Growth and Yield of Broccoli as Affected by the Nitrogen Content of Transplants and the Timing of Nitrogen Fertilization

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Abstract. The nitrogen requirement of broccoli (*Brassica oleracea* var. *italica*) ranges from 300 to 465 kg·ha⁻¹. Recommendations for N fertilization are accordingly high. High fertilizer rates applied at planting result in a high soil mineral N content that remains high for weeks because the N requirement of the crop is low at early growth stages. Therefore, the risk of leaching is high for several weeks until the available N is finally taken up by the crop. Our study had two objectives: 1) to quantify yield responses to preplant fertilization, and 2) to test our hypothesis that the preplant fertilization rate could be reduced without yield losses by increasing the N content in the transplants and improving crop establishment. Field experiments were carried out on transplants with four levels of N content in dry matter (0.018 to 0.038 g·g⁻¹ dry weight), which were tested in all combinations with four fertilization timings. All treatments received the same amount of N fertilizer (270 and 272 kg·ha⁻¹ in 2001 and 2002, respectively), but with different rates of supply at the time of planting (0 to 90 kg·ha⁻¹ N fertilizer plus 30 and 28 kg·ha⁻¹ soil mineral N in 2001 and 2002, respectively). Total and marketable yields increased significantly with an increasing N supply at time of planting. In our experiments, in which topdressing was applied 25 days after planting, an N supply at planting of 80 to 118 kg·ha⁻¹ was required to obtain maximum marketable yields. The N content in transplants had little effect on growth and yield, and there were no significant interactions between the N content in the transplant and fertilizer timing.

The N requirement of broccoli ranges from 300 kg·ha⁻¹ (Everaarts and de Willigen, 1999a) to 465 kg·ha⁻¹ (Zebarth et al., 1995). Therefore, recommended fertilizer application rates are generally high, despite fertilizer recommendations often being lower than plant requirements. This is because both the mineral N present in the soil at time of planting (Hochmuth, 2003; Wehrmann and Scharpf, 1986) and expected N mineralization (Fink and Scharpf, 2000) needs to be taken into account.

Although the yield response of broccoli to the total rate of N fertilization has been reported in a number of studies (Zebarth et al., 1995, and references therein), there is no agreement on the possible benefits and drawbacks of strategies for the timing of fertilizer applications during the growth period. For instance, Everaarts and De Willigen (1999b) recommended the application of the required fertilizer in a single dose at the time of planting, whereas Bowen et al. (1999) reported that it is a general recommendation to growers in British Columbia, Canada, to apply N fertilizer in a split application, half at the time of transplanting, and the remainder 2 weeks later. The intention of the

practice of splitting N fertilizer application is unnecessary because they did not find evidence that applying ammonium nitrate at rates up to 312 kg·ha⁻¹ at planting was detrimental to broccoli. Weier (1992) suggested the provision of at least 30% of the crop's total N requirement at planting because fertilizer treatments with lower basal dressings resulted in lower yields in her experiments. However, Belec et al. (2001), who compared three N supply rates at planting, combined with four N rates 5 weeks later, found that although the marketable yield was significantly affected by the total fertilizer applied, the effects of fertilizer timing within one level of fertilizer were negligible.

It should be noted that fertilizer timing could affect not only plant growth, but also N use efficiency. Based on experiments with sown broccoli, Thompson et al. (2002) disapproved preplant applications that might be inefficiently used because of a low plant requirement during the early growth period. Fink et al. (2001) reported an average N requirement of only 20 kg·ha⁻¹ during the first 3 weeks after planting. Such a low N requirement of the crop, in combination with high fertilizer rates before planting, result in a high soil mineral N content that is prone to leaching for several weeks until taken up by the plants. Therefore, the risk of N loss from leaching could be reduced by low preplant fertilization.

Our study had two objectives: 1) to quantify yield response to preplant fertilization, and 2) to test our hypothesis that preplant fertilization rates could be reduced without yield losses by increasing the N content in the transplants.

Materials and Methods

Seedlings of 'Marathon' broccoli (Sakata Seed Corp., Japan), were grown in a greenhouse in multicellular trays (42 cm² per cell) filled

split application was to provide sufficient N for inflorescence development without applying excessive fertilizer early, when it could burn young plants. However, Bowen et al. (1999) concluded from their own experiments that the

Table 1. N application during transplant cultivation, N content, and dry matter of transplants at time of planting.

N level	Year	N application ^z (mg·L ⁻¹)				N content (g·g ⁻¹)	Dry matter (g/plant)
		Days					
		1	4	8	12		
1	2001	75	0	0	0	0.021	0.17
2	2001	75	75	75	0	0.026	0.20
3	2001	75	150	150	75	0.030	0.23
4	2001	75	225	225	150	0.038	0.23
1	2002	75	0	0	0	0.018	0.17
2	2002	75	75	75	0	0.023	0.19
3	2002	75	150	150	75	0.028	0.23
4	2002	75	225	225	150	0.032	0.29

^aN applied on days 1, 4, 8, and 12 after the second true leaf became visible (see text).

Table 2. Soil nitrate N at planting (0 to 0.3 m) and fertilizer timing. All treatments received a total N fertilization of 270 kg·ha⁻¹ in 2001 and 272 kg·ha⁻¹ in 2002 (i.e., a total N supply of 300 kg·ha⁻¹).

Treatment	Date	Year	N fertilizer distribution			
			Treatment (kg·ha ⁻¹)			
			1	2	3	4
Soil nitrate N	May 10	2001	30	30	30	30
Base fertilization	May 14	2001	0	50	70	90
First top fertilization	June 9	2001	135	110	100	90
Second top fertilization	June 21	2001	135	110	100	90
Soil nitrate N	May 6	2002	28	28	28	28
Base fertilization	May 15	2002	0	50	70	90
First top fertilization	June 10	2002	136	111	101	91
Second top fertilization	June 21	2002	136	111	101	91

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with a mixture of white peat and fine bark. The initial nutrient content of the substrate was 152 mg·L⁻¹ extractable nitrogen, 65 mg·L⁻¹ phosphorus and 195 mg·L⁻¹ potassium. Nitrogen and phosphorus were measured spectrophotometrically (EPOS 5060; Eppendorf, Hamburg, Germany). Potassium was measured using a flame atomic emission spectrometer (AAS vario 6; Carl Zeiss Jena, Germany). Seedlings were watered every day, and in addition, containers were saturated with a nutrient solution on days 1, 4, 8, and 12 after the second true leaf had become visible. The N concentration of the applied solution and the resulting N contents in the transplants are shown in Table 1. At the time of planting, 80 transplants at each level of N supply were taken. The dry matter (dried at 65 °C) and N content (measured with an Auto Analyser, Heraeus, Germany) of transplants are shown in Table 1.

Field experiments were carried out on a sandy soil, an Arenic Luvisol (World Reference Base), with 10.8 and 11.1 mg·g⁻¹ organic matter in 2000 and 2001, respectively. The two-factor experiments were Latin rectangle designs with four levels of transplant N content (Table 1) and four N fertilization strategies (Table 2). Fertilizer was applied broadcast as calcium ammonium nitrate. All 16 factorial combinations were replicated four times.

The field plot size was 5.0 × 4.8 m. Transplants were planted on 15 May 2001 and 16 May 2002, and each plot contained 10 rows, which were 0.5 m apart. Plants were 0.4 m apart within a row, which resulted in a plant density of 50 000 plants/ha. Ten plants per plot were sampled 25 d after planting, to assess early development. When 80% of the heads reached a marketable growth stage, 32 plants from a 6.4 m² central portion of each plot were harvested to determine marketable yield.

Heads were considered marketable when the diameter was greater than 0.12 m and the maturity index was in the range of 3 to 5. The broccoli maturity index was suggested by Sorensen and Grevsen (1994). The index range from 1 (no visible head) to 7 (flowering). Index 4 (fully developed firm head) denotes the developmental stage with optimal market quality. Heads were cut to 17 cm length and leaves were removed.

Soil nitrate N was measured from 16 auger samples taken from soil layers of 0 to 0.3 m and 0.3 to 0.6 m. Soil samples were taken from the whole field at the time of planting and from each plot separately at harvest date. After extraction with 0.0125 M CaCl₂, nitrate N was determined spectrophotometrically (EPOS, Eppendorf, Germany).

Sprinkler irrigation was applied according to the irrigation scheduling computer program BEREST (Gutezeit et al., 1993). The program calculated soil water content in the rooted soil layer on a daily basis using the water holding capacity of the soil, plant growth stage, and potential evapotranspiration as input variables. Irrigation decisions were made on the basis of the calculated soil water content and the expected evapotranspiration and precipitation of the next 5 d.

Analysis of variance, measures of dispersion,

and the Tukey test procedure ($HSD_{p=0.05}$) were calculated using a statistics program (STATISTICA, StatSoft Inc. 2001, Tulsa, Okla.).

Results and Discussion

Although the N supply (soil nitrate N at planting date + N fertilizer) was almost identical in 2001 and 2002, both total fresh weight (Figs. 1 and 2) and marketable yield (Table 3) showed considerable differences between years. The differences were probably caused by different temperature time courses, which have a major impact on the growth and yield of broccoli (Thompson et al., 2002; Zebarth et al., 1995). Although the average air temperature during the entire cultivation period was only slightly higher in 2002, at 17.6 °C, compared to 16.1 °C in 2001, the temperature time courses were quite different between years. The average air temperature in the first 25 d after planting

was higher in 2002, at 16.4 °C, compared to 14.5 °C in 2001, which increased the average growth rate during early crop growth in 2002. Therefore, the first flower buds were visible 25 d after planting in 2002, and 31 d after planting in 2001. During the last week before harvest in 2002, above optimal maximum day temperatures occurred, at 30.4 °C, compared to 24.2 °C in 2001. This reduced the growth rate in 2002 and required an earlier harvest because the heads started to separate earlier, and buds started to bloom.

Analyses of variance did not show significant interactions between the N level in the transplant and fertilizer timing (Table 4). Therefore, our hypothesis that the growth of broccoli shortly after planting could be improved by increasing the N content in the transplants, and thereby allow for a reduction in preplant fertilization without yield loss, was rejected.

Fig. 1. Effect of N supply at planting on above ground fresh weight at harvest. N supply was calculated as the sum of soil nitrate N (0 to 0.3 m) at time of planting plus N base fertilization in 2001 and 2002. Different letters show significant differences within 1 year.

Fig. 2. Effect of N content in the transplant on above ground fresh weight at harvest in 2001 and 2002. Different letters indicate significant differences within 1 year.

Table 3. Effect of N content in transplant and N supply at planting on marketable yield.

N level of transplant	Marketable yield (t·ha ⁻¹)		Level of N supply at planting	Marketable yield (t·ha ⁻¹)	
	2001	2002		2001	2002
1	17.1	11.4	1	13.4	6.3
2	18.6	12.3	2	19.1	13.9
3	19.0	13.9	3	20.5	14.4
4	19.0	13.2	4	20.7	16.5
Tukey HSD ($P=0.05$)	1.9	1.8		1.9	1.8

Table 4. Analysis of variance.

Source	df	Marketable yield		Total yield	
		2001	2002	2001	2002
1, N level of transplant	3	*	*	NS	NS
2, Fertilizer timing	3	*	*	*	*
Interaction (1 × 2)	9	NS	NS	NS	NS
Error	42				

NS, *Nonsignificant or significant at the 0.05 probability level.

Fig. 3. Effect of N supply at planting on above ground fresh weight 25 d after planting in 2001 and 2002. N supply was calculated as the sum of soil nitrate N (0 to 0.3 m) at time of planting plus N base fertilization. Different letters show significant differences within 1 year.

Fig. 4. Effect of N content in the transplant on above ground fresh weight 25 d after planting in 2001 and 2002. Different letters indicate significant differences within 1 year.

Because we did not find significant interactions, the following analysis only considers main factor effects.

Fertilizer distribution. Marketable yield and total yield were significantly affected by fertilizer timing (Table 4).

It should be noted that at the early sampling date in both years, treatments with an N supply of 120 kg·ha⁻¹ resulted in significantly higher growth rates than treatments with 100 kg·ha⁻¹ (Fig. 3). However, the maximum N uptake by the plants until 25 d after planting was only 6 to 21 kg·ha⁻¹ and 12 to 61 kg·ha⁻¹ in 2001 and 2002, respectively.

Previous studies with brassica crops showed that the N supply must often exceed plant requirement to obtain maximum yields (Everaarts, 2000; Fink, 2001; Sanchez et al., 1996). This is because plants could not always access the mineral N in the soil. Heins and Schenk (1987) determined that N uptake and growth of kohlrabi (*Brassica oleracea* var. *gongylodes* L.) was not limited by the nitrate concentration in the soil as long as it was higher than 10 kg·ha⁻¹ in a well-rooted 0 to 0.3 m soil layer. However, higher values could be expected if roots and N are not homogeneously distributed in the soil (Heins and Schenk, 1987). This is obviously the case when fertilizer is applied broadcast and roots of transplants only colonize a small part of the soil. The effect of increasing N supply on the growth rate was already significant 25 d after planting. The differences between treatments persisted until harvest date, although low applications at planting were compensated for by higher topdressings, i.e., all treatments received the same total amount of fertilizer. The lowest N supply at planting, i.e., when no fertilizer was applied at planting, resulted in marketable yield losses of 13% in 2001 and 10% in 2002, when compared to the maximum yield of each year (Table 3). Marketable yields increased significantly with increasing preplant N supply up to 80 and 118 kg·ha⁻¹ in 2001 and 2002, respectively.

Fertilizer was applied broadcast, which is common practice in Europe. Banded applications, as is customary in other regions, might have increased nitrogen use efficiency and might have lead to different results.

Nitrogen content of transplants. The N content in the transplants had little effect on crop growth (Figs. 2 and 4) and marketable yield (Table 3).

Transplants used for field experiments (for example, by Vagen et al., 2004), or transplants provided by commercial growers (data from an unpublished survey carried out in Germany), commonly contain 2.4% to 4.8% N. In our experiments with transplants in the range of 1.8% to 3.8% N, only treatments with the lowest N level (<2.5% N), in which the plants showed visible symptoms of N deficiency, had significantly lower growth rates up to 25 d after planting. The response of marketable yield at harvest date largely mirrored the response of growth up to 25 d after planting (Fig. 4). The lowest N level in the transplants resulted in marketable yield losses of 10% in 2001 and 24% in 2002, when compared to the maximum yield of each year (Table 3). Total fresh weight

at harvest was not significantly affected by the N content in the transplants (Table 4, Fig. 2). Our results agree with previous studies, where different transplant treatments had little effect on broccoli yield (Lamont, 1992, size and transplant age; Dufault and Waters, 1985, container size; Latimer, 1990, drought and mechanical stress). In contrast, Masson et al. (1991) who used fertigation solutions in the N range between 100 and 400 mg·L⁻¹, found that marketable yield increased linearly with increasing rates of N fertilization to transplants.

Summary and Conclusions

To reduce the risk of N loss by leaching during the early growth phase of broccoli, N fertilizer should be applied as a split application. However, too low an application at planting results in strongly decreased total and marketable yields. In our experiments, when topdressing was applied 25 d after planting, an N supply at planting of 80 to 118 kg·ha⁻¹ was required to obtain maximum marketable yields. The N content of transplants had little effect on growth and yield, and there were no significant interactions between the N content in the transplant and fertilizer distribution.

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