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Transfer of Grain Legume Nitrogen within a Crop Rotation Containing Winter Wheat and Winter Barley

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With 3 figures and 5 tables

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Abstract

In a crop rotation trial, conducted from 1985 to 1988 at TU-Munich's research station in Roggenstein, the transfer of grain legume nitrogen was evaluated in crop rotations containing fababeans and dry peas as well as oats (reference crop) and winter wheat and winter barley as following crops. The results obtained can be summarized as follows:

Dinitrogen fixation by fababeans ranged from 165 to 240 kg N ha^{-1}, whereas N_2-fixation by peas amounted from 215 to 246 kg N ha^{-1}. In all seasons the calculated N-balance where only grain was removed was positive, with a net gain being on average 106 (peas) and 84 (fababeans) kg N ha^{-1}.

After the harvest of peas 202 kg N ha^{-1} remained on the field on average over seasons (158 kg N ha^{-1} in the above ground biomass and 44 kg N ha^{-1} as NO_3-N in 0—90 cm depth). As compared to peas, fababeans left 41 kg N ha^{-1} less due to smaller amounts of nitrogen in the straw. After oats very small amounts of residual nitrogen (33 kg N ha^{-1}) were detected.

After the harvest of grain legumes always a very high nitrogen mineralization was observed during autumn especially after peas due to a close C/N-relationship and higher amounts of nitrogen in the straw as compared to fababeans. In comparison with fababeans, N-mineralization after the cultivation of oats remained lower by more than 50 %.

During winter, seepage water regularly led to a considerable decrease of soil NO_3-N content. The N-leaching losses were especially high after cultivation of peas (80 kg N ha^{-1}) and considerably lower after fababeans (50 kg N ha^{-1}) and oats (20 kg N ha^{-1}).

As compared to oats, a higher NO_3-N content in soil was determined at the beginning of the growing period after preceding grain legumes. Therefore, winter wheat yielded highest after preceding peas (68 dt ha^{-1}) and fababeans (60 dt ha^{-1}) and lowest after preceding oats (42 dt ha^{-1}). The cultivation of grain legumes had no measurable effect on yield formation of the third crop winter barley in either of the growing seasons.

Key words: Grain legumes, dinitrogen fixation, crop rotation, nitrogen transfer.

Introduction

In the western part of Germany prices policy of the European Union concerning grain legumes and cereals led to an increase of the area planted with fababeans and peas from 4000 ha in 1980 to more than 100 000 ha in 1987. At present, grain legumes are being grown on 30 000 ha and the importance of organic farming is steadily rising. Hence, is renewed interest in the incorporation of grain legumes in cropping systems, particularly due to the significant contribution of nitrogen from the legumes to subsequent non-legume crops.

In agriculture, especially in organic farming but also for ecological reasons, there is interest

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Table 1. Amounts of precipitation (mm) and average air temperature (°C) during the experimental seasons 1986—1988

year	1986		1987		1988	
month	mm	°C	mm	°C	mm	°C
January	62.9	−0.5	48.1	−5.9	35.7	2.5
February	10.7	−7.8	81.6	−0.8	67.7	1.3
March	50.6	2.5	53.2	−0.8	126.4	2.6
April	96.6	6.7	52.3	9.0	49.3	8.5
May	111.7	13.8	125.2	9.3	43.8	14.1
June	92.2	14.9	128.3	14.7	91.6	15.4
July	122.5	16.5	127.9	17.6	93.9	18.0
August	79.2	16.8	107.1	11.7	113.3	17.8
September	20.6	11.5	90.5	11.7	40.2	13.0
October	65.5	8.7	17.6	6.0	44.7	10.3
November	24.3	3.7	59.0	1.1	47.7	1.8
December	7.1	0.7	63.1	−0.5	116.3	2.1
sum/mean	743.9	7.3	953.9	6.1	870.6	9.0

to know the amount of dinitrogen fixation by cultivated grain legumes and the effects on N-dynamics in the soil in order to utilize legume-N as efficiently as possible.

This paper reports on a study of dinitrogen fixation by fababeans and peas, the dynamics of soil nitrogen after harvest, the N-leaching during winter and the contribution of N to subsequent winter wheat and winter barley.

Materials and Methods

From 1985 to 1988 a crop rotation experiment was conducted at TU Munich's research station in Roggenstein on a sandy loam. The soil was maintained in the optimum range of available P, K and Mg and at a pH of 6.5. The soil's plough layer 0—30 cm contained 1.15 % C and 0.14 % N_t. The experiments included the grain legumes fababean and dry peas as well as oats as reference crop and winter wheat and winter barley as subsequent crops. The experimental layout was a split-plot arrangement with two replications. Grain legumes and oats as first year crops were grown on plots 162 m^2 in size, individual plot size of second year winter wheat and third year winter barley was 24 m^2. The experiments were carried out with cultivars 'Herz Freya' (fababeans), 'Stehgold' (peas), 'Pirol' and 'Panther' (oats), 'Basalt' (winter wheat) and 'Viola' (winter barley). The crops received ammonium nitrate fertilizer at the following rates:

fababeans and peas: 0 kg N ha^{-1}

oats: 50 kg N ha^{-1} (1985 and 1986), 0 kg N ha^{-1} (1987 and 1988)

winter wheat: N_1 = 0 kg N ha^{-1}, N_2 = 50 kg N ha^{-1}

winter barley: 50 kg N ha^{-1}

For the first and second year crops grain yield, yield components and N-uptake at four (legumes) and five (cereals) developmental stages were recorded. For the third year crop of winter barley, only grain yield and yield components were determined. Dinitrogen fixation by legumes was calculated according to the extended difference method (STÜLPNAGEL 1982), where the following formula is applied:

$$N_{fixed} = N_{Legume} - N_{Reference\ crop} + (N_{min\ Legume} - N_{min\ Reference\ crop})$$

After the harvest of grain legumes and oats nitrate content in 0—90 cm soil depth was determined at approximately 4-weekly intervals until ear emergence of the following winter wheat. At each sample date, eight soil samples per plot were taken, subdivided into 3 × 30 cm sections and merged separately for each depth. After homogenizing, the soil samples were held in cold store at −18 °C. The nitrate content of soil samples was determined photometrically by an autoanalyzer (SKALAR).

N-leaching with seepage water after cultivation of grain legumes and oats was calculated according to a method developed by SIMON et al. (1988), where the amount of leached N between two sample dates is determined by the amount of seepage water and the average nitrogen concentration in the soil layer 60—90 cm. The amount of seepage water results from the change of soil water content and the precipitation minus evapotranspiration. The water consumption by winter wheat was neglected during the period from November until March and evaporation was assumed to be the same as evaporation of a fallow.

Rainfall and temperature distribution from seasons 1986—1988 in Roggenstein are shown in Table 1. Seasonal totals and average temperatures ranged from 744 to 954 mm and 6.1 to 9.0 °C, respectively, indicating very different weather conditions between the three growing seasons. 1986 was marked by lower than average total precipitation with even distribution of rainfall throughout the year. Weather in 1987 was characterized by high rainfall and colder than average temperatures in spring (May) and very high rainfall during summer, which adversely affected yield formation of all crop species. 1988 was marked by temperatures above the average throughout the year and evenly distributed rainfall, favouring growth and crop yields of legumes and cereals.

Results

N-balance and residual N after fababeans and peas

In 1986—1988 seasons dinitrogen fixation by fababeans ranged from 165 to 240 kg N ha^{-1}, whereas fixation by peas only varied between 215 and 246 kg N ha^{-1} (Table 2). The amount of nitrogen removed by grain remained constantly lower than the amount accumulated by dinitrogen fixation. On average over the experimental seasons, 64 % (fababeans) and 58 % (peas) of the N fixed was removed by grain. This proportion was particularly low in the cold and wet season of 1987, being 44 % with fababean and 51 % with peas. Hence, the cultivation of grain legumes always led to a net nitrogen gain. On average over the years 1986—1988, the net gains after fababeans and peas were 79 and 96 kg N ha^{-1}, respectively. Net gains were particularly high with fababeans in 1987, due to the very low grain yield and hence reduced amount of N-removal by the grain.

After the harvest of peas 158 kg N ha^{-1} were left behind in the aboveground crop residues on the field. The C/N-ratio of the crop residues was 16 (Table 3). Fababeans left approximately 40 kg N ha^{-1} less in the crop residues, and also a higher C/N-ratio of 34 was determined in comparison with peas. Crop residues of oats contained only 24 kg N ha^{-1} with a C/N-ratio of 70.

In terms of soil nitrate content after the harvest of grain legumes only slight differences were observed between species on average over

Table 2. Dinitrogen fixation, N in the grain, N-net gain and grain yield of fababean and pea in 1986—1988

crop	fababean				peas			
year	1986	1987	1988	Ø	1986	1987	1988	Ø
dinitrogen fixation (kg N ha^{-1})	240[1]	233	165	213	215[1]	225	246	229
N in grain (kg N ha^{-1})	173	104	125	134	138	116	144	133
N-net gain (kg N ha^{-1})[2]	+67	+129	+40	+79	+77	+109	+102	+96
grain yield (dt ha^{-1})	46.8	28.3	40.2	38.4	39.2	53.5	54.5	43.1

[1]estimated; [2]N-net gain = dinitrogen fixation — N in grain.

Table 3. C/N-ratio in the crop residues and residual N after the harvesting of pea, fababean and oats in 1987—1988

	year	1987	1988	Ø	C/N-ratio
	crop residues (kg N ha^{-1})	158	158	158	
peas	nitrate-N in 0—90 cm (kg ha^{-1})[1]	50	37	44	16
	Σ residual N (kg N ha^{-1})	208a	195a	202	
	crop residues (kg N ha^{-1})	150	90	120	
fababean	nitrate-N in 0—90 cm (kg ha^{-1})[1]	52	27	40	34
	Σ residual N (kg N ha^{-1})	202a	117b	161	
	crop residues (kg N ha^{-1})	36	11	24	
oats	nitrate-N in 0—90 cm (kg ha^{-1})	10	8	9	70
	Σ residual N (kg N ha^{-1})	46b	19c	33	

[1] after harvesting

the seasons (fababean 40 and peas 44 kg N ha^{-1}), so that the varying amounts of residual N between the two culture species are due to different amounts of N in the straw (Table 3). After the harvest of oats soil nitrogen content was on average only 9 kg N ha^{-1}.

In the 1987 season higher amounts of residual N in the straw and soil were detected with all species as compared to 1988 (Table 3 and Fig. 1). The high soil nitrogen content and amounts of N in the crop residues must be attributed to the rainfall during grain filling in 1987, favouring vegetative growth and restraining the translocation of N from the shoot to the grain. In the following season favourable weather conditions led to a very high dinitrogen fixation by peas, so that the absolute amount of N in the straw despite higher yield was just as much as in the 1987 season (Table 2).

N-mineralization and N-leaching after harvest

After the harvest of grain legumes it was observed that there was always a very high mineralization of nitrogen during autumn and maximum soil nitrate values were regularly recorded at the beginning of November. Soil nitrate values after peas exceeded 120 kg NO_3-N ha^{-1} in all three seasons and the highest value 175 kg NO_3-N ha^{-1} in 0—90 cm depth was determined at the beginning of November in 1986 (Fig. 1). After a preceding crop of fababeans the soil nitrate contents increased during autumn to 92 kg NO_3-N ha^{-1} (67—118 kg NO_3-N ha^{-1}) on average over the 3 years and were considerably lower as compared to the average for preceding peas. As compared to grain legumes N-mineralization after oats was considerably less during autumn. The nitrogen contents reached only 17—51 kg N ha^{-1} and therefore were more than 50 % lower than after fababeans.

Due to seepage water the soil nitrate values decreased rapidly from the beginning of November (Fig. 1 and Table 4). On average over three years the decrease was particularly high after the cultivation of peas (96 kg N ha^{-1}), whereas the decrease after fababeans was on average considerably lower (54 kg N ha^{-1}). After preceding oats the decrease of soil nitrate values were reduced to 20 kg N ha^{-1} and in every season remained lower as compared to preceding grain legumes. The calculated mean N-leaching during winter was 21 kg N ha^{-1} after oats, whereas the corresponding values for fababeans were 52 kg N ha^{-1} and 78 kg N ha^{-1} for peas. As compared to oats a 2.5 fold (fababeans) and 3.7 fold (peas) amount of N was leached after legumes on average over seasons. Relating to the amount of N left on the field in crop residues the leaching losses were 34 % and 52 % after fababeans and peas, respectively. The comparison of the decrease of soil nitrate values with the calculated leaching losses (Table 4) shows a good agreement for the seasons 1987/88 and 1988/89, but not for 1986/87. Possibly a significant part of nitrate-N was immobilized in the dry autumn of 1986 and thus saved from subsequent leaching.

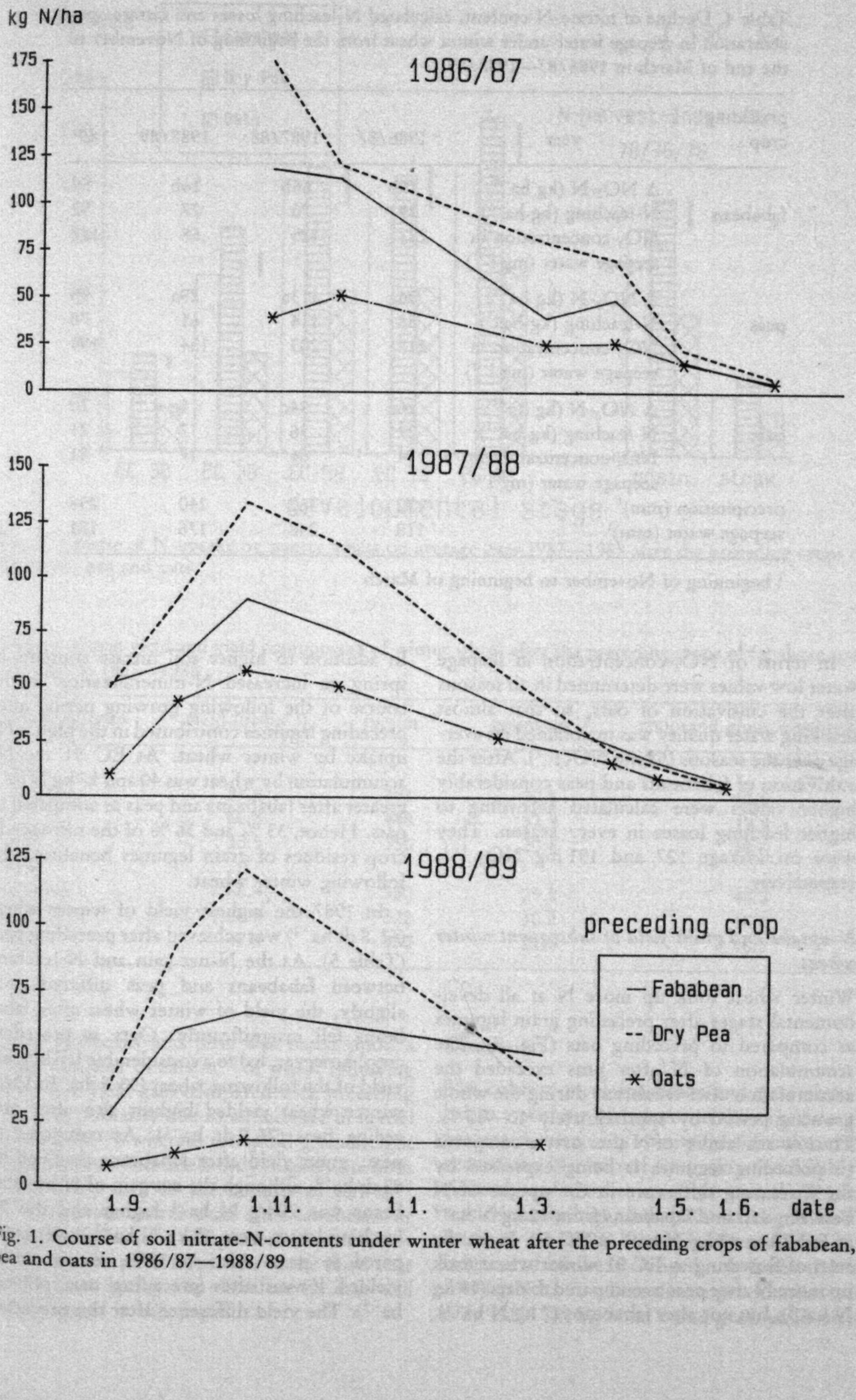

Fig. 1. Course of soil nitrate-N-contents under winter wheat after the preceding crops of fababean, pea and oats in 1986/87—1988/89

Table 4. Decline of nitrate-N-content, calculated N-leaching losses and nitrate concentration in seepage water under winter wheat from the beginning of November to the end of March in 1986/87—1988/89

preceding crop	year	1986/87	1987/88	1988/89	Ø
fababean	Δ NO_3-N (kg ha^{-1})	79b	66b	16b	54
	N-leaching (kg ha^{-1})	59	70	27	52
	NO_3-concentration in seepage water (mg l^{-1})	221	125	68	127
peas	Δ NO_3-N (kg ha^{-1})	96a	113a	79a	96
	N-leaching (kg ha^{-1})	58	114	61	78
	NO_3-concentration in seepage water (mg l^{-1})	217	203	154	191
oats	Δ NO_3-N (kg ha^{-1})	26c	34c	1c	20
	N-leaching (kg ha^{-1})	21	36	7	21
	NO_3-concentration in seepage water (mg l^{-1}	54	64	17	51
precipitation (mm)[1]		172	362	240	258
seepage water (mm)[1]		118	248	176	181

[1] beginning of November to beginning of March

In terms of NO_3-concentration in seepage water low values were determined in all seasons after the cultivation of oats, so that almost drinking water quality was maintained on average over the seasons (51 mg NO_3 l^{-1}). After the cultivation of fababeans and peas considerably higher values were calculated according to higher leaching losses in every season. They were on average 127 and 191 mg NO_3 l^{-1}, respectively.

N-uptake and grain yield of subsequent winter wheat

Winter wheat took up more N at all developmental stages after preceding grain legumes as compared to preceding oats (Fig. 2). The accumulation of N after peas exceeded the accumulation after fababeans during the whole growing period by approximately 10—20 %. The low availability of N after oats as compared to preceding legumes is being expressed by the increasing difference in the uptake of N between oats and fababeans from 12 kg N ha^{-1} at EC 30 to 41 kg N ha^{-1} at EC 59. From the start of flowering to EC 91 winter wheat took up more N after peas as compared to oats (19 kg N ha^{-1}), but not after fababeans (7 kg N ha^{-1}). In addition to higher soil nitrate contents in spring an increased N-mineralization in the course of the following growing period after preceding legumes contributed in the higher N-uptake by winter wheat. At EC 91 the N-accumulation by wheat was 40 and 57 kg N ha^{-1} greater after fababeans and peas as compared to oats. Hence, 33 % and 36 % of the nitrogen in crop residues of grain legumes benefitted the following winter wheat.

In 1987 the highest yield of winter wheat (61.8 dt ha^{-1}) was achieved after preceding peas (Table 5). As the N-net gain and N-leaching between fababeans and peas differed only slightly, the yield of winter wheat after fababeans fell insignificantly. Oats as preceding crop, however, led to a considerable fall in grain yield of the following wheat (33.5 dt). In 1988, winter wheat yielded highest also after preceding peas (76.9 dt ha^{-1}). As compared to peas, grain yield after fababeans declined by 85 dt ha^{-1}, although the net gain of N by fababeans was 20 kg N ha^{-1} higher and the N-leaching losses were 45 kg N ha^{-1} lower compared to peas. Also in 1988, winter wheat yielded lowest after preceding oats (47.4 dt ha^{-1}). The yield difference after the preceding

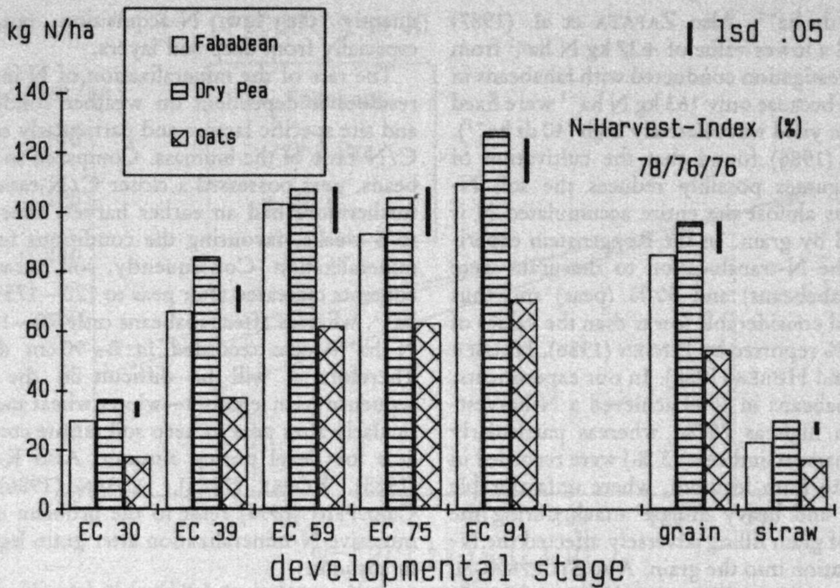

Fig. 2. Course of N-uptake by winter wheat on average over 1987—1988 after the preceding crops of fababean, pea and oats

Table 5. Grain yield and yield components of winter wheat after the preceding crops of fababean, pea and oats in 1987—1988

preceding crop	yield (dt ha^{-1})	ears m^{-2}	grains ear^{-1}	thousand grain weight (g)
1987				
fababean	58.8	391	30.1	40.8
peas	62.8	448	32.9	39.8
oats	33.5	350	20.8	39.6
1988				
fababean	68.4	350	29.9	48.8
peas	76.9	372	30.2	48.6
oats	47.4	360	21.6	46.3

crops fababeans and peas was based upon a higher number of ears m^{-2} of wheat following peas. The yield gain compared with preceding oats was primarily due to an increase in kernel number ear^{-1}, whereas thousand grain weight after legumes increased only slightly in both years. Only in 1987 the number of ears m^{-2} after oats was lower than after fababeans or peas. The cultivation of legumes had no measurable effect on yield formation of the third year crop winter barley and therefore no data will be presented in this paper.

Discussion

The cultivation of fababeans and peas always led to a positive N-balance in the experiments presented here, i.e. dinitrogen fixation exceeded the N-removal by grain considerably. As compared to other investigations, the N gain was relatively high, being 70—110 kg N ha^{-1}. BECK et al. (1991) found in France, that N-balances of fababeans ranged only from +19 to +44 kg N ha^{-1}, where dinitrogen fixation was only 165—181 kg N ha^{-1} and grain yield averaged 34 dt ha^{-1}. Also ZAPATA et al. (1987) reported a lower value of +27 kg N ha^{-1} from their investigation conducted with fababeans in Austria, because only 163 kg N ha^{-1} were fixed and grain yield was relatively high (40 dt ha^{-1}). JENSEN (1986) found that the cultivation of grain legumes possibly reduces the soil N-supply as almost the entire accumulated N is removed by grain. In the Roggenstein experiments the N-translocation to the grain were 57 % (fababeans) and 50 % (peas) and thus remained considerable lower than the values of 80—85 % reported by JENSEN (1986), HAUSER (1987) and HUBER (1988). In our experiments, only fababeans in 1988 achieved a N-harvest-index as high as 75 %, whereas particularly low N-harvest-indices (43 %) were recorded in 1987 with both legumes, where unfavourable weather and heavy disease attack during the period of grain filling adversely affected the N-translocation into the grain. Also STÜLPNAGEL (1982) reports on N-harvest indices of 54, 74 and 45 % in a 3-year experiment, where the lowest value was recorded in a year with very high rainfall from June to August. The N-gain achieved by the cultivation of grain legumes will therefore probably be lower in seasons and regions marked by favourable weather conditions during grain filling compared to the Roggenstein experiments. Provided that yield and N-removal by grain are high, the cultivation of grain legumes saves N-fertilizer, but contributes only little to the N-enrichment of the soil.

After the harvest of fababeans and peas considerable amounts of N in crop residues and soil nitrate (up to 200 kg N ha^{-1}) remained on the field whereas oats left only residual N of approximately 30 kg N ha^{-1}. Even at the time of harvesting the soil nitrate content after legumes was already 47 kg N ha^{-1} in 0—90 depth as compared to 10 kg N ha^{-1} after oats.

In the experiments conducted by HAUSER (1987) the nitrate-N-content in 0—90 cm depth at the time of harvesting of fababeans ranged from 55 to 60 kg N ha^{-1} and was 35—40 kg higher compared to oats. Also STÜLPNAGEL (1982) and LÜTKE-ENTRUP and STEMANN (1990) report on higher soil mineral-N-contents at the time of harvesting of grain legumes as compared to cereals. The primary reason is the poor root system of grain legumes (BRERETON et al. 1986, JUSTUS and KÖPKE 1990) and consequently the low N-acquisition potential especially from deep soil layers.

The rate of the mineralization of N in crop residues is dependent on weather conditions and site specific factors and particularly on the C/N-ratio of the biomass. Compared to fababeans, peas possessed a closer C/N-ratio and furthermore had an earlier harvest time of 2 to 3 weeks, favouring the conditions for N-mineralization. Consequently, soil nitrate-N-contents increased after peas to 120—175 kg N ha^{-1}, whereas after fababeans only 70—118 kg N ha^{-1} were recorded in 0—90 cm depth. Therefore it will be difficult in the crop sequence grain legumes—winter wheat and particularly after peas to keep soil nitrate contents at a low level during autumn. Also KAHNT (1985), KÖPKE (1985), JENSEN (1986) and CLAUPEIN (1994) refer to the problem of the intensive N-mineralization after grain legumes in autumn.

As far as the rainfall during winter suffices for production of seepage water, a part of the nitrate-N may be displaced with this into deeper soil layers and finally be leached out. In Roggenstein, amounts of seepage water ranged from 126 to 248 mm per year in the period of investigation, hence the mineralized legume N was leached to a large extent. The nitrate-N-losses recorded during winter were on average 54 kg N ha^{-1} after preceding fababean, 96 kg N ha^{-1} after peas and 20 kg N ha^{-1} after oats, depending on the amount of rainfall and seepage water. HUBER (1988) reported that the nitrate losses by leaching in a lysimeter corresponded with N-losses calculated by means of changes in NO_3-N-content after preceding fababeans. He determined a N-leaching of 70—90 kg N ha^{-1} in the crop sequence fababean—winter wheat. Also ADAMS and PATTINSON (1985) found leaching losses under winter wheat following peas of 90 kg N ha^{-1}. In lysimeter experiments conducted by JUNG et al. (1988) 49 kg N $ha^{-1}y^{-1}$ were leached after fababeans with the whole aboveground biomass being removed after harvest. These reports agree with our results in that due to the high risk of N-leaching, particularly after peas, the widely-used crop sequence grain legumes—winter wheat is not be considered ideal from an ecological and economic point of view. An alternative is the crop rotation grain legumes—winter barley. Using this crop sequence, experiments carried out by HUBER (1988) revealed that

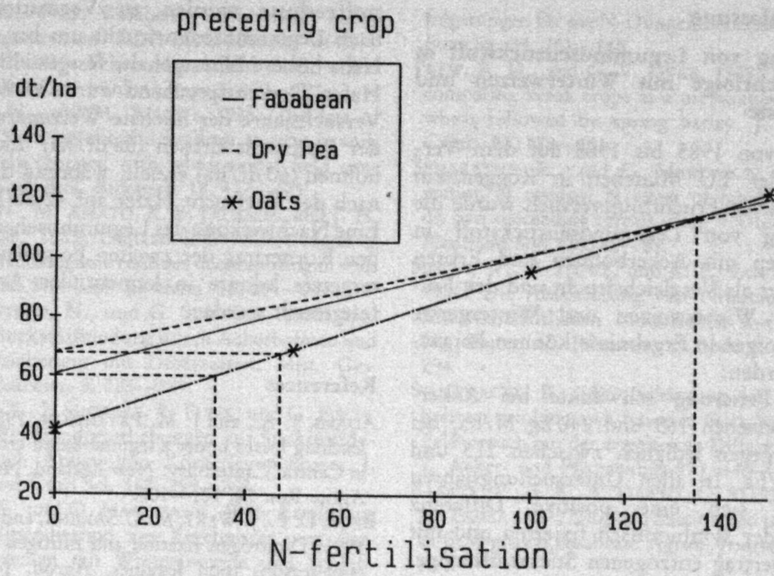

Fig. 3. Mineral N-fertilizer equivalences of the preceding crops of fababean, pea and oats

nitrate leaching could be reduced by approximately 50 %. Also KAHNT (1985) recommends the cultivation of winter barley or rape. On soils with a high water holding capacity and low rate of seepage water a conservation in catch crops may suffice. Catch crops that survive in winter also possess a N-conservation effect comparable to rape (MAIDL et al. 1991).

Despite the N-losses due to leaching, up to 54 kg N ha^{-1} higher nitrate contents after legumes as compared to oats were recorded at the beginning of the growing period in the Roggenstein experiments. HUBER (1988) found up to 25 kg N ha^{-1} higher nitrate contents after fababeans in spring compared to maize, but considerably lower values compared to preceding potato. KÖPKE (1985) detected a nitrate content of 80 kg N ha^{-1} under winter wheat in spring after following fababeans as compared to 50 kg N ha^{-1} after preceding oats. As the nitrate contents vary more strongly in spring after preceding legumes than after cereals, a N_{min}-determination is recommended to calculate the first fertilizer dosage.

The grain yield of unfertilized winter wheat were 18.6 dt ha^{-1} and 26 dt ha^{-1} higher after preceding fababeans and peas, respectively, as compared to oats. One must regard the primary cause for the higher yield after legumes as nitrogen effects. Given a linear course in the fertilizer utilization in the range between 0 and 50 kg N ha^{-1}, the effect of preceding fababeans and peas was equivalent to 35 and 50 kg N ha^{-1} fertilization as compared to oats (Fig. 3). Savings of nitrogen in similar quantities were also demonstrated by DYKE and SLOPE (1978), KÖPKE (1985) and MÜLLER and HAGEMANN (1986).

A contribution of legume nitrogen to the third year crop winter barley could not be determined in our experiment. LADD et al. (1983), KÖPKE (1985), LADD and AMATO (1986) and SENARATNE and HARDARSON (1988), however, demonstrated a significant contribution of legume N to the third year crop. As the utilization rates were very low (5—10 %) in the investigations cited and also other workers such as BOWERMAN and CLARE (1976) or PREW and DYKE (1979) did not observe an effect to the third year crop, the contribution of legume N is probably strongly dependent on site specific factors and on the C/N-ratio of the crop residues. To summarize, the findings from the Roggenstein experiments indicate that the easily mineralizable fraction of N in the crop residues of grain legumes contributes to the second year crop and will be taken up by the plant or will be displaced in deeper soil layers or leached out.

Zusammenfassung

Verwertung von Leguminosenstickstoff in einer Fruchtfolge mit Winterweizen und Wintergerste

In einem von 1985 bis 1988 auf dem Versuchsgut der TU München in Roggenstein durchgeführten Fruchtfolgeversuch wurde die Verwertung von Leguminosenstickstoff in Fruchtfolgen mit Ackerbohnen und Erbsen sowie Hafer als Vergleichsfrucht und den Folgefrüchten Winterweizen und Wintergerste geprüft. Folgende Ergebnisse können herausgestellt werden:

—Die N-Fixierung schwankte bei Ackerbohnen zwischen 165 und 240 kg N/ha, bei Erbsen dagegen lediglich zwischen 215 und 246 kg N/ha. In allen Untersuchungsjahren errechnete sich eine positive Differenz zwischen der symbiontisch fixierten und mit dem Kornertrag entzogenen Stickstoffmenge. Der Stickstoffgewinn betrug bei Erbsen und Ackerbohnen durchschnittlich 106 bzw. 84 kg N/ha.

—Nach der Ernte von Körnererbsen blieben im Mittel der Versuchsjahre 202 kg N/ha auf dem Feld zurück, wovon 158 kg N/ha in den oberirdischen Ernterückständen enthalten waren und 44 kg als Nitratstickstoff in 0—90 cm Bodentiefe vorlagen. Bedingt durch geringere Stickstoffmengen im Stroh hinterließen Ackerbohnen 41 kg N/ha weniger als Erbsen, während nach Hafer eine Reststickstoffmenge von ledliglich 33 kg N/ha festgestellt wurde.

—Nach Aberntung der Körnerleguminosen wurde während der Herbstmonate stets eine sehr hohe Stickstoffreisetzung ermittelt, die bei Erbsen aufgrund des engeren C/N-Verhältnisses und der größeren Reststickstoffmengen höher ausfiel als bei Ackerbohnen. Im Vergleich mit den Ackerbohnen blieb die N-Mineralisierung nach Hafer in den Herbstmonaten um mehr als 50 % zurück.

—Während der Wintermonate erfuhren die Nitratwerte infolge der winterlichen Sickerwassermengen regelmäßig eine starke Abnahme. Besonders hoch waren die N-Auswaschungsverluste nach dem Anbau von Erbsen (ca. 80 kg N/ha), während sie nach Ackerbohnen deutlich geringer ausfielen (ca. 50 kg N/ha). Die Auswaschungsverluste nach Hafer blieben mit 20 kg N/ha erheblich unter den für die Leguminosen ermittelten Werten.

—Trotz der auswaschungsbedingten Stickstoffverluste wurden zu Vegetationsbeginn nach Leguminosenvorfrucht um bis zu 54 kg N/ha höhere Nitratgehalte festgestellt als nach Hafer. Dementsprechend wurde im Mittel der Versuchsjahre der höchste Weizenertrag nach der Vorfrucht Erbsen (68 dt/ha) und Ackerbohnen (60 dt/ha) erzielt, während der Ertrag nach der Vorfrucht Hafer auf 42 dt/ha abfiel. Eine Nachwirkung des Leguminosenanbaus auf den Kornertrag der zweiten Folgefrucht Wintergerste konnte in keinem der Anbaujahre festgestellt werden.

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