Strategies to Increase Nitrogen Use Efficiency and Reduce Nitrate Leaching in Vegetable Production in the Netherlands

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Abstract

Environmental concern and legislation of fertilization requires strategies to increase nitrogen use efficiency and reduce nitrate leaching. Strategies can be fertilizer choice, timing of N availability and fertilizer placement. Rainfall in the experimental year 2007 was moderate and different strategies were therefore not seriously tested. However, for crops that allow regular fertilization, it is questionable whether special fertilizers can do better than calcium ammonium nitrate (CAN) when fertilizers are applied according to good practice (i.e., row application, side dressing and split applications). Specific application of small amounts of N near planted endive showed increased initial growth, even at high levels of soil mineral N, and was found to lead in one of two plantings to increased yield at harvest. Substitution of broadcast N before planting by a starter application close to the plants followed by side dressing maintains maximum production while leaching risk is reduced.

INTRODUCTION

The European nitrate directive and the water framework directive aim at reducing nitrate leaching to achieve good water quality for all purposes. In the Netherlands, legislation on fertilization is based on soil type and crop type. Per crop, specific 'N application standards' are set (i.e., fixed N application rates). These crop specific N-standards were initially based on the current N recommendations. The high nitrate concentrations on sandy soils, especially in the southeast of the Netherlands, indicate that the N-standards have to be cut to levels below N recommendations. This requires fertilization strategies that aim at a more efficient use of N. Current recommendation systems already account for soil mineral N, for N released from previous crop residues, and include split application of fertilizers where this is practically feasible.

Further increase of N use efficiency may be achieved by using specific fertilizers that are less susceptible to leaching like slow release fertilizers or fertilizers with a nitrification inhibitor. Previous experiments were carried out in 2005 and 2006 in which alternatives to current practice were tested to reduce N-surpluses. These alternatives were a combination of reduced N-application and a 'more efficient fertilizer'. Often yield reductions were found, and the question rose whether there were differences in efficiency between fertilizers. Therefore, in 2007, experiments were carried out in which fertilizers were compared at equal N-inputs to test differences in efficiency.

Reducing the risk of N leaching can also be achieved by reducing the total amount of soil mineral N (SMN). This, however, may affect crop growth. Discussion in growers groups and preliminary experiments in endive showed that yield was increased by broadcasting 50 kg N ha^{-1} before planting, despite a high SMN of almost 100 kg ha^{-1}. In 2007, the effect of placement of small amounts of N close to the plants was studied to test the hypothesis that placement of fertilizers in the root zone at early stages of growth stimulates crop growth and reduces the risk of N leaching.

Another option is to reduce organic manure input before sowing, compensated by topdressing at later stage. In current practice in carrot and salsify, often high amounts of manure are applied before sowing. In carrot, high N-availability at the early stages of growth may lead to increased foliage growth and negatively affect yield. Experiments were carried out to test whether reduced manure application positively affects yield and reduces losses by leaching.

MATERIALS AND METHODS

Fertilization experiments were carried out in close collaboration with farmers and extension workers. The following aspects were studied:
1. Comparison of different types of fertilizers
2. Fertilizer placement (often combined with fertilizer type)
3. Timing and split application (often combined with fertilizer type)
4. Variation in the amount of N from organic manure and supplemental fertilizer
5. Levels of total N-input.

Comparison of Fertilizers

Different fertilizers were compared (Table 1) in strawberry (cold storage), winter leek, cauliflower (autumn) and iceberg lettuce (autumn). The experiments were carried out in 2007 and for winter leek also in 2006/07. The fertilizers vary in their properties. Calcium ammonium nitrate (CAN; 27-0-0) is easily soluble. Agroblen (18-8-16) and Scotts R&D (36-0-0) are slow release fertilizers that are applied at planting or shortly thereafter. Entec (26-0-0; in lettuce 14-7-14) contains a nitrification inhibitor that delays the transformation of ammonium to nitrate. For nitrification inhibition to remain effective for sufficiently long periods, a certain localized dose of the fertilizer has to be applied to achieve a threshold concentration. Cultan is a mixture of urea and ammonium sulfate and is applied in high concentration to create a depot. Humifirst is a natural product containing humic acids to improve the physical, chemical and biological characteristics of the soil. It contains no nutrients and is combined with a mineral fertilizer. Orgaplus (3-2-4) is an organic fertilizer and is generally supplemented with a mineral fertilizer.

The level of fertilization was often reduced below the legal N application standard, to better expose possible contrasts between fertilizers. Fertilizers were compared at equal total N-input, and were compared with an unfertilized blank, as well as a high-N treatment (Table 3). Input of P and K was leveled between different fertilizers by application of triple superphosphate and patentkali.

Crop development and soil mineral nitrogen were monitored and at harvest fresh yield, dry matter yield and N-uptake were measured.

N-Application at Planting

The effect of an N application at planting was studied in endive. In 2007, an experiment was carried out in crops of two different planting dates: July 7 and August 7 (Table 2). The endive was grown on beds of 1.8 m wide, three rows per bed, plant spacing 50 cm between rows and 28 cm within rows. Fertilizer was applied one day after planting (dap) and side dress three weeks after planting. In Experiment 1, SMN was high and one day after planting N was applied as a solution of calcium nitrate and applied manually per individual plant: 80 mg N in 80 ml solution. One day after planting of Experiment 2, calcium nitrate was surface applied next to the plant row. In both experiments, N was side dressed with CAN, surface applied between the plant rows. Crop growth was measured by Cropscan (www.cropscan.com) about three weeks after planting. Crops were harvested 48 dap (Exp. 1) and 64 dap (Exp. 2) and fresh weight per head was determined.

Cattle Manure vs. CAN

N-input from manure application before sowing and supplemental applications of CAN was varied to study the effects on N use efficiency and yield in carrots (grown for processing) and salsify. Cattle manure was used, and its fertilizer-equivalency over the growing season was calculated. In carrot, manure applications were 0, 15, 25 and 35 t/ha, supplemented with 2 or 3 applications of CAN (Table 4). In salsify, manure applications were 0, 30, 40 and 50 t/ha, supplemented with 3 or 4 applications of CAN (Table 5). Soil mineral nitrogen was measured at several times during the season.

RESULTS AND DISCUSSION

Comparison of Fertilizers

Yield and N-uptake of the crops with different fertilizers is shown in Table 3. The results are expressed relative to yield and N-uptake with CAN. On average, the different fertilizers had equal or lower yields than CAN, and N-uptake was in most cases lower than with CAN. This means that N-surplus tended to be higher than with CAN and leaching was not reduced by these fertilizers. The advantage of special fertilizers above CAN - as claimed by producers - is often the reduced susceptibility to leaching. Possibly such advantage could not be exposed in 2007 because growing conditions were favorable, with regular rainfall and no excessive rainfall. In such conditions, CAN applied according to good practice (split and well timed applications) is likely to perform equally well in terms of efficiency and leaching risk. Therefore, we subjected fertilizers in another experiment (with strawberry) to more severe leaching conditions, by applying excessive irrigation (350 mm). Strawberry yield was reduced by this irrigation, 24 vs. 31 t/ha, but relative differences in yield and N uptake between the fertilizers remained. This may be because of the split application with CAN. Moreover, the side dressing of all objects with two small applications of calcium nitrate may further have reduced the effect of differences in leaching of N from the different fertilizers.

In our experiments the special fertilizers showed no increased N use efficiency compared to CAN. In the crops studied, regular application of fertilizer is possible. When fertilizers are applied according to good practice (i.e., row application, side dressing, and split applications) it is questionable whether special fertilizers perform better than CAN.

Apart from N use efficiency, advantages of the special fertilizers can be the single application and associated reduced labor costs. This may compensate the increased price compared to CAN. A disadvantage is that once applied, there are no options to adjust to variations in crop growth and mineralization during the growing season.

For crops in which side or topdressing is less appropriate (e.g., spinach), special fertilizers less susceptible to leaching may have an advantage over CAN. However, in our experiments we did not compare effects of single applications of fertilizers.

N-Application at Planting

N-application one day after planting gave increased crop growth and higher crop reflection as measured by Cropscan (Fig. 1). In Experiment 1, crop reflection three weeks after planting was increased by application of 5 kg N ha^{-1} as calcium nitrate solution. This effect was not caused by watering the plants as only water showed no increased reflection. In Experiment 2, increasing N-application at planting increased crop reflection. Differences in early growth were reflected in differences in head weight at harvest in Experiment 1. Both application at planting and side dress increased head weight. In Experiment 2, only the unfertilized treatment showed a reduced head weight, whereas head weight was equal in the other treatments. Harvest of this experiment was late. Heads are usually harvested at a weight of about 0.7 kg and were now almost 0.9 kg. Possibly the differences in crop growth that were visible three weeks after planting had disappeared because of this late harvest.

The experiments confirm growers' experience that N-application before planting is effective, also at a high SMN. To reduce the risk of leaching, N should not be broadcasted but placed within short distance of the plants. In Experiment 1, an amount of 5 kg ha^{-1} applied to the individual plants proved to be sufficient to increase head weight at harvest. Plants that are just planted have a limited root system and initial growth is stimulated by increasing N availability near the plant. Further research in cooperation with farmers should lead to a strategy for minimal SMN at the early stages of growth to reduce the risk of leaching, but taken into account the risk for deficiency. This can be achieved by placement of a small amount of N near the plants to attain a good initial growth, followed by a side dress based on soil sampling for the remaining part of growth.

Cattle Manure vs. CAN

Total yield of both carrot and salsify was little affected by the different treatments and no significant differences were found (Tables 4 and 5). Yield of the unfertilized plots was hardly lower than of the fertilized plots. Soil mineral nitrogen in the unfertilized plots of salsify increased from 62 kg/ha to 88 kg/ha over the first 8 weeks. In this period, mineralization was higher than crop uptake and because of regular but moderate rainfall no leaching occurred. This year was therefore not suited to test the hypothesis that high manure applications before sowing increase the risk of leaching.

Despite absence of differences in carrot yield, the different treatments showed clear differences in foliage color during growth (not shown). Farmers tend to apply a topdressing when the foliage is light green. Foliage color may indicate the N-status of the crop, but is not a good indicator for optimum yield, as we found in this experiment.

CONCLUSIONS

Averaged over five experiments in 2007, no increased N use efficiency was found by using specific fertilizers compared to calcium ammonium nitrate (CAN). It is questionable whether special fertilizers can do better than CAN when fertilizers are applied according to good practice (i.e., row application, side dressing, and split applications).

N applied - even in amounts as small as 5 kg ha^{-1} - at planting increased initial growth of endive, even at high levels of soil mineral N, and may lead to increased yield at harvest. A starter application only near the plants followed by side dress maintains production and reduces the risk of N-leaching.

Variation between N-input from cattle manure before sowing and supplemental applications of CAN showed no differences in yield of carrot and salsify.

Rainfall during the experiments was moderate, and different strategies were therefore not seriously tested.

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Tables

Table 1. Studied fertilizers in different crops and type and number of applications.

Fertilizer	Placement[1] and number of applications			
	Strawberry[3]	Leek	Cauliflower	Iceberg lettuce
CAN[2]	B2	C2+E1	C1 or C1+E1 or E2	A1 or A1+C
Agroblen	F1			F1
Scotts R&D		F1		
Cultan		I1 or G1	G1	
Entec	G1	C2	F1	A1+ F1
Humifirst				A1+H1
Orgaplus	A1	D1		A1

[1] A: applied on the bed before planting and incorporated; B: applied on the bed between (the two) plant rows ; C: row application; D: broadcast before planting and incorporated; E: broadcast; F: incorporated at both sides of the plant row, 5-10 cm from the plant row and 5-10 cm deep; G: incorporated at one side of the plant row, 5-10 cm from the plant row and 5-10 cm deep; H: sprayed onto the plant row; I: incorporated between two plant rows.
[2] Calcium ammonium nitrate.
[3] All objects received two applications of calcium nitrate on the bed between plant rows.

Table 2. Fertilization (kg N ha^{-1}) in two experiments with endive. SMN = soil mineral nitrogen in 0-30 cm before planting.

Treatment	Exp. 1 (SMN 91 kg ha^{-1})			Exp. 2 (SMN 28 kg ha^{-1})		
	Starter[1]	Side dress[2]	Code	Starter[2]	Side dress[2]	Code
Unfertilized	0	0	0-0	0	0	0-0
Only side dress	0	27	0-27	0	70	0-70
Only starter	5	0	5-0	20	50	20-50
Starter and side dress	5	27	5-27	55	15	55-15
Water and side dress	0	27	wtr-27	0	50	wtr-50
NP[3] and side dress	5	27	5NP-27	5	50	5NP-50

[1] Applied as 80 mg NO_3-N in 80 ml water $plant^{-1}$.
[2] Applied as CAN.
[3] Ammonium polyphosphate, 20 kg P_2O_5 ha^{-1}.

Table 3. Yield and N-uptake in five experiments. Results of different fertilizers are expressed relative to that of CAN. Different letters within a row mean statistically significant differences (p=0.05).

Experiment		N-standard[1]	N-level (avail.N)	Fertilizer type: unfertilized	higher CAN-level	CAN	Agroblen	Scotts R&D	Cultan	Entec	Humifirst+CAN	Orgaplus+CAN
Crop yield (marketable; for iceberg lettuce total dry matter yield)												
Strawberry 2007	natural rainfall	160	85[2]	98^{a}	94^{a}	100^{a}	99^{a}			94^{a}		100^{a}
	excess irrigation		85[2]	80^{a}	104^{c}	100^{bc}	94^{bc}			98^{bc}		89^{b}
Leek 2006/07	without OM	235	150	50^{a}	113^{e}	100^{cd}		86^{b}	92^{bc}	100^{cd}		111^{de}
Leek 2007/08	without OM		200	54^{a}		100^{c}		86^{b}	96^{bc}	98^{c}		88^{bc}
	with OM		200	86^{a}	107^{c}	100^{bc}		104^{bc}	102^{bc}	103^{bc}		97^{b}
Cauliflower 2007		220	170	49^{a}	92^{b}	100^{b}			94^{b}	103^{b}		
Iceberg lettuce 2007		170 – 105	80	82^{a}		100^{c}	106^{d}			108^{d}	99^{bc}	94^{b}
AVERAGE crop yield				71	101	100	99	92	96	101	99	96
N-uptake (total crop)												
Strawberry 2007	natural rainfall	160	85	74	97	100	100			93		92
	excess irrigation		85	73	125	100	104			97		94
Leek 2006/07	without OM	235	150	40^{a}	132^{d}	100^{bc}		81^{b}	87^{bc}	86^{bc}		114^{cd}
Leek 2007/08	without OM		200	28^{a}	91^{bc}	100^{c}		76^{b}	102^{c}	101^{c}		94^{bc}
	with OM		200	55^{a}	89^{bc}	100^{c}		88^{bc}	87^{bc}	82^{bc}		74^{ab}
Cauliflower 2007		220	170	35^{a}	121^{c}	100^{b}			85^{b}	80^{b}		
Iceberg lettuce 2007		170 – 105	80	50^{a}		100^{c}	107^{d}			109^{d}	99^{c}	91^{b}
AVERAGE N-uptake				51	109	100	104	82	90	93	99	93

[1] Effective N (kg ha^{-1}). The first value is for the first crop of the growing season, the second value for subsequent crops.
[2] 53 kg N ha^{-1} by the different fertilizers, all received 32 kg N ha^{-1} in two side dresses with calcium nitrate.

Table 4. Fertilization, yield, N-uptake and N-surplus of carrot for processing.

Object	N-input (kg/ha)			Yield (t/ha)		N-uptake (kg/ha)		N-surplus
	Manure	CAN	Total	Total	Marketable	Foliage	Carrot	(kg/ha)
A	0	0	0	98	91	41	112	-112
B	36	0	36	103	96	50	130	-94
C	60	0	60	103	96	35	143	-83
D	0	110	110	107	97	65	178	-70
E	36	74	110	104	93	59	173	-63
F	60	50	110	101	88	46	168	-61
G	84	66	150	102	90	67	173	-22

Table 5. Fertilization and yield of salsify.

Object	N-input (kg/ha)			Yield (t/ha)	
	Manure	CAN	Total	Total	Marketable
A	0	0	0	38	36
B	0	170	170	46	39
C	72	98	170	42	37
D	96	74	170	48	44
E	120	100	220	50	46
F	0	220	220	55	50

Figures

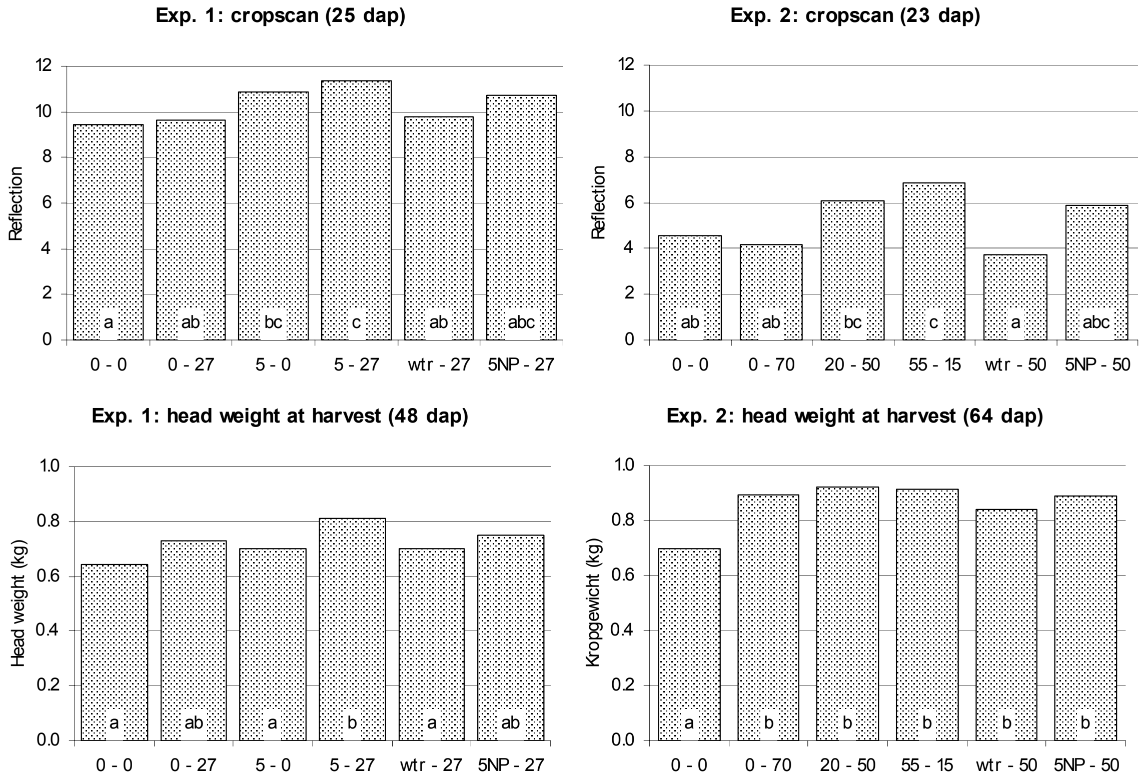

Fig. 1. Crop reflection as measured by Cropscan (top) and head weight at harvest (bottom) of Experiment 1 (left) and Experiment 2 (right). See Table 2 for explanation of the code. Different letters indicate statistically significant differences (0.05).