Nutrient Uptake Traits Related to Sugarbeet Yield

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ABSTRACT

The identification of adaptive traits involved in the response of plants to nutritional stress is necessary for maintaining crop productivity at sustainable levels. The objective of this study was to evaluate the relationships among root elongation rate, root/shoot ratio, nitrate and sulfate uptake rate in sugarbeet (*Beta vulgaris* L. subsp. *vulgaris*, Sugarbeet Group). These relationships were measured in three sugarbeet varieties characterized by different root and sugar yield. Wide differences were observed among the varieties for root elongation rate and nitrate and sulfate uptake rate measured after nutritional deprivation. These differences were not dependent on seed size. A significant relationship among root elongation rate, nitrate and sulfate uptake traits and between these traits and productivity was observed. The above-mentioned morphophysiological traits might be useful indexes in breeding programs aimed at increasing sugar yield under nutritional stress.

Additional Key Words: nutritional stress, root plasticity, yield stability.

INTRODUCTION

The realized yield of cultivated plants is lower than the potential yield due primarily to water-nutritional stress (Blum, 1988; Evans and Fischer, 1999). About 60% of cultivated soils are subjected to nutritional stress (Cakmak, 2002) and intensive fertilization in developed countries has increased environmental pollution (Raun and Johnson, 1999). Cultivation of plants that are more efficient in the absorption and utilization of nutrients could reduce the use of fertilizers, input costs and loss of nutrients to ecosystems (Baligar, 2001). Therefore, the identification of traits conferring adaptations that would maintain yield under low nutrient availability may become important in plant breeding programs. Nutrient uptake efficiency is known to be under genetic and physiological control and may be a useful genetic trait for adaptation to lower soil nutrient conditions. Moreover, nitrate and sulfate uptake capacity has been widely considered a valuable index for selecting hybrids with high yield stability (Cacco et al., 1983).

In maize, yield gain was correlated with the increase in sulfate uptake rate (Saccomani et al., 1984). This relationship was also shown in barley and sugarbeet (Cacco et al., 1980; Saccomani et al., 1981; Clarkson et al., 1992; Saccomani et al., 2002). The productivity in maize and barley was also correlated with nitrate uptake rate after deprivation (Saccomani et al., 1984; Clarkson et al., 1989).

Plant factors influencing nutrient uptake are mainly associated with root characteristics. Root architecture can determine the capacity of plants to acquire soil resources that are irregularly distributed and/or subject to localized depletion (Lynch, 1995). The root system is plastic, which allows the plant to adapt its root architecture in response to water-nutritional stress. This plasticity might increase the plant's adaptation to the environment and its yield stability (Bell and Sultan, 1999; Sinclair and Muchow, 2001). Seed size also influences germination, root growth and nutrient acquisition from the soil, as has been observed by Milosevic et al. (1992) in sugarbeet and by Liao and Yan (1999) in common bean.

The objective of this work was to examine the relationships among root elongation rate, root/shoot ratio, nitrate and sulfate uptake rate, and the influence of seed size on these traits in three sugarbeet varieties characterized by different root and sugar yield. The study of the response of these parameters may allow the identification of plant traits potentially useful for the selection of sugarbeet varieties that are better adapted to lower soil nutrient concentrations.

MATERIALS AND METHODS

Field evaluation

The varieties Aaron, L002 and Rodolfo (Lion Seeds, Maldon, UK), which are characterized by different productivity, were used (Table 1).

Aaron and L002 are diploid with rhizomania resistance, while Rodolfo is triploid with rhizomania and cercospora leaf spot resistance.

Field experiments were conducted between 2000 to 2002 at Rovigo (Italy), Novi Sad (Yugoslavia) and Loiret (France) (Table 2). The experimental design was a randomized complete block using three sugarbeet varieties of two different seed sizes as treatments with four replications. Plots were fertilized according to soil test recommendations. Sugarbeet varieties were sown 2-3 cm deep, with spacing of 5-7 cm between seeds. Emergence counts started when the first seedling was visible and continued at two-day intervals until no further seedlings emerged. At four- to six-leaf stage, plots were hand-thinned to the densities of about 10 plants m^{-2}. To ensure optimal growth conditions, weed, foliar diseases and insects were controlled with chemicals following recommended management practices. Sugarbeets were defoliated, topped and harvested using a three-row harvester. Three rows of each plot were sampled to determine root yield, sugar content and the main nonsugars.

Seedling evaluation

The following set of tests was performed on the same seed lot used in the field. Seeds from each variety were surface-sterilized by immersion in 1% sodium hypochlorite solution for 10 min, then washed with deionized water for 1 h. Seeds were transferred to two layers of filter paper moistened with deionized water in Petri dishes placed in a germinator at 25°C in the dark for 48 h. Seedlings from each variety with 10±2 mm long seminal roots were transplanted inside pleated paper

Table 1. Seed size and yield of three sugarbeet varieties.

Variety	Seed size	Root yield	Sugar content	Sugar yield
	mm	t ha^{-1}	%	t ha^{-1}
Aaron	2.75 - 3.25	77.7	15.4	12.0
Aaron	3.50 - 4.00	80.1	15.5	12.4
L002	2.75 - 3.25	69.2	15.8	10.9
L002	3.50 - 4.00	69.9	15.7	11.0
Rodolfo	2.75 - 3.25	63.7	15.2	9.7
Rodolfo	3.50 - 4.00	65.0	15.2	9.9
LSD (0.05)		4.0	NS	0.9

NS = non-significant difference at the 0.05 probability level.

Table 2. Geographic and other information pertinent to the field trials.

Country	Italy	Yugoslavia	France
Place	Rovigo	Novi Sad	Loiret
Coordinates, long., lat.	11° 4' E, 45° 4' N	19° 12' E, 45° 78' N	2° 25' E, 48° 18' N
Sowing date	24 February 2000 3 March 2001 26 February 2002	23 February 2000 2 March 2001 5 March 2002	17 March 2000 19 March 2001 16 March 2002
Previous crop	Wheat	Wheat	Wheat
Plant density, pl m^{-2}	10	10	10
Row spacing, m	0.45	0.45	0.45
Plot size, m^2	6.75	6.75	6.75
Varieties	Aaron, L002, Rodolfo	Aaron, L002, Rodolfo	Aaron, L002, Rodolfo
Emergence date	13 March 2000 14 March 2001 11 March 2002	9 March 2000 19 March 2001 21 March 2002	8 April 2000 5 April 2001 1 April 2002
Harvest date	1 September 2000 29 August 2001 2 September 2002	4 September 2000 31 August 2001 5 September 2002	15 September 2000 17 September 2001 19 September 2002

moistened with deionized water to hermetic Plexiglass boxes. Primary root lengths were measured initially and after 72 h to determine the root elongation rate.

For nutrient uptake experiments, seedlings were germinated as previously described. Three-day-old seedlings with 10±2 mm long seminal roots, were transplanted on plastic tanks over an aerated solution containing 200 µM $Ca(NO_3)_2$, 200 µM KNO_3, 200 µM $MgSO_4$, 40 µM KH_2PO_4 and microelements, similar to concentrations used by Arnon and Hoagland (1940). The nutrient solution was replaced every 2 days. The boxes and tanks were placed in a growth chamber at 25/18°C and 70/90% relative humidity with a 14 h light (60 W m^{-2}) and 10 h dark cycle. Nitrate- or sulfate-depleted seedlings were obtained by replacing each of the two anions with chloride on the 6th day.

Nitrate influx was measured by placing sixteen-day-old nitrate-depleted seedlings in beakers with complete growth solution containing 200 µM NO_3^-. Nitrate concentration of nutrient solution was evaluated at 10 to 30 min using an Uvikon 922 spectrophotometer (Kontron, France) at 210 nm.

In order to evaluate the sulfate uptake rate, sixteen-day-old sulfate-depleted seedlings were transferred to complete nutrient solution containing 100 µM SO_4^{2-}. Sulfate concentration was determined by sulfate disappearance from the uptake solution at 10 to 30 min using an inductively coupled plasma spectrometer (Ciros^{ccd} Spectro Analytical Instruments, Germany) at 182 nm. The nitrate and sulfate uptake rate was expressed respectively as nanomoles of nitrate and sulfate absorbed per plant per minute.

STATISTICS

Data were subjected to ANOVA using the PLABSTAT software (Utz, 1995). Means were separated using a protected Least Significant Difference test (LSD) at the 0.05 probability level. Correlation analysis was performed to establish relationships among root elongation rate, nitrate uptake rate, sulfate uptake rate and sugar yield. Yield data reported and used for the correlation analysis were expressed as mean values of three locations and three years.

RESULTS

Among the three varieties, the average root fresh weight and root/shoot ratio did not show a significant variation either at steady nutrient supply or after nitrate and sulfate deprivation (data not shown). The root elongation rate ranged from 5.0 to 7.4 mm day^{-1} (Table 3); Aaron showed the highest value (23% greater than L002 and 31% higher than Rodolfo). Increasing root elongation rate has been shown to increase nutrient influx to the root after nutrient deprivation (Sullivan et al., 2000). This effect was evaluated by using correlation analysis to determine the relationships among root elongation rate, and nitrate and sulfate uptake. A correlation coefficient (r) of 0.909 for root elongation rate versus nitrate uptake rate and an r of 0.917 for root elongation rate versus sulfate uptake rate were obtained. Moreover, results indicated a significant ($P < 0.01$) positive relationship between root elongation rate and sugar yield with an r of 0.956 (Fig. 1A). Nitrate and sulfate uptake rate did not show a significant variation among the three sugarbeet varieties at steady nutrient supply (data not shown) and significant differences were found only after nutrient deprivation (Table 3).

Mean values of each variety for nitrate uptake rate ranged from 0.356 to 0.399 nmoles min^{-1} $plant^{-1}$, and it was significantly 5% and 10% greater in Aaron than in L002 and Rodolfo, respectively. This parameter was significantly ($P < 0.01$) correlated with sulfate uptake rate and sugar yield with r values of 0.962 and 0.966, respectively (Fig. 1B). Sulfate uptake rate showed similar patterns of variation and the mean values of the three varieties ranged from 0.216 to 0.332 nmoles min^{-1} $plant^{-1}$. Aaron had the greatest sulfate uptake (respectively 14% and 33% higher than L002 and Rodolfo). Correlation analysis indicated that sulfate uptake was positively ($P < 0.01$) correlated to productivity with an r of 0.971 (Fig. 1C).

Table 3. Root elongation rate, nitrate and sulfate uptake rate after deprivation of three sugarbeet varieties.

Variety	Root elongation rate mm day^{-1}	Nitrate uptake rate -- nmoles min^{-1}	Sulfate uptake rate $plant^{-1}$ ---
Aaron	7.3	0.399	0.332
Aaron	7.4	0.397	0.323
L00	25.8	0.371	0.278
L002	5.5	0.384	0.288
Rodolfo	5.1	0.356	0.223
Rodolfo	5.0	0.363	0.216
LSD (0.05)	0.3	0.010	0.032

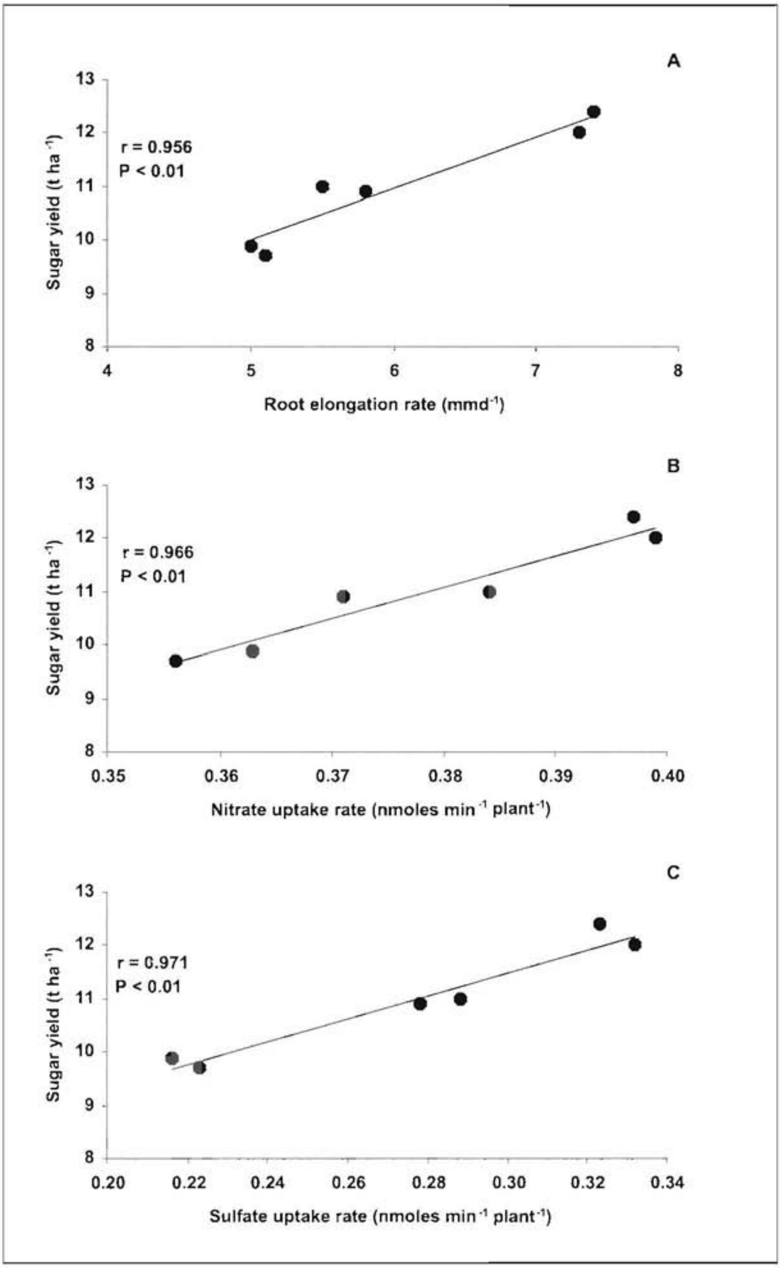

Fig. 1. Relationships among root elongation rate, nitrate uptake rate, sulfate uptake rate and sugar yield.

DISCUSSION

In the field tests, all varieties had a regular pattern of plant density after thinning. As a result, seed size likely had no significant effect on field emergence and productivity parameters among the three varieties. There were no differences regarding the morphophysiological traits examined between the small-seeded and the larged-seeded seedlings. This could depend on the reduced qualitative differences of the seed between the two seed size fractions. Therefore, the influence of the seed dimension on seedling growth could be excluded.

Significant relationships among the root elongation rate, nitrate and sulfate uptake rate traits measured after nutritional deprivation and productivity were observed. This is in agreement with Eghball and Maranville (1993), who demonstrated a relationship between root development and nitrogen influx under combined drought and nitrogen stresses in maize. The relationship between these traits can also be defined as a plastic response to stress. Plasticity allows the plants to overcome the conditions of nutritional stress, increasing the volume of soil explored by the roots, as well as increasing the recovery rate of the internal nutrient concentration back to the normal conditions of fertility, as observed by Zhang and Forde (2000). Therefore, root plasticity allows the plant to face the wide fluctuations of nutrient concentration that take place in the rhizosphere.

Given the reciprocal mechanism of control between sulfur and nitrogen metabolism, a higher sulfate uptake rate might reduce the accumulation of amino-nitrogen in the roots and increase the processing quality according to Thomas et al. (2000), who observed an increase of amino-nitrogen in sugarbeet roots following sulfate deficiency. Therefore, the above-mentioned plant traits are connected to efficiency of soil resource acquisition, and they might be useful selection criteria in breeding programs interested in sugarbeet yield improvement under conditions of nutritional stress.

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