$	0.34$^{\mathbf{ab}}$	0.34$^{\mathbf{ab}}$
$N_{upt.}$ (kg ha^{-1})	27.4$^{\mathbf{b}}$	21.1$^{\mathbf{a}}$	21.5$^{\mathbf{a}}$	20.6$^{\mathbf{a}}$
TOTAL				
N upt. (kg ha^{-1})	136.6$^{\mathbf{b}}$	114.2$^{\mathbf{a}}$	114.0$^{\mathbf{a}}$	112.4$^{\mathbf{a}}$

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Final harvest (precrop faba beans)

After faba beans the highest grain DM yield of winter wheat (5.03 t ha^{-1}) was recorded on F plots (Table 16). Due to the highest DM yield and a N_t concentration in grain DM of 1.52 %, also the highest N uptake with winter wheat grain of 77.5 kg ha^{-1} was recorded on F plots.

Total N uptake of winter wheat after faba beans was 95.8, 85.2, 84.1 and 83.3 kg ha^{-1} on F, Wm, Me and Pe plots respectively. Thus N uptake on F plots was 10.6, 11.7 and 12.5 kg ha^{-1} higher than on Wm, Me and Pe plots respectively.

Table 16: Yield parameters and N uptake of winter wheat following faba beans and different catch crop treatments. Final harvest July 26, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	5.03	4.73	4.55	4.58
Ears (m^{-2})	454	401	416	440
N_t (% DM)	1.52	1.44	1.49	1.49
$N_{upt.}$ (kg ha^{-1})	77.5	69.0	68.2	67.6
STRAW				
DM yield (t ha^{-1})	5.10	5.15	4.85	4.85
N_t (% DM)	0.36	0.31	0.35	0.34
$N_{upt.}$ (kg ha^{-1})	18.3	16.2	15.9	15.7
TOTAL				
N upt. (kg ha^{-1})	95.8	85.2	84.1	83.3

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

5.4.3 Discussion

Catch crop effects on following winter wheat

In both experimental years there was a consistent evidence for a negative effect of catch crop growth and their incorporation on DM yield, N_t concentration in DM and total N uptake of a subsequent winter wheat crop. In both years winter wheat DM yield and total N uptake (grain and straw) at final harvest were the highest when soil was fallowed and no catch crop residues were incorporated at the time of sowing in autumn. However there were no significant differences between catch crops

In the field the first differentiation between winter wheat on F plots and winter wheat on plots previously cropped with catch crops were in both years visible at the end of May and the beginning of June and were expressed with a darker green colour of winter wheat grown on F plots (Table 10 in Appendix). This is in agreement with results of growth analysis sampling accomplished in the second year when winter wheat on F plots in May was not yet developing as good as on Wm plots (Tables 11 and 12) and showed its superior growth not before second sampling at the beginning of June (Tables 13 and 14).

From the present results, it can thus be concluded that winter wheat on F plots was at the end of April or beginning of May supplied with more nitrogen compared to catch crop plots. A rapid uptake of nitrogen can be achieved at this stage of crop maturity (EC 30 - EC 59) because its root system is fully developed, leaf area is big and allows larger transpiration stream (BARRACLOUGH 1986). The N uptake is faster than the DM production, therefore the concentration of nitrogen in plant tissue increases resulting in a darker green colour of wheat leaves (Table 10 in Appendix).

From figures 7 and 9, showing soil nitrate status in the second experimental year, it can be seen that under F plots in the spring (Feb 14 and Mar 20, 2001) there were substantial amounts of nitrate (20 to 40 kg NO_3^--N ha^{-1} more than under catch crop plots) in the 60 - 90 cm soil layer and that this nitrate was not any more present at soil sampling on May 9. Evidently winter wheat roots in April reached and took up efficiently the nitrate from the 60 - 90 cm soil layer. This corresponds to results of BARRACLOUGH (1986) who found winter wheat roots reaching a 100 cm depth at the end of April.

Catch crops in present study decreased grain yield of following winter wheat between 6 - 17 % compared to F and the total N uptake of winter wheat grown after catch crops was reduced up to 28.9 kg ha^{-1}. Similar results were reported by MARTINEZ & GUIRAUD (1990) who found maize and wheat yields to be 10 - 13 % lower on plots where the ryegrass had been used as a catch crop. The highest average grain yield of winter wheat after the cultivated fallow was also reported by MCEWEN et al. (1989) and OPITZ VON BOBERFELD & JASPER (1994) concluding that the main effect was due to N-supply since yields after catch crops could be compensated by mineral N-fertilisation. The reduction in winter wheat yield and N uptake were also reported in other studies (MARTINEZ & GUIRAUD 1990, JENSEN 1992) and were attributed either to extensive net N immobilisation during the decomposition of catch crop residues or to pre-emptive competition (THORUP-KRISTENSEN 1993) both resulting in a temporary N deficiency in the following winter wheat crop.

However decrease in total DM yield and corresponding N uptake of winter wheat were not influenced by N export of 33.8 - 52.5 kg N ha^{-1} from the field with turnip roots in autumn because there were no significant differences after all three catch crops.

Plant density at final harvest in both years after potatoes and faba beans (Tables 9, 15 and 16) suggest that lower DM yield of winter wheat on catch crop plots (Wm, Me and Pe) was to a certain extent caused by less ears per m^2. These results correspond well with findings of

OLESZEK (1987), BIALY et al. (1990) and VAUGHN & BOYDSTON (1997), who reported substantial reduction of wheat germination caused by allelochemicals released from decaying brassica green manure. They all explain toxic effects with the presence of glucosinolates and their toxic hydrolytic break-down products. KUTACEK (1964) demonstrated that extracts of various brassica vegetables inhibited the growth of wheat. A similar effect was observed with isolated 3-indolylmethyl glucosinolate. After the catch crop incorporation it is likely that some toxic (allelophatic) substances appear and their break-down products are released from the decaying plant material influencing soil micro-organisms and growing plants (BROWN et al. 1991, SHEPHERD 1999, PETERSEN 1999).

5.4.4 Resume

I A decrease in grain DM yield of winter wheat between 6 - 17 % were recorded when Wm, Me and Pe catch crops were grown between potato – winter wheat or faba bean – winter wheat cropping sequence.

II Compared to bare fallow catch crops reduced grain and straw N_t concentration in DM and corresponding N uptake of following winter wheat.

III There were no differences between catch crops according to the yield of following winter wheat. N export from the field with turnip roots and incorporation of various residues with different amounts of residue N in autumn did not affect DM yield, N_t concentration in DM and corresponding N uptake of winter wheat. This indicates that nitrogen taken up by catch crops did not have a significant role in nitrogen nutrition of subsequent winter wheat crop.

5.5 Catch crop effects on following spring wheat

5.5.1 First experimental year 1999 / 2000

Precrop potatoes

In the first experimental year 1999 - 2000 spring wheat after potatoes did not show significant differences according to different catch crop treatment in previous autumn (Table 17). The exception was just the total N uptake on Wm plots which was significantly higher compared to Pe plots.

Though differences were not significant there was a clear tendency by all observed parameters. The highest values for DM yield, N_t concentration in DM and N uptake were always determined for spring wheat on Wm plots followed usually by spring wheat grown on Me, F and Pe plots (Table 17).

Grain DM yield ranged between 1.78 and 2.07 t ha^{-1} with N_t concentration in DM of 2.02 - 2.20 %. Straw DM yield was between 3.37 t ha^{-1} on Pe and 3.84 t ha^{-1} on Wm plots with N_t concentration in DM between 0.64 and 0.77 % (Table 17). The highest total N uptake of spring wheat (75.3 kg N ha^{-1}) was determined on Wm plots.

Table 17: Yield parameters and N uptake of spring wheat following potatoes and different catch crop treatments. Harvest time August 10, 2000.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	1.78	2.07	2.00	1.81
Ears (m^{-2})	303	317	313	368
N_t (% DM)	2.11	2.20	2.02	2.06
$N_{upt.}$ (kg ha^{-1})	37.3	45.5	40.3	37.1
STRAW				
DM yield (t ha^{-1})	3.65	3.84	3.84	3.37
N_t (% DM)	0.71	0.77	0.65	0.64
$N_{upt.}$ (kg ha^{-1})	26.0	29.8	24.7	21.5
TOTAL				
N upt. (kg ha^{-1})	63.3$^{\mathbf{ab}}$	75.3$^{\mathbf{b}}$	65.0$^{\mathbf{ab}}$	58.6$^{\mathbf{a}}$

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Precrop faba beans

In the first year after faba beans spring wheat grown on Wm, Me and Pe plots showed no significant differences in any of evaluated parameters (Table 18). However the lowest values for DM yield, N_t concentration in DM and N uptake were determined on Pe plots. On the other hand spring wheat grown on F plots had significantly lower grain and straw DM yield compared with spring wheat on Me plots.

Grain and straw DM yields of spring wheat with corresponding N uptake on Wm and Me plots were higher then on F and Pe plots. Consequently total N uptake of spring wheat was 97.5 and 94.4 kg ha^{-1} on Wm and Me plots and 81.9 and 79.4 kg ha^{-1} on F and Pe plots respectively (Table 18).

Table 18: Yield parameters and N uptake of spring wheat following faba beans and different catch crop treatments. Harvest time August 10, 2000.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	2.65^{a}	3.26^{ab}	3.41^{b}	2.83^{ab}
Ears (m^{-2})	401	407	373	347
N_t (% DM)	2.01	2.02	1.88	1.89
$N_{upt.}$ (kg ha^{-1})	53.4	66.0	64.0	53.3
STRAW				
DM yield (t ha^{-1})	4.39^{a}	5.37^{ab}	5.60^{b}	4.89^{ab}
N_t (% DM)	0.65^{b}	0.59^{ab}	0.54^{a}	0.53^{a}
$N_{upt.}$ (kg ha^{-1})	28.6	31.5	30.4	26.1
TOTAL				
N upt. (kg ha^{-1})	81.9	97.5	94.4	79.4

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

5.5.2 Second experimental year 2000 / 2001

At growth analysis sampling on June 12 in the second experimental year spring wheat DM yield, N_t in DM and corresponding N uptake were the highest after Wm (Tables 19 and 20).

Table 19: Shoot dry matter yield and N uptake of spring wheat following potatoes and different catch crop treatments. Growth analysis sampling on June 12, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
SHOOT				
DM yield (t ha^{-1})	3.10	3.70	3.25	3.67
N_t (% DM)	1.94	2.34	2.00	2.11
$N_{upt.}$ (kg ha^{-1})	59.7	86.8	64.8	77.5

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

After potatoes spring wheat showed no significant differences according to different catch crop treatments in previous autumn. Anyway there was an obvious tendency by all observed parameters. The highest DM yield, N_t concentration in DM and N uptake were recorded by spring wheat grown on Wm plots, followed by spring wheat on Pe, Me and F plots (Table 19).

Table 20: Shoot dry matter yield and N uptake of spring wheat following faba beans and different catch crop treatments. Growth analysis sampling on June 12, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
SHOOT				
DM yield (t ha^{-1})	2.53^{a}	3.16^{b}	2.89^{ab}	2.70^{a}
N_t (% DM)	1.77^{a}	2.14^{b}	1.82^{ab}	1.82^{a}
$N_{upt.}$ (kg ha^{-1})	44.8^{a}	68.0^{b}	52.5^{a}	49.4^{a}

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

At growth analysis sampling on June 12, 2001 after faba beans DM accumulation, N_t concentration in DM and N uptake of spring wheat were significantly influlenced by different treatments in previous autumn (Table 20). The highest values of DM accumulation, N_t concentration in DM and N uptake were determined after Wm. They were significantly higher as after F and Pe. N uptake of spring wheat after Wm was significantly higher also from N uptake after Me.

Further in the growing season, spring wheat on Wm plots showed vigorous growth, thus at the final harvest it was superior in all recorded parameters (Tables 21 and 22). The only exceptions were N_t concentration in straw and corresponding N uptake after potatoes, which were higher on F and Me, plots.

At final harvest in the second year (2001) spring wheat grown after potatoes showed in general the same tendency as in the first year (Table 21). The highest DM yield, N_t concentration in DM and N uptake were determined on Wm plots followed by spring wheat on Me and Pe plots. With exception of grain N uptake and total N uptake which were significantly lower on Pe plots compared with Wm plots all other differences between Wm, Me and Pe were not statistically significant.

The lowest grain DM yield, corresponding N uptake and total N uptake were determined on F plots. Compared with spring wheat on Wm and Me plots these differences were statistically significant (Table 21).

Table 21: Yield parameters and N uptake of spring wheat following potatoes and different catch crop treatments. Harvest time August 2, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	3.98^{a}	5.36^{b}	4.94^{ab}	4.57^{ab}
Ears (m^{-2})	429	508	475	500
N_t (% DM)	1.92	2.00	1.87	1.90
$N_{upt.}$ (kg ha^{-1})	74.0^{a}	107.9^{c}	92.8^{bc}	88.1^{ab}
STRAW				
DM yield (t ha^{-1})	4.61	6.17	5.89	5.46
N_t (% DM)	0.55^{b}	0.52^{ab}	0.50^{ab}	0.44^{a}
$N_{upt.}$ (kg ha^{-1})	25.3	31.0	32.1	25.1
TOTAL				
N upt. (kg ha^{-1})	99.3^{a}	138.9^{c}	124.8^{bc}	113.2^{ab}

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

Catch crop cultivation in previous autumn significantly influenced growth of spring wheat also after faba beans (Table 22). DM yield and N uptake of spring wheat were generally significantly higher on catch crop plots compared with spring wheat on F plots. There were no differences in spring wheat growth on both turnip plots. On the other hand spring wheat grown on Wm plots gave significantly higher DM yields and took up significantly more N as spring wheat on Me, Pe and F plots (Table 22).

Table 22: Yield parameters and N uptake of spring wheat following faba beans and different catch crop treatments. Harvest time August 2, 2001.

Treatment	Fallow	W. mustard	M. Express	Petrowski
GRAIN				
DM yield (t ha^{-1})	3.85$^{\mathbf{a}}$	5.45$^{\mathbf{c}}$	4.55$^{\mathbf{b}}$	4.49$^{\mathbf{b}}$
Ears (m^{-2})	531	509	477	476
N_t (% DM)	1.81	1.85	1.73	1.73
$N_{upt.}$ (kg ha^{-1})	70.1$^{\mathbf{a}}$	99.8$^{\mathbf{c}}$	80.3$^{\mathbf{b}}$	78.9$^{\mathbf{b}}$
STRAW				
DM yield (t ha^{-1})	4.25$^{\mathbf{a}}$	5.99$^{\mathbf{c}}$	4.92$^{\mathbf{b}}$	4.92$^{\mathbf{b}}$
N_t (% DM)	0.45	0.46	0.40	0.43
$N_{upt.}$ (kg ha^{-1})	19.2	28.6	21.7	23.3
TOTAL				
N upt. (kg ha^{-1})	89.3$^{\mathbf{a}}$	128.3$^{\mathbf{b}}$	102.0$^{\mathbf{a}}$	102.2$^{\mathbf{a}}$

Values within a row are significantly different (Tukey; α=0.05) if followed by different letters.

5.5.3 Discussion

Catch crop effects on following spring wheat

An increase in DM yield and N uptake compared to fallowed soil was observed when catch crops were left intact on the field over the winter and incorporated in spring at seed bed preparation for spring wheat. At spring incorporation of catch crops N transformation processes were significantly affected also by the type of a catch crop. Compared with fallow treatment, the positive precrop effect of catch crops ranked as follows: Wm > Me > Pe ≥ F.

The export of nitrogen with roots of turnip Pe in spring between 22.2 and 59.6 kg ha^{-1} decreased DM grain yield between 1 - 17 % in comparison with grain yield of spring wheat after Wm and Me and the total N uptake of spring wheat was decreased up to 26.1 kg ha^{-1}. This indicates that when incorporated in spring catch crops influenced the nitrogen supply of subsequent spring wheat and that N export of 22 kg ha^{-1} with roots of turnip Pe generally caused a significant reduction in total N uptake of succeeding spring wheat compared with N uptake on Wm plots (Figures 10, 11, 12 and 13).

Differences between spring wheat DM yield grown after fallow or after catch crops in the present study coincide well with results reported by JUSTUS & KÖPKE (1995) who reported spring cereals following faba beans, undersown with brassicas or brassicas used as catch crops, to yield up to 1 t ha^{-1} more than without catch crops. Similar results were reported also by THORUP-KRISTENSEN (1994) who found the total DM yield of spring barley following brassica catch crops even 2.1 to 4.3 t ha^{-1} higher than after bare soil. However catch crops caused significant yield reduction in the following spring-sown cereal crop in experiments of FRANCIS et al. (1998) who attributed this reduction to extensive N immobilisation during the decomposition of catch crop residues resulting in temporary N deficiency in the following cereal crop. Reduced grain yield and total N uptake of spring wheat after white mustard compared to spring wheat after fallow was reported also by REENTS et al. (1997).

The effect of catch crops compared to fallowed soil on the nitrogen uptake of succeeding spring wheat in this research varied from -4.7 to 39.6 kg N ha^{-1}. It was mainly related to the amount of assimilated N in the previous autumn, to a winter hardiness of the catch crop, its management (root export) and the extent of soil nitrogen pool in spring.

5.5.4 Resume

I An increase in DM yield and N uptake compared to fallowed soil was observed when catch crops were left intact on the field over the winter and incorporated in spring at seed bed preparation.

II Compared with fallow treatment, the positive precrop effect of catch crops ranked as follows: Wm > Me > Pe ≥ F.

III Nitrogen export from the field with roots had a negative influence on growth of following spring wheat.

5.6 Chemical composition and alimentary value of turnips

5.6.1 Dry matter content

Within all trials the DM content of turnip leaves varied from 6.6 to 9.5 % for Me and between 7.5 and 12.0 % for Pe. DM content of Pe leaves was in both years after both precrops higher compared with Me (Table24).

Table 23: Root and leaf DM content of turnips.

Year		1999		2000	
Previous crop		Potatoes	Faba beans	Potatoes	Faba beans
		DM (%)			
Market Express F1	Root	3.6	3.7	3.7	4.8
	Leaf	9.5	8.1	6.6	9.0
Petrowski	Root	8.1	8.3	6.4	8.4
	Leaf	12.0	10.4	7.5	10.5
White mustard	Shoot	21.6	15.9	11.6	12.3

The DM content of roots ranged from 3.6 to 4.8 % for Me and from 6.4 to 8.4 % for Pe. In both years, after both precrops, DM content of leaves of cultivar Pe was higher than the one of Me. Within the same year and precrop treatment the proportion in root DM concentration and leaf DM content of both cultivars remained constant.

The DM content in shoots of Wm was always higher than in turnip leaves. In the first year the difference in Wm DM content after potatoes and faba beans was nearly 6 %. However in the second year DM content was approximately the same after both precrops.

5.6.2 Mineral content

Mineral content in DM of turnip roots ranged in both years for P between 0.404 - 0.637 %, for K between 2.157 - 5.920 %, for S between 0.560 - 0.845 %, for Mg between 0.143 - 0.265 % and for Ca between 0.608 - 2.329 %. These results correspond with the previously reported data (see Tab. 11 in Appendix).

Table 24: Mineral content of turnip roots (DM basis).

Year	1999				2000			
Previous crop	Potatoes		Faba beans		Potatoes		Faba beans	
Cultivar	Me	Pe	Me	Pe	Me	Pe	Me	Pe
Mineral	% DM							
P	0.524	0.416	0.485	0.416	0.637	0.510	0.424	0.404
K	4.434	2.157	5.133	2.557	5.920	3.566	4.216	2.608
S	0.772	0.845	0.633	0.641	0.560	0.757	0.584	0.599
Mg	0.264	0.245	0.196	0.181	0.265	0.211	0.167	0.143
Ca	1.568	2.329	1.333	1.460	1.033	0.814	0.684	0.608

According to Table 24 the content of P in DM of turnip roots showed no characteristic tendency with respect to precrop or cultivar. However, K content in DM of Me roots was 1.608 to 2.576 % higher than K content in DM of Pe roots. In contrast, S content was always higher in Pe roots. Mg and Ca contents were more influenced by the precrop as by the cultivar because they were, in both years, for both cultivars considerably higher after potatoes.

5.6.3 Nitrate concentration

According to Table 25, the nitrate concentration in fresh turnip roots of cv. Me in the year 1999 was 157 and 234 mg kg^{-1} FM after potatoes and faba beans respectively. The nitrate concentration in Pe roots was lower compared to the concentration in Me roots and was amounting 143 mg kg^{-1} FM after both precrops.

In second experimental year (2000) the nitrate concentration in fresh turnip roots was substantially higher than in the first year (1999). Nitrate in Me roots was for 138 and 74 mg kg^{-1} FM higher than in the first year after potatoes and faba beans respectively. In Pe roots the nitrate concentration after potatoes and faba beans increased for 217 and 99 mg kg^{-1} FM respectively compared to the first year. The highest nitrate concentration in turnip roots (360 mg kg^{-1} FM) was determined in Pe roots after potatoes in the second year.

Table 25: Nitrate concentration in fresh turnip roots.

Year	1999		2000	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans
	mg kg^{-1} FM			
Market Express F1	157	234	295	308
Petrowski	143	143	360	242

In Table 26 nitrate concentrations in turnip roots are defined as the proportion of NO_3^-- N in DM. These data show that NO_3^-- N concentration in DM of roots in both years after both precrops was higher for Me.

Table 26: Proportion of NO_3^-- N in DM of turnip roots.

Year	1999		2000	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans
	% DM			
Market Express F1	0.099	0.143	0.180	0.145
Petrowski	0.040	0.039	0.127	0.065

5.6.4 Ascorbic acid

As shown in Table 27 fresh roots of cv. Pe in both years contained more ascorbic acid than roots of cv. Me. Ascorbic acid concentration in fresh roots of turnip cultivar Pe in the first year was 35.7 mg 100^{-1} g^{-1} FM and was thus twice as high as the amount of ascorbic acid present in Me roots.

Table 27: Ascorbic acid concentration in turnip roots (fresh weight).

Year	1999		2000	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans
	mg 100^{-1}g^{-1} FM			
Market Express F1	-	17.3	22.2	22.6
Petrowski	-	35.7	27.2	28.1

In the second year this difference was smaller since ascorbic acid concentration in Me roots was 22.2 and 22.6 mg 100^{-1} g^{-1} FM after potatoes and faba beans respectively thus only for 5.0 and 5.5 mg 100^{-1} g^{-1} FM lower than in Pe roots.

5.6.5 Glucosinolates (GSLs) in turnip roots

In both years higher concentration of total GSLs were found in Pe roots than in Me roots. It ranged between 11.4 and 15.2 µmol g^{-1} (Table 28). The concentration of total GSLs in Me roots ranged between 7.9 and 10.9 µmol g^{-1}.

Major GSLs in turnip roots in this research were progoitrin, gluconapin and glucobrassicin. A considerable difference between total GSL concentration and GSL profile of both turnip cultivars was found.

Table 28: Total glucosinolate concentration of turnip roots (DM basis).

Year	1999		2000	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans
	µmol g^{-1}			
Market Express F1	10.9	7.9	8.4	9.1
Petrowski	15.2	12.6	12.5	11.4

Detailed glucosinolate composition is summarised in Table 29. It is evident that the content of cv. Me was very low i.e. < 0.1 µmol g^{-1} in both progoitrin and gluconapoleiferin. In contrast cv. Pe showed high progoitrin (2.5 - 3.6 µmol g^{-1}) and a moderate gluconapoleiferin (0.2 - 0.4 µmol g^{-1}) concentrations.

In roots of cv. Me gluconapin and glucobrassicin concentrations in both years ranged between 1.4 - 2.2 µmol g^{-1} and 1.1 - 2.2 µmol g^{-1} respectively. Thus they were prevalent GSLs in roots of cv. Me. Gluconapin and glucobrassicin were present in high concentration also in roots of cv. Pe. Gluconapin concentration in Pe roots ranged between 1.8 and 4.9 µmol g^{-1}. Concentration of glucobrassicin in Pe roots was lower, ranging between 0.8 and 1.1 µmol g^{-1}. The concentration of 4-Hydroxy-glucobrassicin and glucobrassicanapin in both turnip roots varied between 0.1 and

0.7 µmol g^{-1}. The concentration of both GSLs was for 0.1 to 0.3 µmol g^{-1} higher in Pe roots than in Me roots.

Table 29: Individual glucosinolate profile (DM basis) of turnip roots Market Express F1 (Me) and Petrowski (Pe).

Year	1999				2000			
Previous crop	Potatoes		Faba beans		Potatoes		Faba beans	
Cultivar	Me	Pe	Me	Pe	Me	Pe	Me	Pe
	µmol g^{-1}							
Progoitrin 2-hydroxy-3-butenyl	< 0.1	2.5	< 0.1	3.2	< 0.1	3.6	< 0.1	2.5
Gluconapoleiferin 2-hydroxy-4-pentenyl	< 0.1	0.4	< 0.1	0.2	< 0.1	0.3	0.1	0.2
Gluconapin 3-butenyl	2.2	1.8	1.7	1.8	2.2	4.9	1.4	2.2
4-Hydroxy-glucobrassicin 4-hydroxy-3-indolylmethyl	0.2	0.5	0.2	0.3	0.5	0.7	0.3	0.5
Glucobrassicin 3-indolylmethyl	2.2	0.8	1.2	0.7	1.5	1.1	1.1	1.1
Glucobrassicanapin 4-pentenyl	0.4	0.6	0.1	0.3	0.3	0.6	0.1	0.4

5.6.6 Discussion

Turnips as vegetables

As a member of botanical family *Brassicaceae* turnips can contain large quantities of glucosinolates (MULLIN et al. 1980). They are important in view of food quality and human health since upon hydrolysis toxic substances are released (CARLSON et al. 1981).

The results for total glucosinolate (GSL) concentration in turnip roots reported in this study fall within the range reported earlier (CARLSON et al. 1981, CARLSON et al. 1987, SHATTUCK et al. 1991). However turnip Me was very low in both progoitrin and gluconapoleiferin, which are major GSLs found in most turnips (FENWICK et al. 1983, SHATTUCK et al. 1991). This is a typical characteristic of cultivars, grown for human consumption, originating from Japan (CARLSON et al. 1981, CHONG et al. 1982).

Over all experiments in present study, glucosinolate concentration was higher in roots of turnip Pe than in Me. The characteristic pungent odour and biting taste of turnip roots, which is associated with the breakdown products of glucosinolates (FENWICK et al. 1983), was also more dominant in turnip Pe than in Me. This corresponds with DM and sulphur concentration and the total amount of glucosinolates, which are precursors of flavour and odour (MULLIN et al. 1980, FENWICK et al. 1983, PINTO et al. 1998).

Total GSL concentration and the profile of GSLs in roots of both cultivars were relatively stable showing no particular difference between both years. These results lead to the conclusion that glucosinolate concentrations are much less affected by N supply than, for example, DM yield. Similar results were obtained also by GUSTINE & JUNG (1985) who found no change in GSL concentration at fertiliser N rate of 132 kg ha^{-1}, though DM yield was threefold higher.

Another antinutritive factor of turnips could be an excessive accumulation of nitrate since brassica species are frequently mentioned as NO_3^--N accumulators (MAYNARD et al. 1976, GUILLARD & ALLINSON 1989a). It is known that the consumption of vegetables with high nitrate can be potentially dangerous to consumer's health (WOLFF & WASSERMAN 1972), which is due to the potential for nitrate reduction to nitrite and its adverse effect on human health. Therefore, the European Commission's Scientific Committee for Food considered the implications for human health of nitrate in food in 1995 and set an Acceptable Daily Intake (ADI) for the nitrate ion of 3.65 mg/kg body weight (equivalent to 219 mg/day for a 60 kg person) (EEC 1995). In addition maximum nitrate values of 3000 mg NO_3^- kg^{-1} fresh weight for spinach, radish, little radish and red beet and 4500 mg NO_3^- kg^{-1} for lettuce were determined (EEC 1999).

In present research the nitrate concentration in fresh turnip roots ranged between 143 and 360 mg kg^{-1}. In the second experimental year considerably higher nitrate concentration in turnip roots was found. This was a consequence of higher soil nitrate N content that closely correlates with the nitrogen supply of crops (GRIFFITH & JOHNSTON 1961 and MAYNARD et al. 1976). With consideration of results of GUILLARD & ALLINSON (1988, 1989a), who found turnip root concentrations between 64 to 6440 mg NO_3^- kg^{-1} in fresh tissue at fertiliser N rate of 0 and 168 kg ha^{-1} respectively, it can be concluded that turnips grown without fertiliser N do not store higher amounts of nitrate in their root.

Although turnips in this research were grown late in autumn at lower temperatures and decreased light intensity that could encourage higher NO_3^- accumulation (MAYNARD et al. 1976) this was not observed. The critical concentration for N_t of 2.9 % in the whole crop given by GUILLARD et al. (1995) as a value upon which nitrate concentration in turnips raise rapidly was exceeded in both experimental years. Nevertheless no hazardous nitrate concentration in turnip roots was found in present research. These results support the general belief that nitrate concentration in organically grown vegetables is usually much lower than conventional ones (SAMWEL 1995).

The ascorbic acid values for fresh turnip roots found in the present study were consistent with the concentration 25 mg $100^{-1}g^{-1}$ reported by SHATTUCK et al. (1991). In comparison with potatoes grown on the same experimental site (NEUHOFF 2000), turnips showed up to 5 fold higher content of vitamin C. Compared with concentration of ascorbic acid in other brassica vegetables given by BAYERISCHE LANDESANSTALT FÜR ERNÄHRUNG (2001) ranging between 12 (white cabbage – *Brassica oleracea* convar. *capitata* var. *alba*) and 64 mg $100^{-1}g^{-1}$ (kohlrabi – *Brassica oleracea* var. *gongylodes*) both turnip cultivars can be ranked in the middle of the group together with little radish – *Raphanus sativus* var. *radicula* (29 mg $100^{-1}g^{-1}$).

From the above results it can be concluded that the possible antinutritive factors, i.e. nitrate and glucosinolate concentration, in turnip roots did not reach values which could be potentially dangerous for consumers health. Moreover concentrations of glucosinolates found in turnip roots have according to UHL et al. (2001) even beneficial effects on human health. With low nitrate concentrations, organically grown turnip roots could even have a status of dietetic food (less than 250 mg NO_3^- kg^{-1}). High vitamin C concentration in comparison with other vegetables and concentration of sugars in DM of about 50 % (SHATTUCK et al. 1991) could give turnips an important place in human nutrition. Also concentrations of P, K, S, Mg and Ca in turnip roots do not compromise their nutritive qualities.

5.6.7 Resume

I In present research the concentration of possible antinutritive factors, i.e. nitrate and glucosinolate in turnip roots did not reach values which could be potentially dangerous for consumer's health.

II High vitamin C concentration in comparison with other vegetables could give turnips an important place in human nutrition.

III Concentrations of P, K, S, Mg and Ca in turnip roots do not compromise their nutritive qualities.

6 DISCUSSION AND CONCLUSIONS

Hypothesis 1: *Compared with bare soil nitrogen uptake of turnips reduces soil nitrate concentration significantly.*

Post-harvest management treatments imposed in this study affected the amount of soil nitrate in both years. Turnips, sown after the harvest of the main crop potatoes and faba beans, significantly decreased soil nitrate concentration compared with leaving the land fallow. As a result, the accumulation of nitrate in deeper soil layers or even leaching below 90 cm soil depth was diminished. Under fallow treatment, the amount of soil nitrate increased and a large amount of it was already present in deeper soil layers at the beginning of winter discharge. **Thus the first hypothesis was confirmed.**

Hypothesis 2: *Nitrogen sink capacity of turnips corresponds with the nitrogen sink capacity of white mustard commonly used as a catch crop.*

In the first experimental year (1999) the amount of soil nitrate ranged between 21.7 and 25.4 kg NO_3^--N ha^{-1} after potatoes and between 30.7 and 36.3 kg NO_3^--N ha^{-1} after faba beans. One hundred days after sowing nitrogen sink potential of turnips was ranking between 57.1 and 77.3 kg N ha^{-1} showing no significant differences to the one of white mustard (73.2 - 74.2 kg N ha^{-1}). Consequently the average reduction of soil nitrate under all three catch crops showed no significant differences

At the higher soil nitrate content (over 120 kg NO_3^--N ha^{-1} after potatoes and over 66.0 kg NO_3^--N ha^{-1} after faba beans) measured in the second experimental year (2000) turnips took up less N compared to the white mustard. N sink potential of catch crops was ranked as follows: Wm > Pe > Me ≥. The differences in N sink potential between catch crops were at higher soil nitrate content after potatoes significant. As a consequence turnips reduced soil nitrate significantly slower and less efficient as white mustard.

It can thus be expected that the nitrogen sink capacity of turnips, grown as vegetables, will be equal to the one of white mustard as long as soil nitrate content do not exceed 60 kg NO_3^--N ha^{-1}. The soil nitrate content under turnips will be thus reduced as well as under white mustard. On the other hand at soil nitrate contents higher than 60 kg NO_3^--N ha^{-1} lower N uptake of turnips compared to the one of white mustard can be expected. As a consequence the reduction of soil nitrate under turnips, grown as vegetables, is expected to be significantly lower compared to the one under white mustard. **The second hypothesis was thus only partly confirmed.**

Hypothesis 3: *In a short growing season after the harvest of potatoes and faba beans turnips can accumulate considerable amounts of dry matter in marketable roots.*

In 100 days turnips grown as vegetables produced between 1.76 and 2.98 t ha^{-1} of dry matter with corresponding N uptake of 57.1 and 119.5 kg ha^{-1} after potatoes and between 2.26 and 3.61 t ha^{-1} of dry matter with corresponding N uptake of 74.0 and 116.4 kg ha^{-1} after faba beans.

Turnip roots of cv. Market Express represented 53 to 65 % (1.13 - 1.66 t ha^{-1}) of total dry matter thus containing between 43 and 60 % (33.8 - 52.5 kg N ha^{-1}) of all accumulated nitrogen. Roots of cv. Petrowski contained 40 to 63 % (1.16 - 1.52 t ha^{-1}) of total dry matter containing between 32 and 53 % (35.9 - 45.0 kg N ha^{-1}) of accumulated nitrogen.

It should also be emphasised that besides nitrogen export which was the main subject of this research, also the export of P, K, S, Mg and Ca with turnip roots that can reach up to 10.5, 98.3, 15.0, 4.4 and 38.7 kg ha^{-1} respectively should be considered in the whole farm mineral balance if turnips are to become a regular constituent of crop rotation.

It was shown in the present study that organically grown turnips are an effective scavenger of soil nitrate and exhibit a good potential for DM production and N uptake late in autumn. **The third hypothesis was thus confirmed.**

Hypothesis 4: Positive precrop effect of potatoes and faba beans on yields of following winter or spring wheat respectively is not reduced by growing turnip vegetables and subsequent nitrogen export from the field with marketable roots.

Winter wheat

Present study showed that a 6 - 17 % decrease in grain DM yield of winter wheat can be expected when brassica catch crops are grown between potato – winter wheat or faba bean – winter wheat cropping sequence and the reduction of total N uptake of winter wheat can reach 28.9 kg ha^{-1}. However decrease in DM yield and corresponding N uptake were not higher when 33.8 - 52.5 kg N ha^{-1} were exported in autumn with turnip roots. This indicates that nitrogen taken up by catch crops did not have a significant role in nitrogen nutrition of subsequent winter wheat crop. This corresponds with findings of MERBACH et al. (1996) who reported that maize used efficiently only 30 % of nitrogen originating from mulched bird rape covering that way 11% of its needs. These authors also found that 65 % of catch crop N were still present in the soil at the time of maize harvest. NINANE et al. (1996) reported N recovery from mustard to be 25 to 39 % by succeeding sugar beet and at the time of sugar beet harvest between 43 to 61 % of mustard N was still present in soil. About 20 % of the catch crop N incorporated was recovered in the first following crop in studies of JENSEN (1992).

All these examples indicate a relatively low efficiency of N utilisation from catch crop residues by the succeeding crop. This way it could be suggested that in the present study the value of catch crops incorporated in autumn appears to be long term maintenance of soil N status rather than the short term supply of available N for winter wheat growth.

Spring wheat

Increase in DM yield and N uptake compared to fallowed soil was recorded when catch crops were left intact on the field over the winter and incorporated in spring at seed bed preparation for spring wheat. Total N uptake of spring wheat was up to 39.6 kg ha^{-1} higher after spring incorporation of catch crop residues than after fallowed soil. Compared with fallow treatment, the positive precrop effect of catch crops was in the following order Wm > Me > Pe ≥ F. Export of nitrogen with roots of turnip Pe in spring (between 22.2 and 59.6 kg ha^{-1}) decreased DM yield of spring wheat and corresponding N uptake up to 26.1 kg ha^{-1}. This indicates that nitrogen release from catch crop residues incorporated in spring had a direct positive influence on DM yield and N uptake of succeeding spring wheat.

In the present study catch crop growth and residue incorporation in autumn reduced yield of following winter wheat compared with fallow treatment. On the other hand catch crops incorporated in spring had a positive precrop effect on following spring wheat compared with fallow. Nitrogen export from the field with marketable roots in the autumn did not influence succeeding winter wheat whereas nitrogen export with turnip roots in spring had a negative influence on growth of following spring wheat. **The fourth hypothesis was thus partly confirmed.**

Recommendations and relevance for the practical farming

Integrating turnips in arable crop rotation provides a good opportunity for farmers to generate additional income after the harvest of the main crop and at the same time to maintain the practice of growing a catch crop to reduce soil nitrate before winter leaching period. An export over 50 kg N ha^{-1} can be achieved when turnip roots are sold. Therewith the soil nitrogen pool and consequently the risk of leaching are diminished. For management systems which steadily increase the amount of soil organic matter (long term application of organic manure, crop rotation with high amounts of harvest residues) this is of great importance.

The present results show that a reduction of the winter wheat yield can be expected when turnips are included in potato – winter wheat or faba bean – winter wheat cropping sequence. The reduction of the winter wheat yield (6.0 t ha^{-1}) for 15 % (0.9 t ha^{-1}) corresponds to an income loss of 207 €/ha (see table 14 in Appendix). On the other hand the additional income achievable with the sale of turnip roots can exceed 10.000 €/ha (see table 15 in Appendix). The reduction of the winter wheat yield is therefore negligible from the economical point of view. To cover the production costs of turnips per hectare and to compensate the reduction of winter wheat yield not more than 5.3 t of fresh turnip roots must be sold at a price of 0.6 €/kg (see table 13, 14 and 15 in Appendix).

When grown for human consumption the selection of the turnip cultivar plays an important role. In present research two different cultivars were used: Market Express F1, a hybrid cultivar with a white root and very mild taste, and cultivar Petrowsky which is known for its yellow root with a strong taste. Though both cultivars produced approximately the same amount of root DM (1.13 – 1.66 t ha^{-1}) FM yields were essentially different due to their different DM content. Cultivar Market Express F1 yielded between 31.4 and 37.3 t ha^{-1} which is twice as much as cv. Petrowsky with 14.3 to 18.4 t ha^{-1} of FM. Thus higher income from turnip roots of cultivar Market Express F1 can be expected.

Because turnips are not well known as vegetables larger amount of roots might be difficult to sell. Therefore it is noteworthy that first marketable turnip roots can be harvested and sold already 8 weeks after sowing with a possibility to prolong harvest over winter months thus supplying the market for a longer period with smaller amounts of roots. Following this practice turnip cultivar should be carefully selected because roots of some cultivars do not endure temperatures below 0°C and decay soon after first frost. To reach high yields of roots late in the growing season the length of the growing period is crucial. Therefore turnips have to be sown as soon as possible after the harvest of the main crop.

Because the market acceptance for turnip roots might be problematic some alternative brassica vegetables were considered to be integrated into field crop rotation. Savoy cabbage, curly kale and kohlrabi showed a high nitrogen sink potential (151, 154 and 62 kg N ha^{-1}) thus significantly reducing the concentration of soil nitrate before winter compared to the fallow treatment.

When turnips stay on the field over the winter they function well as a catch crop and can be incorporated in the following spring at seed bed preparation for the succeeding crop. In that case turnips conserve ground water even better than white mustard because soil nitrate concentration in spring after turnips is significantly lower than after white mustard. Thus spring soil nitrate which is often jeopardised to be leached in lower soil layers before used by the following crop can be successfully preserved.

If the sole purpose of growing a catch crop is the reduction of soil nitrate before winter leaching period white mustard is preferred over turnips grown as vegetables because at higher soil nitrate content (over 60 NO_3^--N ha^{-1}) the reduction under turnips is significantly lower than under white mustard. Whether turnips grown at the same plant density as white mustard would reduce soil nitrate with the same efficiency needs further consideration.

7 SUMMARY

Cropping systems, which increase soil organic matter content, generally lead to greater mineralization of soil N. The extended soil nitrogen pool as a consequence of a higher proportion of soil organic matter is potentially jeopardised since most of the mineralised nitrogen in agricultural soils is quickly transformed into nitrate, which is prone to leaching. High concentrations of soil nitrate after the harvest of potatoes and faba beans can be successfully controlled with brassica underseeds or catch crops. These strategies act merely temporarily because the nitrogen taken up by plants comes back in the soil liquid phase after its incorporation and mineralization. Since there is often a lack of synchronisation between mineralization of N in soil and crop demand for N extended soil N pool can be a potential burden for the environment.

The objective of the present work was to extend and optimise suggested strategies for reducing nitrate leaching after the harvest of the main crop by growing turnips as field vegetables.

Field experiments

Field experiments were conducted on the organic experimental farm Wiesengut over growing periods 1999/2000 and 2000/2001. Turnips cv. "Petrowski" (Pe) and cv. "Market Express F1" (Me) were grown to evaluate their nitrogen sink capacity, marketable yields and their precrop effect on the following winter- and spring wheat. Commonly used catch crop white mustard (*Sinapis alba* L.) cv. "Zlata (Wm) was used as a reference crop and fallow (F) as a control treatment. The experimental design was a Latin Square with four replications. Single plot size was 6 x 12 m. To evaluate the precrop effect of experimental treatments on following winter and spring wheat plots were divided into two subplots 3 x 12 m. Turnips and mustard were sown at the end of August, shortly after the harvest of potato and faba beans. Seeding rates were 4 and 20 kg ha^{-1} with a row - row spacing of 30 and 10 cm for turnips and mustard respectively. At 10 cm height turnip plants were thinned to achieve a plant density of 30 to 40 plants m^{-2}. At the time of the autumn harvest (100 days after sowing - DAS), turnip roots were exported from the field while turnip leaves were left on the plots. At the same time mustard treatments were mulched and plant rests left on the plots. Directly after harvest winter wheat cv. "Pegassos" was sown at 450 germinative seeds m^{-2} in rows 17 cm apart. Spring wheat cv. "Tasos" was sown at 440 germinative seeds m^{-2} in rows 17 cm apart - as soon as possible after harvest of turnip roots of cv. Pe in March.

Results

After a potato and faba beans harvest the amount of soil nitrate ranged between 20 and 130 kg NO_3^--N ha^{-1}. High variations in both years were mainly caused by heterogeneity of experimental fields, higher summer precipitation in the second experimental year and a 50 % lower potato and faba bean yield in the second year causing substantial accumulation of nitrate in the soil already during the growing season of both main crops.

Organically grown turnips and Wm, sown after a potato and faba bean harvest, functioned late in the autumn as an effective nitrate scavenger, reducing soil NO_3^--N, before winter discharge, in upper 90 cm soil layer up to 80 and 100 kg N ha^{-1} respectively, compared to fallowed soil.

The production of DM biomass for turnip cultivar Me ranged between 1.76 - 3.10 t ha^{-1} corresponding to N uptake of 57.1 - 101.0 kg ha^{-1}. For Pe the total DM yield was between 1.83 - 3.61 t ha^{-1} with N uptake of 60.3 - 119.5 kg ha^{-1} whereas Wm yielded 3.37 - 4.96 t DM ha^{-1} with corresponding N uptake of 73.2 - 207.3 kg ha^{-1}. Marketable roots of turnips were representing 40 to 65 % of total dry matter containing between 32 and 60 % of all accumulated nitrogen. With marketable roots an export of 33.8 – 52.5 kg N ha^{-1} in autumn was achieved.

When catch crop plant residues (white mustard and turnip leaves) were incorporated in autumn, and winter wheat was sown the amount of soil nitrate in following March was not increased more than for 20 kg NO_3^--N ha^{-1} thus ranging between 15.3 and 40.8 kg ha^{-1} in 90 cm soil layer. This indicates that incorporated biomass of Wm, Me and Pe retained a substantial part of the accumulated nitrogen in their tissues. On the other hand, when catch crops were left intact on the field over the winter, soil nitrate-N in spring under Wm ranged between 31.5 and 75.6 kg ha^{-1}. This indicates that Wm left on the field was a subject of a rapid decomposition already during winter, releasing a substantial amount of accumulated nitrogen into the soil solution. Under turnips, the soil nitrate-N status remained approximately on the same level as before winter ranging between 5.8 and 36.6 kg ha^{-1}.

Overall there was a consistent evidence for a negative effect of catch crop growth and their incorporation on DM yield, N_t concentration in DM and total N uptake of a subsequent winter wheat crop. When soil was fallowed, total (grain and straw) DM yield of winter wheat ranged between 9.2 and 12.9 t ha^{-1} with corresponding N uptake between 95.8 and 136.6 kg N ha^{-1}. After catch crops total DM yield of winter wheat was lower, ranging between 7.5 and 12.7 t ha^{-1} with N uptake between 78.2 and 114.2 kg N ha^{-1}.

On the contrary when incorporated in spring catch crops increased the DM yield and corresponding N uptake of spring wheat compared with fallow treatment. The positive precrop effect of catch crops was in the following order Wm > Me > Pe ≥ F. Precrop effect of turnip Pe was presumably dominated by N export between 22.2 and 59.6 kg N ha^{-1} in spring with its roots, thus reducing the amount of available nitrogen for wheat growth compared with Me and Wm. After fallow total DM yield of spring wheat ranged among 5.4 and 8.6 t ha^{-1} with N uptake between 63.3 and 99.3 kg N ha^{-1}. After catch crops total DM yield of spring wheat was higher, ranging between 5.2 and 11.5 t ha^{-1} with corresponding N uptake between 58.6 and 138.9 kg N ha^{-1}.

Discussion and conclusions

In the first experimental year at harvest time of turnips nitrogen uptake of white mustard and both turnips was well synchronised with N supply by organic matter mineralization because the amount of N in plant - soil system was the same under catch crops and bare soil. High variation in the N content of the plant - soil system in the second year indicate that beside leaching process and microbial immobilisation, soil N transformations can be profoundly influenced by growing catch crops. Due to a presence of plant roots, which can stimulate mineralization of organic matter and continuously deplete the equilibrium level of the soil inorganic N pool, under catch crops more N was released from organic matter than under bare soil. However this variation in N content of plant - soil system recorded in the second experimental year was most probably an outcome of leaching, enhanced mineralization under catch crops as well as microbial immobilisation.

Besides influencing soil nitrate dynamics, another important factor in growing catch crops is their effect on subsequent crop. Reduced N uptake of winter wheat, growing after catch crops, should mainly be attributed to extensive N immobilisation by catch crops that crucially influenced nitrogen availability during the following growing season. At the time of incorporation in late autumn, catch crops were still alive therefore availability for microbial attack could be under question since brassicas can contain high concentrations of secondary metabolites that can effectively depress soil microorganisms and thus decomposition of incorporated plant material. Additionally, mineralization during the winter is substantially decreased by low temperatures and soil moisture that reduce oxygen diffusion in the soil thus reducing oxygen supply of microorganisms. Decrease in DM yield and corresponding N uptake of winter wheat were not higher when nitrogen was exported in autumn with turnip roots. This indicates that nitrogen taken up by catch crops possibly did not have a significant role in nitrogen nutrition of subsequent winter wheat crop. This way it could be suggested that in a present study the value of catch crops incorporated in autumn appears to be long-term maintenance of soil N status rather than the short-term supply of available N for winter wheat growth.

Expected reduction of a winter wheat yield is however economicially negligible compared to the income achieved with turnip roots which can be 20 times higher as the loss with winter wheat yield. When sold, an export higher than 50 kg N ha^{-1} can be achieved via turnip roots. This way the soil nitrogen pool and consequently the risk of leaching are diminished. For management systems which steadily increase the amount of soil organic matter (long term application of organic manure, crop rotation with high amounts of harvest residues) this is of a great importance.

When turnips stay on the field over the winter they function well as a catch crop and can be incorporated in the following spring at seed bed preparation for the succeeding crop. In that case turnips conserve ground water even better than white mustard because soil nitrate concentration in spring after turnips is expected to be significantly lower than after white mustard. Thus spring soil nitrate which is often jeopardised to be leached in lower soil layers before used by the following crop can be successfully preserved. However, minor but not significant decrease in grain yield of succeeding spring wheat is to be expected after turnips compared with white mustard.

Turnips sown as vegetables can be successfully integrated into arable crop rotations due to their multiple functions, which are the decrease of soil nitrate before winter, the long term reduction of soil nitrogen pool by N export and the generation of additional income for the farmer.

8 ZUSAMMENFASSUNG

Ackerbau-Systeme, die den Gehalt an organischer Substanz im Boden erhöhen, führen in der Regel zu einer erhöhten Mineralisation von Boden N. Die erhöhte Menge des Bodenstickstoffs als Konsequenz des höheren Anteils von organischer Substanz im Boden ist potentiell jedoch gefährdet, da ein Großteil des mineralisierten Stickstoffs im landwirtschaftlichen Böden schnell in Nitrat transformiert wird, das wiederum einer Auswaschung unterliegt. Hohe Konzentrationen von Bodennitrat nach der Ernte von Kartoffeln und Ackerbohnen können mit Brassicaceen Zwischenfrüchten und Untersaaten erfolgreich kontrolliert werden. Diese Strategien wirken jedoch nur temporär, da der von den Pflanzen aufgenommene Stickstoff nach seiner Inkorporation und Mineralisation wieder in die flüssige Bodenphase eintritt. Da es oftmals an einer Synchronisation zwischen der Mineralisation von N im Boden und dem Stickstoffbedarf der Pflanzen fehlt, kann die erhöhte Stickstoffmenge der Flüssigphase ein Problem für die Umwelt darstellen.

Es war daher das Ziel der vorliegenden Arbeit, die vorgeschlagenen Strategien zur Reduktion der Nitratauswaschung zu optimieren, indem nach der Ernte der Hauptfrucht Stoppelrüben als Feldgemüse angebaut werden.

Feldversuche

Es wurden Feldversuche auf dem Versuchsbetrieb für Organischen Landbau Wiesengut in der Vegetationsperiode 1999/2000 und 2000/2001 durchgeführt. Die Stoppelrüben cv "Petrowski" (Pe) und "Market Express F1" (Me) wurden angebaut, um ihre Kapazität als Stickstoffsenke sowie ihr Potential an marktfähigen Erträgen und ihre Vorfruchtwirkung auf nachfolgenden Winter- bzw. Sommerweizen zu evaluieren. Als Referenzfrucht wurden die üblicherweise eingesetzten Zwischenfrüchte Weißer Senf (Sinapis alba L.) cv. "Zlata" (Wm) eingesetzt. Schwarzbrache (F) diente als Kontrolle. Die Versuchsanlage wurde als Lateinisches Quadrat mit vier Wiederholungen konzipiert. Die Größe der einzelnen Versuchsparzellen betrug 6 x 12 m. Um die Vorfruchtwirkung der Behandlungen auf den nachfolgenden Winter- bzw. Sommerweizen zu evaluieren, wurden die Versuchsparzellen in zwei Unterflächen von jeweils 3 x 12 m unterteilt. Die Stoppelrüben und der Senf wurden Ende August kurz nach der Ernte von Kartoffeln und Ackerbohnen gesät. Die Aussaatdichte betrug 4 bzw. 20 Kilogramm je Hektar bei einem Reihenabstand von 30 bzw. 10 cm für Stoppelrüben bzw. Senf. Bei einer Höhe von 10 cm wurden die Stoppelrüben auf eine Pflanzendichte von 30 bis 40 Pflanzen m^{-2} ausgedünnt. Zur Zeit der Herbsternte (hundert Tage nach der Aussaat) wurden die Wurzeln der Stoppelrüben vom

Feld exportiert, während das Blattmaterial auf den Flächen verblieb. Zur selben Zeit wurden die Senfpflanzen gemulcht. Die Pflanzenreste verblieben auf der Fläche. Unmittelbar nach der Ernte wurde der Winterweizen "Pegassos" mit 450 keimfähigen Samen m^{-2} in 17 cm Reihenabstand ausgesät. Der Sommerweizen "Tasos" wurde mit 440 keimfähigen Samen m^{-2} in 17 cm Reihenabstand ausgesät, sobald dies nach der Ernte der Stoppelrübenwurzeln der cv. Pe im März möglich war.

Ergebnisse

Nach der Kartoffel- und Ackerbohnen-Ernte betrug der Gehalt an Bodennitrat zwischen 20 und 130 kg NO_3^--N ha^{-1}. Die großen Abweichungen zwischen den Versuchsjahren waren überwiegend auf die Heterogenität der Versuchsflächen, den hohen Niederschlag im Sommer während des zweiten Versuchsjahres und auf die um etwa 50 % geringeren Kartoffel- und Ackerbohnen-Erträgen im zweiten Jahr zurückzuführen. Dies führte zu einer erhöhten Akkumulation von Nitrat im Boden bereits während der Wachstumsphase der beiden Hauptfrüchte.

Stoppelrüben und Senf, die nach der Kartoffel- und Ackerbohnen-Ernte gesät wurden, fungierten später im Herbst als effektive Nitratsenke und verminderten den Bodennitrat-Stickstoff vor den Winterverlusten im oberen 90 cm-Bodenbereich um 80 bzw. 100 kg N ha^{-1}, im Vergleich zur Brache.

Die Produktion von TM der Stoppelrüben cv. Me betrug zwischen 1,76 und 3,61 t ha^{-1}, entsprechend einer N-Aufnahme von 57,1 bis 101,0 kg ha^{-1}. Für Pe betrug der Gesamt TM Ertrag zwischen 1,83 und 3,61 t ha^{-1} mit einer N-Aufnahme von 60,3 bis 119,5 kg ha^{-1}. Der Senf produzierte 3,37 bis 4,96 t ha^{-1} Sproßmasse entsprechend einer N-Aufnahme von 73,2 bis 207,3 kg ha^{-1}. Die marktfähigen Wurzeln der Stoppelrüben hatten dabei einen Anteil von 40 bis 65 % der Gesamttrockenmasse und enthielten 35 bis 60 % des gesamten akkumulierten Stickstoffs. Mit den marktfähigen Wurzeln wurden 33,8 bis 52,5 kg N ha^{-1} im Herbst exportiert.

Wurden die Pflanzenreste der Zwischenfrüchte (Senf oder Stoppelrübenblätter) im Herbst eingearbeitet und Winterweizen gesät, erhöhte sich der Bodennitratgehalt im darauffolgenden März um nicht mehr als 20 Kilogramm NO_3^--N ha^{-1}. Die Bodennitratmengen betrugen in den oberen 90 cm des Bodens zwischen 15,3 und 40,8 kg N ha^{-1}. Dieser Sachverhalt weist darauf hin, dass die eingearbeitete Biomasse von Wm, Me und Pe einen wesentlichen Teil des akkumulierten Stickstoffs in ihrem Gewebe zurückhielten. Wenn jedoch die Zwischenfrüchte unversehrt über den Winter auf dem Feld verblieben, betrug der Nitrat-N im Frühjahr unter Wm zwischen 31,5 und 75,6 kg ha^{-1}. Dies Ergebnis zeigt an, dass die auf dem Feld zurückgelassene Biomasse von Wm während des Winters Gegenstand einer schnellen Zersetzung war, die zu einer Freisetzung einer wesentlichen Menge des akkumulierten Stickstoffs in die Bodenlösung führte. Unter den Stoppelrüben blieb der Bodennitrat-N dagegen im wesentlichen auf demselben Niveau wie im vorherigen Winter mit Werten zwischen 5,8 und 36,6 kg ha^{-1}.

Insgesamt wurde deutlich, dass der Anbau von Zwischenfrüchten und ihre Einarbeitung in den Boden negative Effekte auf den TM Ertrag, die Gesamtstickstoffkonzentration in der TM und die Gesamt N-Aufnahme des nachfolgenden Winterweizens hatte. Wurde der Boden hingegen als Brache liegengelassen, ergab sich ein GesamtTM Ertrag (Korn und Stroh) des Winterweizens von 9,2 und 12,9 t ha^{-1}, was einer N-Aufnahme von 95,8 bis 136,6 kg N ha^{-1} entsprach. Nach der Zwischenfrucht betrug der GesamtTM Ertrag des Winterweizens lediglich 7,5 bis 12,7 t ha^{-1} mit einer Stickstoffaufnahme zwischen 78,2 und 114,2 kg N ha^{-1}.

Im Gegensatz dazu führt die Einarbeitung der Zwischenfrüchte im Frühjahr zu einem erhöhten TM Ertrag und entsprechend erhöhter N-Aufnahme des Sommerweizens im Vergleich zur Brache. Dieser positive Vorfruchteffekt der Zwischenfrüchte war für Wm am höchsten mit einer abnehmenden Tendenz für Me, Pe und F. Der Vorfruchteffekt der Stoppelrübe Pe war vermutlich dominiert durch den Stickstoffexport durch die Wurzeln im Frühjahr mit Werten zwischen 22,2 und 59,6 kg N ha^{-1}, was im Vergleich zu Me und Wm zu einer Verminderung des verfügbaren Stickstoffs für das Weizenwachstum führte. Nach der Brache betrug der Gesamt TM Ertrag des Sommerweizens zwischen 5,4 und 8,6 t ha^{-1} mit einer N-Aufnahme zwischen 63,3 und 99,3 kg N ha^{-1}. Nach der Zwischenfrucht lag der Gesamt TM Ertrag des Sommerweizens höher mit Werten zwischen 5,2 und 11,5 t ha^{-1}, was einer N-Aufnahme zwischen 58,6 und 138,9 kg N ha^{-1} entspricht.

Diskussion und Schlußfolgerungen

Im ersten Versuchsjahr war zum Zeitpunkt der Ernte der Stoppelrüben die N-Aufnahme des Senfs und beider Stoppelrübensorten gut mit der N-Zufuhr durch die Mineralisierung der organischen Substanz synchronisiert. Die Mengen von Stickstoff im Pflanze-Boden-System und auf der Brache waren gleich hoch. Der große Unterschied im Stickstoffgehalt im Pflanze-Boden-System im zweiten Versuchsjahr zeigt, dass neben Auswaschungsprozessen und mikrobieller Immobilisierung die N-Transformation erheblich durch das Wachstum von Zwischenfrüchten beeinflusst werden kann. Aufgrund der Gegenwart von Pflanzenwurzeln, die Mineralisation der organischen Substanz stimulieren und kontinuierlich das Gleichgewicht im inorganischen N-Pool des Bodens vermeiden, wurde unter den Zwischenfrüchten mehr Stickstoff aus der organischen Substanz freigesetzt als in der Brache. Dennoch scheint der Unterschied im Stickstoffgehalt des Pflanze-Boden-Systems im zweiten Versuchsjahr vordringlich eine Folge der Auswaschung, der verstärkten Mineralisation unter Zwischenfrüchten sowie der mikrobiellen Immobilisation gewesen zu sein.

Neben der Beeinflussung der Bodennitrat-Dynamik besteht ein wesentlicher Grund für die Verwendung von Zwischenfrüchten in ihrem Effekt auf die nachfolgende Hauptfrucht. Die im Vergleich zur Schwarzbrache verminderte N-Aufnahme des Winterweizens nach den Zwischenfrüchten ist vermutlich überwiegend auf die umfangreiche N-Immobilisierung durch die Zwischenfrüchte zurückzuführen. Sie kann die Stickstoffverfügbarkeit während der nachfolgenden Wachstumsphase wesentlich beeinflussen. Da zum Zeitpunkt der Einarbeitung im späten Herbst die Zwischenfrüchte jedoch noch nicht abgestorben waren, ist deren Verfügbarkeit für den mikrobiellen Abbau jedoch zweifelhaft, da Brassicaceen eine hohe Konzentration sekundärer Pflanzenstoffe beinhalten, die das Wachstum von Boden-Mikroorganismen effektiv unterdrücken und daher die Zersetzung des eingearbeiteten Pflanzenmaterials erschweren können. Zudem kann die Mineralisation während des Winters vor allem durch die niedrigeren Temperaturen, die geringere Bodenfeuchtigkeit und eine reduzierte Sauerstoffdiffusion im Boden vermindert sein. Die Reduzierung des TM Ertrags und der N-Aufnahme war nicht größer, wenn Stickstoff im Herbst durch die Stoppelrübenwurzeln vom Feld exportiert wurde. Dieser Sachverhalt weist darauf hin, dass der von den Zwischenfrüchten aufgenommene Stickstoff keine signifikante Rolle für die Stickstoffversorgung des nachfolgenden Winterweizens hatte. Ausgehend von diesen Ergebnissen scheint somit der Wert der im Herbst eingearbeiteten Zwischenfrüchte eher in dem langfristigen Erhalt des Bodenstickstoff-Status zu liegen, als in der kurzfristigen Versorgung des Winterweizens mit verfügbarem Stickstoff.

Die voraussichtliche Verminderung des Ertrages an Winterweizen ist jedoch unter wirtschaftlichen Gesichtspunkten vernachlässigbar im Vergleich zu den möglichen Einnahmen, die mit dem Verkauf der Rüben erreicht werden können. Sie können den Verlust durch den verminderten Winterweizenertrag um das bis zu 20-fache übersteigen. Mit dem Verkauf der Rüben kann gleichzeitig ein Stickstoffexport von mehr als 50 kg ha^{-1} verbunden sein. Damit kann der Stickstoff-Pool im Boden und somit auch das Risiko der Auswaschung vermindert werden. Für Anbausysteme, die zu einer kontinuierlichen Erhöhung der Menge organischer

Substanz im Boden führen (andauernde Verwendung von organischem Dünger, Fruchfolgen mit hohen Mengen von Ernterückständen) kann dies von großer Bedeutung sein.

Sollten die Rüben auf dem Feld verbleiben, dienen sie als effektive Zwischenfrucht während des Winters und können im darauffolgenden Frühjahr bei der Saatbeetbereitung für die Folgefrucht eingearbeitet werden. In diesem Fall schützen Stoppelrüben das Grundwasser besser als Senf, da der Bodennitratgehalt im Frühjahr nach den Stoppelrüben im Vergleich zum Senf signifikant niedriger ist. Somit kann das Bodennitrat, das anderenfalls gefährdet ist, im Frühjahr noch vor seiner Nutzung durch die nachfolgende Frucht in tiefere Bodenschichten ausgewaschen zu werden, erhalten werden. In diesen Fällen muß jedoch ein geringer – wenn auch nicht signifikanter – Verlust im Kornertrag des nachfolgenden Sommerweizens im Vergleich zum Anbau nach Senf erwartet werden.

Stoppelrüben, die als Feldgemüse angebaut werden, können aufgrund ihrer vielfältigen Funktionen, nämlich die Verminderung des Bodennitrats vor dem Winter, die dauerhafte Reduktion des Stickstoffpools im Boden duch N-Export sowie die Generierung zusätzlichen Einkommens für den Landwirten, erfolgreich in eine Feldfruchtfolge integriert werden.

9 ACKNOWLEDGEMENTS

The author wishes to thank Mr. C. Dahn, Mr. M. Harrichausen, Mrs. H. Leese, Mr. H. Riebeling, Mr. J. Siebigteroth, Mr. F. Täufer and Mr. D. Zedow for excellent technical assistance, Dr. H. Zaller and Dr. D. Neuhoff for useful criticism and Prof. Dr. U. Köpke for his tolerant mentorship.

The gratitude for financial support goes to EDEN-Stiftung Bad Soden/Ts. which generously supported the present research.

10 APPENDIX

Table 1: Treatments and associated agronomic practices.

	Season	
Treatment	**1999 - 2000**	**2000 - 2001**
Harvest of preceding crop	Aug 13 Potatoes	Aug 16 Potatoes
	Aug 6 Faba beans	Aug 10 Faba beans
Ploughing	Aug 16	Aug 17
Seed bed preparation	Aug 18	Aug 25
Sowing of turnips and mustard	Aug 18	Aug 25
Hoeing	Sep 7	Sep 12
	Sep 20	-
Thinning	Sep 7-10.	Sep 19-21
Irrigating	Sep 10	-
	Sep 15	-
Growth analysis sampling of turnips and mustard	-	Oct 20
Turnip harvest of WW subplots	Nov 25	Nov 21
Ploughing and seedbed preparation	Dec 3	Dec 1
Sowing of WW	Dec 3	Dec 1
Turnip harvest of SW subplots	Mar 23	Mar 28
Ploughing of SW subplots	Mar 24	Mar 30
Seedbed preparation	Apr 7	Apr 3
Sowing of SW	Apr 7	Apr 3
Inter row hoeing and harrow combing of WW	Apr 11	Apr 5
Harrow combing of WW	Apr 28	Apr 25
Inter row hoeing and harrow combing of SW	May 20	May 22
Measurement of wheat leaf chlorophyll conc.	May 31	Jun 15
Growth analysis sampling of WW and SW	-	May 11 (WW)
		Jun 7 (WW)
		Jun 12 (SW)
WW harvest	Aug 1	Jul 26
SW harvest	Aug 10	Aug 2

Table 2: Soil sampling dates in growing seasons 1999 – 2000 and 2000 – 2001.

Season	**Soil sampling date**							
1999 - 2000	Aug 28	Dec 3	Mar 21	May 5	Aug 14	-	-	-
2000 - 2001	Sep 14	Oct 17	Nov 27	Feb 14	Mar 20	May 9	June 13	Aug 6

Table 3: Total N (kg ha^{-1}) in plant - soil system (kg NO_3^--N ha^{-1} in soil + kg N ha^{-1} in plant tissue).

	Dec 3, 1999		**Oct 17, 2000**		**Nov 27, 2000**	
Treatment	Potatoes	F. beans	Potatoes	F. beans	Potatoes	F. beans
Fallow	79.7	52.1^{a}	121.0	73.0^{a}	93.5^{a}	88.1^{a}
W. mustard	80.0	95.3^{ab}	123.9	82.5^{ab}	228.6^{c}	131.4^{c}
M. Exp. F1	74.3	95.4^{ab}	141.7	96.4^{b}	143.3^{b}	114.8^{b}
Petrowski	71.5	100.8^{b}	132.2	105.3^{b}	156.3^{b}	126.8^{c}

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Table 4: Turnip DM yields (t ha^{-1}).

Cultivar	Root	Leaf	Root + Leaf	Author
Appin		4.0 – 5.4	5.3 – 7.4	PERCIVAL et al. (1986)
	1.6	5.1	6.7	PENROSE et al. (1996)
	1.6 – 4.6			SHELDRICK & LAVENDER (1981)
Barkant		3.2 – 5.9	6.7 – 10.5	PERCIVAL et al. (1986)
	6.4	7.1		PEARSON & THOMSON (1996)
Civasto		4.1 – 5.2	6.3 – 9.5	PERCIVAL et al. (1986)
Forage Star	3.5 – 4.2	3.7 – 6.6	7.6 – 10.5	REID et al. (1994)
	0.6 – 3.9	3.6 – 6.2	4.4 – 10.1	JUNG & SHAFFER (1993)
Green Globe	3.5	5.4	8.9	REID et al. (1994)
		3.3 – 4.0	7.1 – 8.7	PERCIVAL et al. (1986)
	0.4 – 2.9	2.7 – 5.7	3.5 – 8.6	JUNG & SHAFFER (1993)
M6		2.5 – 3.3	6.2 – 6.7	PERCIVAL et al. (1986)
Manga		2.5 – 4.1	5.7 – 8.8	PERCIVAL et al. (1986)
Ponda		3.8 – 5.1	6.3 – 9.0	PERCIVAL et al. (1986)
	2.1 – 3.9			SHELDRICK & LAVENDER (1981)
Purple Top	3.6	2.3	5.9	PENROSE et al. (1996)
	1.2 – 4.7	2.0 – 4.0	3.2 – 7.6	JUNG & SHAFFER (1993)
			7.6	RAO & HORN (1986)
Rondo	5.5	3.4	8.9	PENROSE et al. (1996)
	0.5 – 3.0	2.1 – 5.3	2.8 – 8.0	JUNG & SHAFFER (1993)
Vobra		3.2 – 3.9	5.8 – 7.0	PERCIVAL et al. (1986)
Weixian	4.9 – 6.7			WANG &WANG, (1994)
Wintergreen	2.5	4.2	6.7	PENROSE et al. (1996)
York Globe		0.5 – 2.5	1.1 – 5.0	PERCIVAL et al. (1986)
Aver. of 21 cv.			4.5 – 6.5	BERENDONK (1992)
Aver. of 4 cv.			2.0 – 2.8	YOUNG (1998)
?			3.1 – 10.2	JUNG et al. (1979)
?			8.6 – 9.7	GREENWOOD et al. (1980)
?	1.9 – 4.3	2.2 – 4.7	4.1 – 9.0	GUILLARD & ALLINSON (1988)

Table 5: Ascorbic acid concentration in turnip roots (mg/100g fresh tissue).

Cultivar	Root	Author
Purple Top White Globe	22.7 – 25.3	SHATTUCK et al. (1991)
	7.9 – 13.5	SINGH & SHARMA (1993)
	6.9 – 13.2	BHAT (1996)
Weixian	29.9	WANG &WANG (1994)
Seven Top	102.3 – 202.2 (leaf)	SHEETS et al. (1955)

Table 6: Concentration of DM in turnips (%).

Root	**Leaf**	**Author**
8.3 – 12.9	11.4 – 13.1	PENROSE et al. (1996)
5.0 – 11.1	7.4 – 16.3	PEARSON & THOMSON (1996)
	11.6 – 12.7	VIEIRA et al. (1998)
	8.4 – 13.8	SHEETS et al. (1955)
6.5 – 8.8	9.1 – 17.2	GUILLARD & ALLINSON (1988)

Table 7: Dry matter yield, N_t concentration in DM and N accumulation of turnip cultivar Petrowski after potatoes and faba beans in spring 2000 (Mar 23) and 2001 (Mar 28)

		DM yield (t ha^{-1})			**N_t conc. (%)**		**N (kg N ha^{-1})**		
Year	**Precrop**	Root	Leaf	∑	Root	Leaf	Root	Leaf	∑
2000	Potatoes	1.10	0.43	1.53	2.03	3.56	22.2	14.9	37.1
	Faba beans	1.49	0.76	2.25	2.08	3.88	30.9	29.5	60.4
2001	Potatoes	1.65	0.46	2.11	3.61	4.81	59.6	22.2	81.6
	Faba beans	1.45	0.50	1.95	3.26	4.56	47.3	22.5	69.8

Table 8: Leaf : root ratio of turnips.

Year	1999		2000			
Harvest time	Nov 25		Oct 20		Nov 21	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans	Potatoes	Faba beans
M. Expres F1	0.23	0.44	1.28	1.28	0.45	0.46
Petrowski	0.51	0.88	3.58	3.74	1.35	1.17

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Table 9: C : N ratio of turnip leaves and white mustard shoot biomass.

Year	1999		2000			
Harvest time	Nov 25		Oct 20		Nov 21	
Previous crop	Potatoes	Faba beans	Potatoes	Faba beans	Potatoes	Faba beans
M. Expres F1	11.4	10.8	7.7	8.5	9.3	11.2
Petrowski	11.6	11.5	7.6	8.5	8.9	11.1
W. mustard	21.4	20.0	9.0	11.4	10.0	12.6

Values within a column are significantly different (Tukey; α=0.05) if followed by different letters.

Table 10: Relative chlorophyll concentration of the upper winter wheat leaf (EC 59); (F-fallow, Wm-white mustard, turnips Me-Market Express F1 and Pe-Petrowski).

Previous crop	Potatoes				Faba beans			
Treatment	F	Wm	Me	Pe	F	Wm	Me	Pe
May 31, 2000	41.4	37.5	37.1	37.5	-	-	-	-
June 15, 2001	41.7	37.3	38.7	37.8	38.9	34.6	35.0	35.2

Table 11: Relative chlorophyll concentration of the upper two spring wheat leaves (EC 45); (F-fallow, Wm-white mustard, turnips Me-Market Express F1 and Pe-Petrowski).

Previous crop …	Potatoes				Faba beans			
Treatment …	F	Wm	Me	Pe	F	Wm	Me	Pe
May 31, 2000	41.9	41.8	42.3	41.4	-	-	-	-
June 15, 2001	41.5	46.1	44.2	44.2	41.6	45.0	42.4	42.5

Table 12: Root and leaf concentration of minerals in turnips (% of DM).

Element	Root	Leaf	Author
N		6.13 – 7.08	Sheets et al. (1955)
		3.52 – 4.44	del Valle & Harmon (1970)
	2.30 – 3.40		Sheldrick & Lavender (1981)
	3.04 – 3.14	3.34 – 3.70	Rao & Horn (1986)
	1.78 – 2.83	2.75 – 4.38	Jung et al. (1986)
	1.55 – 2.66	2.53 – 3.54	Guillard & Allinson (1989)
		3.15	Berendonk (1992) whole plant
		3.14 – 5.43	Simone et al. (1993)
	1.25 – 1.79	1.82 – 3.39	Penrose et al. (1996)
	0.87 – 2.24	2.02 – 4.27	Pearson & Thomson (1996)
		3.03 – 3.48	Young (1998) whole plant
	3.04 – 3.14	1.40 – 6.30	Vieira et al. (1998)
P		0.60 – 0.80	Sheets et al. (1955)
		0.41 – 0.44	Francois (1984)
		0.47	Bohnenkemper (1987)
	0.35 – 0.59	0.30 – 0.61	Guillard & Allinson (1989)
		0.31 – 0.45	Wiedenhoeft & Barton (1994)
	0.46		Wang &Wang (1994)
	0.46 – 0.53	0.37 – 0.40	Reid et al. (1994)
	0.18 – 0.24	0.18 – 0.22	Penrose et al. (1996)
K		4.46 – 5.43	Francois (1984)
		3.89	Bohnenkemper (1987)
	3.05 – 4.08	2.94 – 4.52	Guillard & Allinson (1989)
	3.08 – 3.47	4.53 – 4.89	Reid et al. (1994)
	2.31 – 3.12	2.69 – 3.68	Penrose et al. (1996)
Ca		2.53 – 3.55	Sheets et al. (1955)
		3.26 – 3.93	Francois (1984)
		1.36	Bohnenkemper (1987)
	0.46 – 0.81	2.09 – 2.66	Guillard & Allinson (1989)
	0.58 – 0.71	2.40 – 2.64	Reid et al. (1994)
	0.25		Wang &Wang (1994)
		2.48 – 4.09	Wiedenhoeft & Barton (1994)
	0.38 – 0.76	1.37 – 2.69	Penrose et al. (1996)
Mg		0.19 – 0.25	Francois (1984)
		0.16	Bohnenkemper (1987)
	0.16 – 0.22	0.52 – 0.73	Guillard & Allinson (1989)
		0.28 – 0.48	Wiedenhoeft & Barton (1994)
	0.16 – 0.17	0.31 – 0.38	Reid et al. (1994)
	0.38 – 0.76	0.39 – 0.48	Penrose et al. (1996)
S	0.53 – 0.54	0.56 – 0.57	Reid et al. (1994)
Na		0.22 – 1.16	Francois (1984)
		0.26	Bohnenkemper (1987)
Cl		3.09 – 6.11	Francois (1984)

Table 13: Turnip production costs per ha (adapted from KTBL Betriebsplanung Landwirtschaft 2004/2005)

Treatment	**Time requirement**		**Fuel**	**Other materials**	**Interests**	**Depreciation**	**Insurance**	**Repair costs**	**Labour costs**	**Total**
	Labour	**Machine**	**l/ha**	**€/ha**	**€/ha**	**€/ha**	**€/ha**	**€/ha**	**€/ha**	**€/ha**
Ploughing / 1.05 m, 45 kw Turn over plough, mounted	2.83	2.83	23.8	13.55	4,95	12.95	0.73	23.03	42.51	97.72
Harrowing / 3.0 m,45 kw Seedbed combination, mounted	0.8	0.8	6.3	3.56	1.99	5.06	0.21	7.40	12.01	30.23
Precision sowing / 6 rows, 3.0 m, 37 kw	1.18	1.18	4.4	2.48	3.72	13.91	0.23	13.72	17.76	51.82
Inter row hoeing / 6 rows, 3.0 m, 45 kw	1.36	1.36	5.2	2.98	2.52	7.01	0.35	8.78	20.34	41.98
Inter row hoeing / 6 rows, 3.0 m, 45 kw	1.36	1.36	5.2	2.98	2.52	7.01	0.35	8.78	20.34	41.98
Manual harvest	70.0	70.0							1050.00	1050.00
Transport of harvested roots / tipping trailer 8 t, 45 kw	2.41	2.41	5.69	3.25	12.76	29.71	1.92	23.99	36.22	107.85
Processing and packing / classifying, washing table, 10 kg cases	80.0			12.50	12.50	36.00		3.20	1200.00	1264.20
Special costs (Seeds)				285.00						285.00
Total costs €/ha				326.30	40.96	111.65	3.79	88.90	2399.18	**2970.78**

Table 14: Income reduction of winter wheat growing after catch crops.

Winter wheat	Yield		Income	
	t/ha	Relative %	€/t	Total €
After fallow	6.0	100	230	1380
After catch crops	5.1	85	230	1173
Income reduction (€/ha)				**207**

Table 15: Profit calculation for turnip roots.

	Root yield (t/ha)					
	5	10	15	20	25	30
Waste roots (%)	25	25	25	25	25	25
Marketable roots (t)	3.75	7.5	11.3	15.0	18.8	22.5
Price (€/t)	600	600	600	600	600	600
Income with roots (€/ha)	**2250**	**4500**	**6780**	**9000**	**11280**	**13500**
Turnip Production costs (€/ha)	- 2971	- 2971	- 2971	- 2971	- 2971	- 2971
Income reduction of winter wheat (€/ha)	- 207	- 207	- 207	- 207	- 207	- 207
Profit (€/ha)	**- 928**	**1322**	**3602**	**5822**	**8102**	**10322**

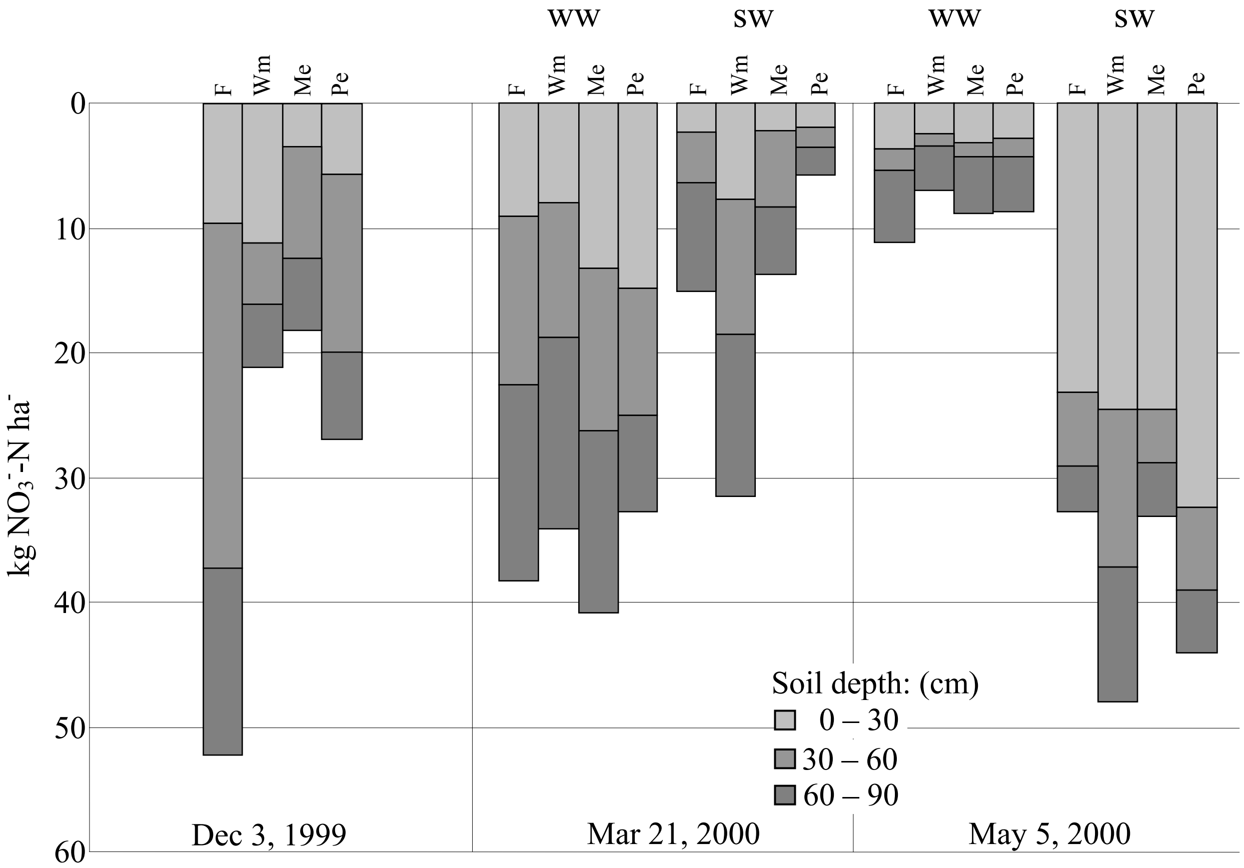

Figure 1: Effect of catch crop treatments and soil tillage on soil nitrate after winter. In 1999 precrop faba beans. **F:** fallow, **Wm:** white mustard, turnips **Me:** Market Express F1 and **Pe:** Petrowski; **WW** winter wheat management (winter wheat failed and was re-sown with spring wheat), **SW** spring wheat management.

11 REFERENCES

ALBLAS, J., H. TITULAER & M. HINKEN. 1992: The course of mineral nitrogen (N_{min}) in the soil profile during the successive cultivation of potatoes and winter wheat on loess soil. In: Crop development for the cool and wet regions of Europe – Nitrogen cycling and leaching in cool and wet regions of Europe, Workshop, October 22-23, Gembeloux, Belgium, 96-98.

ALFÖLDI, T., P. MÄDER, O. SCHACHENMANN, U. NIGGLI & J.M. BESSON. 1992: DOK-Versuch: Vergleichende Langzeituntersuchungen in den drei Anbausystemen Biologisch-Dynamisch, Organisch-Biologisch und Konventionell. III. Boden: N_{min}-Untersuchungen, 1. und 2. Fruchtfolgeperiode. Schweiz. Landw. Fo., 32, 59-82.

ALLISON, F.E. & C.J. KLEIN. 1962: Rates of immobilisation and release of nitrogen following additions of carbonaceous materials and nitrogen to soils. Soil Science, 93, 383-386.

ALLISON, M.F., M.J. ARMSTRONG, K.W. JAGGARD & A.D. TODD. 1998: Integration of nitrate cover crops into sugarbeet (*Beta vulgaris*) rotations. I. Management and effectiveness of nitrate cover crops. Journal of Agricultural Science, Cambridge, 130. 53-60.

ALMEIDA, F.S. 1985: Effect of some winter crop mulches on the soil weed infestation. Proceedings of British Crop Protection Conference – Weeds, 2, 651-659.

ANTONIOUS, G.F., M.J. KASPERBAUER & M.E. BYERS. 1996: Light Reflected from Coloured Mulches to Growing Turnip Leaves Affects Glucosinolate and Sugar Contents of Edible Roots. Photochemistry and Photobiology, 64, 3, 605-610.

AULAKH, M.S., J.W. DORAN, D.T. WALTERS, A.R. MOSIER & D.D. FRANCIS. 1991: Crop Residue Type and Placement Effects on Denitrification and Mineralization. Soil Science Society of America Journal, 55, 1020-1025.

BARRACLOUGH, P.B. 1986: The growth and activity of winter wheat roots in the field : nutrient uptakes of high-yielding crops. Journal of Agricultural Science, Cambridge, 106, 45-52.

BAYERISCHE LANDESANSTALT FÜR ERNÄHRUNG. 2001: Mit Obst, Gemüse und Kartoffeln rund ums Vitamin C. Ernährungsinformation, Nr. 12.

BECKHOFF, J. 1986: Zwischenfrüchte silieren – Häckseln verbessert die Qualität. Top agrar, 8, 59-61.

BERENDONK, C. 1985: Beweidungsversuche mit Ölrettich sowie mehreren Rapssorten unterschiedlicher Blat/Stangel-Verhältnisse und Glucosinolatgehalte. Das wirtschaftseigene Futter, 31, 2, 165-173.

BERENDONK, C. 1987: Leistungen verschiedener Zwischenfruchtarten im Hinblick auf Futtergewinnung, Gründüngung und Nitratverlagerung im Boden. Das wirtschaftseigene Futter, 33, 3, 275-286.

BERENDONK, C. 1987: Stoppelrüben umweltfreundlich anbauen. Landw. Wochenblatt, 26, 23-24.

BERENDONK, C. 1992: Stoppelrüben liefern Futter und binden Stickstoff. Landwirtschaftliches Wochenblatt Westfalen-Lippe, 149, 24, 28-29.

BERGER, D. & H. KRETSCHMER. 1991: Zwischenfruchtanbau – immer eine Maßnahme zur Verringerung der Nitratauswaschung? Feldwirtschaft, 32, 462-464.

BHAT, K.L. 1996: Effect of different levels of nitrogen, phosphorus and potash on root yield and its quality in turnip var. P.T.W.G. Crop Research, 12, 1, 123-125.

BIALY, Z., W. OLESZEK, J. LEWIS & G.R. FENWICK. 1990: Allelopathic potential of glucosinolates (mustard oil glycosides) and their degradation products against wheat. Plant and Soil, 129, 277-281.

BOEHRINGER MANNHEIM. 1995: Methoden der enzymatischen Bioanalytik und Lebensmittel-Analytik. Boehringer Mannheim Biochemica, Mannheim.

BOHNENKEMPER, O. 1987: Was Sie bei der Grünverfütterung von Zwischenfrüchten bedenken sollten. Landwirtschaftsblatt Weser-Ems, 28, 11-13.

BOOLTINK, H.W.G. 1995: Field monitoring of nitrate leaching and water flow in a structured clay soil. Agriculture, Ecosystems and Environment, 52, 251-261.

BOYDSTON, R.A. & A. HANG. 1995: Rapeseed (*Brassica napus*) Green Manure Crop Suppresses Weeds in Potato (*Solanum tuberosum*). Weed Technology, 9, 669-675.

BROWN, P.D., M.J. MORRA, J.P. MCCAFFREY, D.L. AULD & L. WILLIAMS. 1991: Allelochemicals produced during glucosinolate degradation in soil. Journal of Chemical Ecology, 17, 10, 2021-2034.

BROWN, P.D. & M.J. MORRA. 1995: Glucosinolate-Containing Plant Tissues as Bioherbicides. J. Agric. Food Chem., 43, 3070-3074.

BUCHNER, W. 1987: So konservieren Sie Nitrat im Boden. DLG-Mitteilungen, 10, 518-523.

BURNS, I.G. 1980: Influence of the spatial distribution of nitrate on the uptake of N by plants: A review and a model for rooting depth. Journal of Soil Science, 31, 155-173.

BUSER, H. 1988: Zwei neue ZEFA Herbstrübensorten, Typ `rot` und Typ `weiss`. Der Gemüsebau, 2, 15-17.

CARLSON, D.G., M.E. DAXENBICHLER, C.H. VANETTEN, H.L. TOOKEY & P.H. WILLIAMS. 1981: Glucosinolate in Crucifer Vegetables: Turnips and Rutabagas. J. Agric. Food Chem., 29, 1235-1239.

CARLSON, D.G., M.E. DAXENBICHLER, H.L. TOOKEY, W.F. KWOLEK, C.B. HILL & P.H. WILLIAMS. 1987: Glucosinolates in Turnip Tops and Roots: Cultivars Grown for Greens and/or Roots. Journal of American Society for Horticultural Science, 112, 1, 179-183.

CHEVRE, A.M., M. CHEVRE & F. CHOPY. 1998: What about crucifers during the XVIth century? Proc. Int. Symp. on Brassicas, Eds.: Thomas Gregoire & Antonio A. Monteiro, Acta Hort., 459, ISHS, 47-51.

CHONG, C. & B. BIBLE. 1974: Relationship Between Top/Root Ratio and Thiocyanate Content in Roots of Radishes and Turnips. Hort Science, 9, 3, 230-231.

CHONG, C., H.Y. JU & B.B. BIBLE. 1982: Glucosinolate composition of turnip and rutabaga cultivars. Canadian Journal of Plant Science, 62, 533-536.

CLARHOLM, M. 1985: Interactions of bacteria, protozoa and plants leading to mineralization of soil nitrogen. Soil Biology and Biochemistry, 17, 2, 181-187.

COLLINS, H.P., P.E. RASMUSSEN & C.L. DOUGLAS. 1992: Crop Rotation and Residue Management Effects on Soil Carbon and Microbial Dynamics. Soil Science Society of America Journal, 56, 783-788.

CORTEZ, J. & A. CHERQUI. 1991: Plant growth and the mineralization of adsorbed 14C- and 15N-labelled organic compounds. Soil Biology and Biochemistry, 23, 3, 261-267.

CUTTLE, S.P. & S.C. JARVIS. 1995: Clover and Fertiliser Based Strategies to Limit Nitrate Leaching in Conventional Agriculture – Relevance of Research to Organic Farming Systems. Nitrogen Leaching in Ecological Agriculture. A B Academic Publishers, 135-144.

DANGLER, J.M. & C.W. WOOD. 1993: Nitrogen Rate, Cultivar, and Within-row Spacing Affect Collard Yield and Leaf Nutrient Concentration. Hort Science, 28, 7, 701-703.

DE PIERI, L.A., W.T. BUCKLEY & C.G. KOWALENKO. 1996: Micronutrient concentrations of commercially grown vegetables and of soils in the Lower Fraser Valley of British Columbia. Canadian Journal of Soil Science, 76, 173-182.

DENFER VON, D., H. ZIEGLER, F. EHRENDORFER & A. BRESINSKY. 1983: Lehrbuch der Botanik. Gustav Fischer Verlag, Stuttgart, New York, 1161 p.

DILZ, K. 1991: Efficiency of uptake and utilisation of fertiliser nitrogen by plants. In "Nitrogen efficiency in agricultural soils", Eds.: D.S. Jenkinson and K.A. Smith, Elsevier Applied Science, London and New York, 1-26.

DORMAAR, J.F. 1990: Effect of active roots on the decomposition of soil organic materials. Biology and Fertility of Soils, 10, 121-126.

DRURY, C.F., J.A. STONE & W.I. FINDLAY. 1991: Influence of cover crops on denitrification and nitrogen mineralization. In: W.L. Hargrove (Ed.) Cover crops for clean water, Proc. Int.

Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 94-96.

ELERS, B., H.D. HARTMAN. 1987: Biologische Konservierung von Nitrat über Winter. VDLUFA-Schriftenreihe, 20, Kongreßband, 427-439.

ELIA, A., M. GONNELLA, V. MAGNIFICO & P. SANTAMARIA. 1997: Diurnal variation of nitrate accumulation in broccoli rab leaves. Agr. Med., 127, 233-240.

ELLEN, J. 1987: Effect of plant density and nitrogen fertilisation in winter wheat (*Triticum aestivum* L.). 1. Production pattern and grain yield. Netherlands Journal of Agricultural Science, 35, 137-153.

ELTUN, R. 1995: Comparison of Nitrogen Leaching in Ecological and Conventional Cropping Systems. Nitrogen Leaching in Ecological Agriculture. A B Academic Publishers. 103-114.

ERREBHI, M., C.J. ROSEN, S.C. GUPTA & D.E. BIRONG. 1998: Potato Yield Response and Nitrate Leaching as Influenced by Nitrogen Management. Agronomy Journal, 90, 10-15.

EUROPEAN ECONOMIC COMMUNITY. 1980: Council Directive on the Quality of Water for Human Consumption. Official Journal. No. 80/778 EEC L229, 11-11.

EUROPEAN ECONOMIC COMMUNITY. 1995: Commission of the European Communities Scientific Committee for Food. Opinion on Nitrate and Nitrite, expressed on 22 September 1995. Annex 4 to Document III/5611/95.

EUROPEAN ECONOMIC COMMUNITY. 1999: Commission Regulation (EC) No. 1566/1999 of 16 July 1999 amending Regulation (EC) No. 194/97 setting maximum levels for certain contaminants in foodstuffs. Official Journal L 184, 17-17.

FALBE, J. & M. REGITZ. 1990: Römpp Chemie Lexikon. Thieme Verlag, 9. Auflage, Stuttgart, Band 2, 1138.

FENWICK, G.R., R.K. HEANEY & W.J. MULLIN. 1983: Glucosinolates and their breakdown products in food and food plants. CRC Critical Reviews in Food Science and Nutrition. 18, 2, 123-201.

FRANCIS, G.S., K.M. BARTLEY & F.J. TABLEY. 1998: The effect of winter cover crop management on nitrate leaching losses and crop growth. Journal of Agricultural Science, Cambridge, 131, 299-308.

FRANCOIS, L.E. 1984: Salinity Effects on Germination, Growth, and Yield of Turnips. Hort Science, 19, 1, 82-84.

FRANKENBERGER, W.T. & H.M. ABDELMAGID. 1985: Kinetic parameters of nitrogen mineralization rates of leguminous crops incorporated into soil. Plant and Soil, 87, 257-271.

FRANZLUEBBERS, A.J., M.A. ARSHAD & J. A. RIPMEESTER. 1996: Alterations in canola residue composition during decomposition. Soil Biology and Biochemistry, 28, 10/11, 1289-1295.

FREEMAN, G.G. & N. MOSSADEGHI. 1972: Studies on sulphur nutrition, flavour and allyl isothiocyanate formation in *Brassica juncea* L. Coss and Czern., brown mustard. Journal of Science of Food and Agriculture, 25, 685-693.

FRITZ, J. 2000. Reaktionen von Pflücksalat (*Lactuca sativa* L. *var. Crispa*) und Buschbohnen (*Phaseolus vulgaris* L. *var. Nanus*) auf das Spritzpräparat Hornkiesel. Diss. Agr. Bonn, Schriftenreihe Inst. Für Organischen Landbau, Verlag Dr. Köster, Berlin, 136 p

GANGOLLI, S.D., P.A. VAN DEN BRANDT, V.J. FERON, C. JANZOWSKI, J.H. KOEMAN, G.J.A. SPEIJERS, B. SPIEGELHALDER, R. WALKER & J.S. WISHNOK. 1994: Assessment: nitrate, nitrite and N-nitrosocompounds. European Journal of Environmental Toxicology and Pharmacology, Section 292, 1-38.

GLENDINING, M.J., D.S. POWLSON & P.R. POULTON. 1990: Some Agricultural and Environmental Consequences of Long-term Applications of Inorganic Nitrogen Fertilizer. In: Fertilization and the Environment, Edited by: R. Merckx, H. Vereecken and K. Vlassak, Leuven University Press, 189-196.

GOOS, M.J., K.R. HOWSE, D.G. CHRISTIAN, J.A. CATT & T.J. PEPPER. 1998: Nitrate leaching: Modifying the loss from mineralised organic matter. European Journal of Soil Science, 49, 649-659.

GOSS, M.J, P. COLBOURN, G.L. HARRIS & K.R. HOWSE. 1988: Leaching of nitrogen under autumn-sown crops and the effect of tillage. In “Nitrogen efficiency in agricultural soils” Ed. D.S. Jenkinson and K.A. Smith, Elsevier Applied Science, London and New York, 269-282.

GREENWOO, D.J., T.J. CLEAVER, M.K. TURNER, J. HUNT, K.B. NIENDORF & S.M.H. LOQUENS. 1980: Comparison of the effects of nitrogen fertiliser on the yield, nitrogen content and quality of 21 different vegetable and agricultural crops. Journal of Agricultural Science, Cambridge, 95, 471-485.

GREENWOOD, D.J., A. BARNES, K. LIU, J. HUNT, T.J. CLEAVER & S.M.H. LOQUENS. 1980: Relationships Between the Critical Concentrations of Nitrogen, Phosphorus and Potassium in 17 Different Vegetable Crops and Duration of Growth. Journal of Science of Food and Agriculture, 31, 1343-1353.

GREENWOOD, D.J. & A. DRAYCOTT. 1988: Recovery of fertiliser-N by diverse vegetable crops : Processes and models. In: Nitrogen efficiency in agricultural soils, Ed.: D.S. Jenkinson and K.A. Smith, Elsevier Applied Science, London and New York, 46-61.

GRIFFITH, G. & T.D. JOHNSTON. 1961: The nitrate-nitrogen content of herbage. III. The mineral nitrate content of rape and kale. Journal of Science of Food and Agriculture, 12, 348-352.

GROSSMAN, J. 1993: Brassica Alternatives to Herbicides and Soil Fumigants. IPM Practitioner, XV, 7, July, 1-10

GUILLARD, K. & D.W. ALLINSON. 1988: Yield and nutrient content of summer- and fall-grown forage Brassica crops. Canadian Journal of Plant Science, 68, 721-731.

GUILLARD, K. & D.W. ALLINSON. 1989. Seasonal Variation in Chemical Composition of Forage Brassicas. I. Mineral Concentrations and Uptake. Agronomy Journal, 81, 876-881.

GUILLARD, K. & D. W. ALLINSON. 1989a: Seasonal Variation in Chemical Composition of Forage *Brassicas*. II. Mineral Imbalances and Antiquality Constituents. Agronomy Journal, 81, 881-886.

GUILLARD, K., G.F. GRIFFIN, D.W. ALLINSON, W.R. YAMARTINO, M.M. RAFEY & S.W. PIETRZYK. 1995: Nitrogen Utilisation of Selected Cropping Systems in the U.S. Northeast: II. Soil Profile Nitrate Distribution and Accumulation. Agronomy Journal, 87, 199-207.

GUILLARD, K., S.W. PIETRZYK, K.A. CASSIDA, M.H. WIEDENHOEFT, R.L. HOUGH, B.A. BARTON & D.W. ALLINSON. 1995: Seasonal Nitrogen and Carbohydrate Partitioning in Forage Brassicas. Agronomy Journal, 87, 562-569.

GUIOT, J., M. FRANKINET, C. ROISIN & L. GREVY. 1990: Wheat Nitrogen Fertilisation as a Potential Threat to Groundwater Quality. In: Fertilisation and the Environment, Edited by: R. Merckx, H. Vereecken and K. Vlassak, Leuven University Press, 50-59.

HAAS, G., M. BERG & U. KÖPKE. 1998: Grundwasserschonende Landnutzung. Schriftenreihe Institut für Organischen Landbau, 1. Aufl., Verlag Dr. Köster, Berlin, 156 p.

HAAS, G. & U. KÖPKE. 2000: Underseeds in potatoes to minimise environmental burdens. Proceedings 13th IFOAM Scientific Conference, 28 to 31 August, Basel, 391-391.

HAIDER, K. A. MOISER & O. HEINEMEYER. 1987: The Effect of Growing Plants on Denitrification at High Soil Nitrate Concentrations. Soil Science Society of America Journal, 51, 97-102.

HANELT, P. 1998: Lesser known or forgotten cruciferous vegetables and their history. Proc. Int. Symp. on Brassicas, Ed.: Thomas Gregoire and Antonio A. Monteiro, Acta Hort., 459, ISHS, 39-45.

HARRISON, R., D.B. DAVIES & S. PEEL. 1996: Nitrogen uptake by cover crops at 7 sites in the UK: 1990-1993, In: Progress in Nitrogen Cycling Studies. Kluwer Academic Publishers, 203-205.

HART, P.B.S., K.M. GOH & T.E. LUDECKE. 1979: Nitrogen mineralization in fallow and wheat soils under field and laboratory conditions. New Zealand Journal of Agricultural Research, 22, 115-125.

HATHER, J.G., L. PEÑA-CHOCARRO & E.J. SIDELL. 1992: Turnip Remains from Byzantine Sparta. Economic Botany, 46, 4, 395-400.

HAUNZ, F.X., F.X. MAIDL & G. FISCHBECK. 1988: Stickstoff-Fixierung von Körnerleguminosen und deren Bedeutung für den N-Umsatz einer Fruchtfolge. Mitt. Ges. Pflanzenbauwiss., 1, 22-24.

HAVLIN, J.L., D.E. KISSEL, L.D. MADDUX, M.M. CLAASSEN & J.H. LONG. 1990: Crop Rotation and Tillage Effects on Soil Organic Carbon and Nitrogen. Soil Science Society of America Journal, 54, 448-452.

HAYS, S.M. 1990: Turnips: a new hit with sheep. Agricultural Research – U.S. Department of Agriculture, Agricultural Research Service, March 1990, 38, 3, 21-21.

HELAL, H.M. & D. SAUERBECK. 1986: Effect of plant roots on carbon metabolism of soil microbial biomass. Zeitschrift für Pflanzenernährung und Bodenkunde, 149, 181-186.

HEß, J. 1989: Kleegrasumbruch im Organischen Landbau: Stickstoffdynamik im Fruchtfolgeglied Kleegras – Kleegras – Weizen – Roggen. Dissertation Universität Bonn, 127 p.

HILBERT, M. 1987: Stoppelrüben – hohe Erträge, nährstoffreiches Futter. Rinderwelt, Jul./Aug., 114-115.

HOFMAN, G. & O. VAN CLEEMPUT. 1992: Nitrogen cycling in agricultural systems. In: Crop development for the cool and wet regions of Europe – Nitrogen cycling and leaching in cool and wet regions of Europe, Workshop, October 22-23, Gembeloux, Belgium, 1-7.

HOYT, G.D. & R.L. MIKKELSEN. 1991: Soil nitrogen movement under winter cover crops and residues. In: W.L. Hargrove (Ed.) Cover crops for clean water. Proc Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 91-94.

INDIAN BRASSICAS. 1989: Publications & Information Directorate, CSIR, Hillside road, New Delhi, India, 82 p.

JACKSON, L.E., L.J. WYLAND & L.J. STIVERS. 1993: Winter cover crops to minimise nitrate losses in intensive lettuce production. Journal of Agricultural Science, Cambridge, 121, 55-62.

JÄGGI, W., U. WALTHER & H.R. OBERHOLZER. 1990: Einfluss eingearbeiteter organischer Substanzen und von Azotobakter auf mikrobiologische Kennwerte des Bodens und den Pflanzenertrag. Landwirtschaft Schweiz, 3, 12, 693-699.

JENSEN, E.S. 1992: The release and fate of nitrogen from catch-crop materials decomposing under field conditions. Journal of Soil Science, 43, 335-345.

JENSEN, E.S. 1995: Cycling of Grain Legume Residue Nitrogen. Nitrogen Leaching in Ecological Agriculture. A B Academic Publishers. 193-202.

JINGGUO, W. & L. R. BAKKEN. 1989: Nitrogen Mineralization in Rhizosphere and Non-rhizosphere Soil, Effect of the Spatial Distribution of N-rich and N-poor Plant Residues. In: "Nitrogen in Organic Wastes Applied to Soils", Ed. by Jens AA. Hansen and Kaj Henriksen, Environmental Engineering Laboratory, University of Aalborg, Denmark, Academic press, 11-24.

JOFFE, J.S. 1955: Green Manuring Viewed by a Pedologist. Advanced Agronomy, 7, 141-187.

JOSEFSSON, E. & L.Å. APPELQVIST. 1968: Glucosinolates in seed of rape and turnip rape as affected by variety and environment. J. Sci. Food Agric., 19, 564-570.

JU, H.Y., C. CHONG, W.J. MULLIN & B.B. BIBLE. 1982: Volatile Isothiocyanates and Nitriles from Glucosinolates in Rutabaga and Turnip. Journal of American Society for Horticultural Science. 107, 6, 1050-1054.

JUNG, G.A., W.L. MCCLELLAN, R.A. BYERS, C.F. GROSS, R.E. KOCHER & E. REED. 1979: Old forage crops may make comeback. Crops and Soils Magazine, April – May, 17-19

JUNG, G.A., R.A. BYERS, M.T. PANCIERA & J.A. SHAFFER. 1986: Forage Dry Matter Accumulation and Quality of Turnip, Swede, Rape, Chinese Cabbage Hybrids, and Kale in the Eastern USA. Agronomy Journal, 78, 245-253.

JUNG, J., J. DRESSLER & R. KUCHENBUCH. 1989: Nitrogen Balance of Legume-Wheat Cropping Sequences. Journal of Agronomy and Crop Science, 162, 1-9.

JUNG, G.A. & J.A. SHAFFER. 1993: Planting Date and Seeding Rate Effects on Morphological Development and Yield of Turnip. Crop Science, 33, 1329-1334.

JUNG, G.A. & J.A. SHAFFER: 1995. Planting and Harvest Date Effects on Productivity and Root/Shoot Quotient of Four Brassica Cultivars. Agronomy Journal, 87, 1004-1010.

JUSTES, E., B. MARY & B. NICOLARDOT. 1999: Comparing the effectiveness of radish cover crop, oilseed rape volunteers and oilseed rape residues incorporation for reducing nitrate leaching. Nutrient Cycling in Agroecosystems, 55, 207-220.

JUSTUS, M. 1996: Optimierung des Anbaues von Ackerbohnen: Reduzierung von Nitratverlusten und Steigerung der Vorfruchtwirkung zu Sommergetreide. Dissertation Universität Bonn, 131 p.

JUSTUS, M. & U. KÖPKE. 1995: Strategies to avoid nitrogen losses via leaching and to increase precrop effects when growing faba beans. 1. Intern. Workshop on Nitrate Leaching, 11.-

15.10.1993, Copenhagen, Denmark. Biological Agriculture and Horticulture (BAH), Vol 11/1995, 145-155.

KAHNT, G. 1985: Welche Vorfruchtwert haben Körnerleguminosen? DLG-Mitteilungen, 3, 138-140.

KENG, H. 1974: Economic plants of ancient north China as mentioned in *Shih Ching* (Book of Poetry). Economic Botany, 23, 391-410.

KIRKEGAARD, J.A & M. SARWAR. 1998: Assessing the biofumigation potential of crucifers. Proc. Int. Symp. on Brassicas, Ed.: Thomas Gregoire and Antonio A. Monteiro, Acta Hort., 459, ISHS, 105-111.

KLAPWIJK, J. 1996: Flächenbegrünung im Spargelanbau. Gemüse, 8, 505-506.

KÖHNLEIN, J. 1972: Einfluß der winterlichen Stickstoffauswaschung auf die Stickstoffversorgung des Getreides. Landwirtschaftliche Forschung, 25, 1-15.

KÖPKE, U. 1987: Symbiotische Stickstofffixierung und Vorfruchtwirkung von Ackerbohnen (*Vicia faba* L.). Habilitation Thesis, University of Göttingen, 113 p.

KÖPKE, U. 1995: Nutrient Management in Organic Farming Systems: the Case of Nitrogen. Nitrogen Leaching in Ecological Agriculture, A B Academic Publishers, 15-29.

KÖPKE, U. 1996: Legume nitrogen in crop rotation: Reducing losses – increasing precrop effects. In: Symbiotic nitrogen fixation in crop rotations with manure fertilisation, Proceedings of the third meeting in Cophenhagen, March 4th to 5th, Publications of the Institute for Biodynamic Research Darmstad, 8, 32-51.

KREMER-SCHILLINGS, W. 1982: Gründüngung und Fruchtfolge. Landwirtschaftliche Zeitschrift Nr. 24, 19. Juni, 1574-1575.

KTBL, 2004: Betriebsplanung Landwirtschaft 2004/2005, 19. Auflage, Darmstadt, 573 p.

KUO, S., U.M. SAINJU & E.J. JELLUM. 1997: Winter Cover Cropping Influence on Nitrogen in Soil. Soil Science Society American Journal, 61, 1392-1399.

KUTACEK, M. 1964: Glucobrassicin, a potential inhibitor of unusual type affecting the germination and growth of plants: mechanism of its action. Biol. Plantarum (Prague), 6, 88-93.

LAINE, P., A. OURRY, J. MACDUFF, J. BOUCAUD & J. SALETTE. 1993: Kinetic parameters of nitrate uptake by different catch crop species: effects of low temperatures or previous nitrate starvation. Physiologia Plantarum, 88, 85-92.

LAL, R., E. REGNIER, D.J. ECKERT, W.M. EDWARDS & R. HAMMOND. 1991: Expectations of cover crops for sustainable agriculture. In: W.L. Hargrove (Ed.) Cover crops for clean water, Proc Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 1-11.

LEHMANN, J., H.U. BRINNER & E. ROSENBERG. 1991: Zwischenkulturen – was können sie und was können sie nicht? Landwirtschaft Schweiz, Band 4 (4), 151-158.

LEWAN, E. 1993: Evaporation and discharge from arable land with cropped or bare soils during winter. Measurements and simulations. Agricultural and Forest Meteorology, 64, 131-159.

MACDUFF, J.H., S.C. JARVIS & D.H. ROBERTS. 1990: Nitrate Leaching under Grazed Grassland : Measurements Using Ceramic Cup Soil Solution Samplers. In: Fertilisation and the Environment. Edited by: R. Merckx, H. Vereecken and K. Vlassak, Leuven University Press, 72-78.

MAIDL, F.X., J. SUCKERT, R. FUNK & G. FISCHBECK. 1991: Standorterhebungen zur Stickstoffdynamik nach Anbau von Körnerleguminosen. Journal of Agronomy and Crop Science, 167, 259-268.

MARTIN, P. & B. RADEMACHER. 1960: Experimentelle Untersuchungen zur Frage der Nachwirkung von Rapswurzelrückständen. Z. f. Acker- und Pflanzenbau, 111, 2, 105-115.

MARTINEZ, J. & G. GUIRAUD. 1990: A lysimeter study of the effects of a ryegrass catch crop, during a winter wheat/maize rotation, on nitrate leaching and on the following crop. Journal of Soil Science, 41, 5-16.

MARTINEZ, J. & G. GUIRAUD. 1990a: Effects of Cover Crops on Nitrogen Behaviour: A Two Years Lysimeter Study Using ^{15}N. In: Fertilisation and the Environment, Edited by: R. Merckx, H. Vereecken and K. Vlassak, Leuven University Press, 217-224.

MARY, B., S. RECOUS, D. DARWIS & D ROBIN. 1996: Interactions between decomposition of plant residues and nitrogen cycling in soil. Plant and Soil, 181, 71-82.

MAYNARD, D.N., A.V. BARKER, P.L. MINOTTI & N.H. PECK. 1976: Nitrate accumulation in vegetables. Advanced Agronomy, 28, 71-118.

MAYTON, H.S., C. OLIVER, S.F. VAUGHN & R. LORIA. 1996: Correlation of Fungicidal Activity of *Brassica* Species with Allyl Isothiocyanate Production in Macerated Leaf Tissue. Phytopathology, 86, 3, 267-271.

MCCRACKEN, D., M.S. SMITH, J.H. GROVE, C.T. MACKOWN & R.L. BLEVINS. 1994: Nitrate Leaching as Influenced by Cover Cropping and Nitrogen Source. Soil Science Society of America Journal, 58, 1476-1483.

MCEWEN, J., R.J. DARBY, M.V. HEWITT & D.P. YEOMAN. 1989: Effects of field beans, fallow, lupins, oats, oilseed rape, peas, ryegrass, sunflowers and wheat on nitrogen residues in the soil and on the growth of a subsequent wheat crop. Journal of Agricultural Science, Cambridge, 115, 209-219.

MEISINGER, J.J., W.L. HARGROVE, R.L. MIKKELSEN, J.R.WILLIAMS & V.W. BENSON. 1991: Effects of cover crops on groundwater quality. In: W.L. Hargrove (Ed.) Cover crops for clean water, Proc Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 57-68.

MERBACH, W., A. WURBS, H. PFEFFER & C. LATUS. 1993: The effect of catch crops on the 15N nitrogen percolation and leaching during the early winter period. Isotopenpraxis Environ. Health Stud., 29, 93-97.

MERBACH, W., A. WURBS & C. LATUS. 1996: Auswirkung der Stickstoffkonservierung durch Winterrübsen (*Brassica rapa*, var. *oleifera*) auf die N-Verwertung von nachfolgend angebautem Mais und die N-Verlagerung in einem leichtem Boden Nordostdeutschlands. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, 79, 259-262.

MERBACH, W., E. MIRUS, G. KNOF, R. REMUS, S. RUPPEL, R. RUSSOW, A. GRANSEE & J. SCHULZE. 1999: Release of carbon and nitrogen compounds by plant roots and their possible ecological importance. J. Plant Nutr. Soil Sci., 162, 373-383.

MILFORD, G.F.J., A. PENNY, R.D. PREW, R.J. DARBY & A.D. TODD. 1993: Effect of previous crop, sowing date, and winter and spring application of nitrogen on the growth, nitrogen uptake and yield of winter wheat. Journal of Agricultural Science, Cambridge, 121, 1-12.

MILLNER, J.P. 1993: A comparison of six autumn sown Brassica forage crops in the Manavatu. Proceedings Agronomy Society of New Zealand, 23, 43-46.

MITHEN, R.F & H. CAMPOS-DE QUIROZ. 1998: Biochemical genetics of aliphatic glucosinolates. Proc. Int. Symp. on Brassicas, Ed.: Thomas Gregoire and Antonio A. Monteiro, Acta Hort., 459, ISHS, 373-377.

MOSSOBA, M.M., G.J. SHAW, D. ANDRZEJEWSKI, J. A. SPHON & S. W. PAGE. 1989: Application of Gas Chromatography / Matrix Isolation / Fourier Transform Infrared Spectrometry to the Identification of Glucosinolates from Brassica Vegetables. J. Agric. Food Chem., 37, 367-372.

MOUCHOVA, H., J. KLIR & H. LIPPOLD. 1996: Effect of weather conditions and time of N application on the uptake of soil and applied N by winter wheat. Progress in Nitrogen Cycling Studies, (Ed.) O. Van Cleemput et al., Kluwer Academic Publishers, 237-241.

MUEHLCHEN, A.M., R.E. RAND & J.L. PARKE. 1990: Evaluation of Crucifer Green Manure for Controlling Aphanomyces Root Rot of Peas. Plant Disease, Sep., 651-654.

MULLIN, W.J., K.G. PROUDFOOT & M.J. COLINS. 1980: Glucosinolate content and clubroot of rutabaga and turnip. Canadian Journal of Plant Science, 60, 605-612.

NEETESON, J.J., D.J. GREENWOOD & A. DRAYCOTT. 1989: Model calculations of nitrate leaching during the growth period of potatoes. Netherlands Journal of Agricultural Science, 37, 237-256.

NEGRI, E., C. LA VECCHIA, S. FRANCESCHI, B. D`AVANZO & F PARAZZINI. 1991: Vegetable and fruit consumption and cancer risk. Int. J. Cancer. 48, 350-354.

NEUHOFF, D. 2000: Speisekartoffelerzeugung im Organischen Landbau – Einfluß von Sorte und Rottemistdüngung auf Ertragsbildung und Knolleninhaltsstoffe. Diss. Agr. Bonn, Schriftenreihe Inst. für Organischen Landbau, Verlag Dr. Köster, Berlin, 151 p.

NINANE, V., J.P. GOFFART, J.P. DESTAIN & E. FRANCOIS. 1996: Recovery of green manure N by succeeding sugar beet. Progress in Nitrogen Cycling Studies, (Ed.) O. Van Cleemput et al., Kluwer Academic Publishers, 247-250.

OLESZEK, W. 1987: Allelopathic effects of volatiles from some Cruciferae species on lettuce, barnyard grass and wheat growth. Plant and Soil, 102, 271-273.

OOMEN, G.J.M. 1995: Nitrogen Cycling and Nitrogen Dynamics in Ecological Agriculture. In: Nitrogen Leaching in Ecological Agriculture, A B Academic Publishers, 183-192.

OPITZ VON BOBERFELD, W. & J. JASPER. 1994: Vorfruchtwirkung unterschiedlicher Rotationsbrachen auf Winterweizen. Journal of Agronomy and Crop Science, 173, 125-134.

PEARSON, A.J. & N.A. THOMSON. 1996: Effect of nitrogen and phosphate fertiliser on the yield and nitrogen content of Barkant turnips sown as a summer supplementary feed for dairy cows in Taranaki. Proceedings Agronomy Society of New Zealand, 26, 37-43.

PENROSE, C.D., H.M. BARTHOLOMEW, R.M. SULC, S.D. SCHUMACHER & R. DUFF. 1996: Performance of brassica cultivars from New Zealand and United States seed sources in Southeast Ohio, USA, Proceedings of the New Zealand Grassland Association, 57, 111-113.

PERCIVAL, N.S., D.I. BOND & R.M. HUNTER. 1986: Evaluation of new forage brassica cultivars on the central plateau. Proceedings Agronomy Society of New Zealand, 16, 41-48.

PETERSEN, J. 1999: Untersuchungen zur Unkrautbekämpfung mit Bodendeckern in herbizidresistentem Mais. Cuvillier Verlag Göttingen, Dissertation, Universität Hohenheim, 156 p.

PINTO, S., E. ROSA & S. SANTOS: 1998. Effect of 2-propenyl glucosinolate and derived isothiocyanate on the activity of the nematodes *Globodera rostochiensis* (Woll.). Proc. Int. Symp. on Brassicas, Ed.: Thomas Gregoire and Antonio A. Monteiro, Acta Hort., 459, ISHS, 323-327.

POWLSON, D.S., P.C. BROOKES & CHRISTENSEN, B.T. 1987: Measurement of soil microbial biomass provides an early indication of changes in total soil organic matter content due to straw incorporation. Soil Biology and Biochemistry, 19, 159-164.

POWLSON, D.S., P.R. POULTON, T.M. ADDISCOTT & D.S. MCCANN. 1989: Leaching of Nitrate from Soil Receiving Fertilisers Continuously for 135 Years. In "Nitrogen in Organic Wastes Applied to Soils", Ed. by Jens AA. Hansen and Kaj Henriksen, Environmental Engineering Laboratory, University of Aalborg, Denmark, Academic press, 334-345.

POWLSON, D.S. 1993: Understanding the soil nitrogen cycle. Soil Use and Management, 9, 3, 86-94.

POWLSON, D.S. 1994: Water quality and fertiliser use – understanding the nitrate problem. Marshall B.J. & Miller F.A. (Eds), Water services and agriculture: key issues and strategic options, CAS Paper 29, 84-103.

PRAKASH, S. & V.L. CHOPRA. 1996: Origin and evolution. In Oilseed and Vegetable Brassicas : Indian Perspective. Ed.: V.L. Chopra and Shyam Prakash, Oxford & IBH Publishing Co. New Delhi. 35-49.

PRINS, W. H., K. DILZ & J.J. NEETESON. 1988: Current recommendations for nitrogen fertilisation within the EEC in relation to nitrate leaching. Proceedings 276. The Fertiliser Society, London, 27-27.

QUEMADA, M. & M.L. CABRERA. 1995: Carbon and Nitrogen Mineralised from Leaves and Stems of Four Cover Crops. Soil Science Society of America Journal, 59, 471-477.

RAJPUT, C.B.S. & SINGH V.B. 1982: Effect of nitrogen, phosphorus and potassium on growth and yield attributing characters of turnip. Haryana Journal of Horticultural Science, 11, 3/4, 235-239.

RAO, S.C. & F.P. HORN. 1986: Planting Season and Harvest Date Effects on Dry Matter Production and Nutritional Value of *Brassica* spp. In the Southern Great Plains. Agronomy Journal, 78, 327-333.

RECOUS, S. & B. MARY. 1990: Microbial immobilization of ammonium and nitrate in cultivated soil. Soil Biology and Biochemistry, 22, 7, 913-922.

REENTS, H.J. & K. MÖLLER. 1997: Strategien zur Stickstoffnutzung bei Getreide nach Kartoffeln. Lebendige Erde, 4. 309-314.

REENTS, H.J., K. MÖLLER & F.X. MAIDL. 1997: Nutzung des Bodennitrats durch differenzierte Anbaustrategien von Getreide als Nachfrucht von Kartoffeln. Beitr. 4. Wiss.-Tagung Ökol. Landbau, Bonn, 3.- 4. März, 129-135.

REENTS, H.J. & K. MÖLLER. 2000: Effect of different green manure catch crops grown after peas on nitrate dynamics in soils and on yield and quality of subsequent potatoes and wheat.

Proceedings 13th International IFOAM Scientific Conference, 28 to 31 August 2000 Basel, 73-76.

REID, R.L., J.R. PUOLI, G.A. JUNG, J.M. COX-GANSER & A. MCCOY. 1994: Evaluation of Brassicas in Grazing Systems for Sheep: I. Quality of Forage and Animal Performance. Journal of Animal Science, 72, 1823-1831.

REINERTSEN, S.A., L.F. ELLIOT, V.L. COCHRAN & G.S. CAMPBELL. 1984: Role of available carbon and nitrogen in determining the rate of wheat straw decomposition. Soil Biology and Biochemistry, 16, 5, 459-464.

RICHARDS, I.R., P.A. WALLACE & I.D.S. TURNER. 1996: A comparison of six cover crop types in terms of nitrogen uptake and effect on response to nitrogen by a subsequent spring barley crop. Journal of Agricultural Science, Cambridge, 127, 441-449.

RICHTER, G.M., K. BAUMANN & J. RICHTER. 1996: Simulation des Nitrataustrags im Winterhalbjahr aus intensiv genutzten Ackerböden in der Geest. Zeitschrift für Pflanzenernährung und Bodenkunde, 159, 279-288.

ROBERSON, E.B., S. SARIG & M.K. FIRESTONE. 1991: Cover Crop Management of Polysaccharide-Mediated Aggregation in an Orchard Soil. Soil Science Society of America Journal, 55, 734-739.

ROGASIK, J. M. SMUKALSKI & S. OBENAUF. 1992: Cover crop on sandland in Germany : husbandry ad fate of nitrogen. Aspects of applied Biology, 30, Nitrate and Farming Systems, 309-316.

SAMWEL, M. 1995: Bio-Gemüse deutlich geringer belastet. Umweltnachrichten, 64/95, 49-49.

SCHELLER, E & H. VOGTMANN. 1995: Case Studies on Nitrate Leaching in Arable Fields of Organic Farms. Nitrogen Leaching in Ecological Agriculture, A B Academic Publishers, 91-102.

SHATTUCK, V.I., Y. KAKUDA, B.J. SHELP & N. KAKUDA. 1991: Chemical Composition of Turnip Roots Stored or Intermittently Grown at Low Temperature. Journal of American Society for Horticultural Science, 116, 5, 818-822.

SHEETS, O., L. PERMENTER, M. WADE, W.S. ANDERSON & M. GIEGER. 1955: The Effect of Different Levels of Moisture on the Vitamin, Mineral and Nitrogen Content of Turnip Greens. Proceedings of the American Society for Horticultural Science, 66, 258 – 260.

SHELDRICK, R.D. & R.H. LAVENDER. 1981: A comparison of a hybrid stubble turnip (cv. Appin) with other cruciferous catch crops for lamb fattening. 1. Initial evaluation for dry matter yield and forage quality. Grass and Forage Science, 36, 281-289.

SHEPHERD, M.A. & E.I. LORD. 1996: Nitrate leaching from a sandy soil: the effect of previous crop and post-harvest soil management in an arable rotation. Journal of Agricultural Science, Cambridge, 127, 215-229.

SHEPHERD, M.A. 1999: The effectiveness of cover crops during eight years of a UK sandland rotation. Soil Use and Management, 15, 41-48.

SHIPLEY, P.R., J.J. MEISINGER & A.M. DECKER. 1992: Conserving Residual Corn Fertiliser Nitrogen with Winter Cover Crops. Agronomy Journal, 84, 869-876.

SIMONNE, E.H., D.A. SMITTLE & H.A. MILLS. 1993: Influence of irrigation on dry matter production, leaf composition, and nutrient removal by turnip. Journal of Plant Nutrition, 16, 7, 1215-1228.

SIMONNE, E.H., D.A. SMITTLE & H.A. MILLS. 1993: Turnip growth, leaf nutrient composition responses to nitrogen forms. Journal of Plant Nutrition, 16, 12, 2341-2351.

SINGH, A.K. & K.C. SHARMA. 1993: Effect of different levels of NPK on root yield and its quality in turnip. Haryana Journal of Horticultural Science, 22, 4, 321-323.

SINGH, H.B., R.K. KAPILA, J.K. SHARMA & S. LATA. 1996: Effect of Insect Pollination on Seed Yield and its Quality in Turnip (*Brassica rapa* L.). Seed Research, 24, 1, 48-50.

SKALAR ANALYTICAL B. V. 1993: Soil and plant Analysis. Breda, Publ. Nr. 0640693.

SMUKALSKI, M. J. ROGASIK & S. OBENAUF. 1991: Cultivation of cover crops to control nitrate leaching. In: W.L. Hargrove (Ed.) Cover crops for clean water, Proc Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 82-84.

SOLBERG, S.Ø. 1995: Influence of Crops and Cultivation Management on the Nitrogen Leaching Potential on Ecological Farms in South East Norway. In “Nitrogen Leaching in Ecological Agriculture”, A B Academic Publishers, 115-121.

SØRENSEN, J.N. 1992: Effect of catch crops on the content of soil mineral nitrogen before and after winter leaching. Z. Pflanzenernähr. Bodenk., 155. 61-66.

STAGNITTI, F., J. SHERWOOD, G. ALLINSON, L. EVANS, M. ALLINSON, L. LI & I. PHILLIPS. 1998: An investigation of localised soil heterogeneities on solute transport using a multisegment percolation system. New Zealand Journal of Agricultural Research, 41, 603-612.

STANFORD, G., M.H. FRERE & D.H. SCHWANINGER. 1973: Temperature coefficient of soil nitrogen mineralization. Soil Science, 115, 4, 321-323.

STOWE, K.A. 1998: Realised Defence of Artificially Selected Lines of Brassica rapa: Effects of Quantitative Genetic Variation in Foliar Glucosinolate Concentration. Environmental Entomology, 27, 5, 1166-1174.

STÜTZEL, H., W. AUFHAMMER & A. FIEGENBAUM. 1992: Reducing nitrogen losses from faba bean residues by interplanting. Proceedings of the Second Congress of the European Society for Agronomy, Warwick University, 23 – 28 August, 430-431.

THIES, W. 1982: Complex-Formation between Glucosinolates and Tetrachloropalladate (II) and its Utilisation in Plant Breeding. Fette, Seifen, Anstrichmittel, 84, 9, 338-342.

THORUP-KRISTENSEN, K. 1993: The Effect of Nitrogen Catch Crops on the Nitrogen Nutrition of a succeeding Crop, I. Effects through Mineralization and Pre-emptive Competition. Acta Agric. Scand., Sect. B, Soil and Plant Science, 43, 74-81.

THORUP-KRISTENSEN, K. 1993a: Root Development of Nitrogen Catch crops and of a succeeding Crop of Broccoli. Acta Agric. Scand., Sect. B, Soil and Plant Science, 43, 58-64.

THORUP-KRISTENSEN, K. 1994: The effect of nitrogen catch crop species on the nitrogen nutrition of succeeding crops. Fertiliser Research, 37, 227-234.

THORUP-KRISTENSEN, K. 1995: Optimal Strategies for Nitrogen Catch Crop Use : with Emphasis on Root Growth, Pre-emptive Competition and Nitrogen Availability for the succeeding Crop. PhD Thesis, Danish Institute of Plant and Soil Science, Department of Fruit and Vegetables, 63 p.

THORUP-KRISTENSEN, K. & N.E. NIELSEN. 1998: Modelling and measuring the effect of nitrogen catch crops on the nitrogen supply for succeeding crops. Plant and Soil, 203, 79-89.

TOLLSTEN, L. & G. BERGSTRÖM. 1988: Headspace volatiles of whole plants and macerated plant parts of *brassica* and *sinapis*. Phytochemistry, 27, 12, 4013-4018.

UHL, M., H. STEINKELLNER, F. KASSIE, B. LAKY & S. KNASMÜLLER. 2001: Beeinflussung der menschlichen Gesundheit durch Glukosinolate (EFGLU). Zeitschrift für Ernährungsökologie, 2, 1, 56-60.

VALLE DEL, C.G. & S.A. HARMON. 1970: Influence of Seeding Rate, Source and Level of Nitrogen, on Yield, Colour, Leaf Blade Weight, and Nitrogen Content of Turnip Greens. Journal of American Society for Horticultural Science, 95, 1, 62-64.

VAN DAM, A.M. & P.A. LEFFELAAR. 1998: Root, Soil water and nitrogen Dynamics in a catch crop – soil system in the Wageningen Rhizolab. Netherlands Journal of Agricultural Science, 46, 267-284.

VANDENDRIESSCHE, H., L. VANONGEVAL, E. SMEETS & M. GEYPENS. 1996: Monitoring of N-uptake by green manure and of the influence of N-release on N-availability, production and quality of sugar beet. Progress in Nitrogen Cycling Studies, (Ed.) O. Van Cleemput et al., Kluwer Academic Publishers, 147-151.

VAUGHN, S.F. & R.A. BOYDSTON. 1997: Volatile Allelochemicals released by crucifer green manures. Journal of Chemical Ecology, 23, 9, 2107-2116.

VDLUFA-METHODENBUCH. 1991: Band 1, 4. Auflage, VDLUFA Verlag Darmstadt.

VIEIRA, I.S, E.P. VASCONCELOS & A.A. MONTEIRO. 1998: Nitrate accumulation, yield and leaf quality of turnip greens in response to nitrogen fertilisation. Nutrient Cycling in Agroecosystems, 51, 249-258.

VIGIL, M.F. & D.E. KISSEL. 1991: Equations for Estimating the Amount of Nitrogen Mineralized from Crop Residues. Soil Science Society of America Journal, 55, 757-761.

WAGGER, M.G., D.E. KISSEL & S.J. SMITH. 1985: Mineralization of Nitrogen from Nitrogen-15 Labeled Crop Residues Under Field Conditions. Soil Science Society of America Journal, 49, 1220-1226.

WAGGER, M.G. 1989: Time of Dessication Effects on Plant Composition and Subsequent Nitrogen Release from Several Winter Annual Cover Crops. Agronomy Journal, 81, 236-241.

WAGGER, M.G., M.L. CABRERA & N.N. RANELLS. 1998: Nitrogen and carbon cycling in relation to cover crop residue quality. Soil and Water Conservation, 53, 3, 214-218.

WALLGREN, B. & B. LINDEN. 1994: Effects of Catch Crops and Ploughing Times on Soil Mineral Nitrogen. Swedish Journal of Agricultural Research, 24, 67-75.

WANG, H.X. & J.J. WANG. 1994: Newly selected Weixian turnip line with small plants and purple flowers. China Vegetables, 2, 51-52.

WHITMORE, A.P. & T.M. ADDISCOTT. 1985: Computer simulation of changes in soil nitrogen during winter under a crop of winter wheat. Assessment of Nitrogen Fertiliser Requirement. Proceedings of the second Meeting of the NW-European Study Group for the Assessment of Nitrogen Fertiliser Requirement, Haren 14-16 May 1984, Eds.: J.J. Neeteson and K. Dilz, 133-137.

WIDDOWSON, F.V., A. PENNY, R.J. DARBY, E. BIRD & M.V. HEWITT. 1987: Amounts of NO_3^--N and NH_4^+-N in soil, from autumn to spring, under winter wheat and their relationship to soil type, sowing date, previous crop and N uptake at Rothamsted, Woburn and Saxmundham, 1979-85. Journal of Agricultural Science, Cambridge, 108, 73-95.

WIEDENHOEFT, M.H. & B.A. BARTON. 1994: Management and Environment Effects on *Brassica* Forage Quality. Agronomy Journal, 86, 227-232.

WILSON, G.V., D.D. TYLER, J. LOGAN & K. TURNAGE. 1991: Tillage and cover crop effects on nitrate leaching. In: W.L. Hargrove (Ed.) Cover crops for clean water, Proc Int. Conf. W. Tenn. Exp. Stn., Jackson, TN. 9-11 Apr. Soil and Water Conserv. Soc. Am., 71-73.

WIRSING, F. R. SCHENK & R. WINZER. 1991: Dammbegrünung – ein ökologisch orientiertes Anbauverfahren bei Kartoffeln. Feldwirtschaft, 32, 324-327.

WOLFF, I.A., A.E. WASSERMAN. 1972: Nitrates, nitrites and nitrosaminas. Science, 177, 15-19.

YOUNG, L. S. 1998: Growth, Nitrogen Accumulation and Weed Suppression by Fall Cover Crops Following Early Harvest of Vegetables. Hort Science, 33, 1, 60-63.

YSART, G. 1998: MAFF – UK Nitrate in vegetables. Food Surveillance Information Sheet, September, No. 158.

ZEVEN, A.C. 1996: Sixteenth to eighteenth century depictions of cole crops, (*Brassica oleracea* L.), turnips (*B.rapa* L. cultivar group vegetable turnip) and radish (*Raphanus sativus* L.) from Flanders and the present-day Netherlands. Proc. Int. Symp. on Brassicas. Ninth Crucifer Genetics Workshop, Ed.: J.S. Dias, I. Crute and A.A. Monteiro, Acta Hort., 407, ISHS, 29-33.