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Effect of fertigation timing and aeration on nitrogen dynamics in Chinese cabbage cultivation

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Abstract

Different fertigation timing strategies and forced soil aeration in a subsurface drip irrigation system were evaluated for their effect on N availability and accumulation of N by Chinese cabbage (*Brassica rapa* L. ssp. *pekinensis* (Lour.) Hanelt.), as well as for their agronomic effects. In all strategies, 40% of the nutrients were applied broadcast prior to planting. After planting 60% of the nutrients were fertigated either in equal or increasing doses based on an uptake model. In one equal-dose treatment air was forced through the drip tapes when soil moisture was high.

Soil NO_3^- content was low after planting, increased to 23 and 14.5 mg NO_3^--N kg^{-1} soil at 0-30 and 30-60 cm soil depth (i.e. 110 and 69 kg N ha^{-1}, resp.) 4 weeks after planting (WAP) and dropped to 3.6 to 4.5 mg NO_3^--N kg^{-1} 6-8 WAP. The N status of the plants was adequate during initial growth and turned drastically deficient during the exponential growth phase in all treatments. 4 WAP plant N status was low despite high soil nitrate levels. This was probably caused by (1) inadequate access of the root system to the nutrients applied in fertigation due to soil compaction and emitters placed at 15 cm soil depth and (2) limited root functions due to soil moisture above field capacity for 2 weeks. Aeration had no effect on N uptake under the described conditions. 6 WAP the fertigated NO_3^-, which had not been taken up was lost after intensive rainfall. With fertigation according to the model, a slight increase of NO_3^-content in the cabbage head was observed before harvest. Under the conditions of this field experiment, the fertigation strategies with equal weekly rates resulted in more plant biomass and more marketable produce compared to strategies with increasing weekly rates following the N uptake model.

Introduction

Fertigation offers the possibility of 'spoonfeeding' plants according to their actual demand or the desired application. The key questions for a fertigation strategy are: 1) when to start, 2) how to split and 3) when to stop? The fertigation timing is particularly important for N because the soil nitrate concentration should be kept to a minimum in order to reduce potential leaching.

Forced soil aeration by means of injection of atmospheric air under pressure into the soil *via* a subsurface drip irrigation (SDI) system is thought to increase the O_2 concentration in wet soil. It has been postulated that reduced denitrification, enhancement of N mineralisation and uptake by the plants ensue.

Materials and methods

Different strategies of fertigation timing and the effect of aeration on N availability and uptake were studied in the field. Chinese cabbage 'Bilko' was transplanted (45 cm x 50 cm) on June 9 (2000) to a silty clay loam with a SDI system installed at 15 cm depth, 2 drip laterals per bed (1.5 m width) and 30 cm emitter spacing. P_2O_5 and K_2O were supplied at 80 and 340 kg ha-^{1}, respectively. N was supplied at 210 (based on N_{min} target value for Chinese cabbage, *i.e.* 250 kg N ha^{-1} minus 40 kg NO_3^-N ha^{-1} in the soil) or 160 kg N ha^{-1} (based on 80% of the N_{min} target, which is 200 kg N ha^{-1}). 40% of the nutrients were broadcast applied prior to planting (84 and 64 kg N ha^{-1}, resp.) with N applied as Ca cyanamide. The cabbage was transplanted 6 weeks later to avoid any damage from Ca cyanamide on the young seedlings. The remaining 60% of the nutrients were supplied by fertigation as follows:

(1) in equal portions weekly, starting at planting (0W linear),

(2) in equal portions weekly, starting 2 weeks after planting (WAP) (2W linear),

(3) as for (2) but with forced aeration at 0.6 bar for 90 minutes after each irrigation event or when water potential (by tensiometer) exceeded –9.0 kPa (2W linear air),

(4) rates adjusted weekly according to a N-uptake model starting 2 WAP (2W model), and

(5) as for (4) but with N according to 80% of the N_{min} target value (2W model 80%).

$Ca(NO_3)_2$ and a soluble fertiliser with 15 (11.3 NO_3-N + 3.7 NH_4^+-N), 5, and 30 % of N, P_2O_5, and K_2O, respectively were used for fertigation. The crop was drip-irrigated automatically with 5 l m^{-2} when soil water potential 15 cm away from the emitters fell below –12 kPa. Forced aeration was automatically started at soil water potential above –9 kPa, which is not extremely wet but safe in time to avoid oxygen deficiency.

Results

Nitrate in the soil

NO_3^--N contents of the soil sampled 10 cm apart from the drip tape and between two plants are presented in Table 1. One WAP of Chinese cabbage 4.6 mg NO_3^--N kg^{-1} soil were available in the top 30 cm. This represents about 40 kg N ha^{-1} indicating that most of the NO_3^- applied and available before planting could not be retrieved. 4 WAP 23 and 14.5 mg NO_3^--N kg^{-1} soil were available at 0-30 and 30-60 cm soil depth, respectively. In the following 2 weeks rainfall amounted to 70 l m^{-2} and soil moisture was above field capacity. From 6 WAP until harvest, the soil in the top 60 cm contained only 3.1 to 4.5 mg NO_3^--N kg^{-1}, with no differences between treatment.

Table 1. Soil NO_3^--N content

NO_3^--N content (mg kg^{-1}) in 0-30 and 30-60 cm soil depth. Means across treatments at different weeks after planting (WAP).

Depth (cm)	1	3	4	6	8
			WAP		
0-30	4.6	3.5	23.0	3.8	4.5
30-60	-	3.7	14.5	3.4	3.1

Table 2. NO_3^- in the plant

NO_3^- concentration (mg kg^{-1} FW) in the petiole sap (3-6 WAP) and in the head (7 and 8 WAP) of Chinese cabbage as affected by fertigation timing strategy and aeration. The bottom line gives recommended values after Matthäus and Matthäus (1997)

Treatment	3	5	6	7	8
			WAP		
	Petiole sap			Head	
0W linear	4590 a	170a	170 a	200b	180b
2W linear	4090 a	100ab	130 a	140b	160b
2W model	-	30b	120 a	950a	520a
2W model 80%	-	40b	120 a	610ab	320ab
2W linear air	3830 a	110ab	70 a	340b	200b
Recomm.	5000	4000			

Values followed by the same letter in a column are not significantly different at 5% (Tukey test)

Plant N

Plant N status was monitored by NO_3^- analyses initially in the petiole sap of the youngest fully expanded leaf and after heading in the head (Tab. 2) as described by Matthäus and Matthäus (1997). The NO_3^- concentration of the petiole sap 3 WAP was 4000-4500 mg NO_3^- kg^{-1} FW in the linear treatments. At 5 and 6 WAP, NO_3^- concentration in the petiole sap was close to zero in all fertigation and aeration treatments. In the 7^{th} and 8^{th} WAP, NO_3^- concentration in the head was highest in the two 2W model treatments (320-950 mg kg^{-1} FW) where higher rates of NO_3^- were applied 5-6 WAP as the heads developed. However, the NO_3^- level in these heads, *i.e.* in the saleable product, was still beneath regulatory limits.

Approximately 52-83 kg N ha^{-1} had been accumulated in whole shoots at harvest 8 WAP (not shown). There were no treatment effects on shoot N accumulation. Limited N uptake and resulting N deficiency resulted in a low biomass of 48 t ha^{-1} FW and a marketable head yield of 29 t ha^{-1} (trial means, not shown). Within the limits of this trial, the linear fertigation strategies resulted in higher yields compared to the fertigation strategy based on the N uptake model ($P<0.05$, not shown).

Discussion

The low soil NO_3^- levels after planting as well as soil and plant NO_3^- levels from 5 WAP until harvest in contrast to the sufficiently high N input was striking and seeks for explanation.

The Ca cyanamide had been broadcasted 6 weeks before the Chinese cabbage was planted and within that time complete nitrification may have occurred. Part of the NO_3^- may have been leached below 60 cm soil depth where the soil was not sampled.

3 WAP N uptake was still within normal ranges since NO_3^- concentration in the petiole sap was 4000-4600 mg NO_3^- kg^{-1} FW, which is close to the recommended concentrations for Chinese cabbage at this stage (Tab. 2, Matthäus and Matthäus, 1997). Therefore, NO_3^- level in the root zone was possibly still adequate at this stage. Two weeks later (5 WAP) NO_3^- concentration in the petiole sap was less than 200 mg kg^{-1} indicating severe N deficiency. The low plant N status is contradictory to the high NO_3^- level in the top 60 cm of the soil measured 4 WAP. Roots may not have had adequate spacial access to soil nitrate pool or/and root functions might have been inhibited. Reduced root functions may have been caused by hypoxic conditions due to high rainfall intensity and soil moisture above field capacity from 4 to 6 WAP. Access to the fertigated nutrients may have been inadequate because N was supplied through the drippers in 15 cm depth in the compacted silty clay loam soil. Under these conditions, the plants' roots may not have penetrated to the depth that the N (and O_2) was supplied. This would also account for the lack of an effect of forced soil aeration.

6 WAP and later both soil and plant NO_3^- levels were again low. The high rainfall intensity and soil moisture above field capacity from 4 to 6 WAP are likely to have contributed significantly to N loss via leaching and probably to a minor degree via denitrification. Whether soil aeration affected the denitrification process is not yet analysed.

Under the conditions of this trial the fertigation strategies based on equal weekly rates of nutrient supply were agronomically superior to strategies with increasing weekly rates derived from a N uptake model. The model approach may even carry the risk of too high NO_3^- contents in the produce if sink size is low and N availability is not limited.

References

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