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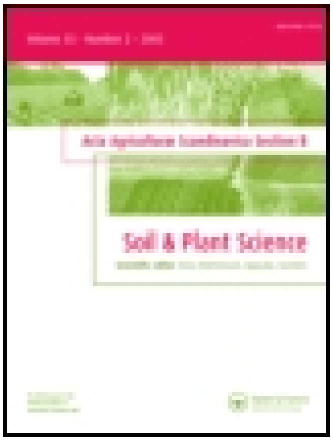

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Effects of Nitrogen Fertilization on Growth and Soil Nitrogen Depletion in Cauliflower

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To examine the possibilities of reducing fertilizer levels and losses of nitrogen, we studied the effects of amount and timing of nitrogen fertilization on growth parameters and on soil nitrogen depletion in cauliflower. A higher nitrogen supply, calculated as the sum of fertilizer nitrogen and mineral nitrogen at transplanting, resulted in a clear increase in nitrogen uptake by the crop and in a higher crop fresh weight. However, curd fresh or dry weight and looseness of the curd were not affected. Therefore we conclude that total nitrogen supply can be reduced to approximately 250 kg ha^{-1} without negative effects on yield. An increase in nitrogen supply of 100 kg ha^{-1} resulted in 17 kg ha^{-1} more residual soil nitrogen, 52 kg ha^{-1} more nitrogen in crop residues, 37 kg ha^{-1} more mineralizable N and 15 kg ha^{-1} more nitrogen in harvested curds. Changing the timing of nitrogen application, by reducing the application at planting and increasing the second application instead, resulted in a higher curd biomass, a larger amount of nitrogen in the curd and less residual soil nitrogen after harvest. Thus, the efficiency of nitrogen use was increased when more nitrogen was supplied at the time of a higher absolute growth and nitrogen demand.

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Key words: crop residues, leaching, nitrogen application, soil mineral nitrogen, split application.

Introduction

Concern about the high level of input in agriculture and its environmental effect is increasing. In vegetable production, in particular, high amounts of nitrogen fertilizer are used. This is partly because even at high levels increasing amounts of nitrogen lead to higher yields (Greenwood, 1990). Furthermore, the cost of fertilizer is low in comparison with the price of the product. The proportion of the fertilizer nitrogen that is finally present in the harvested part is often low (Greenwood et al., 1989; Smit & Van der Werf, 1992). After the harvest of field vegetables, large amounts of soil mineral nitrogen can be found (Neeteson, 1995), which subsequently may be lost through leaching. Considerable amounts of nitrogen are also present in the crop residues left on the soil after harvest and these also constitute a potential loss (Rahn, 1992).

The high input of nitrogen and the low efficiency with which it is used lead to the question whether the input of nitrogen can be reduced and losses to the

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Table 1. Summary of climate data in field experiments with cauliflower. Tmin: average daily minimum air temperature; Tmax: average daily maximum air temperature; Tsum: temperature sum until harvest with a base temperature of 0°C

	Year	Cultivar	Tmin °C	Tmax °C	Tsum °C days	Precipitation mm	Irrigation mm
Exp. 1	1993	Plana	8.2	18.0	1030	52	243
	1994	Plana	8.4	16.9	974	180	57
Exp. 2	1993	Plana	10.0	18.2	909	149	61
	1994	Plana	13.2	23.5	1176	157	147
	1994	Siria	13.5	23.9	1069	145	147
	1995	Plana	12.4	23.9	1269	37	271
	1995	Siria	12.3	24.1	1203	15	271

Table 2. Fertilizer applications and dates of planting and harvest in field experiments with cauliflower

	Year	Cultivar	First N Rate	Second N Rate	Mineral N	N supply	Planting date	Second N application	Final harvest
						kg ha^{-1}			Days after planting
Exp. 1	1993	Plana	80	50	42	172	19/4	36	78
	1993	Plana	120	90	42	252	19/4	36	78
	1993	Plana	160	130	42	332	19/4	36	73
	1993	Plana	80	130	42	252	19/4	36	73
	1994	Plana	80	50	34	164	22/4	42	76
	1994	Plana	140	110	34	284	22/4	42	76
	1994	Plana	200	170	34	404	22/4	42	76
	1994	Plana	80	170	34	284	22/4	42	76
Exp. 2	1993	Plana	120	90	133	343	15/6	45	64
	1994	Plana	140	110	63	313	23/6	35	63
	1994	Siria	140	110	63	313	23/6	35	56
	1995	Plana	140	120	92	352	19/6	54	69
	1995	Siria	140	120	92	352	19/6	54	65

environment can be decreased. When we examine the possibility of reducing the level of fertilizer use in vegetable production, the effect on both yield level and the quality of the product has to be considered.

Not only the amount, but also the timing of nitrogen application can have an influence on growth and nitrogen uptake, and a better timing of nitrogen supply with the nitrogen demand of the crop might increase the efficiency of fertilizer use (Neeteson, 1995). Furthermore, at late fertilization the root system of the crop is more developed, which may increase the efficiency of nitrogen uptake in comparison with early fertilization. Different ways of split application may therefore be a way of reducing losses of fertilizer.

Thus, to optimize the use of nitrogen in field vegetable production, we first need to know the effect of nitrogen level and time of application on crop growth. Secondly, we have to know how soil mineral nitrogen and nitrogen in crop residues after harvests are influenced by variations in nitrogen fertilizer level and timing of the application.

The aim of this study was to determine whether we can reduce nitrogen levels and losses of nitrogen in the form of residual soil nitrogen and crop residues in cauliflower production. Therefore, we studied the effects of nitrogen fertilization on growth parameters and on soil nitrogen depletion. Experiments were conducted using different nitrogen levels and different ways of splitting the applications. To gain insight into the processes that determine yield and the use of nitrogen, the effect of nitrogen level on several growth parameters was determined. The results of root growth studies carried out in these experiments will be presented in a separate paper.

Materials and methods

Cauliflower plants (*Brassica oleracea* L. *convar. botrytis* (L.) Alef var. *botrytis* L.) were grown on a sandy loam at Årslev Research Centre in Denmark (55/18′N, 10/27′E). Row and plant spacings were 0.5 m and 0.6 m, respectively. In Experiment 1 the cultivar Plana was grown at four different fertilizer application treatments during spring in two consecutive years. In Experiment 2 the cultivars Plana and Siria were grown during summer in three consecutive seasons. Meteorological data were taken from the meteorological station at Årslev. A summary of the climate data is presented in Table 1. The experiments were performed as a randomized complete block design with three replicates. Data were analysed with the SAS statistical package (SAS, 1990).

Nitrogen was supplied as calcium ammonium nitrate (27% N). Fertilizer was applied twice, first at planting and again at that time during growth when roots were found at maximum distance from the plants between the rows. Planting and harvest dates

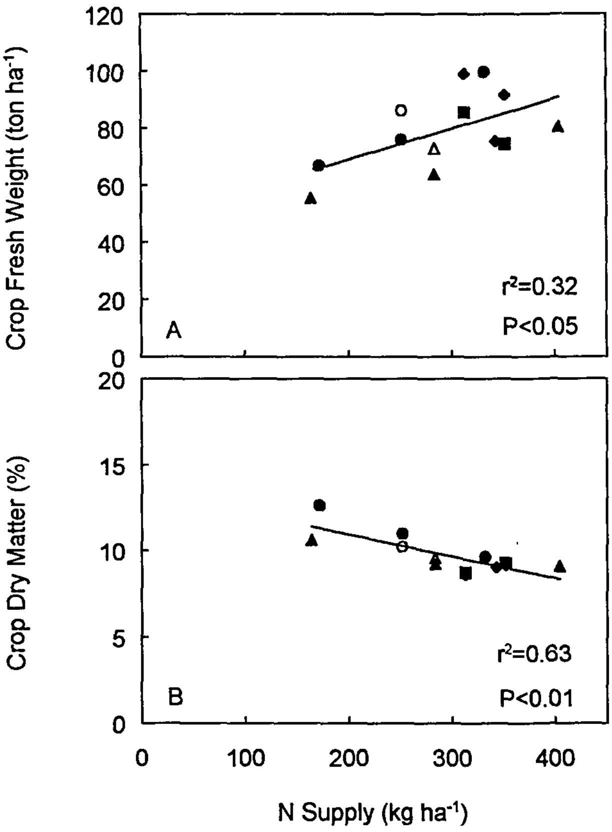

Fig. 1. Relationship between (A) crop fresh weight and (B) crop dry matter percentage and nitrogen supply, calculated as the sum of fertilizer and mineral nitrogen at planting. ● ○ Experiment 1, 1993; ▲ △ Experiment 1, 1994; ◆ Experiment 2, cv. Plana; ■ Experiment 2, cv. Siria. ● ▲ ◆ ■ *Largest part of nitrogen fertilizer at planting;* ○ △ Largest part of nitrogen fertilizer at second application.

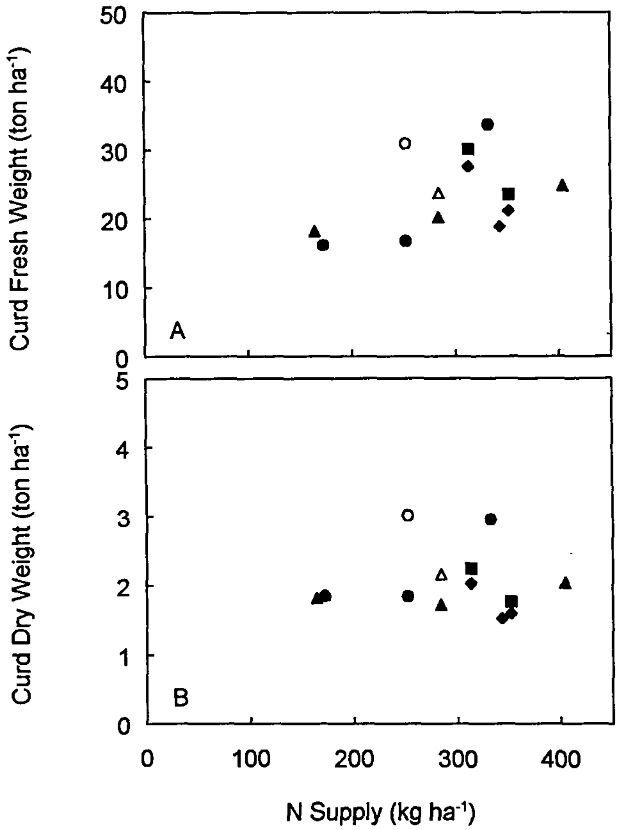

Fig. 2. Relationship between (A) curd fresh weight and (B) curd dry weight and nitrogen supply. Symbols as in Fig. 1.

and fertilizer rates are summarized in Table 2. Irrigation and pest and disease control were carried out according to the guidelines for normal production.

Plants were sampled three times during growth: at planting, before the second fertilizer application, and finally at the optimal harvest date for the curds. At each harvest, 12 plants per plot were harvested. The plants were separated into leaves, stems and curds.

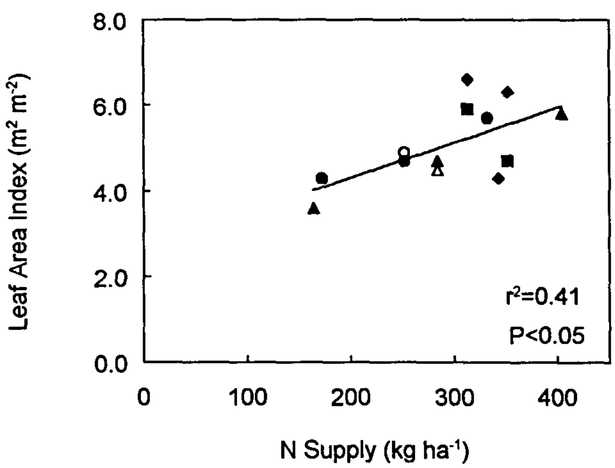

Fig. 3. Relationship between leaf area index and nitrogen supply. Symbols as in Fig. 1.

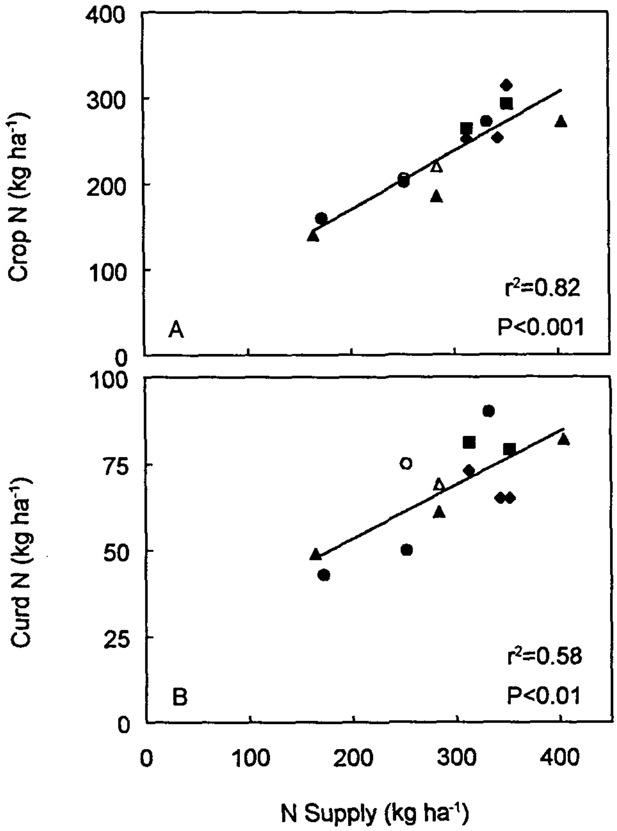

Fig. 4. Relationship between (A) crop nitrogen and (B) curd nitrogen and nitrogen supply. Symbols as in Fig. 1.

Leaf area was measured using a Delta-T area meter. Weights of the plant parts were determined before and after oven-drying at 80°C for 24 h. Total-N and nitrate-N concentrations in the dry plant material were measured using a non-reducing Kjeldahl method. Soil samples were taken on the same dates as plant samples at 0–0.25, 0.25–0.5, 0.5–0.75 and 0.75–1 m depths and were analysed for nitrate-N and ammonium-N after extraction with potassium chloride.

At the final harvest, curd diameter was measured and curd volume was calculated as $2/3 * \pi \times \text{radius}^2 \times \text{height}$, assuming the curd was a half-sphere with a fixed ratio of 1.4 between height and radius. Next, curd specific weight was calculated as the ratio of curd fresh weight and volume. Looseness of the curd is a normal harvest criterion in cauliflower and curds become looser during development. The specific weight of the curd can be used as a measure of looseness and quality. Total nitrogen supply to the crop was calculated as the sum of fertilizer nitrogen and the amount of mineral nitrogen to a depth of 1 m at planting.

Results

Plant growth and yield

Crop fresh weight was higher at higher nitrogen supply. Figure 1A shows the correlation between nitrogen supply and crop fresh weight for the different years, treatments and cultivars. Increased nitrogen supply also reduced the dry matter percentage of the crop. According to the regression, the dry matter percentage of the crop decreased from 11.6 to 8.4% when nitrogen supply increased from 150 to 400 kg ha^{-1} (Fig. 1B). Consequently, a higher nitrogen supply to the crop did not lead to a higher total dry weight production. Curd fresh weight varied between approximately 16 and 34 ton ha^{-1}, as the weight per head varied between 500 and 1000 g (Fig. 2A). The dry matter percentage of the curd decreased with increasing nitrogen supply. Curd dry weight varied between 1.8 and 3.0 ton ha^{-1} (Fig. 2B). The lowest level of nitrogen supply, approximately 170 kg ha^{-1}, resulted in the lowest curd fresh weight. Within experiments trends of a higher curd fresh weight at a higher nitrogen supply existed. However, curd fresh and dry weight production was not related to nitrogen supply when all experiments were included in the

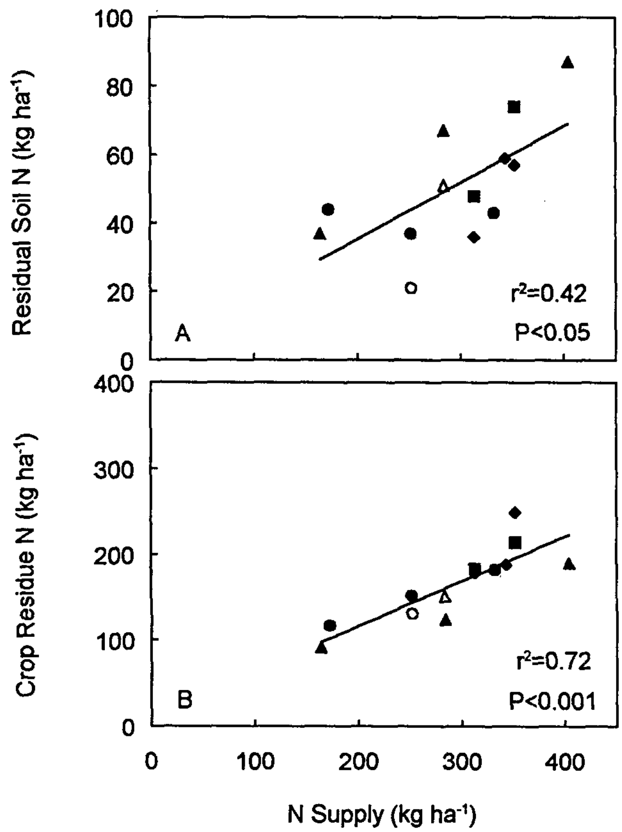

Fig. 5. Relationship between (A) residual soil nitrogen and (B) nitrogen in crop residues and nitrogen supply. Symbols as in Fig. 1.

Table 3. Effect of two different ways of splitting total fertilizer application on plant and soil parameters in field experiments with cauliflower cv. Plana. A high first nitrogen fertilizer rate was followed by a lower second rate, or a low first rate was followed by a higher second rate. Different letters indicate significant differences between fertilizer treatments within a year ($P < 0.05$)

Year	1st N rate	2nd N rate	Crop fresh weight	Crop dry weight	Curd fresh weight	Curd dry weight	Curd diameter	Curd specific weight	Total crop N	Soil residual N	Crop residual N
	kg ha^{-1}					ton ha^{-1}	cm	g dm^{-3}			kg ha^{-1}
1993	120	90	76.0 a	8.3 a	16.8 a	1.8 b	12.2 b	764 a	202 a	37 a	152 a
1993	80	130	86.3 b	8.8 a	30.9 b	3.0 a	15.6 b	686 a	206 a	21 b	131 b
1994	140	110	63.8 a	5.9 a	20.1 a	1.7 a	14.2 a	579 a	185 a	67 a	124 a
1993	80	170	72.8 a	7.0 a	23.8 a	2.2 a	15.8 a	498 b	220 a	51 a	151 a

analysis. The trend for low curd weight and low curd diameter at low nitrogen supply was not significant.

Curd specific weight can be used as a measure of looseness and quality. Curds become looser during development and looseness is considered a quality defect. There was no trend in specific curd weight with increasing nitrogen uptake, which suggests that nitrogen supply did not affect looseness or quality.

Leaf area index at harvest varied between 3.6 and 6.6 m^2 m^{-2} and clearly increased with increasing nitrogen uptake of the crop (Fig. 3). A higher leaf area can result from either a higher leaf biomass or a larger leaf area per unit of leaf weight (specific leaf area). Leaf fresh weight increased with increasing nitrogen uptake ($r^2 = 0.47$, $P < 0.01$), whereas there was no trend in specific leaf area.

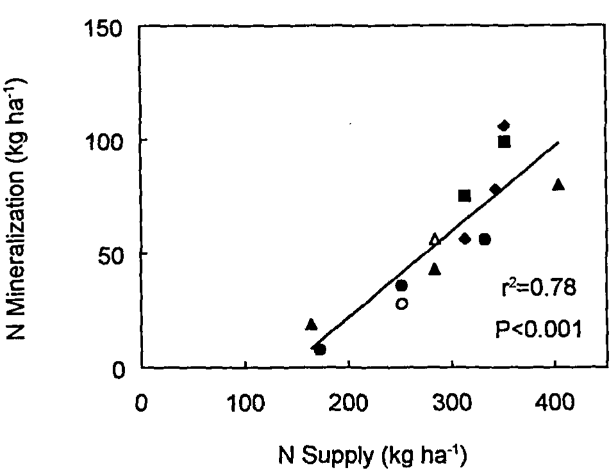

Fig. 6. Relationship between nitrogen mineralization from crop residues and nitrogen supply. Symbols as in Fig. 1. Nitrogen mineralization was calculated using the equation: Mineralized N = 0.75 * Total N + 0.03 * Total C. This equation was derived from the average relationship between nitrogen mineralization and the amount of nitrogen and carbon in the crop residues, estimated by Thorup-Kristensen (1994). The carbon content of the plant material was assumed to be 40%.

Nitrogen relations

Crop nitrogen uptake varied between 136 and 305 kg ha^{-1} and increased with nitrogen supply to the crop (Fig. 4A). The ratio of crop nitrogen uptake to nitrogen supply was highest at low levels of nitrogen supply. According to the regression, it decreased from 0.91 to 0.76 when nitrogen supply to the crop increased from 150 to 400 kg ha^{-1}. The amount of nitrogen in the curd varied between 46 and 84 kg ha^{-1} and was also linearly related to nitrogen supply (Fig. 4B). The ratio of curd nitrogen to nitrogen supply decreased from 0.30 to 0.21 as nitrogen supply increased from 150 to 400 kg ha^{-1}.

A higher nitrogen uptake by the crop resulted in higher total nitrogen concentrations in the leaves ($r^2 = 0.48$, $P < 0.01$) and in the curd ($r^2 = 0.62$, $P < 0.01$). The nitrate concentration based on fresh weight was always lower than 500 ppm.

Mineral soil nitrogen after harvest ranged between 20 and 90 kg ha^{-1} and was higher at higher nitrogen supply (Fig. 5A). In addition, a higher nitrogen supply and crop nitrogen uptake resulted in larger amounts of nitrogen in crop residues (Fig. 5B). When nitrogen supply increased from 150 to 400 kg ha^{-1}, the amount of nitrogen in crop residues increased from 90 to 221 kg ha^{-1}. A total increase in nitrogen supply of 100 kg ha^{-1} resulted in 17 kg ha^{-1} more residual soil nitrogen, 52 kg ha^{-1} more nitrogen in crop residues and 15 kg ha^{-1} more nitrogen in harvested curds.

Effect of timing of nitrogen application

The effect of splitting fertilizer applications in either a high initial application and a lower second rate, or a low first rate followed by a higher second application is shown in Table 3. Curd diameter, fresh and dry weights were higher when the largest amount of fertilizer was applied late. Curd specific weight was not affected in the first year and was reduced in the second. The total nitrogen uptake by the crop was similar with different splittings of fertilizer application, but when the largest part of the nitrogen fertilizer was applied late, the amount of residual soil nitrogen was lower. Similar trends were found in 1993 and 1994 but in 1994 the difference was not significant.

Discussion

Plant growth and yield

The yield and quality of cauliflower were not affected when total nitrogen supply, i.e. fertilizer plus soil mineral nitrogen, was above 250 kg ha^{-1}. Variation in yield was large between 250 and 400 kg ha^{-1}, but curd weight was not related to nitrogen supply. This implies that a total nitrogen supply of 250 kg ha^{-1} is adequate for an optimal yield. At this nitrogen level, crop uptake was about 200 kg ha^{-1}. Looseness of the curds was not related to nitrogen supply, which shows that lowering the nitrogen supply did not affect the product quality. The optimum nitrogen fertilization rate for cauliflower found in other studies ranges from 100 to 300 kg ha^{-1}, whereas the present results indicate that it would vary between 110 and 210 kg ha^{-1}. In a recent study, Everaarts & De Moel (1995) found an optimum rate of 224 kg ha^{-1} minus mineral soil nitrogen to a depth of 0.6 m. This is very close to the level found in the present study. The optimum application will depend on several factors. The harvest criterion varies, and optimum supply will probably be higher when curds are harvested at a larger size. Furthermore, the availability of nitrogen from sources other than fertilizer and the likelihood of nitrogen loss during the growing season are important.

Higher crop uptake of nitrogen was associated with an increase in leaf area, as found for Brussels sprouts (Booij et al., 1996) and wheat (Van Keulen & Stol, 1991). Nitrogen supply had a greater influence on vegetative growth than on reproductive growth: total plant fresh weight increased with nitrogen supply, but there was no trend in curd fresh weight. Dry matter production did not increase with nitrogen supply. At higher nitrogen concentrations the dry matter percentage was reduced (cf. Riley & Guttormsen, 1993). Thus, a higher fresh weight production at a higher nitrogen supply resulted from more water in the product rather than from a higher biological production. This shows that a higher nitrogen supply could ensure economic returns but was not a necessity in achieving optimal biological production.

Nitrogen relations

A reduced nitrogen uptake efficiency with increasing nitrogen supply has been found for several other vegetable crops (e.g. Greenwood & Draycott, 1988; Greenwood et al., 1989; Sørensen, 1996). An increase in the amount of nitrogen in crop residues and in the amount of soil mineral nitrogen with increasing nitrogen supply to cauliflower was also found by Everaarts et al. (1996). In their study, soil mineral nitrogen ranged from 50 to 80 kg ha^{-1} and the amount of nitrogen in crop residues from 100 to 120 kg ha^{-1} at optimum nitrogen supply, which was 224 kg ha^{-1}. At a nitrogen supply of 250 kg ha^{-1} in the present study, soil mineral nitrogen after harvest was 44 kg ha^{-1} and 143 kg ha^{-1} nitrogen was found in crop residues.

The amount of the nitrogen that is likely be released by mineralization depends not only on the amount of nitrogen in the crop residues but also on the C/N ratio of the material (Frankenberger & Abdelmagid, 1985; Marstorp & Kirchmann, 1991). A higher nitrogen concentration will result in a faster mineralization. The potential amount of nitrogen released from mineralization was estimated using the equation for the relationship between nitrogen mineralization and the amount of nitrogen and carbon in the crop residues, estimated by Thorup-Kristensen (1994): Mineralized $N = 0.75 * \text{Total } N + 0.03 * \text{Total } C$. According to this calculation, net mineralization of nitrogen increased with nitrogen supply. When nitrogen supply increased from 150 to 400 kg ha^{-1}, the amount of nitrogen in crop residues increased from 90 to 221 kg ha^{-1} and the predicted net mineralization increased from 3 to 97 kg ha^{-1} (Fig. 6). When soil mineral nitrogen after harvest is added to these values, the estimated amount of leachable nitrogen ranges from 30 to 165 kg ha^{-1}.

This residual soil nitrogen and nitrogen from crop residues form a potential loss, but could also represent a considerable fertilizer value (Rahn et al., 1993; Dragland et al., 1995; Greenwood et al., 1996). Soil mineral nitrogen can be contained if it is taken up by a subsequent crop, which could be either vegetables after an early cauliflower crop or a catch crop after a late cauliflower crop.

Effect of timing of nitrogen application

The observed improvement in nitrogen use efficiency by postponing the largest part of the nitrogen application is in accordance with the results of Welch et al. (1985). In contrast, Everaarts & De Moel (1995) found that split application did not increase yield. The reason for this is perhaps that the second application was given earlier in the growing season in their study, when absolute demand for nitrogen was not yet high. Another difference is that plants were harvested later and possibly when larger in size. It may be that the difference between the treatments is greatest shortly after the application and disappears when plants are grown for longer and to a larger size.

Conclusion

The amount of fertilizer typically applied to cauliflower in Denmark is about 250 to 300 kg ha^{-1}. The results of this study show that the total nitrogen supply can be reduced to approximately 250 kg ha^{-1} without any negative effect on yield or quality. In the present study this would mean that the fertilizer application could be reduced to between 110 and 210 kg ha^{-1}. Besides saving on fertilizer input, this will reduce the amount of nitrogen residues in the soil and the crop. As only 15% of the nitrogen is harvested when nitrogen supply increases, the remaining nitrogen is left in the field either as crop residues or soil nitrogen. A large proportion of this residual nitrogen is susceptible to leaching already in the succeeding winter season. As it is inevitable that after crop growth nitrogen is present as soil and crop residues, the total crop rotation should be designed in such a way that the residual nitrogen can be utilized by subsequent crops.

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