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Paavo Elonen – In Memoriam

Responses of yield and N use of spring sown crops to N fertilization, with special reference to the use of plant growth regulators

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The role of plant growth regulators (PGR) in nitrogen (N) fertilization of spring wheat and oats (CCC), fodder barley (etephon/mepiquat) and oilseed rape (etephone) in crop rotation was studied in 1993–1996 on loamy clay soil. Carry over effect of the N fertilization rates (0–180 kg ha^{-1}) was evaluated in 1997. N fertilization rate for the best grain/seed yield (120–150 kg ha^{-1}) was not affected by PGRs. The seed and N yields of oilseed rape were improved most frequently by recommended use of PGR. The yields of oats were increased in 1995–96. Even though PGR effectively shortened the plant height of spring wheat, the grain yield increased only in 1995. N yield of wheat grains was not increased. Response of fodder barley to PGR was insignificant or even negative in 1995.

The data suggest that PGRs may decrease some N leaching at high N rates by improving N uptake by grain/seeds, if the yield is improved. The carryover study showed that in soils with no N fertilization, as well as in soils of high N rates, N uptake was higher than in soils with moderate N fertilization (60–90 kg ha^{-1}), independent of PGRs. According to soil mineral N contents, N leaching risk is significant (15–35 kg ha^{-1}) only after dry and warm late seasons. After a favourable season of high yields, the N rates did not significantly affect soil mineral N contents.

Key words: barley, chlormequat, cereals, etephon, grain quality, mepiquat, oats, oilseed rape, yield, wheat

Introduction

High nitrogen (N) fertilization inputs and use of plant growth regulators (PGR) could increase yield and N use efficiency of spring sown crops in Scandinavia, where short growing seasons and varied weather conditions are the norm. Fertilizer N applied at rates up to 90–100 kg ha^{-1} on spring cereals appears to increase nitrate leach-

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Table 1. Weather conditions at Jokioinen in 1993–1997 and the 30-year average. Number of rainy days (>0.1mm) in parenthesis. Data provided by the Finnish Meteorological Institute.

	mean air temperature, C°					
	1993	1994	1995	1996	1997	1961–90
May	13.6	7.8	8.7	8.8	7.7	9.4
June	11.4	12.1	16.7	13.1	16.1	14.3
July	15.6	19.0	15.3	13.9	17.8	15.8
August	12.9	15.1	15.1	17.0	17.8	14.2
September	5.7	10.0	10.3	8.3	10.0	9.4
	precipitation, mm (number of rainy days)					
	1993	1994	1995	1996	1997	1961–90
May	1 (4)	34 (13)	87 (22)	65 (15)	16	35
June	56 (18)	66 (19)	121 (15)	52 (16)	101	47
July	107 (14)	1 (1)	53 (15)	136 (23)	141	80
August	136 (20)	54 (12)	65 (10)	14 (9)	44	83
September	13 (11)	105 (19)	45 (19)	20 (11)	78	65

ing very little as compared with no N fertilization (e.g. Bergström and Brink 1986). However, if severe lodging occurs in humid soil conditions, the efficiency of fertilizer N to produce high yield is reduced and the risk of nitrate leaching may increase. Under dry soil conditions nitrogen uptake is also reduced (Kaila and Elonen 1970). PGR-like chlormequat chloride (CCC) prevents lodging (Tolbert 1960) and may also decrease drought sensitivity by increasing the root system, as has been shown for wheat on clay soil (Teittinen 1975, Sten and Wünsche 1990). Thus, CCC may increase fertilizer N use under various weather conditions. By increasing yield components of barley (Waddington and Cartwright 1986, Moes and Stobbe 1991) such PGRs as mepiquat chloride and etephon may also promote nutrient uptake, suggesting higher optimum of N fertilizer rate than without PGR use. PGRs could, thus, minimize the risks of high N applications, which is important because of the environmental effects of the leaching of excess nitrate and also for economic reasons.

The goal of this paper is to evaluate the joint effects of PGR and N fertilization and how these possibly can be utilized for improving yields and N use efficiency. The main questions addressed are: Does the use of PGRs change the optimum N fertilization rates and N uptake on spring cereals and oilseed rape. Even if the crop response to PGRs has been the subject of much research, information on the response of oilseed rape and spring cereals at high N rates is still needed. To achieve optimum N rate for yields, application rates of fertilizer N varying between zero and 180 kg/ha N and PGRs were used according to the recommendations for the best effect for crop yield. To evaluate the environmental effects of N fertilizer use, soil mineral nitrogen was analysed before sowing and after harvest. Finally, we focused on the year-to-year carryover effect of N fertilization and PGRs to predict the long-term effects of different N rates on soil fertility.

Material and methods

Site and weather conditions of the experimental field

The data was collected from a field experiment (82.5 m x 115 m), established at the Agricultural Research Centre of Finland in Jokioinen (60° 49’N; 23° 28’E) on loamy clay soil in 1993–1997. The weather conditions in Jokioinen are given in Table 1.

Vol. 8 (1999): 423–440.

Experimental design and treatments

The experiment used a split-plot design with four replicates. The effects of PGR were studied in the main plots, which were divided into seven subplots (2.5 m x 12.5 m) according to N fertilization rates of 0, 30, 60, 90, 120, 150 and 180 kg ha^{-1}(= $N_0 - N_{180}$). A similar design was applied to four crops separately on the same field area side by side. The annual cropping sequence in the first cropping block was spring sown wheat (cv. Satu), oats (cv. Yty), barley (cv. Loviisa), and oil seed rape (cv. Kulta). The second adjacent cropping block was planted first with oil seed rape, the third block with oats, and the fourth one with barley. All plant species were sown once in each block in 1993–1996. Crop stands were treated by PGRs as recommended as follows: Chlormequat chloride (CCC) was sprayed at the 3–4 leaf stage at the beginning of stem elongation for wheat (375 g ha^{-1}, water volume 200 dm^3 ha^{-1}) in 1995 twice because of heavy rain right after the first treatment, and for oats (1125 g ha^{-1}). Cerone (ethephon 480 g dm^{-3}) was sprayed for oil seed rape at the beginning of flowering (240 g ha^{-1}) and Terpal (mepiquat/ ethephon for barley at the 2-node stage (305/155 g ha^{-1}). Rain delayed the treatments in 1995. In 1997, all cropping blocks were sown with barley at fertilizer N rate of 30 kg/ha to control for year-to-year carryover effect. No PGRs were used in 1997.

The results were studied statistically by employing ANOVA and Tukey's tests HSD (Honestly Significant Difference) to the significant (P=0.05) differences between group means.

Soil

For analyses of soil texture (Elonen 1971), organic carbon (Sippola 1982), pH and extractable nutrients (Vuorinen and Mäkitie 1955) of the experimental field, the soil was sampled in September 1994 at depths of 0–25 cm and 25–60 cm from N_{90} subplots of each replicate and cropping block (i.e., 32 samples). Ten subsamples were taken from the topsoil and three subsamples from the deeper layers. The experimental field can be characterized as loamy clay soil, low in organic carbon (2–3% at 0–25 cm and below 1% in subsoil) and high in phosphorus content (30–40 mg dm^{-1}) to the soil depth of 25 cm. Other nutrient contents were adequate in subsoil as well, according to the common classification used in Finland. Soil pH varied 6.1–6.5 between blocks in 0–25 cm, 6.6–6.9 in subsoil.

Field operations and observations

Before sowing, autumn-ploughed soil was tilled by a rotary harrow and fertilized with 250 kg ha^{-1} of PK fertilizer (30 kg ha^{-1} P, 35 kg ha^{-1} K). In 1993–1994, the PK fertilizer contained also 3% N, which was added to the N rates. PK fertilizer was drilled parallel to the sowing direction across the plots. Different N rates were applied in NH_4NO_3 fertilizer at sowing by combine drilling to a soil depth of 8 cm. Herbicides for spring cereals (tribenuron-methyl 7.5 g ha^{-1} with water volume 200 dm^3 ha^{-1} in 1993–1994, 1996) and insecticides for oilseed rape (deltamethrin 2.5 g ha^{-1} in 1993 and 7.5 g ha^{-1} in 1994, lambda-cyhalothrin 3.75 g ha^{-1} in 1995 and 5.0 g ha^{-1} in 1996) were used in accordance with general recommendations. In 1995, however, cereals were sprayed with mecoprop/MCPA/clopyralid 800/400/43 g ha^{-1} on the same day as PGR application. The plant height was measured in the beginning of August at three locations per subplot (1995–1996), and lodging was observed on each subplot before harvesting. At harvest, straw was left in each plot.

Yield analyses

Grain and seed yields were recorded by harvesting 10 m x 2.1 m per subplot. Grain/seed moisture was determined gravimetrically from a subsample (40 g). The remainder of the subsample (1 kg) was dried and non-grain residues were sorted out to determine the purity of yield and other quality components. Pure grain yields were calculated by using grain moisture of 15%. For rape, seed moisture of 9% was used. Total N in grains and seeds was analysed according to the near-IR reflectance technique (McGuire 1986). The total N was multiplied by 6.25, or for wheat by 5.7 for the protein content. The oil content of rape seeds was measured by the near-IR reflectance technique. The Hagberg falling number was determined by a falling number apparatus (ICC standard 107, ICC 1968). The volume weight of the grain was determined according to the official method of the State Seed Testing Station of Finland by weighing four volumes of 250 ml. The weight of 1000 seeds was calculated from the average weight of four counted lots of 100 seeds.

Soil mineral N analyses

The soil was sampled in each replicate and at five fertilization rates of 0, 90, 120, 150 and 180 kg ha^{-1} after harvest in 1994 (barley block) and 1996 (wheat block) and from the same blocks before sowing in 1995 and 1997. The soil was very dry in September 1996. Samples were taken from soil layers of 0–25 cm and 25–60 cm (i.e. 40 samples per sampling time). Twenty subsamples per whole plot were taken from the top layer and ten subsamples from the deeper layer. The subsamples were bulked and the soil was homogenized. One subsample per plot was taken and stored frozen (–18°C) in plastic bags until analysis. The extractable ammonium and nitrate N content was analysed from thawed soil samples (100 g) by extracting in 250 ml 2 M KCl for two hours (Esala 1995) and analysing the extract by Skalar Auto-Analyser (Krom 1980, Greenberg et al. 1980). The dry matter content of the soil was determined by drying 40 g moist soil overnight at 105°C.

Results and discussion

Crop response

Lodging, stem shortening and response of crop yield varied among plant species and were highly dependent on weather conditions (Tables 2a–d). Generally, PGRs improved the grain yield at moderate and high N fertilizer rates (Tables 3a–d). Optimum N rate for yields was not, however, changed by using the regulators. For spring wheat and barley, the highest yields and protein content were recorded at N rates of 150 or 180 kg ha^{-1}, in agreement with Esala and Larpes (1986ab). The optimum N rate for yields of oats and oilseed rape varied more between years, and in the rainy season of 1995, the highest yields were obtained at the highest N rate.

N yield was determined by dividing the protein content of grain/seed by 6.25 (5.2 for wheat) and multiplying by the grain/seed yield (first corrected for grain or seed moisture, 15 or 9%) from Tables 3a–d. N yield was mostly increased by PGR use, if affected (P=0.05). As N yield in ears represents 65% of N uptake by cereals (Hansson et al. 1987), differences over 10 kg ha^{-1} were remarkable. These effects were, however, infrequently recorded.

Wheat

The yield of spring wheat was increased by CCC at N fertilisation rates over 90 kg ha^{-1} in 1995–1996. In 1995 when June was very rainy the yield increase was even 1000 kg/ha, and N fertilization could be reduced by 30 kg ha^{-1} to achieve the same yield. No statistically significant increase was, however, found in 1993–1994, when the temperatures in June were below average (Tables 1, 3a). In addition, severe drought damage was recorded in 1994 in both treatments. In agreement with Steen and Wünsche (1990), CCC efficiently shortened stem (Table 2a). Lodging occurred only in 1993 after heavy rains in July (107 mm), and was effectively reduced by PGR use. Grain moisture at harvest was increased by PGR in 1995–1996, suggesting the delaying effect of CCC on maturation processes reported by Mukula et. al (1966). The grain quality was slightly weakened by CCC in 1995–1996, as protein content and 1000 grain weights were lowered at most N rates (Table 3a). Because of the decrease in N content of grains, N yield was significantly increased by PGRs only in 1994, at N rate of 97 kg ha^{-1}, i.e., 11 kg ha^{-1}.

Vol. 8 (1999): 423–440.

Table 2a. Effect of N fertilization on plant height (1995–96), lodging (no lodging in 1994–1996), and grain moisture at harvest (1993–1996) of spring wheat, without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Plant height, cm										
1995:	PGR-	63	80	85	90	92	95	94	86	7
	PGR+	42	49	52	57	62	66	67	57	"
	$HSD_{0.05}$								2	
1996	PGR-	81	88	90	91	89	88	86	88	4
	PGR+	58	67	71	74	76	75	75	71	"
	$HSD_{0.05}$								2	
Lodging, %										
1993:	PGR-	0	0	0	0	0	16	32	7	9
	PGR+	0	0	0	0	0	2	9	2	"
	$HSD_{0.05}$								3	
1994–1996: no lodging										
Grain moisture at harvest, %										
1993:	PGR-	29.7	24.0	24.2	26.3	28.7	30.1	31.7	27.8	2.9
	PGR+	30.7	24.4	24.2	25.5	27.4	27.4	29.0	26.9	"
	$HSD_{0.05}$								n.s.[2]	
1994	PGR-	16.0	16.7	16.8	18.4	19.3	20.7	20.5	18.4	2.4
	PGR+	17.3	17.7	17.1	19.4	19.7	21.8	20.9	19.1	"
	$HSD_{0.05}$								n.s.	
1995	PGR-	28.8	27.8	27.5	28.1	29.0	30.6	29.6	28.8	2.0
	PGR+	30.1	29.3	29.0	28.9	30.2	31.0	30.4	29.8	"
	$HSD_{0.05}$								0.9	
1996	PGR-	22.0	22.1	25.3	27.8	29.9	31.4	32.5	27.3	1.8
	PGR+	24.6	23.1	26.1	28.2	30.2	32.0	33.2	28.2	"
	$HSD_{0.05}$								0.9	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates
[2] n.s.= not significant

Oats

CCC increased oats yield by 400–1000 kg ha^{-1} at high N fertilization rates in 1995–96, but had no influence on crop yield in the dry year of 1994 (Tables 1, 3b). The yield increase was related to stem shortening (Table 2b). In 1993, CCC reduced lodging, but yield was improved only at the N rate of 157 kg ha^{-1}. Grain moisture at harvest were increased, and grain weights were generally decreased by PGR. Significant increases in N yield by PGR use were recorded in 1995 at N rates of 150 and 180 kg ha^{-1}, (14 and 12 kg ha^{-1}, respectively) and in 1996 at N rates of 90 and 180 kg ha^{-1}, (5 and 13 kg ha^{-1}, respectively).

Barley

The effect of etephon/mepiquat on yield was inconsistent, influenced to a large extent by the weather conditions, as was reported also by e.g. Erviö et al. (1995). In 1993 the effect was insignificant at all N rates even if lodging occurred (Tables 2c, 3c). In the dry year of 1994 PGR increased yield by 300 kg/ha at high N rates, even if no lodging was recorded. After the heavy rains

Table 2b. Effect of N fertilization on plant height (1995–96), lodging (no lodging in 1994–1995), and grain moisture at harvest (1993–1996) of oats, without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Plant height, cm										
1995:	PGR-	58	70	80	90	97	108	109	87	13
	PGR+	56	70	75	84	86	97	100	81	"
	$HSD_{0.05}$								5	
1996	PGR-	69	106	121	128	134	133	129	117	10
	PGR+	64	93	101	108	113	116	117	102	"
	$SD_{0.05}$								2	
Lodging, %										
1993:	PGR-	0	0	2	19	46	52	65	26	22
	PGR+	0	0	2	5	20	30	42	14	"
	$HSD_{0.05}$								11	
1996:	PGR-	0	0	0	0	0	2	14	2	n.s.[1]
	PGR+	0	0	0	0	0	0	0	0	"
	$HSD_{0.05}$								n.s.	
Seed moisture at harvest, %										
1993:	PGR-	21.7	20.3	20.7	23.3	23.1	25.6	25.7	22.9	2.7
	PGR+	22.1	21.0	21.5	22.7	24.4	25.4	26.6	23.4	"
	$HSD_{0.05}$								n.s.	
1994	PGR-	25.8	20.3	19.0	19.4	20.0	20.0	20.2	20.7	2.1
	PGR+	27.0	21.9	20.7	20.9	21.2	20.9	20.8	21.9	"
	$HSD_{0.05}$								1.3	
1995	PGR-	25.3	22.8	20.9	20.6	19.7	19.2	18.4	21.0	3.5
	PGR+	26.5	24.3	21.7	22.4	21.3	21.0	19.4	22.4	"
	$HSD_{0.05}$								0.9	
1996	PGR-	28.2	22.0	19.5	18.7	17.5	16.7	17.2	20.0	1.7
	PGR+	30.0	24.8	22.2	20.7	19.1	17.6	17.1	21.7	"
	$HSD_{0.05}$								0.9	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

in early season of 1995, ethephon/mepiquat even lowered the yield, although the PGR also shortened the stem length. In 1996, when PGR effectively reduced lodging at high N rates, positive response (400–500 kg/ha) occurred at N rates of 90 and 120 kg/ha. At higher N rates no yield increase was found, even if etephon treatments have been reported to increase barley yields when they reduce lodging (Dahnous et al. 1982). Both positive and negative grain yield responses to etephon were reported also earlier (Dahnous et al. 1982, Simmons et al. 1988). Grain moisture at harvest was higher in treated plots, indicating the delaying effect. Grain quality was little affected (Tables 2c, 3c). PGR use showed negative response to N yields (3 to 12 kg ha^{-1}) at N rates of 30–120 kg ha^{-1} in 1995, with the grain yield decrease. PGR use increased N yields only at the N rate of 120 kg ha^{-1}, in 1994 (i.e., 3 kg ha^{-1}) and in 1996 (i.e., 10 kg ha^{-1}).

Vol. 8 (1999): 423–440.

Table 2c. Effect of N fertilization on plant height (1995–96), lodging, and grain moisture at harvest (1993–1996) of fodder barley, without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Plant height, cm										
1995:	PGR-	36	40	48	57	62	69	74	55	7
	PGR+	30	33	36	42	47	54	56	43	"
	$HSD_{0.05}$								6	
1996	PGR-	45	70	88	95	89	84	83	79	16
	PGR+	43	62	82	92	94	91	81	78	"
	$HSD_{0.05}$								n.s.[1]	
Lodging, %										
1993:	PGR-	0	0	6	10	13	23	23	11	14
	PGR+	0	0	3	5	9	13	11	6	"
	$HSD_{0.05}$								2	
1994–1995:	no lodging									
1996:	PGR-	0	0	0	5	49	92	96	35	26
	PGR+	0	0	0	0	6	49	71	18	"
	$HSD_{0.05}$								10	
Seed moisture at harvest, %										
1993:	PGR-	30.8	28.7	28.0	28.5	29.3	31.7	30.0	29.5	2.8
	PGR+	33.3	30.7	29.4	30.1	30.7	31.3	30.5	30.8	"
	$HSD_{0.05}$								0.8	
1994	PGR-	28.3	25.5	25.2	25.5	26.0	26.7	27.2	26.3	2.0
	PGR+	29.5	28.0	28.1	28.1	28.5	28.8	30.1	28.7	"
	$HSD_{0.05}$								0.4	
1995	PGR-	24.3	17.0	16.0	15.9	16.6	17.0	18.5	17.9	2.8
	PGR+	25.6	18.9	21.3	20.0	19.9	18.8	19.2	20.5	"
	$HSD_{0.05}$								0.9	
1996	PGR-	23.5	15.8	15.2	15.6	16.5	18.8	19.9	17.9	4.5
	PGR+	23.8	17.2	16.8	16.7	18.1	20.0	21.5	19.2	"
	$HSD_{0.05}$								n.s.	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

Oilseed rape

Oilseed rape yields were generally improved by ethephone in both dry and wet seasons (Tables 1, 3d). The yield increase was not related to shortened stem or prevented lodging as strongly as was observed for cereals (Table 2d), but rather because of increased branching. This was obvious in 1994, as after a rainless July the seed yield was improved 250 kg ha^{-1} by PGR at N rates of 120 and 150 kg ha^{-1}. In 1993 and 1996 yield increases also reached 250 kg ha^{-1}at higher N rates. After the wet early season of 1995 the yield response to PGR was on average only slightly less than in other years. On the other hand, clearly positive effects of PGR over the whole N range were shown this year. Seed weight increased in 1994–1995, but generally seed quality was very little affected by ethephone.

Positive response of PGR use in N fertilization was found each year: In 1993–1994, the N

Table 2d. Effect of N fertilization on plant height (1995–96), lodging (no lodging in 1994–1995), and seed moisture at harvest (1993–1996) of oilseed rape, without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Plant height, cm										
1995:	PGR-	42	48	58	62	68	73	75	61	9
	PGR+	43	46	56	60	65	70	72	59	"
	$HSD_{0.05}$								2	
1996	PGR-	79	97	106	113	118	120	122	108	13
	PGR+	70	91	96	105	111	112	118	100	"
	$HSD_{0.05}$								3	
Lodging, %										
1993:	n.d.[2]									
1996:	PGR-	0	0	5	9	23	40	40	17	14
	PGR+	0	0	2	5	7	19	21	8	"
	$HSD_{0.05}$								9	
Seed moisture at harvest, %										
1993:	PGR-	15.2	13.3	13.9	14.4	15.0	15.1	16.9	14.8	2.3
	PGR+	14.5	14.2	13.8	15.2	16.1	16.3	16.7	15.2	"
	$HSD_{0.05}$								n.s.[3]	
1994	PGR-	14.0	14.1	14.9	15.1	15.4	15.4	16.1	15.0	2.0
	PGR+	14.2	14.7	15.2	15.3	15.6	16.1	16.3	15.4	"
	$HSD_{0.05}$								0.2	
1995	PGR-	14.5	13.9	13.4	13.6	13.6	14.0	14.3	13.9	1.4
	PGR+	14.7	14.1	13.5	13.6	14.0	14.5	14.9	14.2	"
	$HSD_{0.05}$								0.3	
1996	PGR-	9.5	9.5	10.0	10.9	12.8	14.2	15.8	11.8	2.2
	PGR+	9.9	9.6	10.1	10.9	12.6	13.7	14.6	11.6	"
	$HSD_{0.05}$								n.s.	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates
[2] n.d.= not determined
[3] n.s.= not significant

Table 3a. Effect of N fertilization on grain yield and quality of spring wheat (1993–96), without and with the use of plant growth regulators (PGR-/PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Grain yield, kg ha^{-1}										
1993:	PGR-	2250	3170	3860	4240	4650	4900	5000	4010	740
	PGR+	2070	3040	3880	4320	4650	4540	5200	4000	"
	$HSD_{0.05}$								n.s.[2]	

Table 3a. continues

Vol. 8 (1999): 423–440.

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
1994	PGR-	2710	3550	3730	3730	3760	4100	3980	3650	980
	PGR+	2820	3780	3810	4130	3960	4210	4120	3830	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	2190	3150	3840	4390	5050	5740	5180	4220	1160
	PGR+	2470	3460	4230	4800	5910	6400	6190	4780	“
	$HSD_{0.05}$								530	
1996	PGR-	2480	3510	4300	4930	5280	5690	5880	4580	520
	PGR+	2450	3500	4470	5210	5620	6050	6110	4770	“
	$HSD_{0.05}$								70	
Protein content, %										
1993:	PGR-	11.1	11.1	12.1	13.3	14.9	15.7	16.2	13.5	1.1
	PGR+	11.1	10.7	11.4	13.0	14.4	15.4	16.0	13.1	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	11.2	12.1	14.1	15.8	17.3	17.9	18.6	15.3	2.3
	PGR+	10.9	12.0	13.8	15.6	17.4	17.5	18.3	15.0	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	10.9	10.8	11.2	11.8	13.0	14.6	15.5	12.6	0.9
	PGR+	9.7	9.6	10.0	10.4	11.6	12.8	13.9	11.2	“
	$HSD_{0.05}$								0.3	
1996	PGR-	10.0	9.8	10.6	11.4	12.0	12.5	13.3	11.4	0.8
	PGR+	9.7	9.6	10.1	10.6	11.3	12.2	12.9	10.9	“
	$HSD_{0.05}$								0.1	
Falling number										
1993:	PGR-	235	245	228	235	224	220	215	229	n.s.
	PGR+	246	237	234	238	243	232	230	237	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	261	244	247	243	236	231	228	241	27
	PGR+	265	258	259	251	230	223	229	245	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	210	232	249	267	290	262	309	260	55
	PGR+	215	202	218	206	236	263	309	235	“
	$HSD_{0.05}$								23	
1996	PGR-	320	293	291	292	295	298	297	298	24
	PGR+	300	293	285	300	300	304	301	298	“
	$HSD_{0.05}$								n.s.	
1000 grain weight, g										
1993:	PGR-	31.2	32.9	33.7	34.0	34.7	34.9	35.1	34.7	1.6
	PGR+	29.2	30.4	31.0	32.3	33.3	34.2	34.1	32.1	“
	$HSD_{0.05}$								0.6	
1994	PGR-	32.4	33.6	31.8	32.4	31.1	31.8	31.7	32.1	2.2
	PGR+	32.2	32.8	31.2	31.4	31.2	32.4	31.2	31.8	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	33.7	36.5	36.5	36.4	37.1	37.5	35.9	36.2	2.2
	PGR+	31.7	33.5	34.2	34.2	35.2	35.5	34.6	34.1	“
	$HSD_{0.05}$								1.0	
1996	PGR-	33.0	34.3	35.0	35.2	35.4	35.1	34.9	34.7	1.6
	PGR+	31.1	32.0	32.7	32.9	32.6	32.0	31.4	32.1 “	
	$HSD_{0.05}$								n.s.	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

Table 3b. Effect of N fertilization on grain yield and quality of oats (1993–96), without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Yield, kg ha^{-1}										
1993:	PGR-	2940	4420	5410	5880	6150	6120	6390	5330	640
	PGR+	2950	4320	5430	5900	6320	6550	6460	5420	"
	$HSD_{0.05}$								n.s.[2]	
1994	PGR-	2850	3950	4470	4710	4870	4890	4830	4370	510
	PGR+	2800	3890	4450	4780	4850	4890	4960	4380	"
	$HSD_{0.05}$								n.s.	
1995	PGR-	2230	3300	3950	4810	5550	6300	6670	4690	1140
	PGR+	2580	3740	4380	5320	6050	6910	7320	5190	"
	$HSD_{0.05}$								n.s.	
1996	PGR-	2510	3900	4720	5040	5190	5110	4420	4410	570
	PGR+	2600	4030	5030	5600	5710	5540	5500	4860	"
	$HSD_{0.05}$								430	
Protein content, %										
1993:	PGR-	9.3	9.3	10.3	11.2	12.2	12.9	13.3	11.2	0.9
	PGR+	9.3	9.3	10.3	11.1	12.1	12.6	13.2	11.1	"
	$HSD_{0.05}$								n.s.	
1994	PGR-	9.2	10.2	11.6	13.4	15.4	15.8	16.5	13.2	1.5
	PGR+	9.6	9.9	11.7	13.4	14.8	15.6	16.5	13.1	"
	$HSD_{0.05}$								n.s.	
1995	PGR-	9.4	8.9	9.0	9.2	10.4	11.7	12.9	10.2	1.7
	PGR+	9.3	8.8	8.8	9.6	10.7	12.2	13.0	10.3	"
	$HSD_{0.05}$								n.s.	
1996	PGR-	9.1	9.1	9.5	10.5	11.3	12.4	12.7	10.6	0.8
	PGR+	9.1	9.0	9.4	10.0	10.3	11.5	11.9	10.2	"
	$HSD_{0.05}$								0.3	
1000 grain weight, g										
1993:	PGR-	33.2	32.5	33.3	32.8	33.4	33.6	32.5	33.0	1.6.
	PGR+	31.8	31.3	31.9	32.3	33.0	32.8	33.0	32.3	"
	$HSD_{0.05}$								0.4	
1994	PGR-	27.1	26.0	26.2	26.6	27.8	28.3	29.2	27.3	2.0
	PGR+	25.9	24.9	24.6	24.9	26.6	26.6	27.6	25.9	"
	$HSD_{0.05}$								0.7	
1995	PGR-	31.0	31.7	31.7	32.6	32.7	34.4	34.2	32.6	2.1
	PGR+	30.6	31.6	31.0	32.7	32.7	33.1	33.4	32.1	"
	$HSD_{0.05}$								n.s.	
1996	PGR-	32.8	32.9	34.2	33.9	33.2	32.8	32.2	33.2	1.9
	PGR+	32.1	33.6	33.5	34.0	32.8	31.0	30.4	32.5	"
	$HSD_{0.05}$								0.6	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

yield increase was 5–8 kg ha^{-1} at N rates of 90–150 kg ha^{-1}. In 1995, the increase was found at N rates of 60, 90, and 180 kg ha^{-1} (4, 6 and 11 kg ha^{-1}, respectively). In 1996, the increase was statistically significant only at N rate of 150 kg ha^{-1}, being 7 kg ha^{-1}.

Vol. 8 (1999): 423–440.

Table 3c. Effect of N fertilization on grain yield and quality of fodder barley (1993–96), without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Yield, kg ha^{-1}										
1993:	PGR-	2980	4410	5280	5500	5850	6100	6040	5170	1060
	PGR+	3180	4430	5340	5580	6170	6390	6220	5330	“
	$HSD_{0.05}$								n.s.[1]	
1994	PGR-	2520	3950	5010	5540	5660	5840	5860	4910	440
	PGR+	2610	4070	5060	5600	5940	6140	6120	5080	“
	$HSD_{0.05}$								180	
1995	PGR-	1160	1570	2240	2770	3700	4190	4670	2900	900
	PGR+	1040	1330	1520	1980	2960	3480	4650	2420 “	
	$HSD_{0.05}$								n.s.	
1996	PGR-	2040	3360	4310	5320	5940	6540	6920	4920	1150
	PGR+	2220	3550	4630	5860	6360	6430	6880	5130	“
	$HSD_{0.05}$								n.s.	
Protein content, %										
1993:	PGR-	9.3	9.4	10.5	10.9	12.4	12.6	13.8	11.3	1.1
	PGR+	9.4	9.4	9.8	10.5	11.9	12.4	13.4	11.0	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	8.5	8.8	9.9	11.0	12.2	13.3	14.2	11.1	0.7
	PGR+	8.3	8.5	9.5	10.9	12.0	12.8	13.6	10.8	“
	$HSD_{0.05}$								0.1	
1995	PGR-	10.2	9.2	8.6	8.8	9.8	10.2	11.5	9.7	1.3
	PGR+	10.1	9.1	9.0	8.8	9.5	9.8	10.7	9.6	“
	$HSD_{0.05}$								n.s.	
1996	PGR-	9.6	8.1	8.8	9.0	9.7	11.4	12.0	9.8	1.7
	PGR+	9.5	8.7	8.2	9.0	10.1	11.1	11.8	9.8	“
	$HSD_{0.05}$								n.s.	
1000 grain weight, g										
1993:	PGR-	32.2	33.5	33.1	33.2	33.0	32.9	33.1	33.0	n.s.
	PGR+	31.8	32.5	33.8	34.0	34.4	34.3	33.5	33.5	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	32.9	35.9	37.3	36.9	36.6	36.9	35.9	36.1	2.1
	PGR+	32.3	35.6	36.7	36.5	35.8	36.7	36.0	35.7	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	31.7	33.2	36.0	36.9	39.4	40.1	41.3	36.9	2.0
	PGR+	30.5	31.0	32.3	34.5	37.2	37.3	39.0	34.5	“
	$HSD_{0.05}$								1.9	
1996	PGR-	31.3	32.4	33.4	33.9	32.6	32.5	33.0	32.7	2.8
	PGR+	31.3	33.1	33.8	33.6	32.7	31.5	32.3	32.6	“
	$HSD_{0.05}$								n.s.	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

Residual effect

Carryover effect of N fertilization rates

According to barley yields harvested in 1997, the growth was better in plots with high N rates than in those with low rates (Table 4). However, the yields in N_0-plots compared well with the growth in N_{120}–N_{180} plots. These data indicate that soil N reserves are not especially low after cultivation without N fertilizer. Measurements

Table 3d. Effect of N fertilization on seed yield and quality of oilseed rape (1993–96), without and with plant growth regulators (=PGR- / PGR+). $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Yield, kg ha^{-1}										
1993	PGR-	1450	1740	1900	2170	2180	2220	2250	1990	540
	PGR+	1450	1910	2170	2370	2420	2420	2410	2170	“
	$HSD_{0.05}$								140	
1994	PGR-	970	1430	1520	1610	1760	1950	1660	1560	650
	PGR+	1040	1480	1710	1810	2020	2170	1990	1750	“
	$HSD_{0.05}$								240	
1995	PGR-	500	530	810	1170	1680	2180	2490	1340	370
	PGR+	560	680	990	1380	1750	2290	2750	1490	“
	$HSD_{0.05}$								80	
1996	PGR-	930	1310	1630	1950	2000	2060	2070	1710	340
	PGR+	1080	1370	1770	2090	2220	2310	2280	1870	“
	$HSD_{0.05}$								n.s.[2]	
Protein content, %										
1993:	PGR-	18.8	18.1	18.5	19.5	20.8	22.3	23.1	20.1	1.9
	PGR+	17.8	17.9	18.4	19.8	21.0	21.9	22.6	19.9	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	18.9	19.8	22.2	23.5	25.3	25.6	27.0	23.2	2.5
	PGR+	19.1	20.3	22.5	23.1	24.2	25.6	26.4	23.0	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	16.7	16.5	15.9	15.9	16.7	18.5	21.1	17.3	2.0
	PGR+	16.5	16.3	16.0	16.7	17.2	19.5	21.9	17.7	“
	$HSD_{0.05}$								n.s.	
1996	PGR-	17.5	16.5	17.4	18.2	21.3	22.3	23.4	19.5	1.3
	PGR+	17.9	16.8	16.7	17.9	20.4	22.0	23.0	19.2	“
	$HSD_{0.05}$								0.3	
Oil content, %										
1993:	PGR-	48.0	48.2	47.6	46.8	45.5	43.9	43.8	46.2	2.2
	PGR+	48.6	48.5	48.1	46.8	45.3	44.1	44.0	46.5	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	49.2	47.9	45.6	45.8	44.5	43.8	42.4	45.6	2.2
	PGR+	48.6	48.9	46.7	46.1	45.1	43.8	42.6	46.0	“
	$HSD_{0.05}$								n.s.	
1995	PGR-	51.2	51.5	51.7	51.3	50.1	48.8	46.6	50.1	2.2
	PGR+	51.6	51.7	51.6	50.4	49.0	47.7	45.5	49.6	“
	$HSD_{0.05}$								0.2	
1996	PGR-	50.2	51.5	50.6	49.5	46.4	45.5	43.7	48.2	1.9
	PGR+	50.6	51.1	50.8	50.1	46.3	45.4	44.5	48.4	“
	$HSD_{0.05}$								n.s.	
1000 seed weight, g										
1993:	PGR-	2.28	2.24	2.18	2.19	2.16	2.20	2.20	2.21	0.10
	PGR+	2.26	2.20	2.23	2.17	2.19	2.17	2.22	2.21	“
	$HSD_{0.05}$								n.s.	
1994	PGR-	1.98	2.06	2.10	2.14	2.23	2.32	2.34	2.16	0.15
	PGR+	2.06	2.10	2.19	2.24	2.29	2.39	2.42	2.24	“
	$HSD_{0.05}$								n.s.	

Table 3d. continues

Vol. 8 (1999): 423–440.

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
1995	PGR-	2.41	2.42	2.37	2.31	2.37	2.41	2.45	2.39	0.23
	PGR+	2.45	2.47	2.41	2.38	2.41	2.48	2.58	2.45	“
	$HSD_{0.05}$								0.03	
1996	PGR-	2.55	2.46	2.41	2.35	2.34	2.34	2.28	2.39	0.13
	PGR+	2.58	2.51	2.47	2.38	2.37	2.34	2.35	2.43	“
	$HSD_{0.05}$								0.03	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates
[2] n.s.= not significant

Table 4. Effect of N fertilization rates and PGR treatment of previous years (1993–1996) on the yield and grain protein of fodder barley in 1997 in each cropping block, at 30 kg/ha N rate. $HSD_{0.05}$ indicates Tukey’s honestly significant difference (P=0.05).

		N rate[1], kg ha^{-1}								
		0	30	60	90	120	150	180	mean	$HSD_{0.05}$
Yield, kg ha^{-1}										
Block 1	PGR-	3550	3320	3150	3040	3290	3470	3490	3330	450
	PGR+	3410	3220	3130	3040	3200	3450	3440	3270	“
	$HSD_{0.05}$								n.s.[2]	
Block 2	PGR-	3670	3400	2980	3070	3190	3540	3610	3350	540
	PGR+	3480	3360	3040	3160	3300	3760	3860	3420	“
	$HSD_{0.05}$								n.s.	
Block 3	PGR-	3100	2980	3040	3020	3070	3290	3700	3170	570
	PGR+	3040	2930	2930	2980	2900	3170	3720	3100	“
	$HSD_{0.05}$								n.s.	
Block 4	PGR-	3230	3250	3130	3080	3420	4120	4200	3490	740
	PGR+	3260	3190	3080	2970	3300	3820	3930	3360	“
	$HSD_{0.05}$								n.s.	
Protein content, %										
Block 1	PGR-	9.1	9.0	8.9	9.0	9.5	9.5	9.8	9.3	0.7
	PGR+	9.2	8.9	8.8	8.9	9.2	9.0	9.4	9.1	“
	$HSD_{0.05}$								n.s.	
Block 2	PGR-	9.4	9.6	9.4	9.3	9.4	9.5	9.5	9.4	n.s.
	PGR+	9.4	9.6	9.4	9.4	9.4	10.0	10.0	9.6	“
	$HSD_{0.05}$								n.s.	
Block 3	PGR-	9.0	8.7	8.9	8.7	8.8	8.8	9.3	8.9	0.5
	PGR+	8.9	8.7	8.7	8.7	8.5	8.6	9.1	8.7	“
	$HSD_{0.05}$								n.s.	
Block 4	PGR-	9.0	9.2	9.2	9.0	9.2	9.9	10.0	9.4	0.9
	PGR+	8.9	9.2	9.2	8.9	9.2	9.5	9.7	9.2	“
	$HSD_{0.05}$								n.s.	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates
[2] n.s.= not significant

Table 5. Effect of N fertilization rates and PGR treatment of previous years (1993–1996) on the N yield of fodder barley in 1997, at 30 kg ha^{-1}N rate. $HSD_{0.05}$ indicates Tukey's honestly significant difference (P=0.05).

	N rate[1], kg ha^{-1}								
	0	30	60	90	120	150	180	mean	$HSD_{0.05}$
N yield, kg ha^{-1}									
PGR-	46.1	44.0	41.8	41.5	44.1	49.1	51.0	45.4	4.6
PGR+	44.9	43.2	41.4	41.3	43.1	48.2	50.8	44.7	"
$HSD_{0.05}$								n.s.[1]	

[1] In 1993–1994, the PK fertilizer contained also 3% N, adding 7 kg ha^{-1} to the N rates

[2] n.s.= not significant

of grain protein contents show, however, that nitrogen uptake into grains was the highest in soils with high N rates.

The average N yield of grains (kg ha^{-1}) in four cropping blocks was affected by previous N fertilization (Table 5). The N yields in grains indicate that PGRs had no significant effect on the residual mineral nitrogen. The N yields were, however, better in the non N fertilized soils than in the soils of moderate rates (N_{60} and N_{90}). Obviously, this was a result of accumulation of residual N in non-fertilized plots which had produced low grain and N yields. In soils of moderate N fertilizer rates and better N yields, more nitrogen had been used in previous years and less N was available in 1997. At high N rates crops did not use all available N, which is shown by the high N yields in the carryover study. As a long-term effect, this suggests more N losses from fields of both non- and over-optimal N supply than from fertilization at moderate N rates.

Leachable soil mineral nitrogen

Net mineralization during a growing season changes crucially between years, averaging 55 kg ha^{-1} in clay soils in southern Finland that are low in organic matter (Lindén et al. 1992a, Esala 1994). Also leaching of nitrate by heavy rains may be substantial after the mineralization of organic nitrogen in warm conditions (Turtola and Jaakkola 1985). Our data show the impact of weather conditions on soil mineral nitrogen after harvest (Figures 1–2). In September 1994, after a very dry and warm July and August, soil NO_3- and NH_4- N reserves were much higher in plots of high N fertilization rates than in plots of low N fertilization. This obviously indicates the inefficient use of fertilizer N in July. Based on measurement in early spring 1995, much more N (10–20 kg ha^{-1}) may have been leached during autumn rains and winter, or immobilized, from plots with N fertilization over 120 kg ha^{-1}. At lower N rates, increasing N fertilization increased leaching risk very little, as was found also by Jaakkola (1984) and Lindén et al. (1992b). The N data in mg kg^{-1} can be estimated N kg ha^{-1} in plough layer (0–25 cm) by multiplying the values by 2.3 (assuming that the dry bulk density of soil is 1.1). Some of the possibly leached nitrogen (5 kg ha^{-1}) was found from the subsoil in May 1995, but was no longer useful for early plant growth (Esala and Leppänen 1998). After the rainy and productive season of 1996 not much mineral nitrogen was found (Fig. 2). The risk of N leaching during winter 1996–1997 did not remarkably differ between N fertilizer rates, as soil mineral N content in May 1997 was rather similar between plots, in agreement with Sippola and Yläranta (1985). These data show that after a favourable growing season with high yields, the N leaching risk is low even at very high N fertilizer rates. However, after a dry and warm July and August, and a rainy September the N leaching risk is obvious (10–35 kg ha^{-1}) at N fertilizer rates of over 100 kg ha^{-1}.

Vol. 8 (1999): 423–440.

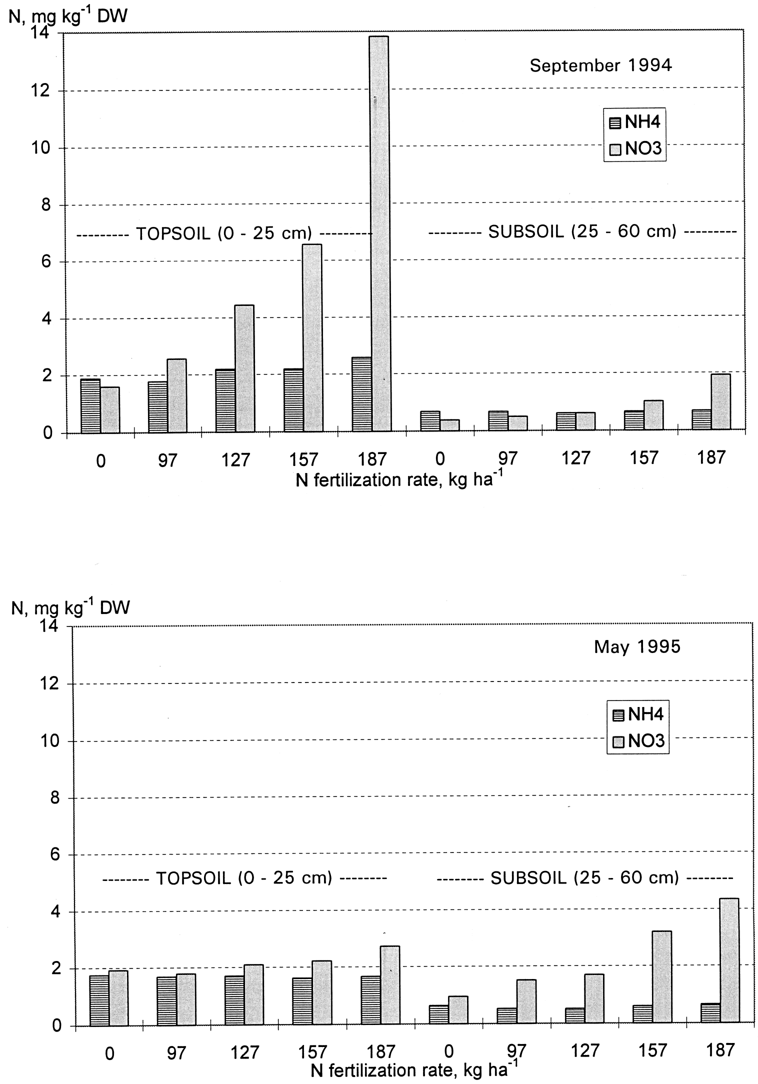


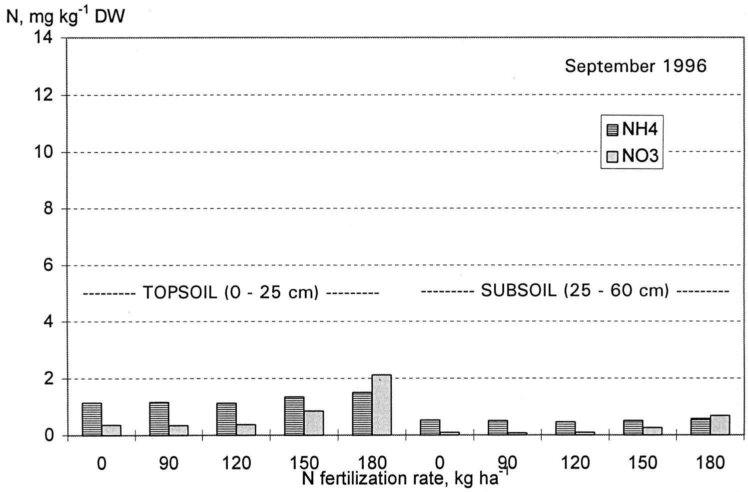
Fig. 1. Response of soil mineral nitrogen to N fertilization after harvest of barley (above) and before the following growing season (below). $HSD_{0.05}$ for NO_3-N in September in top layer 2.2 and in sublayer 1.1, in May 0.5 and 1.4, respectively. $HSD_{0.05}$ for NH_4-N in September in top layer 0.5 and in sublayer not significant (n.s.), in May 0.3 and n.s., respectively.

Conclusions

Use of PGRs did not change the optimum N fertilization rate for yield formation, even if the use of PGRs improved the crop and N yield in rainy seasons in particular. Application of PGR resulted in higher seed and N yield of oilseed rape even in dry years. Grain quality was slightly weakened by PGRs, if affected at all.

The data suggest that PGRs, if applied as recommened, increase N uptake and for decrease the leaching risk for oilseed rape, and for oats in rainy summers. N use by wheat and barley were significantly decreased by delayed PGR use after the rainy early season of 1995.

Use of high nitrogen fertilization rates leads to a risk of soil mineral N leaching after harvest, but only after a dry and warm July–August. To minimize the N leaching risk, N fertilization



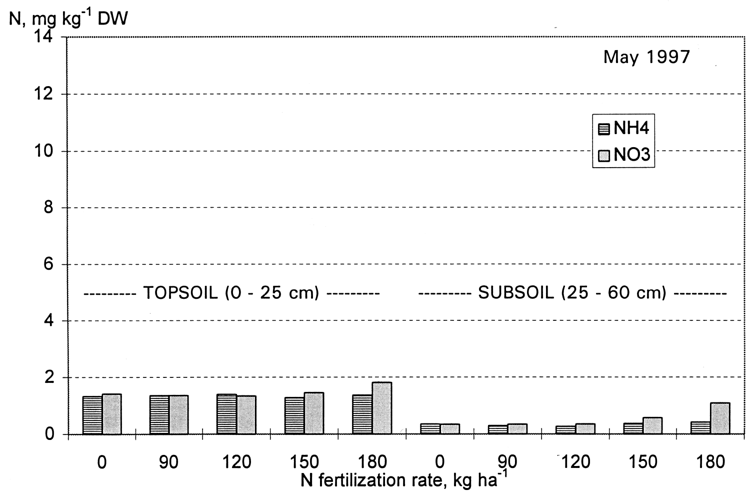


Fig. 2. Response of soil mineral nitrogen to N fertilization after harvest of spring wheat (above) and before the following growing season (below). $HSD_{0.05}$ for NO_3-N in September in top layer 0.7 and in sublayer 0.3, in May 0.3 and 0.3, respectively. $HSD_{0.05}$ for NH_4-N not significant.

over 90–100 kg ha^{-1} should be avoided for spring cereals, at least in the conditions described here. This agrees with the agro-environmental program of Ministry of Agriculture and Forestry in Finland. However, the data also indicate that soil N reserves are not especially low after cultivation without N fertilizer that has caused low yield levels.

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SELOSTUS

Typpilannoituksen ja kasvunsääteiden vaikutukset kevätviljojen ja rypsin satoon sekä typen käyttöön

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Voidaanko typpilannoituksen hyötyä parantaa kasvunsääteiden avulla vai lisäävätkö kasvunsääteet typen käyttöä tuottamatta lisää satoa? Näitä kysymyksiä sekä typpilannoituksen jälkivaikutuksia tutkittiin edesmenneen professori Paavo Elosen hietasavimaalle perustamassa kenttäkokeessa vuosina 1993–1997. Koekasveja viljeltiin neljässä vierekkäisessä lohkossa viljelykierrossa, seitsemällä eri typpitasolla (0–180 kg/ha).

Suurin sato saatiin typpilannoituksen tasolla 120–150 kg/ha. Vuoden 1993 suositusten mukaiset kasvunsäädekäsittelyt, jotka vuonna 1995 tosin viivästyivät sateiden vuoksi, eivät vaikuttaneet tähän optimitasoon. Kasvunsääteet kuitenkin saattoivat lisätä jyvä- ja typpisatoja varsinkin suurilla typpilannoitusmäärillä, tehostaen siten typen ottoa. Lisäystä ei kuitenkaan havaittu kaikilla viljelykasveilla. Ainoastaan rypsi (cv. Kulta) hyötyi kasvunsäädekäsittelystä (Cerone) kaikkina koevuosina, jopa kuivana kesänä 1994. Kasvunsääde (CCC) lisäsi myös kauran (cv. Yty) jyvä- ja typpisatoja, mutta vain sateisina kesinä, jolloin lakoutuminen selvästi väheni käsittelyn myötä. Kevätvehnällä (cv. Satu) vuosittainen vaihtelu oli suuri, ja kasvunsääteen (CCC) edullinen vaikutus jyväsatoon oli merkittävä vain vuonna 1995, jolloin alkukesä oli hyvin sateinen ja loppukesä kuiva. Tällöin kasvunsääde lyhensi selvästi vehnän korren pituutta (30 cm). Typpisadot eivät kuitenkaan kohonneet, koska kasvunsääde laski jyvän typpipitoisuutta. Kasvunsääteen (Terpal) vaikutus rehuohran (cv. Loviisa) jyvä- ja typpisatoihin vaihteli suuresti eri vuosina. Typpisadot jopa laskivat merkitsevästi viivästyneen käsittelyn vaikutuksesta vuonna 1995. Kasvunsääteet lisäsivät yleensä puintikosteutta, mutta muuten jyvän laatu heikkeni vain vähän tai käsittelyillä ei ollut vaikusta valkuaispitoisuuksiin ja 1000 jyvän painoon, paitsi vehnällä vuonna 1995. Rypsin 1000 siemenen paino kasvoi vuosina 1994–95 kasvunsääteen ansiosta.

Typpilannoituksen ja kasvunsäädekäsittelyjen jälkivaikutusta tutkittiin vuonna 1997, jolloin koko koealueelle kylvettiin rehuohraa. Typpilannoitustaso oli kaikissa koeruuduissa 30 kg/ha. Tulosten mukaan paras sato saatiin koealueilta, jotka lannoitettiin aiempina vuosina suurimmalla typpimäärällä. Myös typpisato oli näissä ruuduissa suurin, runsaat 50 kg/ha. Koevuosien lannoitustasoilla 60–90 kg/ha typpisato oli tätä 10 kg/ha pienempi. Ilman typpilannoitusta viljellyissä ruuduissa ero oli vain 5 kg/ha. Pienempi ero osoitti, että maahan kertyy typpeä, mikäli typpilannoitusta ei käytetä lainkaan. Tällöin heikoksi jäävä kasvusto ei todennäköisesti pysty tyhjentämään maan typpivaroja yhtä tehokkaasti kuin kohtuullisesti lannoitetut kasvustot. Vastaavasti korkeilla typpilannoitustasoilla (150–180 kg/ha) kasvi ei pysty hyödyntämään kaikkea käytettävissä olevaa typpeä, riippumatta kasvunsääteiden käytöstä.

Suuret typpilannoitusmäärät lisäsivät korjuun jälkeisiä maan mineraalityppipitoisuuksia, mutta vain kuivan kesän jälkeen. Syksyllä 1994 maan nitraattityppipitoisuudet olivat 15–35 kg/ha suuremmat typpilannoitustasoilla 127–187 kg/ha verrattuna pienempiin typpilannoitusmääriin. Keväällä 1995 mineraalityppeä oli eniten jankossa suuria typpimääriä saaneilla koeruuduilla, osoittaen mahdollista huuhtoutumista. Vuoden 1996 suotuisan, hyviä satoja tuottaneen kasvukauden jälkeen maan minaraalityppipitoisuudet olivat lähes samanlaiset eri lannoitustasoilla. Typen huuhtoutumisen välttämiseksi tulokset puoltavat typpilannoitustasoa 90–100 kg/ha. Tutkimus tukee näin nykyisiä ympäristötukiehtoja.

Tulosten mukaan kasvunsääteet voivat parantaa typen hyväksikäyttöä, mutta tutkituilla aineilla todennäköisimmin vain rypsin ja sateisina kesinä kauran viljelyssä.