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I. Discription of the experimental areas, climate, plant production and mineral N in soil

N-omsætning og N-transport i en sandblandet lerjord og en grovsandet jord bevokset med vårbyg

I. Beskrivelse af forsøgsarealerne, klima, planteproduktion og mineralsk N i jorden

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Contents

Summary

As part of a N-balance-project concerning denitrification, N-mineralization and nitrate leaching, running from spring 1987 to spring 1990, a basic physical and chemical characterization were done of the two experimental areas; a sandy loam (Askov) and a coarse sand (Jyndevad). The main crop was spring barley. At Askov the treatments were: unfertilized, 100 kg NH_4^+-N/ha in pig slurry applied in the spring and 133 kg N/ha in N-fertilizer. At Jyndevad the treatments were: unfertilized, 50 kg NH_4^+-N/ha in pig slurry applied in the spring, 100 kg NH_4^+-N/ha in pig slurry applied in the spring, 100 kg NH_4^+-N/ha in pig slurry applied in late autumn, 100 kg NH_4^+-N/ha in pig slurry applied in the spring with ryegrass as an undersown catch crop and 120 kg N/ha in N-fertilizer.

Climatic descriptions based on automatic registrations are given.

In general, the results show that the yield response to inorganic-N in slurry is equivalent to the same amount given in N-fertilizer. The yield of the treatment that received slurry in the autumn was slightly above the yield of the unfertilized treatment. The yield and especially the N-uptake in the treatment with grass as a catch crop was in some years higher than the corresponding treatment without grass. This effect was due to mineralization of the catch crop during the growth period of the barley.

In spring at Askov there were no significant differences between the treatments in soil inorganic-N, and given as an average of the treatments, the total inorganic-N to a depth of 100 cm ranged from 32 to 46 kg N/ha. In spring at Jyndevad the values of inorganic soil-N to a depth of 80 cm were in general low with only minor differences between the treatments. An exception was the treatment with autumn applied slurry; apart from this treatment the values as an average ranged from 11 to 26 kg N/ha. In general there were only minor differences at harvest between the treatments that had received 'optimal' amounts of slurry and N-fertilizer, respectively. The soil inorganic-N in the N-fertilized treatment ranged from 21 to 55 kg N/ha at Askov and from 17 to 24 kg N/ha at Jyndevad.

Key words: Soil characterization, inorganic-N, N-uptake, N-utilization, pig slurry, N-fertilizer, roots, catch crop, spring barley.

Resumé

Som en del af et N-balanceprojekt, hvor der er målt denitrifikation, N-mineralisering og nitratudvaskning igennem en 3-årig periode fra foråret 1987 til foråret 1990, er der gennemført en grundlæggende fysisk og kemisk karakterisering af de to anvendte forsøgsarealer, en grov sandblandet lerjord (Askov) og en grovsandet jord (Jyndevad). Hovedafgrøden var vårbyg suppleret med en behandling med efterafgrøde på den grovsandede jord. I Askov var behandlingerne: ugødet; 100 kg NH_4^+-N/ha i svinegylle tilført om foråret og 133 kg N/ha i handelsgødning. I Jyndevad var behandlingerne: ugødet; 50 og 100 kg NH_4^+-N/ha i svinegylle tilført om foråret; 100 kg NH_4^+-N/ha i svinegylle tilført om efteråret; 100 kg NH_4^+-N/ha i svinegylle tilført om foråret og med rajgræs som isået efterafgrøde samt 120 kg N/ha i handelsgødning.

Klimabeskrivelser er givet på grundlag af automatiske registreringer.

Udbytteresultaterne viser generelt, at der kan opnås samme udbytte med tilførsel af svinegylle som med handelsgødning, når man sammenligner på basis af tilført uorganisk kvælstof. Udbyttet efter tilførsel af gylle i efteråret var kun svagt højere end udbyttet i det ugødede led. Udbytte og N-optagelse i behandlingen med efterafgrøde var i nogle år højere end i den tilsvarende behandling uden efterafgrøde. Denne effekt kan tilskrives mineralisering af efterafgrøden i vårbyggens vækstperiode.

Om foråret var der i Askov ingen signifikant forskel mellem jordens indhold af uorganisk N i de enkelte behandlinger, og i gennemsnit af alle behandlinger pr. dato var jordens indhold af uorganisk N til 100 cm's dybde på 32 til 46 kg N/ha. I Jyndevad om foråret var indholdet af uorganisk N til 80 cm's dybde lavt, og der var kun små forskelle mellem behandlingerne, med undtagelse af behandlingen med efterårstilført gylle. I gennemsnit af alle led pr. dato minus det led, der fik gylle om efteråret, varierede jordens indhold af uorganisk N til 80 cm's dybde fra 11 til 26 kg N/ha. Ved høst var der generelt kun små forskelle i uorganisk N i jorden mellem de led ,der havde fået 'optimale' mængder af henholdsvis gylle og handelsgødning. I Askov varierede indholdet af uorganisk N pr. dato til 100 cm's dybde i det handelsgødede led fra 21 til 55 kg N/ha. I Jyndevad opgjort til 80 cm's dybde var den tilsvarende variation mellem årene 17 til 24 kg N/ha.

Nøgleord: Jordkarakterisering, uorganisk kvælstof i jord, N-optagelse, N-udnyttelse, svinegylle, handelsgødning, rødder, efterafgrøde, vårbyg.

Introduction

Studies of N dynamics in the soil plant system of farm land are essential for evaluation of the influence of climatic variations, fertilization strategy and cropping system on crop yield, crop N-uptake and losses of nitrogen by leaching and denitrification.

In 1985, as a follow-up of the *NPo-redegørelsen* (23), the Danish Parlament established the NPo-action plan with its primary objective to reduce nitrogen losses from agriculture, in particular in connection with application of manure and slurry. At the same time it was realized that the scientific basis was insufficient to provide a reliable evaluation of the effects of the proposed measures. Accordingly, the NPo research programme (24) was initiated to provide a multidisciplinary and comprehensive study of the entire transport and transformation cycle of nitrogen and phosphorous. Concerning the transport and transformation - including the losses - of nitrogen in the root zone of agricultural soil the main concern was the impact of amount of applied N-fertilizer and slurry/manure and the application time of slurry/manure.

Until then, most of the investigations had been focused on only one or a few of the processes/pools in the nitrogen-cycle in the root zone; as many of the investigations were not performed under in-situ conditions (2, 6, 13, 14, 15, 17, 20), thus making it difficult to combine the data from these investigations for a generalization purpose.

Hence, as part of the NPo research programme, a N-balance project on field scale has been carried out for a period of three years, from spring 1987 to spring 1990, on a sandy loam and a coarse sandy soil. The purpose of the project was to estimate nitrate leaching, denitrification and net-N-mineralization in relation to the use of different levels of pig slurry versus N-fertilizer. Furthermore, the aspects of undersown grass as a catch crop, and autumn application of slurry were investigated at the coarse sandy soil site. As a part of the N-balance project, this paper describes the experimental design, the areas and the climate, and presents data on dry matter production, N-uptake and the content of inorganic-N in the root zone. Data of nitrate leaching, denitrification and net-N-mineralization will be published successively in separate papers.

Another purpose of the project was to create a data set to validate nitrate leaching models (7, 10).

Materials and methods

Experimental areas

The areas selected for the field experiments were situated at the experimental stations Askov and Jyndevad both located in the southern part of Jutland. The soil at Askov is a sandy loam classified according to the Soil Taxonomy System as a Typic Hapludalf (25). The soil at Jyndevad is a coarse sand classified as a Orthic Haplohumod (26). These soil types each represent about 24 % of the total area in Denmark (42).

Before the start of the field experiments in spring 1987 soil samples for texture and chemical analyses were taken. The particle size fractions and contents of humus of the experimental areas are given in Table 1 and 2. The analyses have been made according to Danish Standard Methods (5).

Table 1. Askov. Particle size fractions and humus, per cent. Mean of treatments.
Askov. Tekstur, procent. Gennemsnit af forsøgsledene.

Depth *Dybde* cm	Humus *Humus*	Clay *Ler* < 2 μm	Silt *Silt* 2-20 μm	Coarse silt *Grovsilt* 20-63 μm	Fine sand *Finsand* 63-200 μm	Coarse sand *Grovsand* 200-2000 μm
0-10	2.3	10.9	10.6	14.6	25.2	36.5
10-23	2.3	10.7	11.1	14.5	25.2	36.2
23-40	1.5	11.3	10.7	14.0	25.5	36.9
40-60	0.8	14.4	10.1	12.4	26.3	36.1
60-80	0.4	15.6	9.3	11.5	27.8	35.5
80-100	0.2	15.8	9.5	11.6	28.4	34.4

The soil at Askov was characterized by a clay content of about 11 % in the tilth increasing to nearly 16 % at 80-100 cm depth with a corresponding decrease in the sum of the two silt fractions. The content of fine and coarse sand was about 26 and 36 %, respectively, with only small variations between the depths. The soil at Jyndevad was characterized by a clay content of 4.4 % in the tilth decreasing to 3.8 % at 60-80 cm depth, and with a rather high content of coarse sand - about 70 % in the tilth increasing to about 80 % at 60-80 cm depth. The total sand content ranged between 87 % in the upper depth to 94 % at 60-80 cm depth.

Table 2. Jyndevad. Particle size fractions and humus, per cent.
Jyndevad. Tekstur, procent.

Depth *Dybde* cm	Humus *Humus*	Clay *Ler* < 2 μm	Silt *Silt* 2-20 μm	Coarse silt *Grovsilt* 20-63 μm	Fine sand *Finsand* 63-200 μm	Coarse sand *Grovsand* 200-2000 μm
0-10	2.8	4.5	3.0	2.9	17.1	69.7
10-20	2.9	4.2	3.1	2.5	17.6	69.7
20-40	2.2	4.5	2.5	2.1	17.2	71.4
40-60	1.1	4.0	1.0	2.7	15.8	75.3
60-80	0.5	3.8	1.0	1.2	14.3	79.2

The water retention characteristics, the relative air diffusivity and the saturated hydraulic conductivity were measured on 100 cm^3 undisturbed samples taken in 1987, Fig.1 and Table 3.

The pF-curves have been measured as described by *Schjønning* (33). The saturated hydraulic conductivity was measured by the constant head method (16) with the technical equipment described by *Anderson* (4). The relative air diffusivity was measured as described by *Schjønning* (34).

At Askov the soil was drained uniformly from about pF=2 to pF=4.2, but at a decreasing water content with depth. The field capacity defined as the water content at pF=2 (37) to 100 cm depth was 248 mm. The root zone capacity to 100 and 80 cm depth, defined as water content between pF=2 and pF=4.2, was 176 mm and 146 mm , respectively. The porosity was 0.39 to 0.40 m^3/m^3, increasing slightly with depth. At pF=2 the values of air content ranged from 0.08 to 0.19 m^3/m^3, increasing with depth.

Table 3. Relative air diffusivity measured at pF 2.0 and saturated hydraulic conductivity (Ks).
Relativ luftdiffusivitet målt ved pF 2,0 og mættet hydraulisk ledningsevne (Ks).

Depth *Dybde*	Relative air diffusivity, per thousand *Relativ luftdiffusivitet, 0/00*		Ks mm/hour, *mm/time*	
cm	Askov	Jyndevad*	Askov	Jyndevad*
8-12	8	43	14	185
33-37	12	51	31	88
63-67	22	112	68	667

* Heidmann (11)

At Jyndevad the soil was drained strongly between pF=1 and pF=1.7, thus the water content at pF=1.7 was relatively small and decreasing with depth. The field capacity defined as the water content at pF=1.7 (37) to 80 cm depth was 139 mm. The root zone capacity to 80 and 60 cm depth, defined as water content between pF=1.7 and pF=4.2 was 109 and 91 mm , respectively. The corresponding values for the root zone capacity calculated for pF=2.0 instead of pF=1.7 were 73 and 63 mm. The porosity was about 0.43 m^3/m^3 independent of the depth, thus the air content at pF=1.7 was 0.21 and 0.23 m^3/m^3 in the tilth and just below the tilth and 0.32 m^3/m^3 in the lowest depth. The results of the measurements of relative air diffusivity at pF=2 (Table 3) show that the diffusivity increased with depth and that the figures at Jyndevad were about a magnitude of five higher compared with the figures at Askov. Below a critical value for this parameter of 5 to 20 ‰ growth of cereals is affected negatively (9). Thus there was no problem with soil aeration at Jyndevad while there was a risk of bad soil aeration at Askov.

The dry bulk density was measured on the same samples as the water retention. The data for Askov at the depth 8-12, 33-37 and 63-67 cm, respectively, were 1.58 , 1.59 and 1.60 g/cm^3. The corresponding values for Jyndevad for the same depth were 1.49 , 1.51 and 1.51 g/cm^3.

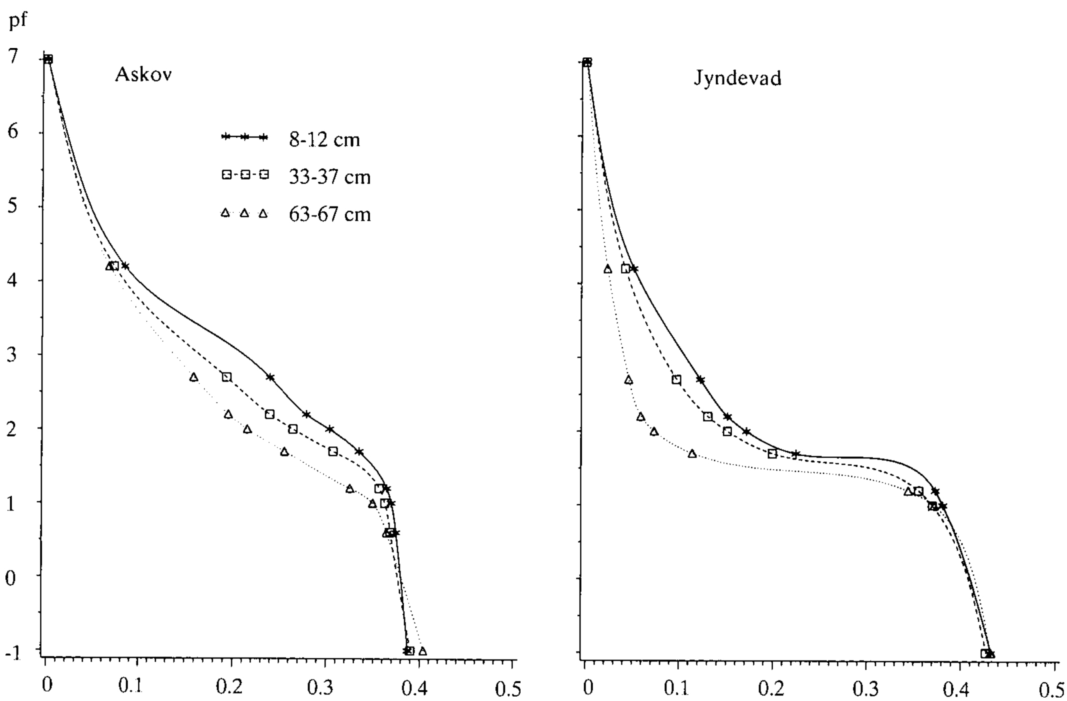


Fig. 1 Soil water retention curves. Water content, m^3/m^3

Retentionskurver *Vandindhold*

The saturated hydraulic conductivities given in Table 3 show that this parameter was an order of magnitude higher at Jyndevad compared with Askov at 8-12 and 63-67 cm depth, and that the figures at Askov increased with depth while the lowest value at Jyndevad was found at a depth of 33-37 cm . At Askov the field was drained at 110 cm depth. The distance between the drainpipes was 15 m, with one pipe placed between the two blocks and one on each side of the blocks. According to the FAO classification the drainage characteristics were 2-3 at Askov and 6 at Jyndevad.

The soil chemical analyses are given in Table 4 and 5. Analyses for pH (H_2O), phosphorus (Pt), potassium (Kt), cations excl. H^+, CEC, tot.-N and org.-C have been performed according to Danish Standard Methods (5).

Table 4. Askov. Soil chemical analysis on samples taken in spring 1987. Mean of the treatments.
Askov. Jordkemiske analyser på prøver udtaget i foråret 1987. Gennemsnit af forsøgsledene.

Depth *Dybde* cm	pH(H_2O)	Pt*	Kt*	Cations** excl. H^+	CEC**	Org.-C per cent %	Tot.-N per cent %	C/N
0-10	5.9	3.9	8.6	6.0	12.9	1.34	0.123	10.9
10-23	6.0	4.0	10.1	6.1	12.9	1.35	0.125	10.8
23-40	6.1	3.1	7.3	5.6	11.6	0.99	0.090	11.0
40-60	6.3	2.0	5.9	6.2	11.0	0.45	0.042	10.6
60-80	5.8	1.4	6.7	5.5	10.9	0.24	0.024	10.0
80-100	5.2	1.7	6.6	4.4	10.8	0.14	0.017	8.1

* mg/100 g soil, *jord*   ** meq/100 g soil, *jord*

The values of pH, Pt and Kt can be considered as normal for arable land on the two soil types in Denmark. The cation exchange capacity decreased slightly in the Askov soil with depth while the soil at Jyndevad showed a marked decrease below the 40 cm depth. At Askov the percentage base saturation was 47 % in the tilth decreasing to 41 % at 80-100 cm. At Jyndevad the percentage base saturation was 50 % in the top soil and 11 % at 60-80 cm depth. The org.-C in the top soil at Askov and Jyndevad was 1.35 and 1.70 %, respectively, while the corresponding values for tot.-N were 0.124 and 0.105 %. At all depth the values of org.-C were highest at Jyndevad while the opposite was the case for tot.-N. Thus the C/N-ratio was about 10 at Askov compared with values of 16.1 to 20.4 at Jyndevad. Furthermore, the values of tot.-N, and especially org.-C, at Jyndevad must be considered rather high compared with results from other Danish investigations (11, 37), thus the C/N-ratio at Jyndevad is to be considered as relatively high.

Table 5. Jyndevad. Soil chemical analyses on samples taken in spring 1987.
Jyndevad. Jordkemiske analyser på prøver udtaget i foråret 1987.

Depth *Dybde* cm	pH(H_2O)	Pt*	Kt*	Cations** excl. H^+	CEC**	Org.-C per cent %	Tot.-N per cent %	C/N
0-10	6.4	5.2	5.4	5.8	11.5	1.68	0.103	16.5
10-20	6.3	5.7	5.0	6.0	11.9	1.72	0.107	16.1
20-40	6.4	2.8	3.3	4.4	11.6	1.31	0.076	17.2
40-60	6.2	0.8	2.4	1.5	8.0	0.67	0.033	20.4
60-80	6.0	0.6	1.5	0.6	5.4	0.33	0.018	17.6

* mg/100 g soil, *jord* ** meq/100 g soil, *jord*

Experimental design

At both localities the crop was spring barley (*Hordeum vulgare* L., cvs Alis, Triump and Grit). At Askov the measurements were carried out in a field experiment described by *Larsen et al.* (19). The treatments at Askov, with the abbreviations given in brackets, were:

1. Unfertilized (0 N).
4. Pig slurry, 100 kg NH_4^+-N/ha in the spring (PS S 100 N).
8. N-fertilizer, 133 kg N/ha (NPK 133 N).

At Jyndevad the treatments were:

1. Unfertilized in the actual year (0 N). In the previous years - starting in 1987 - the plots were treated as in treatment 3.
2. Pig slurry, 50 kg NH_4^+-N/ha in the spring (PS S 50 N).
3. Pig slurry, 100 kg NH_4^+-N/ha in the spring (PS S 100 N).
4. Pig slurry, 100 kg NH_4^+-N/ha in the autumn (PS A 100 N).
5. Pig slurry, 100 kg NH_4^+-N/ha in the spring.
   Ryegrass as an undersown catch crop (*Lolium perenne* L., cv. Sisu)(PS S 100 N CC). The amount of grass seed was 8 kg/ha.
6. N-fertilizer, 120 kg N/ha (NPK 120 N).

At Askov the present field experiment was started in 1985. The experiment was carried out as a randomized block design with two replications. At Jyndevad the experiment was started in 1987. The experiment was carried out as a randomized block design with four replications. At Askov the net plots were (7 x 7) m^2 and at Jyndevad (9 x 10) m^2.The plots for harvest were 17.5 m^2 at Askov and 15 m^2 at Jyndevad. The rest of the net plots were used for soil samples, crop samples etc.

At Askov before the experiment started the field was grown with spring barley from 1982 to 1984 and fertilized with degassed pig slurry (110-120 kg NH_4^+-N/ha). At Jyndevad, the field was used from 1982 to 1983 for an experiment with grass and clover receiving from 0 to 450 kg N/ha in N-fertilizer. From 1984 to 1986 the field was grown uniformly with spring barley, maize and potatoes fertilized with 90 kg N/ha in N-fertilizer, 150 kg N/ha in N-fertilizer supplemented with about 50 kg NH_4^+-N/ha in slurry from young cattle, and 140 kg N/ha in N-fertilizer, respectively.

Because the field experiment at Jyndevad was started in the spring 1987, the treatment with autumn applied slurry was amended with slurry in the spring 1987 as PS S 100 N. At Askov the unfertilized plots have not received fertilizer since 1984.

Table 6. Applied pig slurry in PS S 100 N at Askov and in PS S 100 N, PS A 100 N and PS S 100 N CC at Jyndevad.
Tilført svinegylle i PS S 100 N i Askov og i PS S 100 N, PS A 100 N og PS S 100 N CC i Jyndevad.

		Amount *Mængde*	NH_4^+-N	Total-N	Total-P	Potassium *Kalium*	Dry matter *Tørstof*
				kg/ha			per cent, %
Askov	29.04.87	28000	96	136	42	78	5.1
	08.04.88	28600	95	154	64	76	7.6
	14.03.89	27800	105	156	51	76	6.4
Jyndevad	21.04.87	24800	110	194	48	77	9.5
	26.11.87	33800	102	146	32	63	3.0
	29.03.88	28600	93	146	52	73	6.3
	06.12.88	27900	101	159	50	77	7.0
	31.03.89	23900	108	161	44	68	7.8
	04.12.89	21100	96	128	36	56	5.5
	04.04.90	26500	102	131	41	59	4.9

In Table 6 the actual amounts of applied pig slurry are given together with the contents of NH_4^+-N, total-N, total-P, potassium and dry matter content. In this Table, PS S 50 N at Jyndevad is omitted, because it is just half the amount applied to PS S 100 N. The N-fertilizer used was calcium ammonium nitrate. At Askov the N-fertilized treatment was applied with about the same amount of P and K as the slurry applied treatment, while at Jyndevad the N-fertilized treatment was applied with about 30 kg P/ha and 80 kg K/ha. At Jyndevad PS S 50 N was supplied with PK-fertilizer up to the same level as NPK 120 N.

At Askov the area was ploughed in the beginning of December. At both localities the slurry was surface applied followed by harrowing or disc ploughing at Askov and ploughing at Jyndevad. Thus PS A 100 N at Jyndevad was ploughed in the end of November/beginning of December, while the other treatments at Jyndevad were ploughed in the spring.

The incorporation of the slurry was carried out within 1-3 hours and 1/2-1 hour after application at Askov and Jyndevad, respectively. Based on the air temperature and the period of time from application to incorporation of the slurry the NH_3-volatilization in percent of applied ammonium has been estimated to 1-4 % with the exception of Askov 1987 where the loss has been estimated to 7-15 % (12, 43, 44). Weeds were controlled by herbicides.

The field experiment at Askov was not irrigated, while the field experiment at Jyndevad was irrigated at an estimated water deficit of about 30 mm based on measurements in the NPK 120 N plots. In 1987 the field was irrigated 9 July with 23 mm and in 1988 15 June with 30 mm. In 1989 the field was irrigated 5 times (25 and 31 May, 21 and 30 June and 12 July) with a total of 139 mm. In 1990 the field was irrigated 23 July with 38 mm.

Sampling and analyses

The sampling program is given in Table 7.

Crop

Samples of 0.5 m^2 of barley, the catch crop and the stubble at harvest were taken in each plot. The samples of the barley were divided in below ground stem, stem and ear. The samples of the catch crop include above ground biomass. Dry matter was measured after drying for 16 hours at 80°C. In the laboratory total-N was determined after the Kjelddahl principle. Organic-C in the dried plant material was determined by combustion using a Leco IR 12 apparatus.

Roots

A steel auger of a diameter of 54 mm was used. In each plot two soil samples at 0-20 cm were taken in the rows of the barley and between the rows, respectively. Furthermore, one sample

Table 7. Sampling programme.
Plan for måleprogram.

	Soil inorganic-N *Uorganisk-N i jord* Askov: 0-100 cm Jyndevad: 0-80 cm	Crop samples of barley *Afgrødeprøver af byg*	Root samples of barley[1] *Rodprøver af byg*[1]	Crop samples of the catch crop *Afgrødeprøver af efterafgrøden*	Samples of the stubble of barley *Stubprøver af byg*
1. Spring application of slurry *Forårsudbringning af gylle*	+			+	
2. 14 days after germination *14 dage efter spiring*		+			
3. End of tillering *Afslutning af buskning*	+	+	+[2]		
4. Earing *Skridning*		+			
5. Dough becoming hard *Gulmodenhed*	+	+	+		
6. Harvest *Høst*	+	+		+	+
7. Askov: Autumn ploughing *Efterårspløjning* Jyndevad: Autumn application of slurry *Efterårsudbringning af gylle*	+			+	

[1] Only 0 N and PS S 100 N at both locations. *Kun 0 N og PS S 100 N begge steder.*
[2] In 1987 at Askov and 1987 and 1988 at Jyndevad. *I 1987 i Askov og 1987 og 1988 i Jyndevad.*

at 20-80 cm at Askov and at 20-50 cm at Jyndevad was taken in the rows of the barley and between the rows, respectively. The samples were divided in sections of 10 cm.

In the laboratory the samples were dried for 48 hours at 40°C. The soil was washed from the roots as described by *Andersen* (1) with a sieve with a mesh-size of 0.40 mm. Dry matter was measured after drying for 16 hours at 80°C. Total-N was determined as mentioned for the crop samples.

Soil inorganic-N

The soil samples were taken by use of soil augers. The type of soil auger differed depending on the locality and the water content of the soil. The sampling was done stepwise in sections of 20 cm. In each treatment per block six samples were taken at 0-20 cm and four at 20-100 cm at Askov and 20-80 cm at Jyndevad.

The samples were deep-frozen within 2-6 hours until analysis. In the laboratory the extraction of the soil samples was started as soon as the soil samples were thawed to avoid unwanted microbial and chemical transformations of N, which may take place very fast after a freezing-thawing procedure (21, 45). The soil samples were extracted with 1 M KCl (soil-water proportion 1:2). NO_3^--N and NH_4^+-N were analyzed using a Technicon autoanalyzer.

Results

Climate

At both localities the three winter periods were unusually warm, especially in 1988/89 and 1989/90. The summer 1987 was relatively cold while the rest of the period was near the normal temperature at both places (Fig. 2a and b).

In 1987/88 and the summer 1988 the precipitation was higher than normal, especially during the winter period 1987/88. In the last year the precipitation during the summer period was considerably lower than normal, especially at Askov. During the autumn period the precipitation was lower than normal while in January and February 1990 the precipitation was considerably higher than normal, especially at Askov. Summarised from 1 April to 31 March the precipitation at Askov has been 1098, 979 and 698 mm for each of the three years, respectively, with an

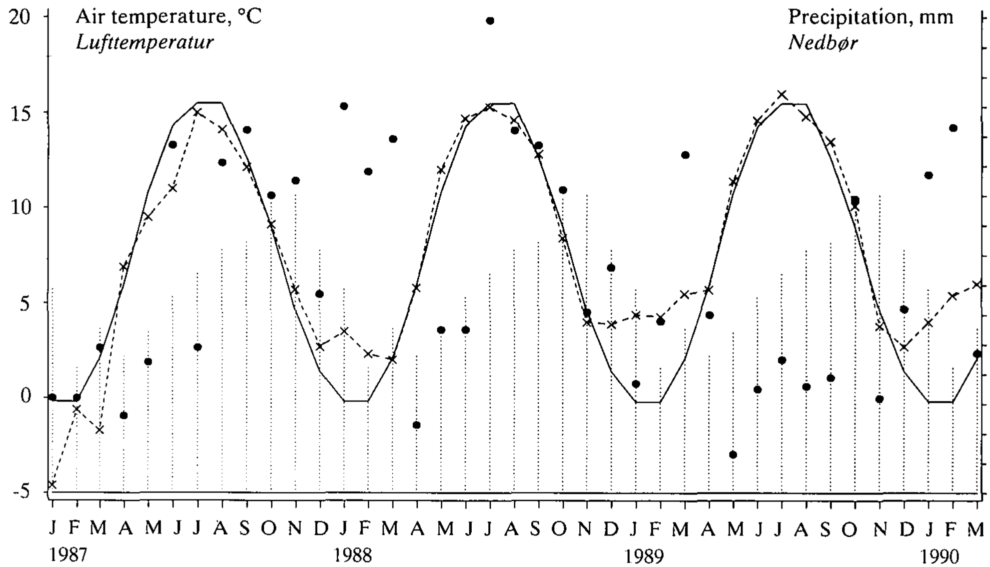


Fig. 2a. Askov. Average monthly air temperature and accumulated monthly precipitation at 1.5 m above ground (28, 29, 30, 31). x---x: air temperature for the actual month; ————: average air temperature 1961-90; ●: precipitation for the actual month; : average precipitation 1961-90.

Askov. Gennemsnitlig lufttemperatur pr. måned og summeret månedlig nedbør i 1,5 m højde (28, 29, 30, 31). x---x: lufttemperatur for de pågældende måneder; ————: gennemsnitlig lufttemperatur 1961-90; ●: nedbør for de pågældende måneder; : gennemsnitlig nedbør 1961-90.

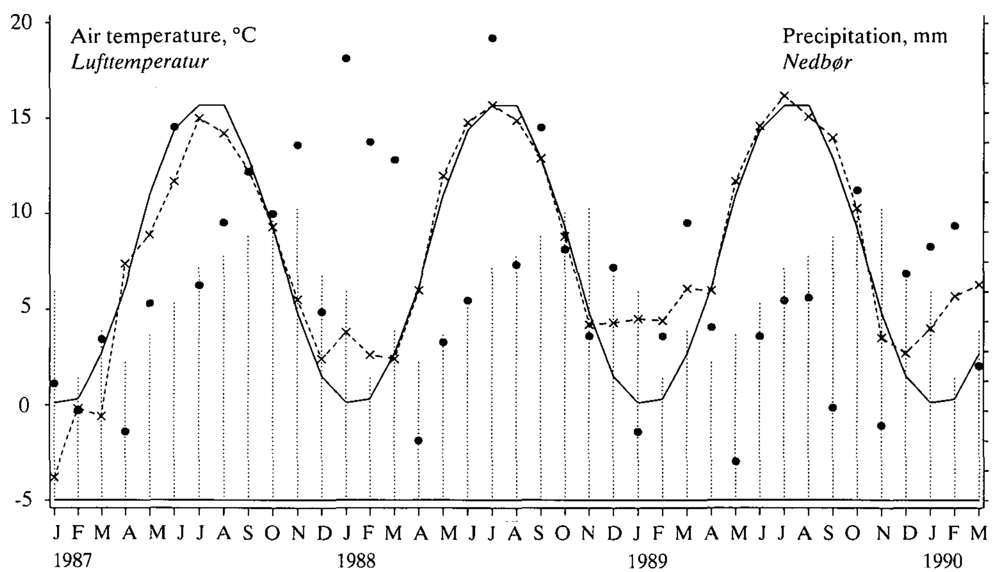


Fig. 2b. Jyndevad. See fig. 2a for text and legend.

Jyndevad. Se fig. 2a for figurtekst og signaturforklaring.

average of 925 mm. The corresponding figures from Jyndevad were 1149, 887 and 719 mm with an average of 918 mm. The average yearly precipitation for the same period for 1961-90 was 862 and 859 mm for Askov and Jyndevad, respectively (31). So the first year must be regarded as very wet while the last year was relatively dry. Both Askov and Jyndevad are located in a rather rainy area which is reflected in the fact that the average yearly precipitation for 1961-90 for Denmark is only 707 mm (31).

Dry matter production and N-uptake

The yield and N-uptake in the unfertilized treatment at Askov were relatively low, differing slightly from year to year (Table 8 and 9, and Fig.3 and 4). At harvest the highest N-uptake in grain, straw and stubble in the unfertilized treatment was found in 1989 (40.5 kg N/ha) while the lowest was found in 1988 (25.8 kg N/ha). The yield in the N-fertilized treatment was in 1987 and 1989 slightly higher compared with that in the slurry applied treatment although the differences at harvest were not significant. Regarding the N-uptake in these two years the differences were more marked, which in general are also valid concerning 1988 which shows the highest differences between the two treatments. The last two years the rate of N-uptake showed a marked difference between the two treatments (Fig.4). In the period from when the first samples of crop were taken, about 14 days after germination and until the end of tillering, the N-uptake was highest in the N-fertilized treatment while in the following period until earing, the N-uptake was highest in the slurry applied treatment.

At Jyndevad yield and N-uptake in the treatments fell in three groups (Tabel 8 and 9, and Fig. 5 and 6). The lowest yield and N-uptake were found in the unfertilized treatment and in the treatment with autumn applied slurry. In the unfertilized treatment the N-uptake at harvest in grain, straw and stubble varied from 35.8 kg N/ha in 1987 to 47.4 kg N/ha in 1989. The highest yield and N-uptake were found in the N-fertilized treatment and the two treatments receiving the full amount of slurry in the spring, while the treatment receiving half the amount of slurry lay in the middle between the two groups. In 1988 and 1989 there was a tendency to a higher N-uptake in the treatment with undersown grass compared with the corresponding treatment without undersown grass. This difference was further marked in 1990 where the highest yield and N-uptake at harvest were found in the treatment with undersown grass. Even though the yield and

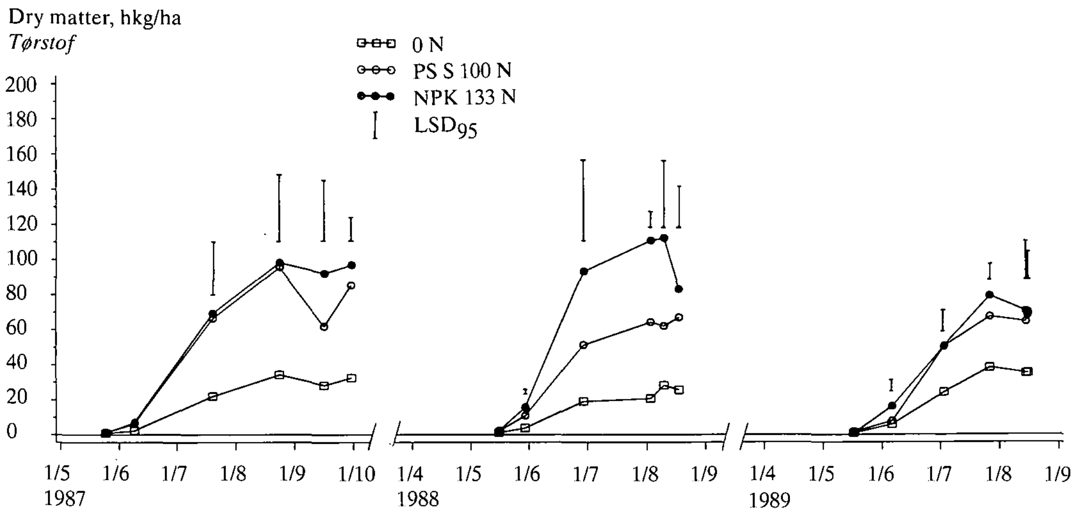


Fig. 3. Askov. Dry matter production in above ground biomass and total of straw, grain and stubble at harvest. The last values each year represent the harvest.

Askov. Tørstofproduktion i overjordisk biomasse og total af halm, kerne og stub ved høst. De sidste værdier hvert år er fra høsten.

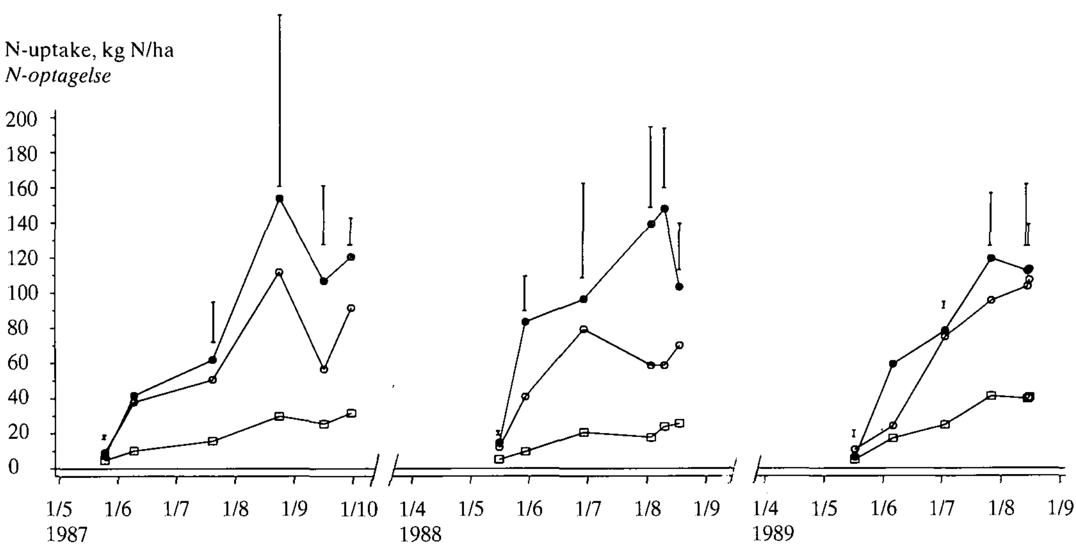


Fig. 4. Askov. N-uptake in above ground biomass and total of straw, grain and stubble at harvest. The last values each year represent the harvest. See Fig. 3 for legends.

Askov. N-optagelse i overjordisk biomasse og total af halm, kerne og stub ved høst. De sidste værdier hvert år er fra høsten. Se fig. 3 for signaturforklaring.

Table 8. Yield of harvest. 85 per cent dry matter.

Høstudbytter. 85 % tørstof.

	Treatment	Straw, *halm*, hkg/ha				Grain, *kerne*, hkg/ha				Harvest index, *høstindex*			
	Forsøgsled	1987	1988	1989	1990	1987	1988	1989	1990	1987	1988	1989	1990
Askov	0 N	15.7[1]	11.1	11.9		16.1	14.4	22.6		0.51[1]	0.57	0.66	
	PS S 100 N	55.8[1]	26.6	27.4		33.7	45.0	39.5		0.38[1]	0.63	0.59	
	NPK 133 N	61.8[1]	33.6	26.8		41.3	56.3	40.7		0.40[1]	0.63	0.60	
	LSD_{95}	12.7	11.9	12.2		4.5	20.0	3.4		0.08	n.s.	n.s.	
Jyndevad	0 N	10.7	13.8	14.1	14.6	24.2	27.3	30.8	24.7	0.69	0.66	0.69	0.64
	PS S 50 N	27.2	21.2	28.1	25.0	49.8	38.1	49.7	38.8	0.64	0.64	0.64	0.59
	PS S 100 N	39.8	27.8	33.4	34.5	58.8	45.8	56.9	51.4	0.60	0.62	0.63	0.60
	PS A 100 N		16.6	14.2	19.4		28.4	32.1	28.4		0.65	0.70	0.60
	PS S 100 N CC	44.3	33.4	35.9	41.8	60.5	46.8	57.2	60.5	0.58	0.58	0.61	0.59
	NPK 120 N	45.8	32.3	35.0	40.3	64.4	49.5	60.0	59.1	0.58	0.60	0.63	0.59
	LSD_{95}	6.5	3.3	4.9	6.8	3.5	3.7	6.6	4.8	0.03	0.02	0.03	n.s.

[1] Including grass harvested with straw. The grass was by a mistake sown at the same time as the barley. *Inklusiv græs høstet sammen med halmen. Græsset blev ved en fejltagelse sået samtidig med bygafgrøden.*

Table 9. N-uptake in straw and grain at harvest.
Optaget kvælstof i halm og kerne ved høst.

	Treatment	Straw, *halm*, kg N/ha				Grain, *kerne*, kg N/ha			
	Forsøgsled	1987	1988	1989	1990	1987	1988	1989	1990
Askov	0 N	12.7[1]	8.8	5.2		16.7[1]	14.9	32.2	
	PS S 100 N	45.5[1]	14.5	16.8		41.3[1]	52.4	79.2	
	NPK 133 N	49.7[1]	16.7	17.9		64.3[1]	81.0	86.0	
	LSD_{95}	8.5	n.s.	9.1		6.2	32.5	0.4	
Jyndevad	0 N	4.7	6.9	6.0	9.2	28.4	35.4	37.4	29.1
	PS S 50 N	11.0	9.4	10.7	12.9	57.8	44.1	57.7	41.4
	PS S 100 N	19.4	14.8	16.1	15.4	80.1	60.7	74.5	62.9
	PS A 100 N		8.2	6.6	13.2		37.0	40.9	32.1
	PS S 100 N CC	27.0	23.2	22.5	22.3	82.9	66.2	85.9	77.7
	NPK 120 N	21.5	18.8	15.9	16.4	83.3	67.8	80.4	75.1
	LSD_{95}	3.5	2.2	3.6	5.7	8.0	5.2	9.2	8.5

[1] See table 8 for explanation. *Se tabel 8 for forklaring.*

N-uptake at harvest in the N-fertilized treatment and PS S 100 N and PS S 100 N CC were nearly the same, the rate of N-uptake in 1988 and especially 1987 shows the same difference as at Askov for the first part of the growing season (Fig.6).

The results of the nitrogen left in stubble at harvest show the same general trend as the total N-uptake (Table 10). The level of nitrogen left in the stubble differed considerably from year to year probably depending on the height of the stubble. The C/N-ratio was in general inversely proportional to the amount of spring applied nitrogen even though the highest C/N-ratio at Jyndevad in 1987 was found in the N-fertilized treatment.

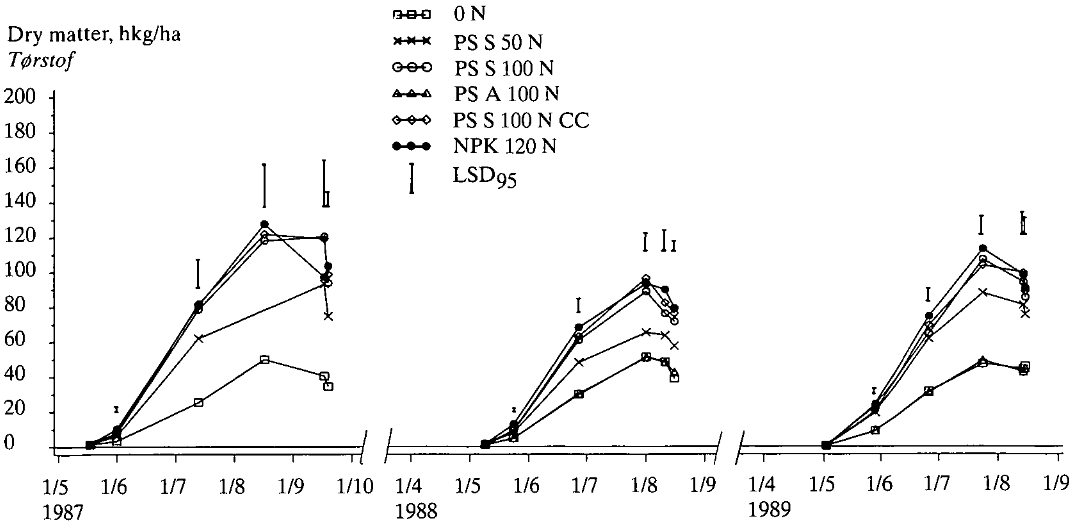


Fig. 5. Jyndevad. Dry matter production in above ground biomass and total of straw, grain and stubble at harvest. The last values each year represent the harvest.

Jyndevad. Tørstofproduktion i overjordisk biomasse og sum af halm, kerne og stub ved høst. De sidste værdier hvert år er fra høsten.

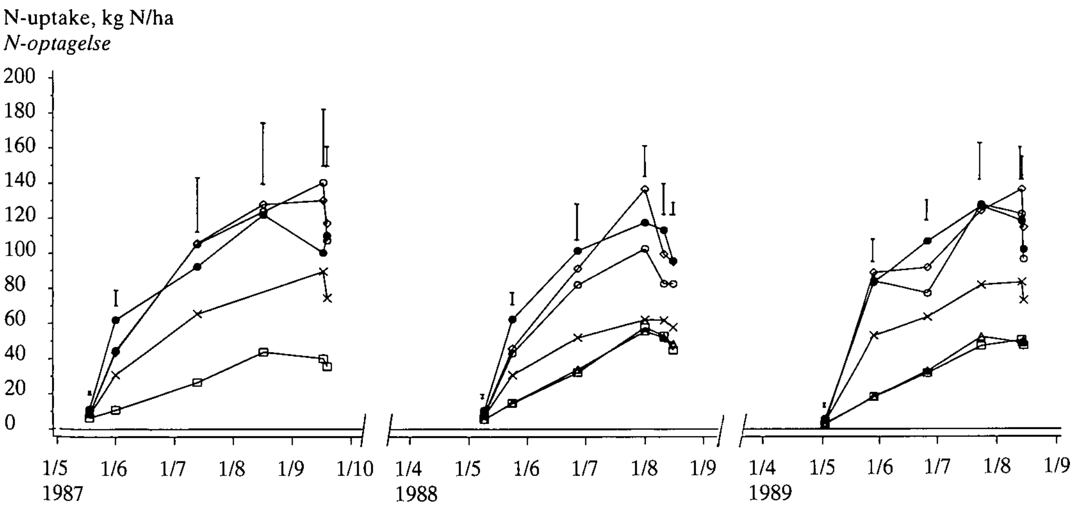


Fig. 6. Jyndevad. N-uptake in above ground biomass and total of straw, grain and stubble at harvest. The last values each year represent the harvest. See Fig. 5 for legends.

Jyndevad. N-optagelse i overjordisk biomasse og total af halm, kerne og stub ved høst. De sidste værdier hvert år er fra høsten. Se fig. 5 for signaturforklaring.

Table 10. N-uptake and C/N in stubble at harvest.
Optaget kvælstof og C/N i stub ved høst.

	Treatment	kg N/ha			C/N		
	Forsøgsled	1987	1988	1989	1987	1988	1989
Askov	0 N	2.6	2.1	3.1	103	87	90
	PS S 100 N	4.9	3.2	11.1	89	87	55
	NPK 133 N	6.8	5.7	9.2	63	52	55
	LSD_{95}	2.4	n.s.	4.2	n.s.	n.s.	5
Jyndevad	0 N	2.8	2.6	4.1	86	74	91
	PS S 50 N	5.8	4.4	4.8	72	75	94
	PS S 100 N	7.8	7.1	5.8	61	59	70
	PS A 100 N		3.2	2.3		74	106
	PS S 100 N CC	7.3	5.6	6.2	61	64	72
	NPK 120 N	5.4	9.0	5.8	91	49	76
	LSD_{95}	1.7	1.5	2.5	13	11	n.s.

At both localities the accumulated dry matter and total N-uptake in the roots were highest in the slurry applied treatment except the dry matter at Jyndevad on the first date in 1988 (Table 11 and 12). Furthermore, the differences were highest for the N-content. At Jyndevad the total N-content in the unfertilized treatment was reduced in 1987 and 1988 between the two dates of sampling. This decrease was caused by a lower N-concentration in the roots as the dry matter production did not show the same decrease. At both localities between 50 to 81 % of the dry matter was located within the upper 20 cm of the root zone. The corresponding figures of the N-content were 61 to 86 %, and even though the root depth was greater at Askov compared with Jyndevad, there was in general a more marked decrease in both the dry matter production and the N-content below 20 cm at Askov compared to Jyndevad.

In Table 13 the root/top-ratios for the dry matter production and the N-uptake are shown. In general there was a marked decrease in the ratio from the date of end of tillering until dough becoming hard, especially for the dry matter production. On all the dates both ratios was highest in the unfertilized treatment. On the date for dough becoming hard, each year, both ratios, generally, were lowest at Jyndevad which also showed a slighter variation between the years.

As mentioned before, grass was sown in all the treatments at Askov in 1987. Shortly after harvest the grass was sprayed with glyphosat (Roundup®). The N-uptake in the grass just after harvest was 12.0 kg N/ha in the unfertilized treatment, 9.6 kg N/ha in the slurry applied treatment and 6.6 in the N-fertilized treatment.

In Table 14 the dry matter, N-uptake and C/N-ratio are given for the undersown grass in PS S 100 N CC at Jyndevad. The first samples were taken at harvest because the growth of the grass during most of the growing season was negligible. In 1987/88 the growth and N-uptake were relatively small during the autumn but rather high during the following winter period. In 1988/89 and 1989/90 this was opposite and the last year there appeared to have been a small reduction in the N-content during the winter period while the dry matter production remained the same. The C/N-ratios just before ploughing shows only small a variation.

Inorganic-N in soil

At Askov (Fig. 7) there were no significant differences in the spring between the treatments, and as average of the treatment the total inorganic-N varied from 32 kg N/ha in 1988 to 46 kg N/ha in 1989. At the end of tillering the highest values were found in the N-fertilized treatment and the lowest in the unfertilized treatment, even though the differences were only significant in 1989. This was also the case at the time for dough becoming hard and at harvest in 1988 and 1989. The lowest value at harvest was found in 1987 where the average of the treatments was 21 kg N/ha. In 1988 and 1989 the values at harvest in the unfertilized treatment ranged from 23 to 32 kg N/ha, respectively. The corresponding values for the N-fertilized treatment were 42 and 55 kg N/ha. Just before ploughing at the end of the autumn, only the data from 1987 show a significant difference between the unfertilized treatment and the other treatments. Furthermore, the values in 1989 were notably higher at this time of year compared with the years before. This

Table 11. Askov. Dry matter and N-content in roots.

Askov. Tørstofproduktion og kvælstofindhold i rødder.

	Depth	hkg/ha			kg N/ha		
	Dybde		PS S			PS S	
	cm	0 N	100 N	LSD_{95}	0 N	100 N	LSD_{95}
1987	0-10	2.5	3.5	n.s.	3.7	6.5	n.s.
End of tillering	10-20	2.1	1.4	0.6	3.4	2.9	n.s.
Afsluttende buskning	20-30	0.9	0.6	n.s.	1.3	1.1	n.s.
	30-40	0.2	0.2	n.s.	0.3	0.4	n.s.
	40-50	0.3	0.3	n.s.	0.4	0.5	n.s.
	50-60	0.1	0.2	n.s.	0.2	0.4	n.s.
	0-60	6.1	6.2	n.s.	9.2	11.7	n.s.
Dough becoming hard	0-10	5.7	7.8	n.s.	7.2	9.6	n.s.
Gulmodenhed	10-20	2.1	2.0	n.s.	2.7	2.6	n.s.
	20-30	1.3	1.3	n.s.	1.5	1.7	n.s.
	30-40	0.3	0.8	n.s.	0.4	1.0	n.s.
	40-50	0.4	1.3	n.s.	0.5	1.4	n.s.
	50-60	0.3	1.2	n.s.	0.3	1.2	n.s.
	60-70	0.1	0.4	n.s.	0.1	0.4	n.s.
	70-80	0.1	0.1	n.s.	0.2	0.1	n.s.
	0-80	10.3	14.9	n.s.	12.9	18.0	n.s.
1988	0-10	7.2	11.4	n.s.	9.5	16.7	n.s.
Dough becoming hard	10-20	4.5	4.9	n.s.	5.7	7.8	1.2
Gulmodenhed	20-30	1.4	3.1	n.s.	1.8	4.0	n.s.
	30-40	0.6	1.0	n.s.	0.5	1.1	n.s.
	40-50	0.3	1.4	n.s	0.2	1.5	n.s.
	50-60	0.2	0.6	n.s.	0.2	0.5	n.s.
	60-70	0.4	0.2	n.s.	0.3	0.1	n.s.
	70-80	0.0	0.2	n.s.	0.0	0.2	n.s.
	0-80	14.6	22.8	0.6	18.1	31.9	n.s.
1989	0-10	7.7	11.0	0.5	8.6	13.6	n.s.
Dough becoming hard	10-20	5.3	4.3	n.s.	6.6	5.8	0.3
Gulmodenhed	20-30	2.5	1.4	n.s.	2.3	1.3	n.s.
	30-40	1.3	1.3	n.s.	1.1	1.1	n.s.
	40-50	0.6	1.0	n.s.	0.6	0.9	n.s.
	50-60	0.1	0.0	n.s.	0.1	0.0	n.s.
	0-60	17.5	18.9	n.s.	19.3	22.6	n.s.

Table 12. Jyndevad. Dry matter and N-content in roots.
Jyndevad. Tørstofproduktion og kvælstofindhold i rødder.

	Depth	hkg/ha			kg N/ha		
	Dybde		PS S			PS S	
	cm	0 N	100 N	LSD_{95}	0 N	100 N	LSD_{95}
1987	0-10	4.1	4.2	n.s	6.5	7.8	n.s.
End of tillering	10-20	3.2	3.9	n.s	4.9	7.1	n.s.
Afsluttende buskning	20-30	2.3	2.4	n.s	3.2	3.4	n.s.
	30-40	0.3	0.3	n.s.	0.4	0.4	n.s.
	0-40	9.9	10.7	n.s.	15.0	18.6	n.s.
Dough becoming hard.	0-10	3.5	4.5	n.s.	4.0	5.4	1.3
Gulmodenhed	10-20	2.5	4.4	n.s.	3.2	6.6	n.s.
	20-30	2.4	3.9	n.s.	2.7	5.3	n.s.
	30-40	0.5	0.7	n.s.	0.4	0.5	n.s.
	40-50	0.4	0.5	n.s.	0.3	0.3	n.s.
	0-50	9.3	14.0	4.4	10.6	18.1	n.s.
1988	0-10	4.6	3.9	n.s.	7.8	7.8	n.s.
End of tillering	10-20	5.7	5.1	n.s.	9.4	10.0	n.s.
Afsluttende buskning	20-30	4.4	4.5	n.s.	5.6	7.8	n.s.
	30-40	1.2	1.3	n.s.	0.5	1.1	n.s.
	0-40	15.9	14.8	n.s.	23.2	26.7	n.s.
Dough becoming hard	0-10	4.7	6.7	1.7	4.4	8.1	1.6
Gulmodenhed	10-20	3.3	5.4	n.s.	4.1	6.8	n.s.
	20-30	3.4	4.2	n.s.	4.0	5.2	n.s.
	30-40	1.7	1.7	n.s.	0.7	0.8	n.s.
	40-50	1.0	1.3	n.s.	0.0	0.3	n.s.
	0-50	14.1	19.3	n.s.	13.2	21.2	7.7
1989	0-10	3.9	5.1	n.s.	6.4	6.9	n.s.
Dough becoming hard	10-20	3.9	5.4	n.s.	6.6	9.2	n.s.
Gulmodenhed	20-30	3.2	6.8	2.3	4.7	8.0	1.8
	30-40	1.7	2.1	n.s.	1.2	1.5	n.s.
	40-50	0.6	1.6	n.s.	0.6	0.7	n.s.
	0-50	13.3	21.0	4.1	19.6	26.2	3.1

Table 13. Root/top-ratio. The roots include below ground stem.
Rod/top-forhold. I rod er indregnet underjordisk stængel.

			Biomass Tørstof			Total-N		
			0 N	PS S 100 N	LSD_{95}	0 N	PS S 100 N	LSD_{95}
Askov	1987	End of tillering *Afsluttende buskning*	2.93	1.09	n.s.	1.04	0.41	n.s.
		Dough becoming hard *Gulmodenhed*	0.38	0.19	n.s.	0.51	0.18	n.s.
	1988	Dough becoming hard *Gulmodenhed*	0.77	0.39	0.15	1.05	0.57	0.39
	1989	Dough becoming hard *Gulmodenhed*	0.50	0.33	0.01	0.49	0.26	n.s.
Jyndevad	1987	End of tillering *Afsluttende buskning*	3.21	1.61	1.29	1.54	0.55	0.60
		Dough becoming hard *Gulmodenhed*	0.22	0.15	0.04	0.26	0.17	0.04
	1988	End of tillering *Afsluttende buskning*	3.43	1.77	0.99	1.72	0.77	0.57
		Dough becoming hard *Gulmodenhed*	0.32	0.26	n.s.	0.25	0.23	n.s.
	1989	Dough becoming hard *Gulmodenhed*	0.31	0.22	0.01	0.43	0.23	0.10

Table 14. Jyndevad. Dry matter, N-uptake and C/N in above ground biomass in grass as an undersown catchcrop. Mean ± standard error (n = 4).
Jyndevad. Tørstof, N-optagelse og C/N i overjordisk biomasse i græs som efterafgrøde. Gennemsnit ± s.e (n = 4).

	hkg/ha	kg N/ha	C/N
17.09.87	0.7 ± 0.3	2.0 ± 0.9	
23.09.87	1.2 ± 0.3	3.2 ± 0.8	
03.12.87	2.6 ± 0.3	6.9 ± 0.7	
24.03.88	7.0 ± 0.6	17.8 ± 2.5	19 ± 1
22.08.88	1.9 ± 0.3	5.2 ± 0.5	
09.12.88	9.0 ± 0.7	18.1 ± 1.2	
29.03.89	9.9 ± 0.5	23.0 ± 1.3	20 ± 1
21.08.89	1.9 ± 0.3	4.5 ± 0.6	
04.12.89	12.8 ± 1.4	27.1 ± 2.7	
28.03.90	12.2 ± 0.9	24.7 ± 1.0	22 ± 1

difference was mainly caused by a higher N-content in the tilth.

In spring at Jyndevad (Fig. 8) the inorganic-N in the soil was very low except for the treatment with autumn applied slurry. Given as average values minus the treatment with autumn applied slurry, the values ranged from 11 kg N/ha in 1988 to 26 kg N/ha in 1987. At the end of tillering the highest amount was found in PS S 100 N, PS S 100 N CC and NPK 120 N, while the lowest values were found in 0 N and PS S 50 N. In 1989 there was a significant difference between the treatment with undersown grass and the corresponding treatment without grass. At the time for dough becoming hard, the level was in general low and with only small differences between the treatments. From dough becoming hard to harvest, the level increased each year but still with only small differences between the treatments. In 1987 and 1989 at harvest the average of the treatments for the total inorganic-N was 21 and 25 kg N/ha, respectively. In 1988 the corresponding values ranged between 24 kg N/ha in the treatment with N-fertilizer to 35 kg N/ha in the treatment with autumn applied slurry. Concerning the last samples taken each year just before autumn application of slurry there were in general no differences between the treatments except PS A 100 N in 1988 , which was on a higher level compared with the other treatments, and PS S 100 N CC in 1989, which was on a lower level compared with the other treatments. At Jyndevad the ammonium content below the tilth was rather constant, especially in the autumn and winter periods, even if there seems to be some differences between the years with the lowest level in 1989/90. One exception of this low ammonium content below the tilth was the treatment with autumn applied slurry in the spring 1988.

Discussion

Dry matter production and N-uptake in barley

In relation to normal yield

At Askov the normal grain yield of barley for the years 1987, 1988 and 1989 was 41 , 49 and 38 hkg/ha (85% dry matter) (39, 40, 41). The normal grain yield is the average of all the plots fertilized with optimal amount of N-fertilizer. The corresponding values at Jyndevad for the years 1987 to 1990 were 47, 48, 59 and 58 hkg/ha (31, 39, 40, 41). By comparing these values with the actual yield in this experiment, it can be seen that the grain yield at Askov 1988 and especially Jyndevad 1987 was somewhat different from the normal yield. An explanation for the relatively high yield at Jyndevad 1987 is probably a high residual fertility. Comparing the variation in the yield at the two localities, it can be seen that the results from Askov show the highest variation. The main reason for this must be that the plots at Jyndevad were irrigated, thus avoiding any significant water deficit. At Askov the precipitation in 1987 and 1988 was relatively high (Fig. 2a). Hence the E_a/E_p-ratio for the period from 14 days after germination until dough becoming hard was 0.96 and 0.88 in the N-fertilized treatment for 1987 and 1988, respectively.

Fig. 7a-c. Askov. Mineral N in soil.

Askov. Uorganisk N i jorden.

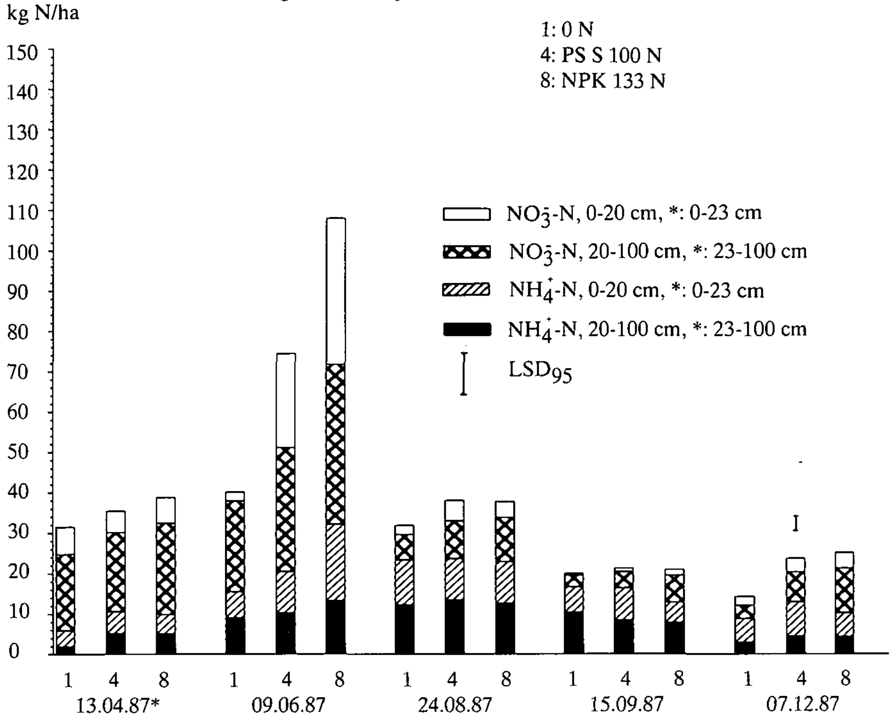


Fig. 7a.

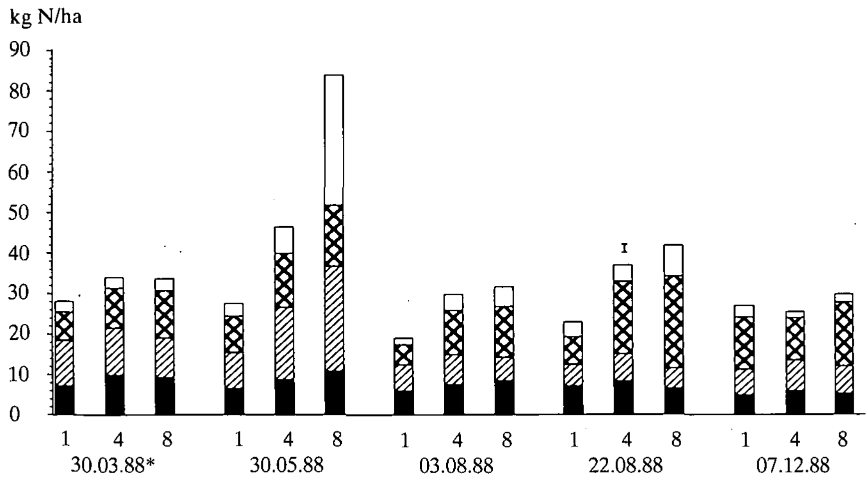


Fig. 7b.

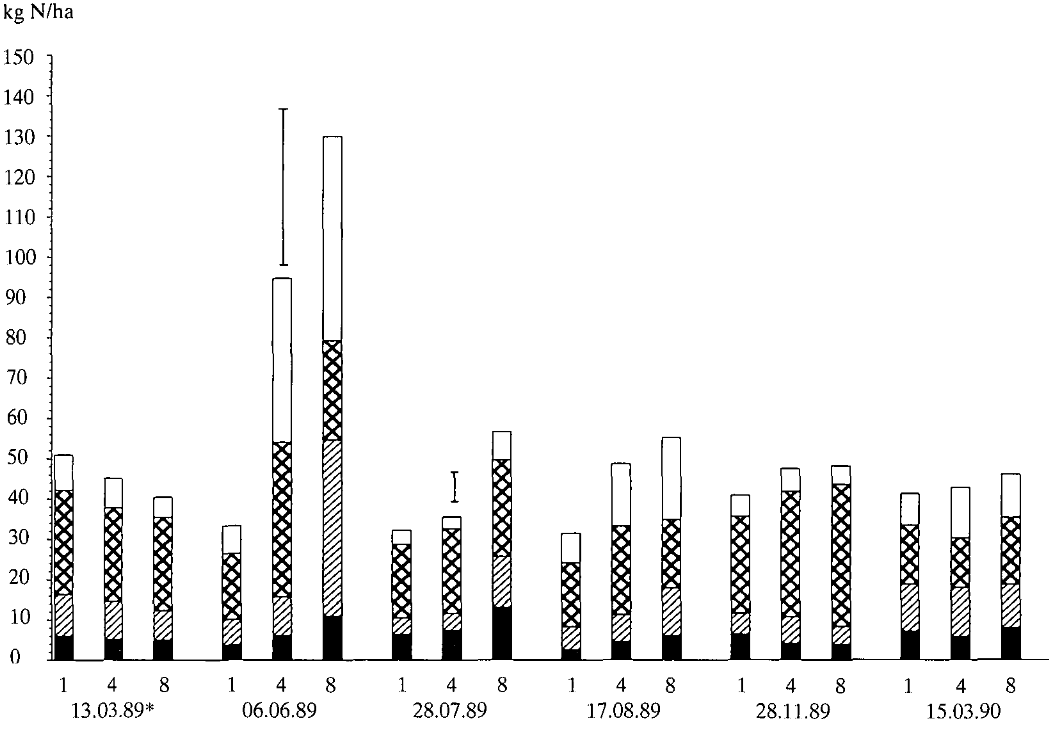


Fig. 7c.

In 1989, where the precipitation during the summer period was realtively low (Fig. 2a), the E_a/E_p-ratio was 0.63 in the N-fertilized treatment. Thus the water deficit must be the main explanation for the low yield in 1989 at Askov. The actual evapotranspiration was calculated in the nitrate leaching project which was a part of this N-balance project (8).

Harvest index

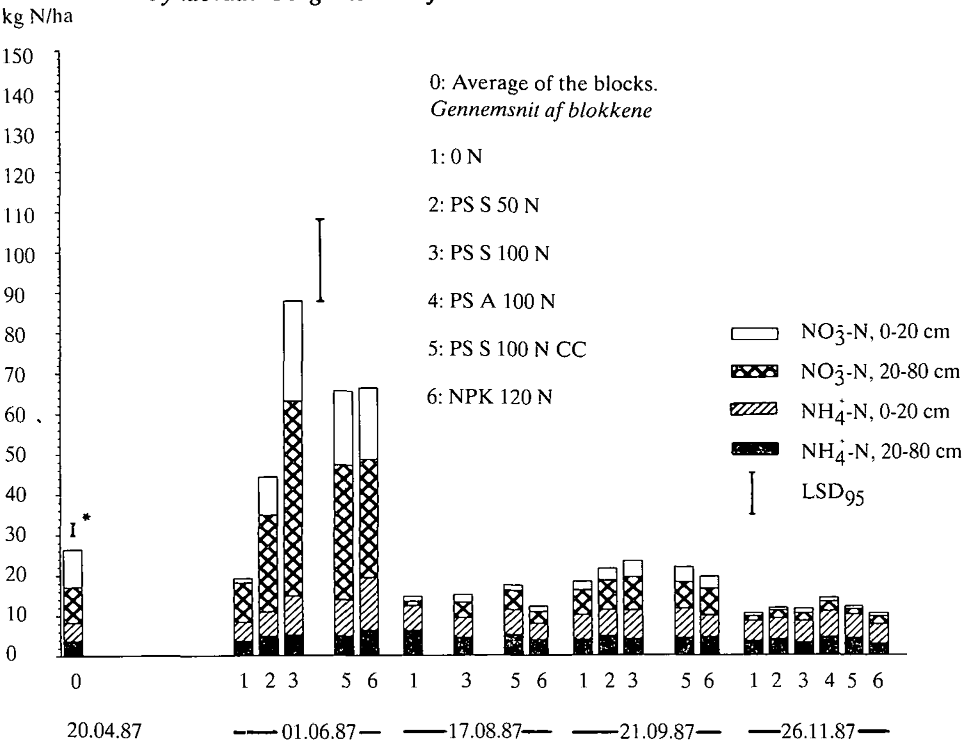
At the same level of applied inorganic-N the harvest index (Table 8) has not differed between the treatments, but the index decreased with increasing level of applied mineral N at Jyndevad as a result of the relatively higher increase in straw production compared with grain production.

Variation between the treatments in the first part of the growth period

The incorporation of the slurry by ploughing, as at Jyndevad, or by harrowing/disc ploughing, as at Askov, would result in a lower average depth of the inorganic-N compared with N-fertilizer

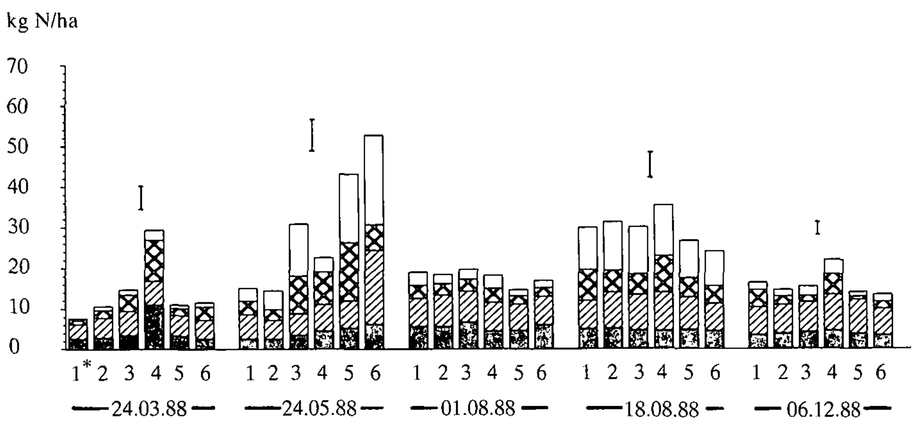
Fig. 8a-c. Jyndevad. Mineral N in soil.

Jyndevad. Uorganisk N i jorden.



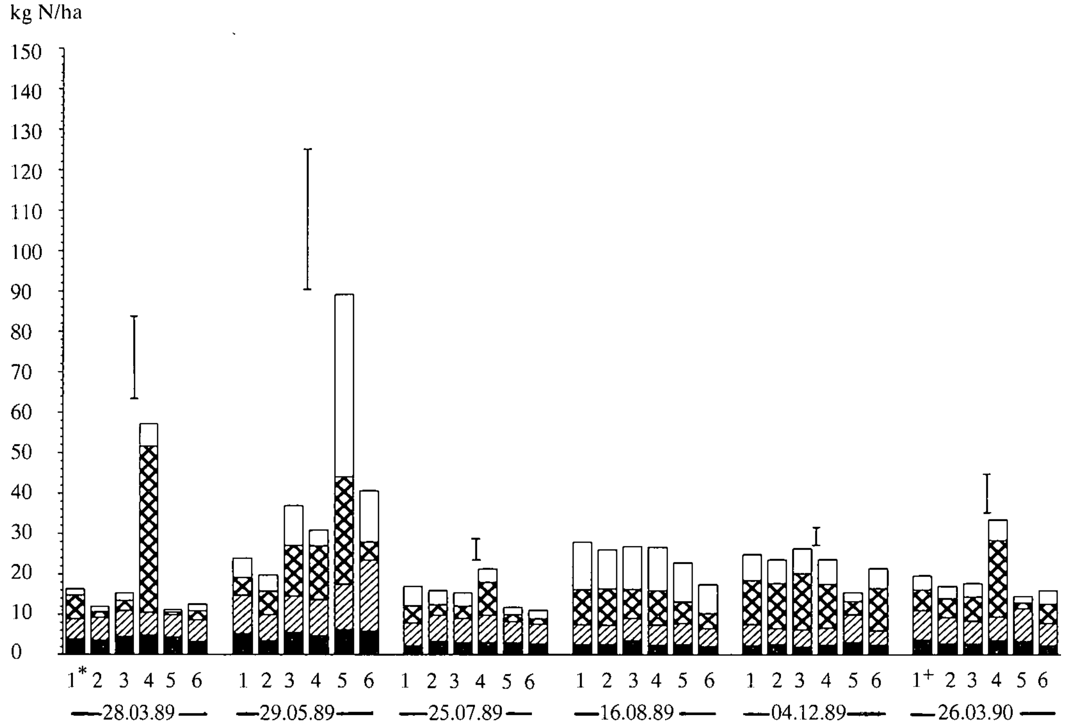
* Standard error (s.e.) n=4

Fig. 8a.



* Unfertilized (0 N) in 1987. *Ugødet (0 N) i 1987.*

Fig. 8b.



* Unfertilized (0 N) in 1988. *Ugødet (0 N) i 1988*

+Unfertilized (0 N) in 1989. *Ugødet (0 N) i 1989.*

Fig. 8c.

applied to the surface. This fact could be further accentuated by percolation from the tilth in the period from applying the slurry and until N-fertilization if the soil temperature is high enough to cause nitrification. Depending on the difference in the distribution of inorganic-N in the soil, this could lead to a higher N-uptake in the start of the growing season in the treatment with N-fertilizer compared with a treatment with an equal amount of inorganic-N applied in slurry. At Askov 1989 this was probably the main reason for the difference between the rate of N-uptake in NPK 133 N and PS S 100 N. Thus the slurry was applied 14 March while the N-fertilizer was applied 19 April. For the period in between, the percolation from 100 cm depth was calculated to 82 mm (8). This explanation is further confirmed by the fact that the amount of NO_3^--N below the tilth at the end of tillering (6 June) was higher in PS S 100 N compared with NPK 133 N even though the total amount of inorganic-N in the root zone was highest in NPK 133 N (Fig. 7c). At Askov 1988 the N-fertilizer was given only a week after the slurry application and no percolation from the tilth was estimated during this period. At Jyndevad the N-fertilizer was given 3 and 16 days after the slurry application in 1987 and 1988, respectively. Furthermore, only in 1988 there was a minor percolation from the root zone in the actual period. The differences in the rate of N-uptake in the N-fertilized treatment and PS S 100 N in 1988 at Askov, and 1987 and 1988 at Jyndevad could therefore not be explained this way, but maybe to a certain degree by the tillage depth after slurry application. At Askov the slurry must have been distributed equally from the surface down to about 10 cm depth, while most of the slurry must have been placed in 20 cm depth after ploughing at Jyndevad. Another explanation could be a difference in N-mineralization/immobilization in the start of the growing season (27, 35, 36) with the highest immobilization in the slurry applied treatment. At Askov 1987 and Jyndevad 1989, where no difference in the rate of N-uptake was seen, the N-fertilizer was given 6 and 18 days after the slurry was applied. At Askov there was no percolation during this period and at Jyndevad the percolation was 17 mm. Hence the climatic conditions might explain some of the differences in the rate of N-uptake between the years but not all. Thus *Petersen* (32) found no significant differences between the rate of N-uptake in spring barley treated with 120 kg NH_4^+-N/ha in slurry compared with 125 kg N/ha in N-fertilizer in 1988 at Askov, and on a coarse sandy soil located close to Askov.

In relation to applied mineral N

The yield and N-uptake as function of applied inorganic-N can be described by a quadratic regression with decreasing rate of yield and N-uptake by increasing level of applied inorganic-N (18). For an actual year and field unique functions can be assumed to exist. If the response of inorganic-N in slurry is equal to the inorganic-N in N-fertilizer and there is no effect of mineralization of the organic-N, the yield and N-uptake as function of applied inorganic-N would belong to the same response curve. A response curve for slurry application above the curve for N-fertilizer would indicate an effect of mineralization of the organic-N, while a curve below would indicate both an insignificant effect of the organic-N and a less utilization of the inorganic-N in the slurry compared with the N-fertilizer or a high NH_3-volatilization. Fig. 9 and 10 show the yield of grain and N-uptake as function of applied inorganic-N at Askov. In Fig. 11 and 12 the corresponding figures for Jyndevad are given. In Fig. 11 and 12, respectively, PS A 100 N is omitted because this treatment is exceptional in this context.

On the basis of the mean rate of yield as function of applied inorganic-N, the results from Askov 1987 and 1988 seem to indicate less utilization of the inorganic-N in the slurry compared with the N-fertilizer and/or an insignificant effect of the organic-N in the slurry even though the yield and N-uptake in the two treatments in 1988 were not significantly different. *Larsen et al.* (19) concluded on the basis of results from the same experiment, but for the period 1985 to 1988, that the mean yield response curve for inorganic-N in slurry and N-fertilizer was the same, which is equivalent with an insignificant effect of the organic-N in the slurry, or a combination of less utilization of the inorganic-N in the slurry compensated by an effect of mineralization of the organic-N. The analyses by *Larsen et al.* (19) were done on the basis of three levels of N-fertilizer, and three levels of pig slurry which were injected into the soil, but the individual years were not analyzed. Thus the analyses done in this paper do not contradict the conclusion by *Larsen et al.* (19) but indicate that the conclusion may not be valid for each individual year. The difference between the N-fertilized treatment and the slurry applied treatment is further stressed considering the nitrogen removed in grain and straw. Thus the mean rate of N-uptake was in 1987 and 1988 higher in the N-fertilized treatment than in the treatment applied with slurry. This is in accordance with the results of *Larsen et al.* (19) who found that the N-utilization, defined as nitrogen removed by the actual crop minus nitrogen removed by unfertilized crop divided by applied inorganic-N, which is equivalent to the mean N-uptake rate, was 48 % in PS S 100 N and 63 % in the N-fertilized treatment as average of the years 1985 to 1988. The corresponding figure for injected slurry was 59 %. In 1987, the relatively high NH_3-volatilization, as mentioned earlier, is probably part of the explanation for the relatively low grain yield and N-uptake in the slurry applied treatment. The other years the NH_3-volatilization does not seem to have been significant unless it occurred after soil tillage. A high denitrification in one or both of the fertilized treatment could also effect the grain yield and N-uptake including the comparison between the treatments. *Maag* (22) measured denitrification from June 1987 to December 1989. In general the denitrification was rather low with the exception of spring 1989 in the N-fertilized treatment, where the denitrification was estimated to 30 kg N/ha. Thus the denitrification in

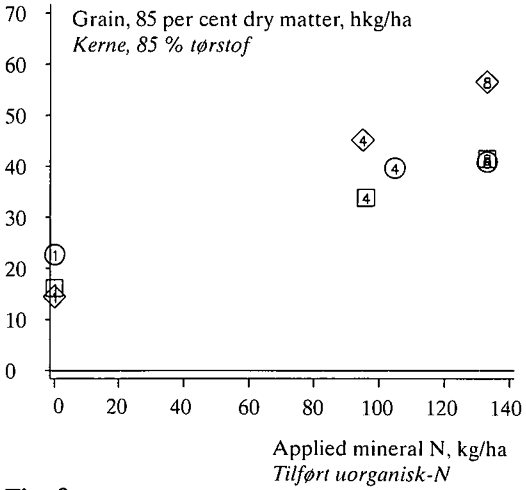


Fig. 9.

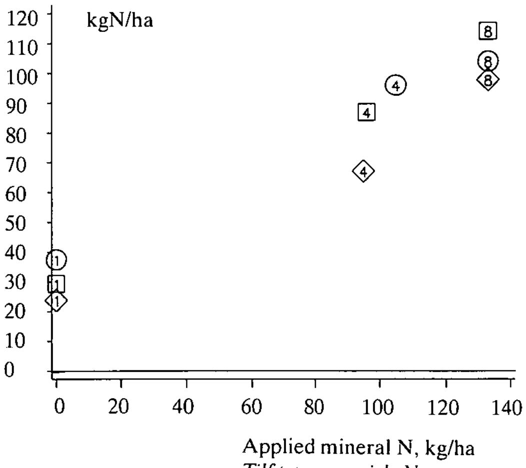


Fig. 10.

Fig. 9. Askov. Yield at harvest as function of applied mineral N. 1(0 N); 4(PS S 100 N); 8(NPK 133 N): Treatments. □: 1987; ◇: 1988; ○: 1989.

Askov. Kerneudbytte ved høst som funktion af tilført uorganisk-N. 1(0 N); 4(PS S 100 N); 8(NPK 133 N): Forsøgsled. □: 1987; ◇: 1988; ○: 1989.

Fig. 10. Askov. N removed in grain and straw at harvest as function of applied mineral N. See Fig. 9 for legend.

Askov. N fjernet i kerne og halm som funktion af tilført uorganisk-N. Se fig. 9 for yderligere forklaring.

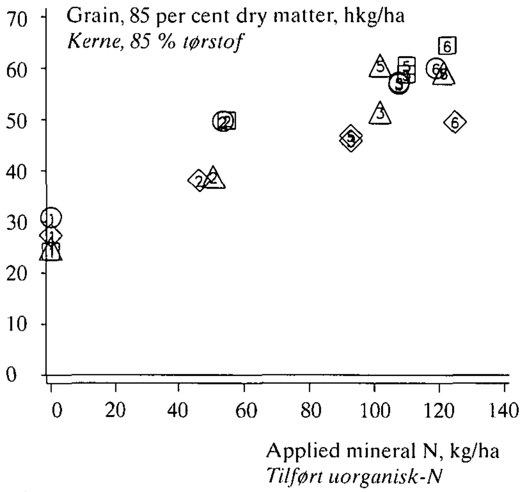


Fig. 11.

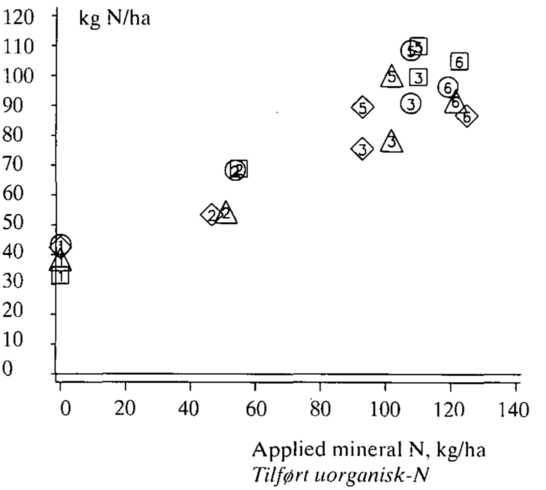


Fig. 12.

Fig. 11. Jyndevad. Yield at harvest as function of applied mineral N. 1(0 N); 2(PS S 50 N); 3(PS S 100 N); 5(PS S 100 N CC); 6(NPK 120 N): Treatments. □: 1987; ◇: 1988; ○: 1989; △: 1990.

Jyndevad. Kerneudbytte ved høst som funktion af tilført uorganisk-N. 1(0 N); 2(PS S 50 N); 3(PS S 100 N); 5(PS S 100 N CC); 6(NPK 120 N): Forsøgsled. □: 1987; ◇: 1988; ○: 1989; △: 1990.

Fig. 12. Jyndevad. N removed in grain and straw at harvest as function of applied mineral N. See Fig. 11 for legend.

Jyndevad. N fjernet i kerne og halm som funktion af tilført uorganisk N. Se fig. 11 for yderligere forklaring.

spring 1989 might have resulted in lower grain yield and N-uptake in the N-fertilized treatment compared with the slurry applied treatment.

At Jyndevad the results of grain yield (Fig. 11) seem to indicate a similar effect of the inorganic-N in the slurry compared with N-fertilizer in 1988 and 1989. In 1987 and 1990 there seems to have been a slightly better effect of the N-fertilizer compared with the slurry. Concerning the nitrogen removed in grain and straw (Fig. 12), only 1990 showed a tendency to a difference in the rate of N-uptake between slurry and N-fertilized crop. Unless NH_3-volatilization occurred after soil tillage at Jyndevad, it, as mentioned earlier, could only have had minor influence on the grain yield and N-uptake in the slurry applied treatment. This is also valid concerning the denitrification which in general has been insignificant at Jyndevad (22).

The above discussion is based on the assumption that the prehistory of the treatments has been the same. Because the fields have only been treated different in a relatively short period of years, the effect the prehistory must be assumed to be small. Furthermore it can be shown that a effect of the prehistory, in this case, would not disable the conclusion, on the contrary.

Autumn application of slurry

The low grain yield and N-uptake in the treatment with autumn applied slurry at Jyndevad can be explained by the high nitrate leaching in this treatment in the period from application until spring the next year (8). Thus in the winter 1987/88 nitrate leaching was equivalent to the amount of NH_4^+-N in the slurry. In the winter period 1988/89 and 1989/90 66 and 133 kg NO_3^--N/ha were leached in the same period. These figures are consistent with the estimated values of inorganic-N in the profile (Fig. 8). In 1989 and 1990 the surplus of inorganic-N compared with the other treatments were about 40 and nearly 20 kg N/ha, respectively. In spring 1989 and 1990 the inorganic-N was mainly below the tilth and in 1989 it was leached during the spring and the growing season (8).

Effect of the catch crop

The higher N-uptake in the straw in PS S 100 N CC compared with PS S 100 N in 1987 must be regarded as accidental because the experiment was started in 1987 and the effect of the undersown grass must be considered as insignificant. The higher grain yield, in 1990 especially, in PS S 100 N CC compared with PS S 100 N, must be ascribed to the mineralization of the grass. This effect was further expressed in the differences in N-uptake both in the straw and grain in the years 1988-1990. The mineralization of the grass was also expressed in the soil inorganic-N at the time for end of tillering (Fig. 8b and c), especially in 1989. The fact that the mineralization was mainly expressed in the N-uptake and only slightly in the yield was probably caused by the level of the yield which was close to the optimal level, and because mineralization of the grass was too late to affect the yield significantly, even though the N-uptake was still increasing.

Stubble

The differences in the N-uptake and C/N-ratio in the stubble might in general be ascribed to the level of applied inorganic-N. In general the C/N-ratio decreased with increasing level of applied nitrogen because the nitrogen content increased more than the dry matter. The amount of nitrogen left in the stubble might be considered to have only a minor influence on mineralization/immobilization and on the N-balance.

Roots

The results of root biomass at Askov are in accordance with *Andersen* (1) who found very few roots expressed as cm per cm^3 below 80 cm depth. At Jyndevad the root depths are in accordance with the results of *Andersen* (1), *Andersen et al.* (3) and *Simmelsgaard* (37). Even though the differences between the unfertilized treatment and the treatment applied with slurry are only statistically significant on some of the dates at Jyndevad, the higher biomass and especially N-content in the roots from the slurry applied treatment must be the result of nitrogen deficit in the unfertilized treatment. At Jyndevad 1987 and 1988, the decrease between the dates of sampling in the unfertilized treatment was probably caused by translocation of nitrogen from root to the top. At both Askov and Jyndevad the root/top-ratio decreased with increasing level of applied nitrogen. This effect must be the result of the fact that the growth of the root was favoured because it was closest to the limiting factor nitrogen. The root/top-ratio for both biomass and N-content for the slurry applied treatment showed the highest variation at Askov. The reason is probably that the plots were irrigated at Jyndevad giving more uniform growth conditions between the years as compared to Askov.

Dry matter production and N-uptake in the catch crop

At Jyndevad the differences in the growth of the undersown grass can be explained by the different time of harvest of the spring barley. In 1987 the harvest was delayed about a month due to rain. Hence the dry matter production and N-uptake of the grass were relatively low in the autumn that year compared with the following years. The low N-uptake of the grass in autumn 1987 was to a certain degree compensated by a rather high N-uptake during the winter period compared with 1988/89 and 1989/90. Each winter period was characterized by a relatively high air temperature. In spite of this, the last year, especially, differed in the dry matter production and N-uptake during this period compared with the years before. The reason for this is probably a period of 6 days from 30 December 1989 to 4 January 1990 with average temperatures between -1 to -2°C, which might have caused a reduction in the living plant material. In 1987 there were 10 days with an average temperature below zero °C in the first part of December, while there were only two days with frost in 1988/89. The general level of N-uptake during the autumn and winter period is in accordance with *Simmelsgaard* (38) who under similar circumstances found a N-uptake of 19 and 24 kg N/ha in March 1990 and 1991, respectively.

Inorganic-N in soil

Askov

At Askov the differences between the treatments in soil inorganic-N in the spring may be ascribed to the different climatic conditions. Thus the lowest average value was found in 1988 where a very high percolation in the winter period had leached a relatively larger amount of the mineralized nitrogen below 1 m depth compared with the other years. The differences in soil inorganic-N during the growth period, especially, at the time of end of tillering may be ascribed to the increasing amount of applied inorganic-N. These differences were also seen at harvest in 1988 and 1989 but not in 1987; probably because there was considerable nitrate leaching during the summer period (8), and because the grass, which was harvested with the barley straw (Table 8), continued the N-uptake until harvest.

Inorganic-N in bare soil during the autumn and winter period is the result of the inorganic-N left at harvest, the net-N-mineralization during the autumn and winter period, and the nitrogen leaching, denitrification and N-bulk deposition during the period. The N-mineralization can be regarded as consisting of a 'background' mineralization, and a mineralization as a result of the actual applied nitrogen in slurry including the effect of the nitrogen left in roots and stubble. As it can be seen from Table 10 and 11, the N-fertilized and slurry applied crop have in general left a higher amount of nitrogen in roots and stubble at harvest compared to the unfertilized treatment assuming that the nitrogen left in the roots in the N-fertilized treatment was at the same level as the slurry applied treatment. This implies that the differences on 7 December 1987 might be the result of a higher net-N-mineralization in the fertilized treatments compared with the unfertilized treatment. During the following winter period the highest leaching was found in the fertilized treatment (8), thus on 30 March 1988 the soil inorganic-N was about the same level in all the treatments. In 1988 the differences at harvest in soil inorganic-N were expressed in the nitrate leaching during the autumn with the highest leaching in the fertilized treatments (8) even though the differences were not significant. Hence 7 December 1988, the concentration of soil inorganic-N was about the same in all the treatments. In the following winter period the differences between the treatments were relatively insignificant, thus in spring 1989 the concentrations of soil inorganic-N were on the same level in the different treatments. In the last year the differences at harvest were not expressed in the leaching during the autumn, on the contrary, the high leaching in the unfertilized treatment was mainly caused by a 30 mm higher percolation from the root zone in the start of the leaching period (8). The difference was caused by a rather dry summer period with the lowest evapotranspiration in the unfertilized treatment (8).

Jyndevad

At Jyndevad the highest inorganic-N in spring was found in 1987. This was probably caused by the time of soil sampling this year which was nearly one month later than the following years, and because the precipitation in the winter and in beginning of the spring was considerable lower than the following years (Fig. 2b). At the end of tillering the differences in soil inorganic-N might be explained by the differences in applied inorganic-N. In 1987 the relatively high content of soil inorganic-N in both PS S 100 N and PS S 100 N CC in relation to the N-fertilized treatment may be explained by the fact that the amount of organic-N in the slurry applied treatment this year was considerable higher compared with the following years (Table 6). The differences between PS S 100 N and PS S 100 N CC in the growth period 1987 must be accidental. In 1988 and especially 1989 the higher soil inorganic-N in PS S 100 N CC compared with PS S 100 N must be ascribed to the mineralization of grass which was ploughed in the spring.

After the growing season, the level at Jyndevad of soil inorganic-N was at a lower level compared with the corresponding treatment at Askov. Beside the fact, that the calculations at Askov were carried out for 0-100 cm and at Jyndevad for 0-80 cm depth, the difference can be explained by the higher content of organic-N in the soil at Askov causing a higher potential for N-mineralization and the difference in field capacity, which with the same net-N-mineralization and climatic conditions will cause higher soil inorganic-N at Askov compared to Jyndevad.

In December 1989 and March 1990 the low figures of nitrate-N in the treatment with undersown grass (Fig.8c) must be ascribed to the N-uptake of the catch crop. The effect of the autumn applied slurry was seen in the high figures of soil inorganic-N in spring and also for the growth period in 1989 as discussed in relation to the N-uptake in this treatment. This is in accordance with the leaching pattern in this treatment (8). The main effects of the treatments on the concentration of soil inorganic-N on the dates for soil sampling in November/December and in the spring were found in PS A 100 N and PS S 100 N CC as already discussed. However, a conclusion concerning the net-N-mineralization and nitrate leaching based on these measurements would in general be incorrect because considerable N-mineralisation/immobilization and nitrate leaching can happen between the dates of sampling. Thus by the end of a period between two dates of soil sampling there might be no difference between the treatments even though there had been considerable difference during the period. A good example of this is the large amount of nitrate leached in the winter period 1987/88 in the treatment with autumn applied slurry. Another example is the leaching pattern between harvest 1988 and 6 December 1988 at Jyndevad. Thus the nitrate leaching in PS S 50 N and PS S 100 N was 50 kg NO_3^--N/ha and 51 kg NO_3^--N/ha, respectively, while the corresponding figures in the N-fertilized treatment were only 32 kg NO_3^--N/ha (8).

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