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Nitrate Content, Soluble Solids Content, and Yield of Table Beet as Affected by Cultivar, Sowing Date and Nitrogen Supply

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***Abstract*. The objective was to provide results to optimize the production of table beet (*Beta vulgaris* L.) with respect to yield and quality. Field experiments were carried out over 2 years, where the effects of nitrogen (N) supply, sowing date, and cultivar were tested in a block design with four replications. In addition to yield, soluble solids and nitrate N contents of roots were measured to assess quality. Sowing date was an important factor for determining yield and quality of table beet. Sowing dates later than June at the experimental site are not recommended because they resulted in an increase in nitrate N content in fresh weight of up to 3027 mg·kg^{-1} and an average yield loss of 46% compared to sowings in April. Soluble solids content (SSC) was only slightly affected by planting date. Nitrogen supply did not affect SSC, but increasing N supply led to a major increase in nitrate N content, especially if combined with late sowing dates. It was concluded for early sowing dates that N supply be determined to achieve the maximum yield. With an early sowing date, nitrate N content in fresh weight at harvest was <563 mg·kg^{-1}, even with a high N supply of 250 kg·ha^{-1}. Late sowing dates required a reduced N supply to keep harvest nitrate contents below the 2500 mg·kg^{-1} required by the processing industry. Recommendations for optimizing N supply, sowing date ,and cultivars for table beet should always take into account strong interactions between these factors.**

Table beets produced for canning or dietary juices are required to meet the quality requirements of the processing industry. One quality parameter is the nitrate content of the roots, which should be as low as possible. Nitrate content in fresh weight is of major importance to the grower because table beets are not salable if nitrate exceeds threshold values required by local laws. For instance, there is a limit of 2500 mg·kg^{-1} in table beet juice in Switzerland (Künsch et al., 1986), and 250 mg·kg^{-1} is the permitted maximum for baby food in Germany (BGBl., 1994).

A plant's ability to accumulate nitrate depends strongly on species and plant parts. Fruits such as the tomato seldom contain >100 mg·kg^{-1}, irrespective of environmental conditions (Venter, 1984). In contrast, storage organs such as tubers or roots show a broad range of nitrate content, with values of 532 to 3060 mg·kg^{-1} in radish and 930 to 8000 mg·kg^{-1} in table beet reported (Richardson, cited in Buckenhüskes and Gierschner, 1988). The effects of N and cultivar on beet pulp nitrate and sugars of sugar beet, which is the same species as table beet, are well described (Lauer, 1995, 1997; Smith and Martin 1977). But only a few studies in the literature identify the environmental factors controlling nitrate content in table beet. Some studies focusing on the effect of N supply indicate that high fertilizer rates increase the risk of high nitrate content in table beets, especially when fertilizer was applied late in the growing season (Lee et al., 1971; Peck et al., 1974). Other authors emphasize the choice of cultivars as a measure of controlling the risk of high nitrate content (Matthäus et al., 1996; Grzebelus and Baranski, 2001). However, studies with carrots have shown that single-field experiments are not suitable for assessing the effects of cultivars on nitrate content, because results may vary from year to year and from site to site (Gutezeit and Fink, 1999). Therefore, more data are required to be able to draw general conclusions.

Besides nitrate content, sugar content is a relevant quality parameter of table beet. The concentrations of sucrose solutions are conveniently expressed as °Brix (Chen, 1989). Soluble solids content (°Brix readings from a refractometer) are commonly used to assess sugar content or the taste of plant juices. For instance, soluble solids content was used as an estimate of sucrose content in sugar cane (Mamet, 1999), of sweetness and taste of melons (Fujiwara and Sakakura, 1999) and, in combination with the acid content of a juice, as a measure of fruit maturity and palatability (Fellers, 1991). The use of soluble solids content to assess the quality of table beet was suggested by Peck et al. (1974), who determined that late fertilization caused significantly lower °Brix values.

However, there is little information on how to optimize cropping practices, since some practices can affect yield and quality in opposite directions. N fertilization significantly increases yield, but can also decrease quality through excessive nitrate content and reduce soluble solids content (Becker, 1989; Lee et al., 1971; Peck et al., 1974; Salo et al., 1992). The objective of our study was to provide data as a basis for optimizing fertilization, cultivar selection, and sowing date with respect to the yield and quality of table beet.

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Materials and Methods

The field experiments were carried out at Institute of Vegetable and Ornamental Crops, Großbeeren, Germany, in a sandy soil (according to the World Reference Base (WRB) for Soil Resources an Arenic Luvisol) with 10.8 and 11.1 mg·g^{-1} organic matter in 1998 and 1999, respectively. The estimated N-mineralization was 4 kg·ha^{-1} per week. In these experiments, the effects of N supply, plant density, sowing date, and cultivar were tested in a block design with four replications. The first experiment in a split-split-plot arrangement included four treatments: 1) N at 100 kg·ha^{-1}, 550,000 plants/ha; 2) N at 175 kg·ha^{-1}, 550,000 plants/ha; 3) N at 250 kg·ha^{-1}, 550,000 plants/ha; and 4) N at 175 kg·ha^{-1}, 420,000 plants/ha. The four treatments were tested in all combinations with two cultivars and three sowing dates in 1998 and with two sowing dates in 1999. Whole plots were sowing dates, subplots were N supply, and sub-subplots were cultivars. The second experiment in a split-plot arrangement included three treatments: 1) N at 175 kg·ha^{-1}, 1,200,000 plants/ha; 2) N at 250 kg·ha^{-1}, 1,200,000 plants/ha; and 3) N at 175 kg·ha^{-1}, 950,000 plants/ha. The three treatments (subplots) were tested in all combinations with three sowing dates (whole plots) in 1998, and with two sowing dates (whole plots) in 1999. An analysis of growth and total N accumulation in these experiments was published in the context of a model validation study (Feller and Fink, 2002a), which required the inclusion of the range of plant densities. In the context of the present paper, only treatments with plant densities recommended for commercial practice are considered (treatments 1, 2, and 3 from Expt. 1, and treatments 1 and 2 from Expt. 2). Therefore, all results presented here apply to these treatments only, so plant density is not considered as a variable.

Table 1 shows the sowing and harvest dates, as well as the tested cultivars, which represent different characteristic types of table beet relevant for the industry: 'Bolivar' and 'Boltardy' are ball-shaped roots harvested at a diameter of ≈10 cm; 'Kosak' is cylindrical and is ready to harvest when it has a diameter of 5 cm and a length of 15 cm; 'Rote Kugel' is a so-called baby beet type grown for the fresh market, with high plant densities, and is harvested when it reaches a diameter of ≈5 cm.

Soil nitrate N was measured from 16 auger samples taken from a soil layer of 0 to 0.6 m over the whole field at each sowing date (Table 1). After extraction with 0.0125 M $CaCl_2$, nitrate-N was determined photometrically (EPOS, Ep-

Table 1. Sowing and harvest dates, tested cultivars, soil mineral N, N-fertilization, precipitation (P), and irrigation (I) of the experiments.

Year	Sowing date	Harvest date	Cultivar Expt. 1	Cultivar Expt. 2	Soil mineral N (kg·ha^{-1}) Sowing	Harvest[z]	N fertilization treatment (kg·ha^{-1}) 100[y]	175[y]	250[y]	P (mm)	I (mm)
1998	17 Aug. early	14 Apr.	Boltardy, Bolivar	Rote Kugel	22	9	78	153	228	154	100
1998	21 Sept. medium	2 June	Boltardy, Bolivar	Rote Kugel	13	20	87	162	237	198	40
1998	12 Oct. late	14 July	Boltardy, Bolivar	Rote Kugel	58	22	42	117	192	244	20
1999	30 Aug. early	15 Apr.	Boltardy, Kosak	Rote Kugel	14	18	86	161	236	84	160
1999	27 Sept. medium	14 June	Boltardy, Kosak	Rote Kugel	40	12	60	135	210	65	180

[z]Mean value of the treatments with 250 kg·ha^{-1} N supply.
[y]Treatment N supply = soil mineral N at sowing + N fertilization.

pendorf, Germany) as described by Hoffmann (1997). The difference between measured soil nitrate N and the N supply target value (N at 100, 175 and 250 kg·ha^{-1}) was applied broadcast as two equal side dressings of calcium ammonium nitrate 1 week after emergence and 5 weeks after emergence (Table 1).

Seeds were sown in rows 15 cm apart for the 'baby beet' cultivar Rote Kugel, and 30 cm apart for the other cultivars. The plant distance within the rows was adjusted to achieve the treatment plant densities by manually removing surplus seedlings. Sprinkler irrigation was applied according to the irrigation scheduling computer program BEREST. The program calculated soil water content in rooted soil layer on a daily basis, using water holding capacity of the soil, plant growth stage and potential evapotranspiration as input variables. Irrigation decisions were made considering the calculated soil water content and the expected evapotranspiration and precipitation of the next 5 d. In each irrigation event 20 mm of water was applied. Accumulated precipitation and irrigation are shown in Table 1.

The highest daily amount of rainfall was 34 mm in 1998 and 15 mm in 1999, respectively. Therefore, leaching of fertilizer N below the root zone of table beets was unlikely.

Plants were sampled at 2- or 3-week intervals, with 14 plants sampled on each occasion. When fresh matter was equal to or less than the previous sample, i.e., when growth ceased caused by low temperature or by dropping of old leaves, the sampling date was defined as the harvest date (Table 1). Results presented in this study refer to samples taken at the harvest date. The marketable yield of roots was determined from harvest plots of 2.5 m^2, which were located in the center of field plots. Field plot size was 3 × 4.5 m with two margin rows and three margin plants on each end of the rows. Borders of field plots were 0.8 m apart. To assess nitrate-N content (NC) and soluble solids content (SSC) at harvest date, subsamples of 14 plants were taken randomly from each harvest plot.

Nitrate-N determinations were carried out potentiometrically using a nitrate ionplus electrode (Sure-Flow, Orion–Research, Beverly) as described by Cantliffe et al. (1970), and soluble solids concentration was measured by a refractometer (model Brix PR-1; ATAGO Co., LTD, Japan) following the sampling procedure described in the manufacturer's manual (Schneider 1979). Weather data were recorded on site by a standard weather station (VDI 1993).

Statistics. Analysis of variance, regression parameters and measures of dispersion were calculated using a statisticsprogram (StatSoft Inc. 2001, STATISTICA Tulsa, Okla.).

Results and Discussion

Analyses of variance are shown separately for Expt. 1 (Table 2) and Expt. 2 (Table 3). There were significant interactions between sowing date (SD) and nitrogen (N) supply in both experiments, and between sowing date and cultivar (C) in Expt. 1. To depict interactions of N supply and sowing date more clearly, treatment means are shown in graphs (Figs. 1 and 3), where averages were calculated for the two cultivars tested in Expt. 1 (Figs. 1A and 3A).

Nitrate N content. Nitrate N content was significantly affected by the main effects and there were significant interactions between SD × N (Tables 2 and 3) and SD × C (Table 2). Early sowing dates resulted in low nitrate-N contents with effects produced by N supply in both experiments (Fig. 1). Increasing N supply led to a major increase in NC if combined with late sowing dates.

The marked effect of N supply on NC of table beet (Cantliffe, 1973; Lee et al., 1971; Peck et al., 1974) and sugar beet (Smith and Martin, 1977) is well described in the literature whereas little is known about the effects of sowing dates. Obviously, NC is not directly affected by sowing date but is possibly affected by plant age at harvest or by environmental conditions before harvest, which in turn are essentially determined by sowing date for a given location, irrigation regime, and weather pattern. As in our experiments (Fig. 1), Wonneberger and Wedler (1988) found increasing NC with later sowing dates. They suggested that this trend was due to different plant ages, thereby assuming that increasing plant age results in decreasing NC. This result is, however, not always the case. For instance, Peck et al. (1974) reported decreasing NC in table beet for well-fertilized plots, but not for plots without N fertilization. Additional samples taken before harvest date in our experiments (data not shown) also indicated decreasing NC in treatments with early sowing dates and high N supply, whereas treatments with both low

Table 2. Effects of sowing date (SD), cultivar (C), and nitrogen (N) supply on yield, nitrate N content, and soluble solids of table beets shown as F test significances (Expt. 1).

Effect	1998 Bolivar and Boltardy Yield	Nitrate N content	Soluble solids	1999 Bolivar and Kosak Yield	Nitrate N content	Soluble solids
SD	*	*	*	NS	*	*
C	*	*	*	NS	*	*
N	*	*	NS	*	*	NS
SD × C	NS	*	*	NS	*	NS
SD × N	NS	*	NS	NS	*	*
C × N	NS	NS	NS	NS	NS	NS

NS,*Nonsignificant at $P > 0.05$ or significant at $P \leq 0.05$.

Table 3. Effects of sowing date (SD) and nitrogen (N) supply on yield, nitrate N content, and soluble solids of table beets shown as F test significances (Expt. 2).

Effect	1998 Yield	Nitrate N content	Soluble solids	1999 Yield	Nitrate N content	Soluble solids
SD	*	*	*	*	*	*
N	*	*	NS	NS	*	NS
SD × N	NS	*	*	NS	NS	NS

NS,*Nonsignificant at $P > 0.05$ or significant at $P \leq 0.05$.

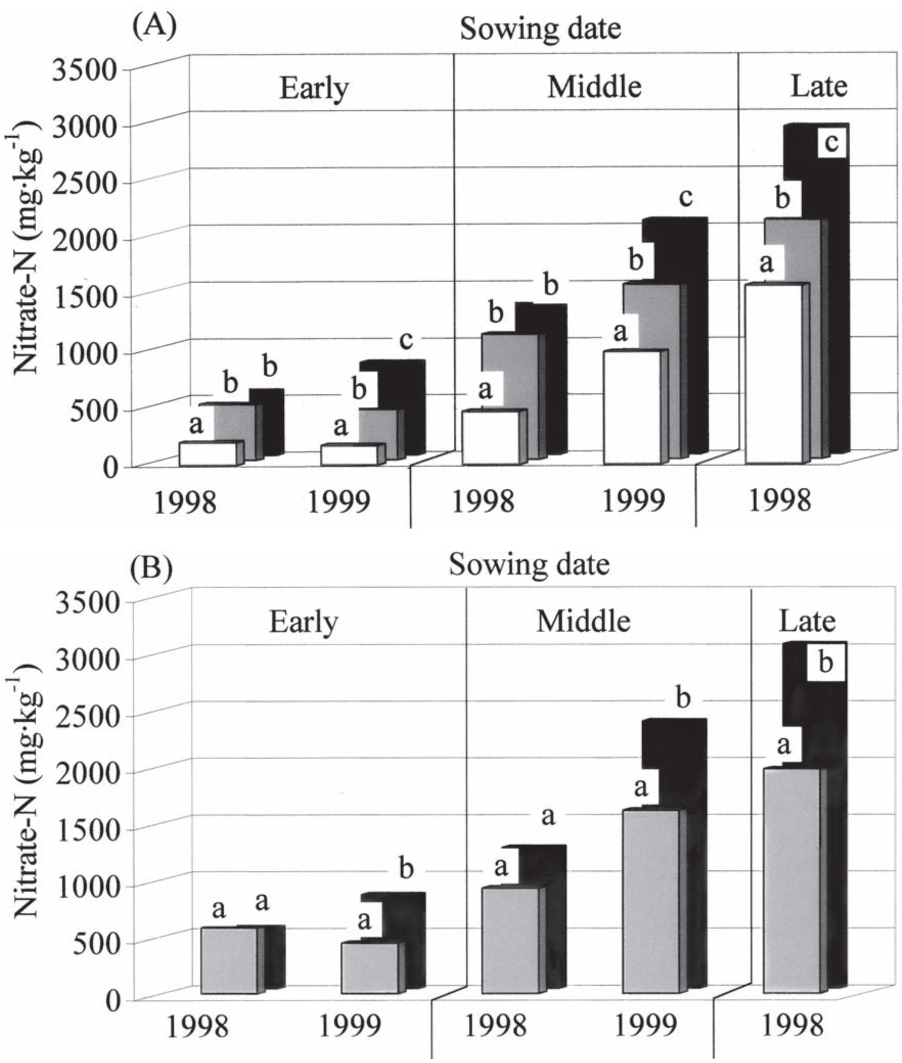

Fig. 1. Dependence of nitrate N in the fresh weight of table beets on N supply and sowing date in Expt. 1 (**A**), and Expt. 2 (**B**). N supply: no shading = 100 kg·ha^{-1}; light shading =175 kg·ha^{-1}, and dark shading = 250 kg·ha^{-1}. Letters show significant differences within sowing date and year ($P \leq 0.05$).

N supply and late sowing dates did not show significant correlations between plant age and NC. Michalik and Grzebelus (1995) found an increasing NC when comparing harvests of 100, 120, or 140 d after sowing. These partly contradictory results indicate that plant age is not the exclusive factor for determining the NC in table beet.

Therefore, we analyzed the effects of environmental conditions before harvest. Early sowing dates resulted in longer growing seasons and relatively earlier harvest dates (Table 1), which were related to comparatively high temperature and photosynthetically active radiation (*PAR*) before harvest. A regression analysis accounted for 83% of the variance in nitrate content when the mean *PAR* over 20 d before harvest and N supply were used as independent variables (Fig. 2). These results are in agreement with Cantliffe (1993) who also found a negative correlation between NC and irradiance in table beet. Further regression approaches that included other periods of time for *PAR* or the effect of temperature did not improve the fit of the regression model.

Residuals of the regression shown in Fig. 2 are in part caused by significant cultivar effects and significant interactions of SD × C (Table 2). Early sowing dates resulted in no differences between the cultivar tested (Table 4), whereas, for instance, 'Boltardy' showed significant lower NC at later sowing dates in 1998 and 1999. Contradictory effects of cultivars on NC of table beet were reported by Wonneberger and Wedler (1988). However, as mentioned in the introduction, studies with carrots have shown that single-field experiments are not suitable to assess the effects of cultivar on NC because results may vary considerably from year to year and from site to site (Gutezeit and Fink, 1999).

Soluble solids content. Harrill (1998) stated that °Brix, as a measure of soluble solids content (SSC), varies directly with plant quality. For table beet, Harrill (1998) suggested a quality scale that assigned a °Brix of 6, 8, 10, and 14 to quality labels of poor, average, good, and excellent, respectively. In our experiments, SSC ranged from 10 to 14 °Brix, i.e., no treatment resulted in poor quality as determined by Harrill's scale. Comparisons of SSC within sowing dates showed only one treatment with a significantly higher SSC (early sowing date in 1999, N at 100 kg·ha^{-1}). When the main effects were compared, the N supply did not affect SSC (Tables 2 and 3). This result agrees with those from other table beet experiments (Peck et al., 1974; Wonneberger and Wedler, 1988) and grapes (Kliewer, 1996). Peck et al. (1974) found that only late N fertilization caused significantly lower SSC.

Early sowing dates always resulted in higher SSC when compared to the medium sowing dates (Table 4). However, this was not caused by differences in plant age at harvest. In our experiments, SSC was not correlated with plant age (data not shown), a result that was also reported for table beet by Michalik and Grzebelus (1995). This result is opposed by reports on fruits, such as 'Cavendish' banana, where the sugar content and SSC regularly increase continuously during development (Wills et al., 1984). Moreover, in contrast to nitrate-N content, SSC was not related to irradiance or

Table 4. Effects of sowing date and cultivar on yield, nitrate N content in fresh weight, and soluble solids of table beets (Expts. 1 and 2).

	1998				1999			
Sowing date	Cultivar	Yield (t·ha^{-1})	Nitrate N content (mg·kg^{-1})	Soluble solids °Brix	Cultivar	Yield (t·ha^{-1})	Nitrate N content (mg·kg^{-1})	Soluble solids °Brix
Early	Boltardy	84.3	352	12.1	Boltardy	84.6	482	12.9
Early	Bolivar	85.2	483	12.3	Kosak	81.9	467	14.3
Medium	Boltardy	72.6	575	11.4	Boltardy	82.9	1323	10.5
Medium	Bolivar	86.3	1350	10.1	Kosak	77.4	1735	12.7
Late	Boltardy	37.4	1949	12.7				
Late	Bolivar	47.3	2422	11.7				
LSD$_{(P = 0.05)}$ Expt. 1		7.6	176	0.4		6.8	112	0.6
Early	Rote Kugel	106.6	559	12.5	Rote Kugel	119.1	634	12.9
Medium	Rote Kugel	78.8	1083	10.8	Rote Kugel	98.7	1979	11.3
Late	Rote Kugel	45.9	2499	11.9				
LSD$_{(P = 0.05)}$ Expt. 2		6.6	309	0.6		11.0	256	0.8

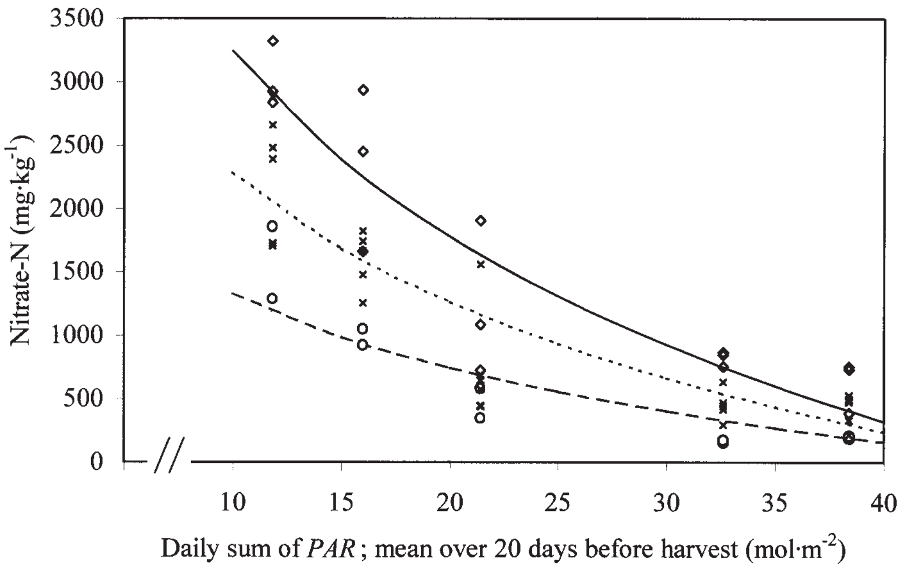

Fig. 2. Nitrate-N in the fresh weight of table beets related to the mean daily sum of photosynthetic active radiation (*PAR*) over 20 d before harvest and N supply. Points denote means of measurements. N supply: (○; -----) 100, (x; ……) 175 and (◊; —) 250 kg·ha^{-1}. Curves were computed with: NC = 53.9 + 32.2 × N supply – 8.44 × N supply·ln (daily sum of *PAR*), R = 0.91, n = 180

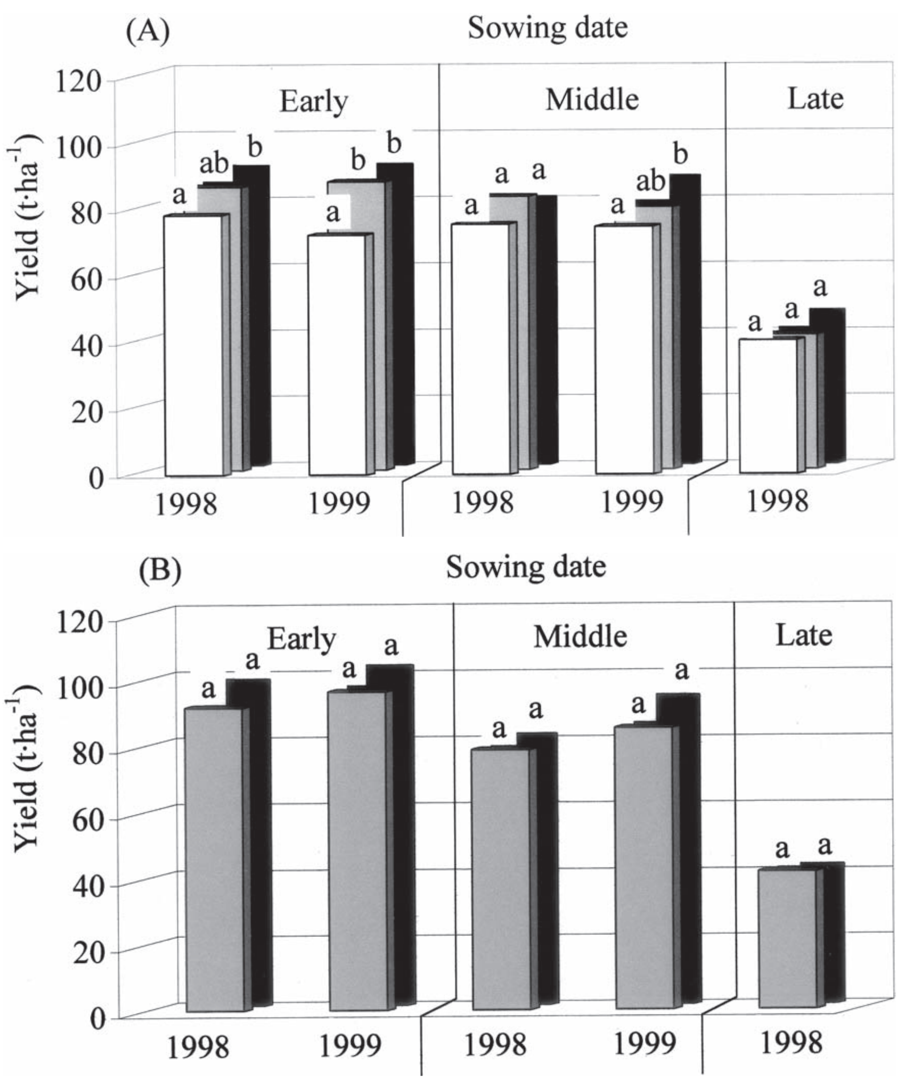

Fig. 3. Dependence of yield of table beets on N supply and sowing date in Expt. 1 (**A**), and Expt. 2 (**B**). N supply: no shading = 100 kg·ha^{-1}; light shading =175 kg·ha^{-1}, and dark shading = 250 kg·ha^{-1}. Letters show significant differences within sowing date and year ($P \leq 0.05$).

temperature before harvest. Therefore, the reasons for increased SSC with early sowing dates remain unexplained.

Cultivar effects on SSC were characterized by interactions of SD × C in 1998 (Expt. 1, Table 2), i.e., 'Bolivar' showed a higher SSC than 'Boltardy' with medium and late sowing dates, but not with early sowing dates. In 1999, 'Bolivar' showed significant lower SSC than 'Kosak', irrespective of sowing dates. Partly significant differences indicated that the selection of cultivars might be a measure of controlling SSC of table beet. However, taking into account that there is no additional published information on the effects of cultivars, the available data are not sufficient to draw general conclusions.

Yield. An N supply of 250 kg·ha^{-1} did not result in a increase in yield compared to 175 kg·ha^{-1} (Fig. 3), whereas an N supply of 100 kg·ha^{-1} in Expt. 1 led to significantly lower yields in all comparisons to 250 kg·ha^{-1} (Fig. 3 A). Our results showed that the optimal N supply with regard to yield was between 175 and 250 kg·ha^{-1}. This result agrees with Wonneberger and Wedler (1988), who suggested that an N supply above 200 kg·ha^{-1} does not result in additional yield increases. Based on other independent research, Feller and Fink (2002b) also recommended 227 kg·ha^{-1} for table beet cultivars similar to those grown in Expt. 1.

Sowing date had a major effect on yield (Tables 2 and 3), and, in contrast to effects on SSC and nitrate content, no interactions with other investigated experimental factors occurred. Compared to early sowing dates, a late sowing resulted in yield losses of 50% in Expt. 1 and 42% in Expt. 2. Significant yield losses due to sowing dates later than June were also reported by Wonneberger and Wedler (1988) for table beets and by Lauer (1997) for sugar beets.

Yield was significantly affected by cultivar only in Expt. 1 in 1998 (Table 2), where 'Boltardy' yielded less than 'Bolivar'.

Summary and Conclusions

Recommendations for optimizing N supply, sowing date and cultivars with respect to yield and quality of table beet must consider the strong interactions between these experimental factors. An important factor for determining the yield and quality of table beet was the sowing date. Late sowing dates—later than June at the experimental site—are not recommended because they resulted in considerably limited yields and in considerably increased nitrate-N content. Nitrate N increases at harvest were associated with decreases in *PAR* before harvest. For early sowing dates, the N supply was determined to have achieved optimal yield because the nitrate N content at harvest was low, even with high N supplies. Medium or late sowing dates needed a reduced N supply, when taking yield losses into account that occur thereby to meet the nitrate content standards required by law or the processing industry.

Soluble solids content was only slightly affected in our experiments, and all treatments received a rating of good or better on Harrill's scale for table beet. Cultivars had significant effects on beet soluble solids, but there was too little information from these trials to derive general recommendations for the selection of cultivars for table beet production.

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