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The effect of nitrogen and the method of application on nitrogen uptake of cauliflower and on nitrogen in crop residues and soil at harvest

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Abstract

The effects of the rate of nitrogen and of the method of application on the nitrogen utilization of cauliflower were studied during two seasons and at four locations. Maximum nitrogen uptake by the crop was around 310 kg per hectare. Uptake of nitrogen was influenced neither by the method of application (band placement vs broadcast) nor by splitting the applications (twice vs once). The utilization efficiency decreased with increasing nitrogen rates. Independent of the amount of nitrogen applied, about 50 per cent of the nitrogen taken up in the above-ground plant parts was removed from the field with the product.

The amount of soil mineral nitrogen at harvest increased with an increase in nitrogen applied, but was not significantly influenced by band placement. With broadcast application, more nitrogen was sometimes found between the rows as compared to in the row. With band placement at the highest fertilizer rate, considerably more nitrogen was found where the fertilizer had been placed. The 'loss' of nitrogen from the crop/soil system during cultivation increased with increased availability of nitrogen. At the optimum application of nitrogen fertilizer around 100–120 kg ha^{-1} of nitrogen remained in crop residues and about 50–80 kg ha^{-1} in the soil (0–60 cm). Practical implications for the reduction of loss of nitrogen from crop and soil after harvest are discussed.

Keywords: cauliflower, *Brassica oleracea* var. *botrytis*, nitrogen fertilization, band placement, nitrogen uptake, crop residues, soil nitrogen distribution.

Introduction

Band placement of fertilizer, as compared to broadcast application, may increase yield in Brassica vegetables (Everaarts, 1993b). Therefore in seven experiments during three seasons the effects of band placement of nitrogen on quality and yield of cauliflower were studied (Everaarts & De Moel, 1995). In four of these seven experiments the effects of the amount of nitrogen, and of the method of application, on crop growth, nitrogen uptake and the efficiency of nitrogen use were evaluated. In view of possible future regulations limiting the amount of nitrogen that might be lost by leaching from crop residues and soil after harvest, the uptake of nitrogen by the crop at harvest, the distribution over the plant parts and the mineral nitrogen in the soil were determined, to assess the potential loss of nitrogen from crop residues and soil. This paper presents the results of these observations.

Materials and methods

General

The four experiments described here form part of a series of seven experiments in which the effects of band placement of nitrogen fertilizer on the quality and yield of cauliflower were studied (Everaarts & De Moel, 1995). The present experiments were carried out in 1990 and 1992, as late summer or early autumn cultivations, with the cultivars Fremont (1990) and Plana (1992). Planting distance was 0.75 × 0.50 m. The amounts of soil available mineral nitrogen at planting and the amount of nitrogen applied in the experiments are presented in Tables 1 and 2. Nitrogen was broadcast or band placed at planting. The second application of the split application was applied broadcast. The experiments 1, 2, 3, and 4 treated here are experiments 2, 3, 5 and 7 respectively in Everaarts & De Moel (1995), where further details regarding experimental lay-out, location and soil characteristics are given.

Where appropriate, statistical analysis was done through analysis of variance with

Table 1. The amount of mineral nitrogen in the soil before planting (kg ha^{-1}).

Expt	Soil layer (cm)		
	0–30	30–60	0–60
1	50	32	82
2	66	51	117
3	31	23	54
4	32	80	112

Table 2. The amount of nitrogen applied (kg ha^{-1}).

Expt	0	*N*	2*N*	3*N*	4*N*	2*N*+*N*[1]
1	0	44	88	132	176	88+44
2	0	32	64	96	128	64+32
3	0	88	176	264	352	176+88
4	0	74	148	222	296	148+74

[1] Split application; second application around five weeks after planting.

the Genstat 5 programme (Payne *et al.*, 1993). Because in the experimental lay-out of Experiments 1 and 2 no contrast zero nitrogen vs nitrogen application is considered, this contrast is not considered either in Experiments 3 and 4, and the indicated significance of the effects in Experiments 3 and 4 applies only to treatments in which nitrogen was applied.

Plant sampling

When about fifty per cent of the plants had been harvested, four separately located plants with a marketable curd were chosen randomly in each plot from three replicates in Experiments 1 and 2 and from four replicates in Experiments 3 and 4 for all treatments at the same time. The fresh and dry weight (after drying at 70 °C for 48 hours) of the inflorescence, the lower part of the leaves and bracts surrounding the inflorescence, the leaves and the stem was determined. In the plant material of Experiment 1 the nitrogen content was determined using the Kjeldahl-method, based on drying at 105 °C. No correction was made for the difference of drying at 70 °C. For the other experiments (Experiments 3 and 4 in three replicates) the nitrogen content in the plant material was determined using the indophenolblue method.

Soil sampling

Soil samples were taken at the time of plant sampling, at the locations of the four randomly chosen plants, according to the scheme in Figure 1, and pooled for each bore hole 1 to 4. The method of soil sampling was the same for both methods of fertilizer application. Such sampling is expected to give a representative impression of the spatial distribution of the mineral nitrogen in the soil (Van Noordwijk *et al.*, 1985). A composite soil sample of all four bore holes was collected from the treatments *N*, 3*N* en 2*N*+*N*. For the conversion of mineral nitrogen in mg per kg to kg per hectare, a density of 1.3 kg per dm³ was used for Experiments 1, 2 and 4 and a density of 1.2 kg per dm³ for Experiment 3.

Results and discussion

Uptake of nitrogen and dry matter production

In Experiments 2 (P=0.005) and 3 (P<0.001) only, application of nitrogen significantly increased the total above-ground uptake of nitrogen by the crop. Uptake of nitrogen was not significantly influenced by band placement or split application.

In Experiments 1, 2 and 4 the crops without nitrogen application took up around 150–200 kg of nitrogen per hectare (Figure 2a). When nitrogen fertilizer was applied the uptake of nitrogen initially increased, but maximum uptake was not more than 200–250 kg per hectare. In Experiment 3 the uptake of nitrogen without nitrogen application, was lower compared to that in the other experiments, but with nitrogen application uptake of nitrogen increased to over 300 kg per hectare.

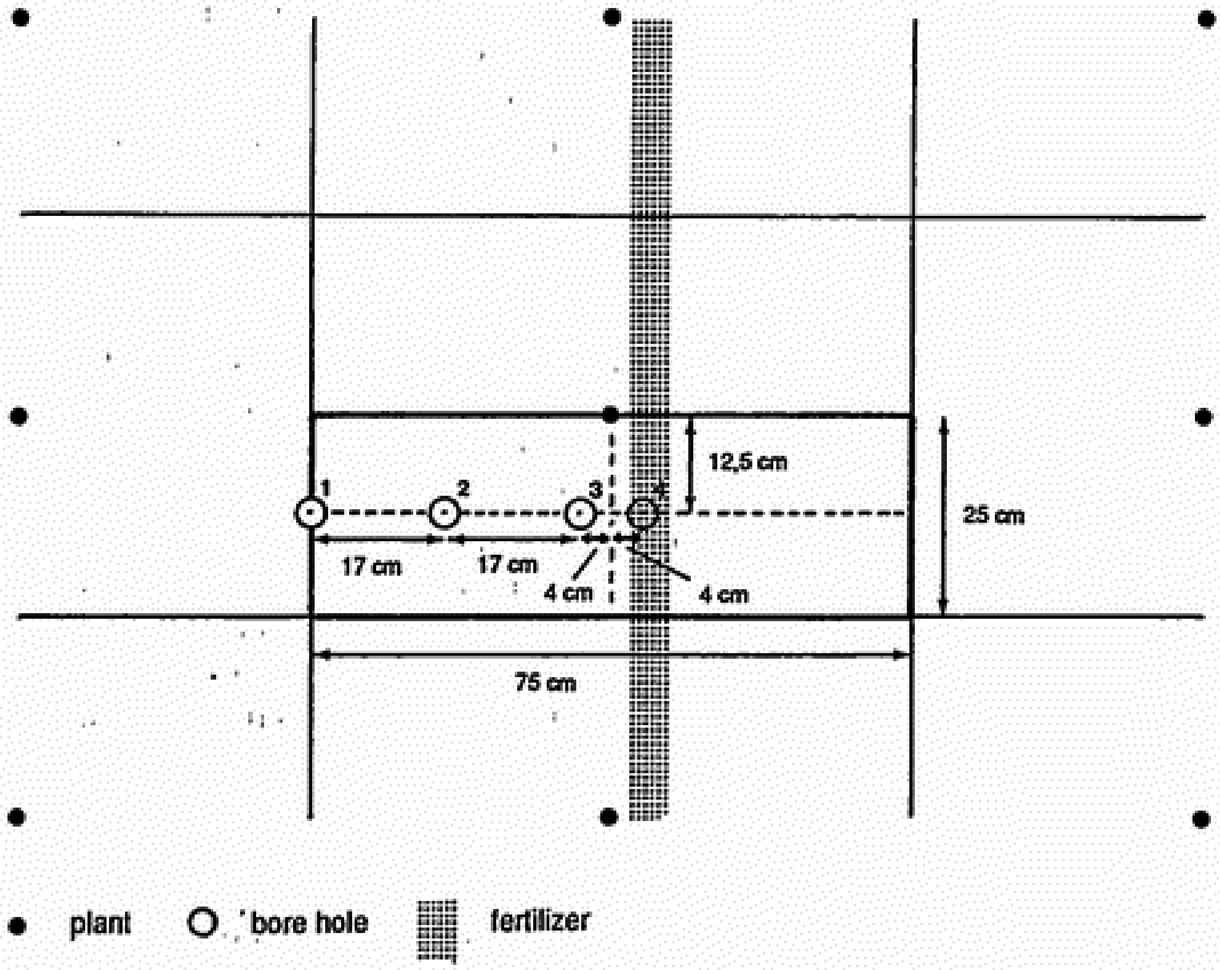


Figure 1. The location of the soil samples around a plant.

In Experiment 3 with the lowest amount of nitrogen taken up (Figure 2b), 23 kg of product dry matter was produced per kg of nitrogen taken up. This amount decreased to 12 kg dry matter with the highest uptake of nitrogen with broadcast application. With increasing uptake of nitrogen, the efficiency of the utilization of nitrogen in the production of product dry matter consequently decreased and the percentage of nitrogen in the crop increased (data not shown). Product here is the inflorescence and the lower part of the leaves and bracts surrounding the inflorescence.

With the lowest amount of nitrogen taken up in the Experiments 1, 2 and 4, the amount of product dry matter produced per kg of nitrogen taken up was 17, 15 and 13 kg respectively, and these amounts decreased only slightly to 15, 12 and 12 kg with the highest broadcast nitrogen application. There was only limited increase in uptake with application of nitrogen and there was also only a limited increase in the percentage of nitrogen in the crop. The lowest amount of nitrogen taken up in these experiments was already close to the maximum amount taken up.

It is clear that with around 200 kg of nitrogen taken up, production of product dry matter in Experiment 3 was higher compared to the other experiments. The production of product dry matter in the Experiments 1, 2 and 4 was apparently limited by factors other than the amount of nitrogen taken up. Differences between cultivars do not play a role here, as the same cultivar was used in Experiments 3 and 4.

Nitrogen in the product

The amount of nitrogen that is removed from the field with the product is around 50 per cent of the nitrogen present in the above-ground plant parts. This percentage, the nitrogen harvest index, was not influenced by the treatments (Table 3). The nitrate concentration in the edible part was not determined. However, with high nitrogen input, no high nitrate values have been found (Nilsson, 1980; Weier & Scharpf, 1988).

Fremont and Plana are cultivars that produce a high amount of leaf mass (Aalbersberg & Stolk, 1993). The nitrogen harvest index of these cultivars is somewhat higher as compared to values reported in literature (Everaarts, 1993a). Collection of data on the nitrogen harvest index of different cultivars is recommended to be able to assess the nitrogen use efficiency of cauliflower cultivars.

Nitrogen in crop residues

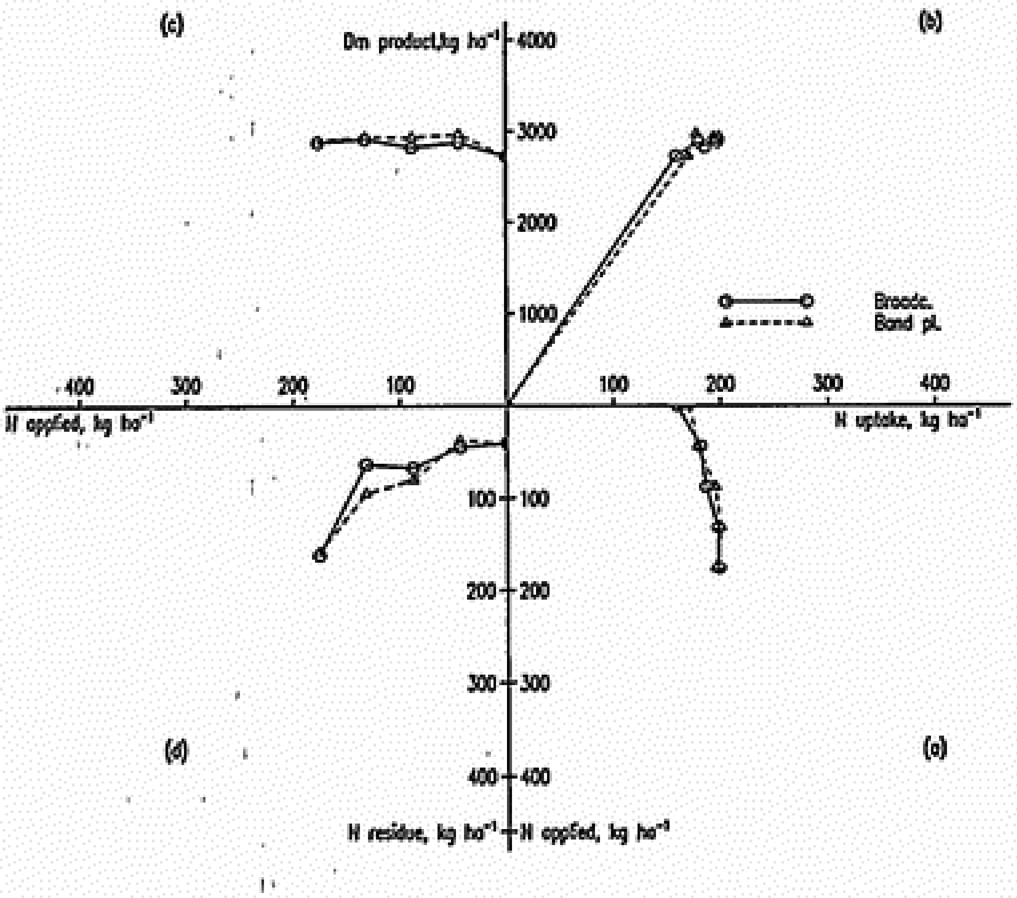
The amount of nitrogen in crop residues increased with increased application rates of nitrogen (Table 4). In fact more nitrogen remains in plant material in the field, as not all plants are harvested and no account was taken of the nitrogen in fallen leaves and roots. Part of the nitrogen in the residues can quickly mineralize depending on treatment of the residues (Scharpf & Schrage, 1988; Rahn *et al.*, 1992; De Neve *et al.*, 1994). With a harvest date late in the season, it may subsequently be lost by leaching during winter.

Table 3. The nitrogen harvest index (%).

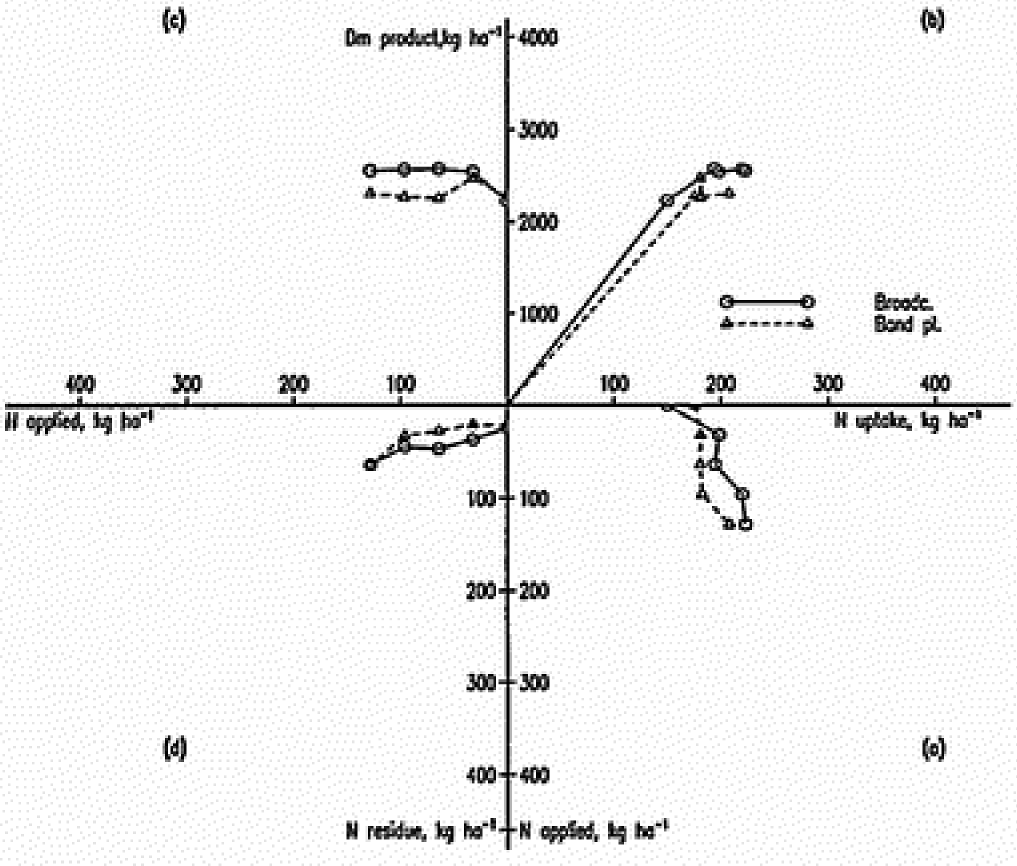
Expt	Application method	Nitrogen applied (Table 2)						LSD (α=0.05)
		0	*N*	2*N*	3*N*	4*N*	2*N*+*N*	
1	broadc.	50	49	50	50	52	54	–
	band pl.	48	51	50	50	52	51	
2	broadc.	56	52	53	51	51	53	–
	band pl.	53	54	52	52	50	49	
3	broadc.	45	45	46	46	43	47	–
	band pl.		46	49	44	45	42	
4	broadc.	48	47	47	50	46	47	–
	band pl.		47	49	47	46	48	

Significance	Expt 1	2	3	4
nitrogen	ns	ns	ns	ns
application	ns	ns	ns	ns
nitro. x appl.	ns	ns	ns	ns

Expl 1


(c)
(b)
Dm product, kg ha⁻¹
4000
3000
2000
1000
Broadc.
Band pl.
400
300
200
100
100
200
300
400
N applied, kg ha⁻¹
N uptake, kg ha⁻¹
100
200
300
400
(d)
(a)
N residue, kg ha⁻¹
N applied, kg ha⁻¹

Expl 2


(c)
(b)
Dm product, kg ha⁻¹
4000
3000
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Broadc.
Band pl.
400
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200
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100
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300
400
N applied, kg ha⁻¹
N uptake, kg ha⁻¹
100
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(d)
(a)
N residue, kg ha⁻¹
N applied, kg ha⁻¹

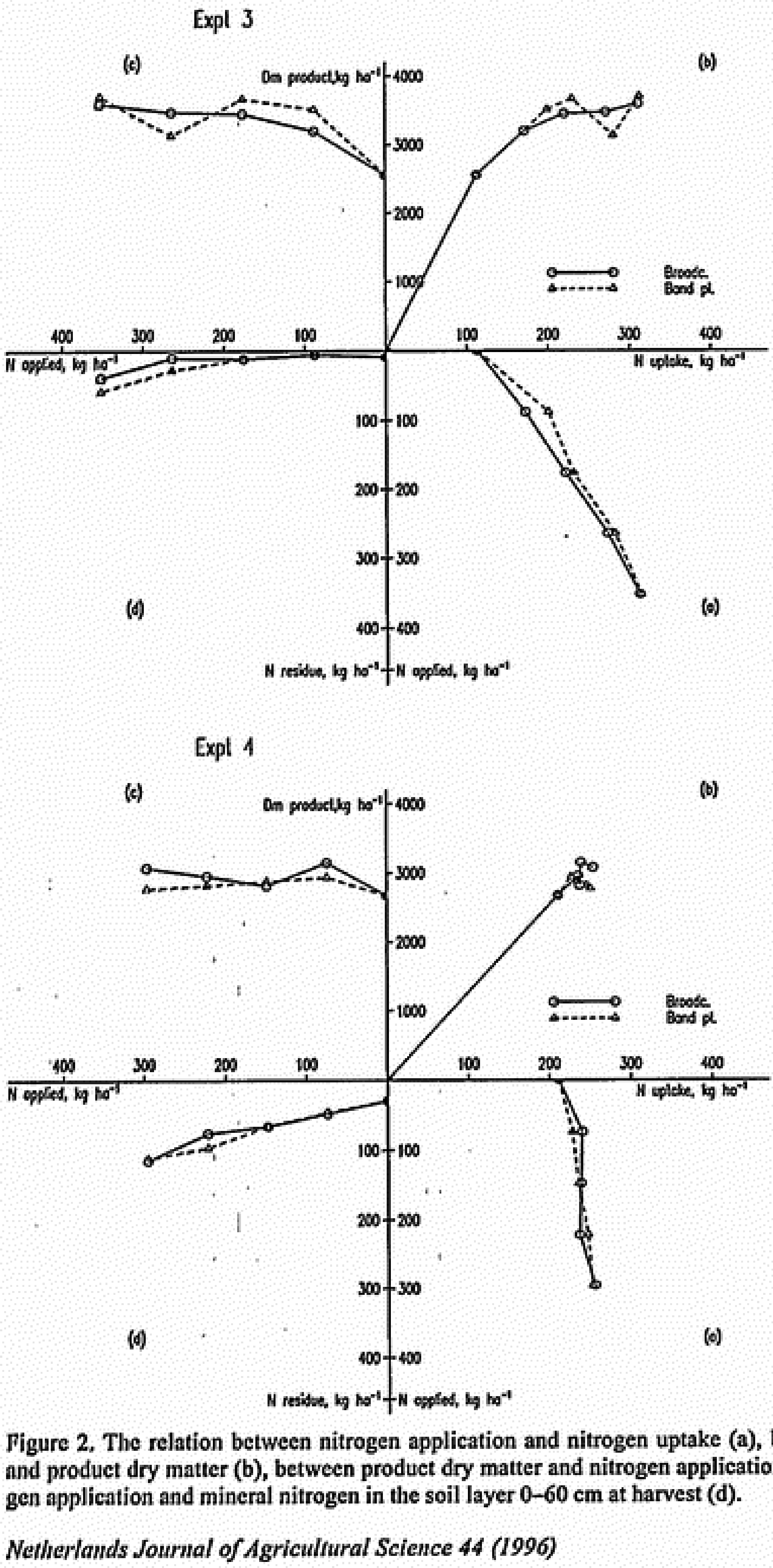

Figure 2. The relation between nitrogen application and nitrogen uptake (a), between nitrogen uptake and product dry matter (b), between product dry matter and nitrogen application (c), and between nitrogen application and mineral nitrogen in the soil layer 0–60 cm at harvest (d).

Table 4. The amount of nitrogen in crop residues (kg ha^{-1}).

Expt	Application method	Nitrogen applied (Table 2)						LSD (α=0.05)
		0	*N*	2*N*	3*N*	4*N*	2*N*+*N*	
1	broadc.	81	92	93	99	96	88	–
	band pl.	90	88	97	100	94	96	
2	broadc.	66	97	94	109	112	101	24
	band pl.	83	85	88	87	105	107	
3	broadc.	62	95	119	146	179	157	33
	band pl.		109	118	157	174	177	
4	broadc.	110	128	126	119	137	128	
	band pl.		120	120	132	137	128	–

Significance	Expt 1	2	3	4
nitrogen	ns	P=0.007	P<0.001	ns
application	ns	ns	ns	ns
nitro. × appl.	ns	ns	ns	ns

Nitrogen in the soil at harvest

Amount

The amount of mineral nitrogen in the soil at harvest increased with higher amounts of nitrogen applied, but was not significantly influenced by the method of application (Figure 2d, Table 5). The highest amounts of mineral nitrogen in the soil were found in Experiments 1 and 4. In view of the high uptake of nitrogen by the crop without nitrogen application in these experiments, there apparently was considerable mineralization after planting.

In Experiment 3 only a limited amount of mineral nitrogen was found in the soil at harvest. In this experiment there was only a limited amount of soil available nitrogen present at planting. The crop without fertilization in this experiment took up a comparatively limited amount of nitrogen and therefore mineralization after planting probably also was small. Uptake with application of nitrogen was high and there was considerable 'loss' of nitrogen from the crop/soil system (see below). This combination of factors probably resulted in low amounts of mineral nitrogen in the soil at harvest. However high and frequent rainfall during the harvest period in this experiment might also have contributed to the low amounts of mineral nitrogen found at harvest.

Spatial distribution

With the exception of Experiment 3, the vertical distribution of the mineral nitrogen

Table 5. The amount of mineral nitrogen in the soil at harvest (kg ha^{-1}).

Expt	Soil layer (cm)	Application method	Nitrogen applied (Table 2)						LSD (α=0.05)	Before planting
			0	*N*	2*N*	3*N*	4*N*	2*N*+*N*		
1	0–30	broadc.	26	27	45	47	122	61	57	50
		band pl.	25	20	52	74	114	62		
	30–60	broadc.	15	18	22	16	40	19	14	32
		band pl.	16	17	27	21	44	19		
2	0–30	broadc.	12	18	18	20	33	23	14	66
		band pl.	13	11	14	14	30	25		
	30–60	broadc.	12	19	29	25	32	23	15	51
		band pl.	9	9	13	19	35	22		
3	0–30	broadc.	5	4	7	6	13	14	6	31
		band pl.		3	7	11	12	9		
	30–60	broadc.	4	2	5	4	26	9	16	23
		band pl.		2	5	17	46	12		
4	0–30	broadc.	12	17	19	24	25	24	5	32
		band pl.		13	19	25	23	28		
	30–60	broadc.	18	31	47	53	90	65	18	80
		band pl.		33	46	71	89	65		

Significance	Soil layer 0–30 cm				Soil layer 30–60 cm			
Expt	1	2	3	4	1	2	3	4
nitrogen	P=0.001	P=0.007	P=0.003	P<0.001	P<0.001	P=0.005	P<0.001	P<0.001
application	ns	ns	ns	ns	ns	ns	ns	ns
nitro. x appl.	ns	ns	ns	ns	ns	ns	ns	ns

over the soil layers 0–30 and 30–60 cm at harvest was comparable to the vertical distribution of the mineral nitrogen in the experiments at planting (Table 5). This suggests a more or less uniform utilization of the soil layer 0–60 cm. The total amount of mineral nitrogen in each soil layer, 0–30 and 30–60 cm, was not influenced by band placement and, except for Experiment 3, not by split application of the nitrogen either.

The horizontal distribution of the nitrogen in the soil layer 0–60 cm at harvest varied (Figure 3). In Experiment 2 it is clear that with broadcast application most of the nitrogen is taken up close to the plant. A similar pattern was mentioned by Hofman *et al.* (1992). This agrees with the obconical spatial development of the root system of cauliflower (Weaver & Bruner, 1927) and indicates a not entirely rooted soil profile. As a result of the high amount of soil mineral nitrogen available at planting in this experiment (Table 1), the development of the root system in this case possibly

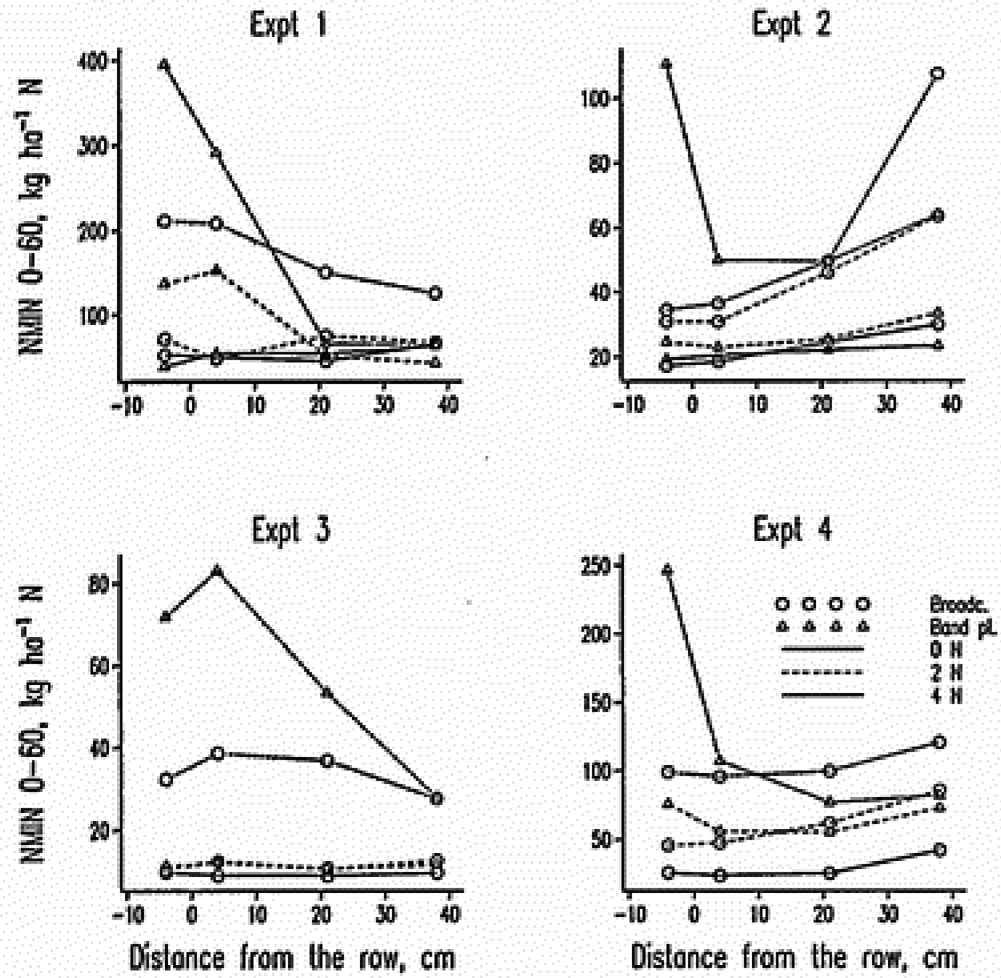

Figure 3. Spatial distribution of mineral nitrogen in the soil layer 0–60 cm at harvest.

was limited. A similar but weaker pattern is observed in Experiment 4. In Experiments 1 and 3 distribution of soil nitrogen at harvest with broadcast application was more even, or even more nitrogen was found in the row as compared to between the rows (Expt 1), indicating a more thoroughly rooted soil.

With band placement at the level of 2*N* in Experiment 4, slightly more nitrogen was present where the fertilizer had been placed (–5 cm) compared to between the rows. This pattern was more clear with 4*N* band placement in Experiments 1, 2 and 4. In these experiments the amount of nitrogen between the rows with band application is always lower compared to the same level with broadcast application. In Experiment 3 at the level of 4*N* band placement more nitrogen was found in the row as compared to between the row. In this case slightly more nitrogen was found on the other side of the row (+5 cm) as to where the fertilizer had been placed (–5 cm).

Nitrogen in the crop/soil system

The 'loss' of nitrogen from the crop/soil system during cultivation in relation to the amount of nitrogen available is presented in Figure 4. In this relation no account was taken of the amount of nitrogen in fallen leaves or roots.

In general the 'loss' from the crop/soil system increased with an increase in available nitrogen. In Experiments 1 and 4 there were no systematic differences in 'loss-

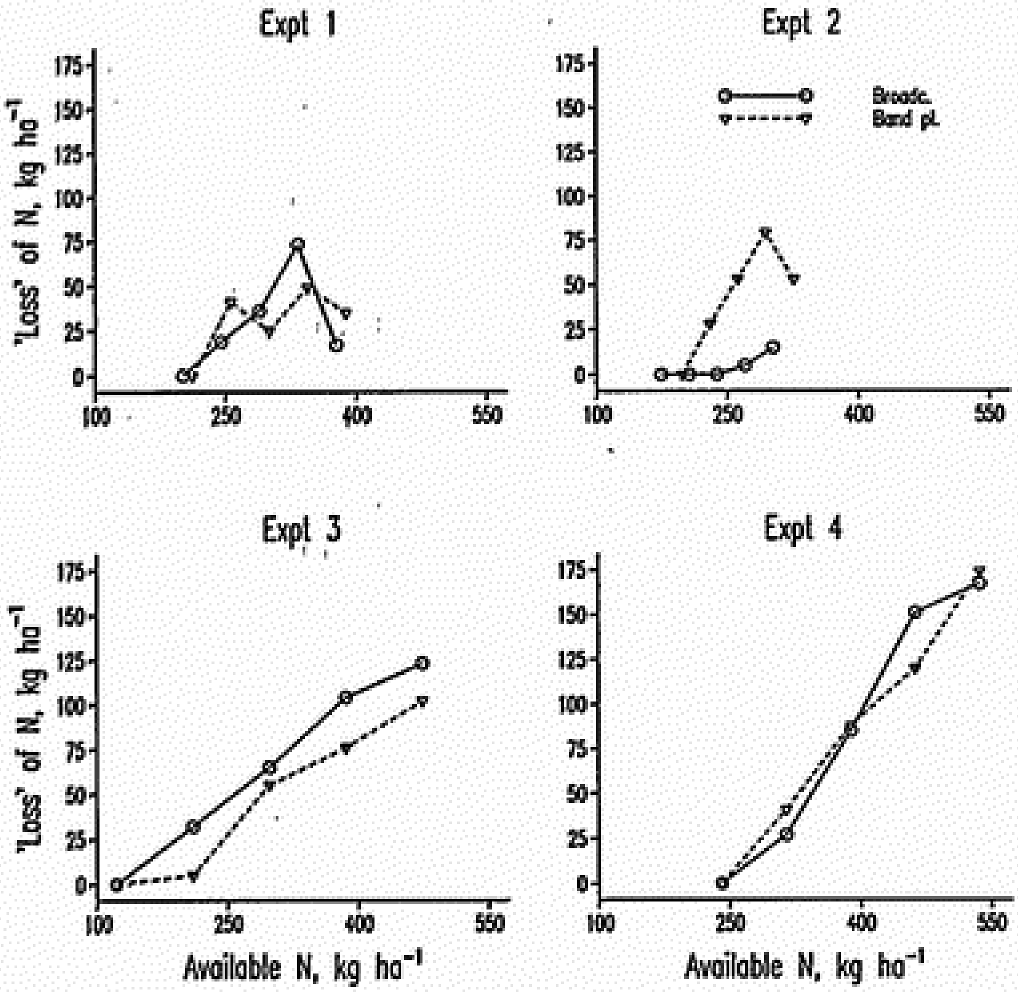

Figure 4. The 'loss' of nitrogen from the crop/soil system during cultivation in relation to the amount of nitrogen available. ('loss' = available nitrogen minus nitrogen present in the crop and soil (0–60 cm) at harvest; available nitrogen is nitrogen present in the crop and soil (0–60 cm) at harvest at 0 N plus fertilizer nitrogen).

es' between broadcast application and band placement. In Experiment 3 band placement resulted in a consistently lower 'loss' compared to broadcast application. The limited 'loss' with broadcast application in Experiment 2 was mainly due to the low uptake of nitrogen by the crop without application of nitrogen (Figure 2).

In view of the magnitude of the 'losses', it seems unlikely that denitrification or volatilization of nitrogen during cultivation will have contributed to 'losses'. Leaching also seems unlikely, as under Dutch conditions during the summer evapotranspiration usually exceeds rainfall. Frequent rainfall during the harvest period in Experiment 3 may have contributed to low amounts of mineral nitrogen in the soil. Greenwood *et al.* (1992), however, found indications that in the case of onions nitrogen in the roots and immobilization could play an important role in causing 'losses' from the crop/soil system.

Conclusions and practical implications

The optimum nitrogen application for cauliflower is 224 kg per hectare minus mineral nitrogen at planting in the soil layer 0–60 cm, applied broadcast (Everaarts & De Moel, 1995). With this application about 100–120 kg of nitrogen per hectare remains in crop residues in the field and around 50–80 kg of nitrogen per hectare (based on Experiments 1, 2 and 4) is found in the soil (0–60 cm). In view of these amounts, to prevent loss of nitrogen after harvest from the soil and especially from the crop residues, measures would have to be taken.

With a harvest early in the season a second crop could be grown, utilizing nitrogen from the soil and crop residues. With harvests before August, part of the nitrogen in crop residues and soil could also be taken up by nitrogen catch crops (Everaarts, 1993b). With harvests later in the season this is no option because of the too short remaining growing period for catch crops. Leaving crop residues undisturbed and carrying out soil tillage only during, or even after, winter is a strategy to limit losses through leaching (Wehrmann & Scharpf, 1989).

In sampling the soil for mineral nitrogen after harvest, but also during cultivation, account will have to be taken of a possible uneven distribution of the nitrogen in the soil.

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