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ORIGINAL PAPER

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Nitrogen acquisition by pea and barley and the effect of their crop residues on available nitrogen for subsequent crops

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Abstract Nitrogen acquisition by field pea (*Pisum sativum* L.) and spring barley (*Hordeum vulgare* L.) grown on a sandy loam soil and availability of N in three subsequent sequences of a cropping system were studied in an outdoor pot experiment. The effect of crop residues on the N availability was evaluated using ^{15}N-labelled residues. Field pea fixed 75% of its N requirement and the N_2 fixation almost balanced the N removed with the seeds. The barley crop recovered 80% of the ^{15}N-labelled fertilizer N supplied and the N in the barley grain corresponded to 80% of the fertilizer N taken up by the crop. The uptake of soil-derived N by a test crop (N catch crop) of white mustard (*Sinapis alba* L.) grown in the autumn was higher after pea than after barley. The N uptake in the test crop was reduced by 27% and 34% after pea and barley residue incorporation, respectively, probably due to N immobilization. The dry matter production and total N uptake of a spring barley crop following pea or barley, with a period of unplanted soil in the autumn/winter, were significantly higher after pea than after barley. The barley crop following pea and barley recovered 11% of the pea and 8% of the barley residue N. The pea and barley residue N recovered constituted only 2.5% and <1%, respectively, of total N in the N-fertilized barley. The total N uptake in a test crop of mustard grown in the second autumn following pea and barley cultivation was not significantly influenced by pre-precrop and residue treatment. In the short term, the incorporation of crop residues was not important in terms of contributing N to the subsequent crop compared to soil and fertilizer N sources, but residues improved the conservation of soil N in the autumn. In the long-term, crop residues are an important factor in maintaining soil fertility and supplying plant-available N via mineralization.

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Introduction

Due to the intervals of bare soil, the nitrogen cycle in arable cropping systems is known to be more "leaky" than in well-established grasslands or forests (Addiscott et al. 1991). The plant availability of N is influenced by the inputs and losses of N, cropping system, soil type, tillage and residue management. The crop species may influence the availability of soil N during and after growth via: (1) its effects on the mineralization-immobilization turnover and losses of N, due to deposition of organic materials in the rhizosphere (Robinson et al. 1989), (2) its efficiency in utilizing fertilizer and soil N sources in the soil profile and (3) the amounts and chemical composition of crop residues (Parr and Papendick 1978; Jenkinson 1981).

Grain legumes, such as pea, soybean (*Glycine max*) and common bean (*Phaseolus vulgaris*), may contribute large amounts of N to a cropping system via symbiotic N_2 fixation, but a major part of the N entering the cropping system via fixation is removed with the harvested plant parts (Peoples and Craswell 1992). Grain legumes influence N cycling of agroecosystems in several other ways than the fixation of dinitrogen: (1) they are less efficient in utilizing soil N sources than cereal crops, due to their superficial root systems (termed the N-sparing or N-conserving effect) (Senaratne and Hardarson 1988; Peoples and Craswell 1992; Chalk et al. 1993), (2) grain legumes may deposit relatively high amounts of N in exudates and root sloughings during growth, which constitute a major pool of labile N during reproductive development and post-harvest (Sawatsky and Soper 1991; Jensen 1996 a) and (3) grain legume residues are known to be relatively high in N compared to cereal residues and consequently they constitute a more labile N-pool in the autumn, in contrast to cereal residues, which immobilize N during early decomposition (Bremer et al. 1991; Jensen 1996b,c). The N conserved, deposited in the rhizosphere or recycled from high-N crop residues may increase the availability of N to succeeding crops and the potential for N leaching in a temperate agroecosystem. Besides the effects on N availability, grain legumes influence subsequent crops via other rotational effects such as improved soil structure and breaking of cycles of cereal pests and diseases (Herridge 1982).

My aim was to determine the effects of pea and barley cultivation and the effect of the management of their above-ground residues on the N availability in three subsequent sequences of a cropping system within large pots.

Materials and methods

Climate, soil and pots

The experiment was carried out in the open at Risø, which has an average annual precipitation of 550 mm. Average minimum and maximum air temperatures during the growing season (April to August) at Risø are 8 ° and 17 °C, respectively. Average minimum and maximum temperatures in the autumn (September–November) are 6 ° and 13 °C, respectively.

The soil was a sandy loam (Typic Hapludalf) with 11.4% clay (<0.002 mm), 13.6% silt (0.02–0.002 mm), 48.6% fine sand (0.2–0.02 mm) and 24.6% coarse sand (2–0.2 mm) from the 0- to 20-cm soil layer in the Risø experimental field. The soil contained 1.2% total C and 0.13% total N, and pH in water was 6.9. The soil was homogenized and sieved (1 cm) and fertilized with basic nutrients consisting of 214 mg KH_2PO_4 and 126 mg KCl kg^{-1} soil (dry weight basis).

The plants were grown in cylindrical PVC pots with a surface area of 500 cm^2, height 40 cm and a volume of 20 l. Lodging was prevented by a wire framework around each pot. A rubber stopper in the bottom of the pot could be removed to allow free drainage of water percolating the soil and collection in a 10-l reservoir below the pot. Each pot was filled with 20.5 kg dry soil. Pots were watered to a predetermined weight (75% WHC) 1–3 times a week depending on the water use and precipitation.

Experimental procedures

The experiment consisted of four sequences (Fig. 1): (I) main-crop field pea (P) and spring barley (B) April–August, (II) a test crop (N catch crop) following the pea and barley from late August to late November, (III) spring barley (unplanted soil in the autumn and winter) from April to August in the 2nd year and (IV) a test crop of mustard following barley from August to early November in the 2nd year. Residue management treatments were imposed after sequence I: Residues were either incorporated in the topsoil (+res) or removed (–res) in late August.

Sequence I: main crops

A total of 18 pots were sown to spring barley (*Hordeum vulgare* L. cv. Golf) on 17 April and thinned to 20 plants pot^{-1} after seedling emergence. Field pea (*Pisum sativum* L. cv. Bodil) was sown in 16 pots and thinned to 14 plants pot^{-1} after seedling emergence.

Sixteen barley pots were fertilized with 3.0 g N pot^{-1} as KNO_3. Four of the pots received KNO_3 with 2.41 atom% ^{15}N excess, whereas the remaining 12 pots received unlabelled N. The pea pots were fertilized with 0.1 g N pot^{-1} as KNO_3. The 12 pots received unlabelled N and the remaining four pots were supplied with N, which was labelled with 10.0 atom% ^{15}N excess. Two pots of barley were fertilized with 0.1 g N pot^{-1} labelled with 10.0 atom % ^{15}N excess and these plants were used as a reference for determining N_2 fixation in pea. The N fertilizer was added with 200 ml water pot^{-1}. Pots were placed in groups of pea and barley and completely randomized within species group.

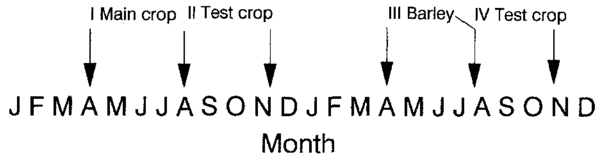

Fig. 1 Sequences of the cropping system

Plants were harvested on 14 August. Plants fertilized with ^{15}N-labelled N were separated into seeds and straw, and roots were washed free of soil. The yield of dry matter, N concentration and ^{15}N enrichment were determined. The soil was sampled from the top 20 cm with a stainless steel auger and extractable soil inorganic N determined on 14 and 25 August.

Sequence II: test crop

On 29 August the top 6 cm of soil (on average 4.1 kg pot^{-1} on a dry weight basis) was removed from each of the pots not receiving ^{15}N-labelled fertilizer N, pooled for each plant species and homogenized (1 cm sieve). To six samples of 4.1 kg (dry weight) pea soil, 14.06 g pea straw was added with 2.76% N, 43.2% C and 1.34 atom% ^{15}N excess. To six samples of 4.1 kg (dry weight) barley soil, 17.8 g barley straw was added with 0.89% N, 44.4% C and 3.43 atom% ^{15}N excess. The soil portions with or without residue amendments were returned to pots. The ^{15}N-labelled residues were produced by growing plants in large pots with sand (Jensen 1996b) and ground to pass a 3-mm sieve.

Three pots of each of the four treatments, P–res, P+res, B–res and B+res, were sown to white mustard (40 seeds pot^{-1} thinned to 25 plants). The mustard plants were harvested on 27 November and separated into shoots and roots. Dry matter yield, N concentration and ^{15}N enrichment were determined from the plant parts. Soil was sampled from the top 20 cm for determination of KCl-extractable inorganic N.

Sequence III: spring barley

Three replicate pots of each treatment were left unplanted during the autumn and holes in the bottom allowed free drainage of excess precipitation. In the mittle of December, pots were placed in a greenhouse at 4 °C. The pots were placed outside again and sown to spring barley on 23 April and thinned to 20 plants pot^{-1} after seedling emergence. In addition eight pots were filled with 21 kg soil (dry weight basis) freshly sampled from the same field that soil was sampled from the previous year. Four or the pots were amended with 13.83 g pea residue with 2.51% N, 41.9% C and 1.16 atom% ^{15}N excess. Residues were incorporated into the top 6 cm of soil (P+res_s). The remaining four pots were not amended with crop residues (P-res_s). The eight pots were sown to spring barley. All pots were fertilized with 1.5 g N pot^{-1} as unlabelled KNO_3. Barley plants were harvested on 6 August and the plant material was separated into seeds and straw+awns+crown roots. Dry matter yield, N concentration and ^{15}N enrichment were determined.

Sequence IV: test crop

Pots grown to spring barley were all sown to white mustard on 10 August and plants thinned to 25 pot^{-1} after seedling emergence. Mustard shoots and roots were harvested on 2 November. The dry matter yield, N concentration and ^{13}N enrichment were determined from the material and the soil was sampled for determination of KCl-extractable soil inorganic N.

Analytical methods

The dry matter yield was determined after drying for 20 h at 80 °C. Total N and ^{15}N enrichment in plant parts were determined simultaneously using an N analyzer coupled on-line to an isotope ratio mass spectrometer. The soil inorganic N was extracted from 10 g fresh soil with 100 ml 2 *M* KCl. The NO_3-N and NH_4-N in extracts were determined using colorimetric methods on a Technicon Autoanalyzer II (Jensen 1994a).

Calculations and statistics

The atom% ^{15}N of plant material was corrected for the natural abundance of ^{15}N in the soil (0.3703 atom% ^{15}N) to obtain the atom% ^{15}N excess. Symbiotic dinitrogen fixation in field pea was calculated using spring barley fertilized with 0.1 g N pot^{-1} as the reference crop and the equation of Fried and Middelboe (1977) after correcting the atom% ^{15}N excess for seed-borne N. The total N harvest index (NHI_t) was calculated as the percentage total plant N present in the seed. Analysis of variance was carried out on data using the ANOVA procedure in SAS (1990), and $LSD_{0.05}$ values were calculated for comparison if the treatment effect was significant.

Results and discussion

Sequence I: main crops

The total dry matter production was 110 g pot^{-1} in field pea and 183 g pot^{-1} in barley with 57% and 44% of the total dry matter in seeds, respectively (data not shown). The total N uptake was 2.5 g N pot^{-1} in pea and 3.0 g N pot^{-1} in barley with 77% and 64% of the total N found in the seeds (Fig. 2).

Symbiotic dinitrogen fixation constituted 75% of the total N acquired by pea (Fig. 2), which is similar to results from field studies (Rennie and Dubetz 1986; Evans et al. 1989). The N balance, comparing plant acquisition of N from different sources and outputs of N in seeds and residues, shows that N_2 fixation almost equalled the N removed with seeds in the pea crop (Fig. 2). This agrees well with N balances from field studies (Jensen 1989; Armstrong et al. 1994). The N concentration of above-ground pea crop residues was 1.09% N (data not shown), which is rather low (Jensen 1989). The N_2 fixation may have been low during reproductive growth, which may have forced the plant to remobilize N from vegetative plant parts more efficiently.

The barley crop recovered 80% of the ^{15}N-labelled fertilizer N supplied and the amount of fertilizer N taken up more than balanced the N removed with the seeds (Fig. 2). A relatively high concentration of N was found in the barley straw (1.0% N) and roots (1.5% N). This resulted in a rather low total N harvest index of 64% (Fig. 2).

The above-ground residue N concentrations were different from concentrations normally observed in the field. Thus, it was decided to use ^{15}N-labelled residues from another experiment. It was also decided to reduce the amount of residue added compared to the actual production in the pots, in order to obtain residue N and C concentrations in the topsoil, which would be more realistic (ca. 0.2% residue C of soil dry weight) than if all residues from pot-grown plants were incorporated.

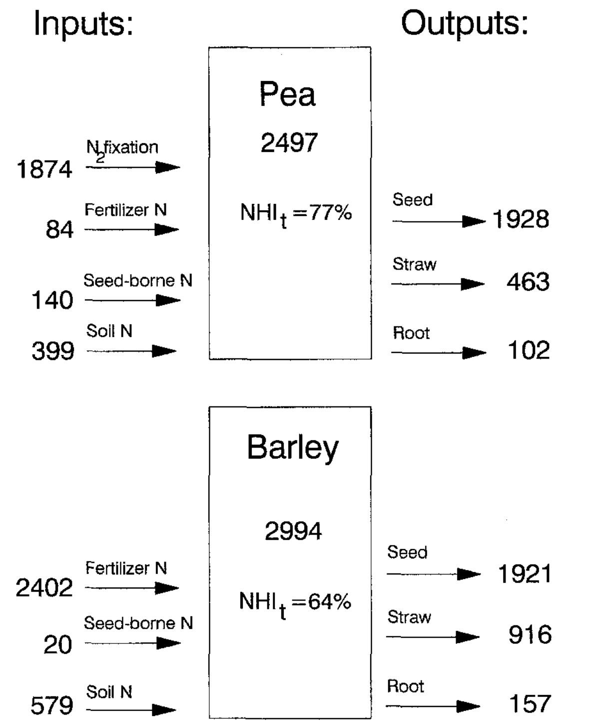

Fig. 2 Balance of N for field pea and spring barley. Values are mg N pot^{-1} except for NHI_t. *NHI_t* total N harvest index. Fertilizer N supply pot^{-1}: barley, 3000 mg N; pea, 100 mg N

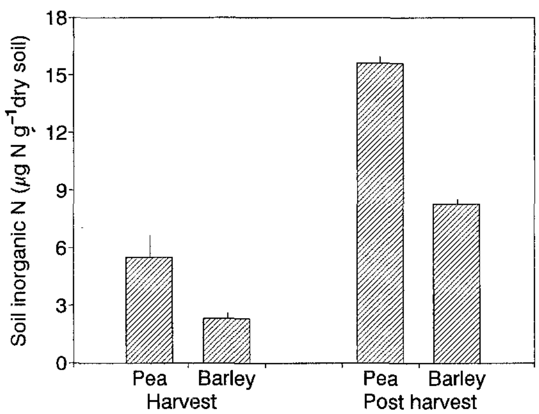

Fig. 3 Soil inorganic N concentration at harvest of main crops and 11 days after harvest. *Bars* represent one standard deviation

The uptake of soil-derived N was found to be greater in barley than in pea plants (Fig. 2). The estimated soil N uptake in pea is based on the assumption that the ratio of soil-derived to labelled N uptake in pea is the same as in the reference crop of barley (receiving only 0.1 g N pot^{-1}). The difference in soil uptake between pea and barley may also be due to pool substitution (Hart et al. 1986). The barley

Table 1 Dry matter production and nitrogen uptake by a mustard catch crop succeeding pea and barley (sequence II). *% Ndfr* % N derived from residues, – no residues, + residues incorporated, *NA* not available

Preceding plant	Residue treatment	Total DM (g pot^{-1})	Origin of N (mg N pot^{-1})		%Ndfr	Residue N recovery (%)
			Soil	Residues		
Pea	–	23.3	326	NA	NA	NA
	+	20.4	238	43	15.3	11.2
Barley	–	17.7	256	NA	NA	NA
	+	10.1	169	4	2.3	2.5
$LSD_{0.05}$		12.6	32	8	3.5	2.1

Table 2 Dry matter production and nitrogen uptake in spring barley as influenced by preceding plant and residue management (sequence III). *%Ndfr* % of N derived from residues, – no residues, + residues incorporated

Preceding plant	Residue treatment	Seed DM (g pot^{-1})	Straw DM (g pot^{-1})	Origin of N (mg N pot^{-1})			%Ndfr	Residue N recovery (%)
				Total	Soil	Residues		
Pea	–	73.4	82.6	1764	1764	NA	NA	NA
	+	74.3	85.0	1773	1729	44	2.5	11.3
Barley	–	67.7	80.2	1492	1492	NA	NA	NA
	+	68.1	83.6	1557	1544	13	0.8	8.3
$LSD_{0.05}$		6.1	2.0	178	180	23	1.3	NS
Pea	–	89.3	92.9	1970	1970	NA	NA	NA
(spring)[a]	+	90.3	96.6	2109	2053	56	2.7	16.1
$LSD_{0.05}$		NS	NS	68	NS	NA	NA	NA

crop received 3.0 g ^{15}N-labelled N pot^{-1}, whereas the pea was supplied with only 0.1 g N pot^{-1}. Thus the substitution effect may have been larger in the barley treatment.

At harvest the concentration of KCl-extractable soil inorganic N was almost twice as high after pea than after barley, and concentrations increased rapidly from harvest during the subsequent 11 days (Fig. 3). Jensen (1996a) found that the KCl-extractable inorganic N-concentration was similar at the time of pea and barley harvest and that it increased more rapidly after pea during the month following harvest, partly due to the mineralization of N in rhizodeposits.

Sequence II: test crop

The dry matter production and total N uptake by a test crop of white mustard were significantly higher after pea than after barley both without and with incorporation of crop residues (Table 1). The higher uptake of N after pea than after barley without residue incorporation was probably due to differences in net mineralization of N caused by differences in the quality of roots and rhizodeposits (Jensen 1996a). The incorporation of residues reduced the uptake of soil-derived N by 27% after pea and 34% after barley (Table 1). It was expected that net immobilization occurred during early decomposition of residues with wide C/N ratios such as in the barley residues, which had a C/N ratio of 50 (Janzen and Kucey 1988; Ocio et al. 1991; Aulakh et al. 1991; Jensen 1996c). It is also likely that net immobilization of N occurred after pea residue incorporation, even if the C/N ratio of pea residues was as low as 16. McKenney et al. (1995) found net immobilization of N during initial turnover of red clover material with a C/N ratio of 15, and Jensen (1994c, 1996c) found that pea residues caused significant net immobilization of soil N and reduced the leaching of nitrate in the autumn. Net immobilization of N may occur during early decomposition of soybean residues (e.g. Aulakh et al. 1991; Green and Blackmer 1995), but the soybean residues used in these studies had C/N ratios of 41–43. The results showed that incorporation of pea and barley residues is a tool for conserving N in the autumn and reducing the N leaching potential after cultivation of these crops.

The test crop recovered 11.2% of the pea and 2.5% of the barley residue N, which is similar to recoveries of pea residues in field-grown winter oilseed rape and winter barley in the autumn (Jensen 1994b).

Sequence III: spring barley

Dry matter yields of spring barley grown in the growing season following pea and barley with an intervening period (August to April) of unplanted soil were significantly higher after pea than after barley (Table 2). Strong et al. (1986) found that the yield of wheat following field pea was significantly higher than after barley, mainly due to an increased level of residual soil inorganic N after pea after the establishment of wheat. However, the lower yield in the barley after barley treatment may also partly be due to yield reductions caused by take-all (*Gaeumannomyces*

Table 3 Dry matter production and nitrogen uptake by a mustard catch crop grown in the 2nd year as influenced by pre-precrop and residue management (sequence IV). *%Ndfr* % of N dervied from residues, – no residues, + residues incorporated

Pre-precrop treatment		Total DM ($g\ pot^{-1}$)	Origin of N ($mg\ N\ pot^{-1}$)			%Ndfr	Residue N recovery (%)
Plant	Residues		Total	Soil	Residues		
Pea	–	12.7	235	235	NA	NA	NA
	+	13.4	261	254	17	6.3	4.3
Barley	–	12.4	227	227	NA	NA	NA
	+	14.4	281	276	5	1.9	3.3
Significance[a]		NS	NS	NS	0.008	0.039	0.037
Pea	–	18.2	249	249	NA	NA	NA
(spring)[b]	+	20.9	289	258	26	9.0	7.4
Significance[a]		0.049	0.019	NS	NA	NA	NA

[a] Level of significance for the main effect
[b] Pea residues were incorporated in the spring

graminis) and eyespot (*Pseudocercosporella herpotrichoides*) fungi (Herridge 1982).

The total N uptake in N-fertilized barley was significantly higher after pea than after barley (Table 2). In soil without residue incorporation, this effect may be due to (1) differences in amounts of available soil N at harvest of the preceding crops (N-sparing effect, Chalk et al. 1993) and (2) the effects of roots and rhizodeposition on the mineralization-immobilization turnover of N in the soil during the autumn and winter, resulting in a greater net immobilization of N after barley due to a higher C/N ratio of barley below-ground residues (Jensen 1996a). The difference in net mineralization of N in the autumn was revealed in the different uptake of N in the test crop grown on pots with similar precrop and residue treatments (Table 1).

Residue incorporation in the autumn did not influence the total N uptake in the following barley crop, but in the treatment with pea residue incorporation in the spring both the amounts of barley seed and straw N (data not shown) were increased by residues, resulting in a significantly greater amount of total N compared to the unamended soil (Table 2).

The recovery of residue-derived N was significantly higher after pea (11.3%) than after barley (8.3%). The release and uptake in barley of residue N from the preceding barley crop were similar to recoveries reported for wheat residue N in a subsequent crop (Fredrickson et al. 1982; Powlson et al. 1985; Bremer and Van Kessel 1992) and for barley residue N (Thomsen and Jensen 1994). The recovery of pea residue N in the barley crop was similar to the recovery of pea residue N in the field (Jensen 1994b) and for soybean residues (Norman et al. 1992; Bergersen et al. 1992). The recovery of pea residue N in the following spring barley was apparently higher from pea residues being incorporated in the spring than from pea residues incorporated in the autumn. However, when including the recovery of residue N in the drainage water from the bare soil pots after autumn incorporation (data not shown), the total recovery of autumn-incorporated residue N was found to 15.7%, which is very similar to the recovery of 16.1% for spring-incorporated pea residues (Table 2).

The percentage of total N in the N-fertilized barley crop being derived from residue N was similar for seeds and straw (data not shown), being 2.5% of total barley N in the pea residue treatment and 0.8% after barley residue incorporation (Table 2). Similar values have been reported for the contribution of ^{15}N-labelled wheat, lentil, barley and pea crop residue N to succeeding N-fertilized crops (Bremer and Van Kessel 1992; Jensen 1994b; Thomsen and Jensen 1994). These values shows that residue N from a preceding crop only contributes a small proportion of total N to the following N-fertilized crop.

Sequence IV: test crop

The uptake of soil-derived and total N in the test crop grown in the second autumn was not influenced by pre-precrop species and residue treatment (Table 3). However, more residue-derived N was recovered from pea than from barley residues, and consequently the percentage of N derived from residues and percentage recovery of residue N was higher with pea as the pre-precrop. There was a tendency that the N uptake after the barley pre-precrop was higher with residue incorporation, which could be due to re-mineralization of N immobilized during the first months of residue decomposition. At the time of test crop harvest, the inorganic N concentration in soil cropped to barley with subsequent residue incorporation was 7 $\mu g\ N\ g^{-1}$ soil, whereas the soil contained 13 $\mu g\ N\ g^{-1}$ soil in the other treatments.

Spring incorporation of pea residues significantly increased both the total dry matter production and total N uptake of the mustard test crop. The significantly greater total N uptake was due to the uptake of residue-derived N (7.4% recovery), since the uptake of soil-derived N was similar with and without pea residue incorporation in the spring (Table 3).

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