Root traits and competitiveness against weeds in sugar beet

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abstract

Weed control without using chemicals is strongly limiting sugar beet cultivation in a low-input and/or organic agriculture. The aim of this work was to evaluate, in two sugar beet breeding lines characterized by high (L1) and low (L2) yield, some root morpho-functional traits (root elongation rate, total root length and number of root tips) that might be useful for sugar beet competitiveness against weeds. The above traits were evaluated on eleven-day old seedlings grown on a hydroponic nutrient solution whereas root length density and weed density were measured in field trials. The most productive line L1 was characterized by superior root elongation rate, total root length and number of root tips as compared to L2 and the main sugar beet weeds. L1 also showed, under field condition, a higher root length density and a lower weed density highlighting a superior competitive ability against weeds (less number of weeds per area unit) and overall productivity. These morpho-functional traits could be useful for the selection of sugar beet lines requiring minor technical inputs for weed control and more suited to a low-input and/or organic agriculture.

Keywords: **competition ability, root apparatus, sugar beet, weeds**

Introduction

Weeds represent one of the most yield-limiting factor for annual crops. The development of cultivated plants with high competitiveness against weeds is a prerequisite to the diffusion of a sustainable agriculture (Bond and Grundy, 2001). The cultivation of more antagonistic varieties could results in economic and environmental benefits particularly in a low input and/or organic farming (Turner *et al.*, 2007). Selection for yield, disease resistances, etc. of commercial varieties was accompanied by a reduced competitive ability against weeds (Mason *et al.*, 2008), despite early studies indicated the existence of some degree of variability useful to sugar beet breeding for competitiveness (Callaway and Forcella, 1993). Crop ability in weed limiting was related to numerous shoot morpho-physiological traits such as rapid development, height, leaf area, leaf position and light interception (Didon and Boström, 2003). The identification of cultivars whose productivity is less dependent on the use of herbicides initially occurred in rice highlighting the fundamental role of the root apparatus. (Gibson *et al.,* 1999; Fofana and Rauber, 2000). The current sugar beet varieties are poor competitors against weeds, especially at the early stage, because of their low stand (around 8-10 plants m^{-2}), slow shoot development, limited height also with a low weed density with a yield loss that can reach 100% with high infestation (Wilson *et al.*, 2001; Deveikyte and Seibutis, 2006; Heidari *et al.*, 2007). The development of more competitive sugar beet varieties is now an urgent requirement. Until now, sugar beet ability to compete was related to a more rapid leaf development at the early stage and to light interception by the leaf apparatus (Paolini *et al.*, 1999). Root traits for weed control have not been seriously considered although several studies highlighted the strict relation of morpho-physiological traits root length, root surface, number of root tips and nutrient uptake rate with the nutrient acquisition (Roumet *et al.*, 2006; Sorgonà *et al.*, 2007). These traits, determinant of maize and sugar beet yield (Saccomani *et al.*, 1981; Vamerali *et al.*, 2003; Stevanato *et al.*, 2010) might be also determinant of the weed control. The aim of this work was to study, in two sugar beet lines characterized by high and low yield, the influence of some root traits on the competitiveness against weeds.

Materials and methods

Plant material

The two breeding lines characterized by high (L1: 72 t ha^{-1}) and low (L2: 58 t ha^{-1}) root yield were supplied by Lion Seeds Ltd (Maldon, UK). The yield data were obtained from field experiments conducted in 2004-2005 at Rovigo (Italy) and Pithiviers (France) using a randomized block design with four replicates. The seeds of the main sugar beet weeds (*Sorghum halepense* L. Pers., *Solanum nigrum* L., *Chenopodium album* L., *Abutilon theophrasti* Med., *Polygonum persicaria* L. and *Echinochloa crus-galli* L. Pal. Beauv.) were supplied by the CRA-CIN Sede di Rovigo (Italy).

Figure 1. Total root length, root surface area and number of root tips of sugar beet lines and main weeds of sugar beet grown in hydroponic solution. The error bars represent the standard error of the mean. Means followed by different letter are significantly different (p<0.01)

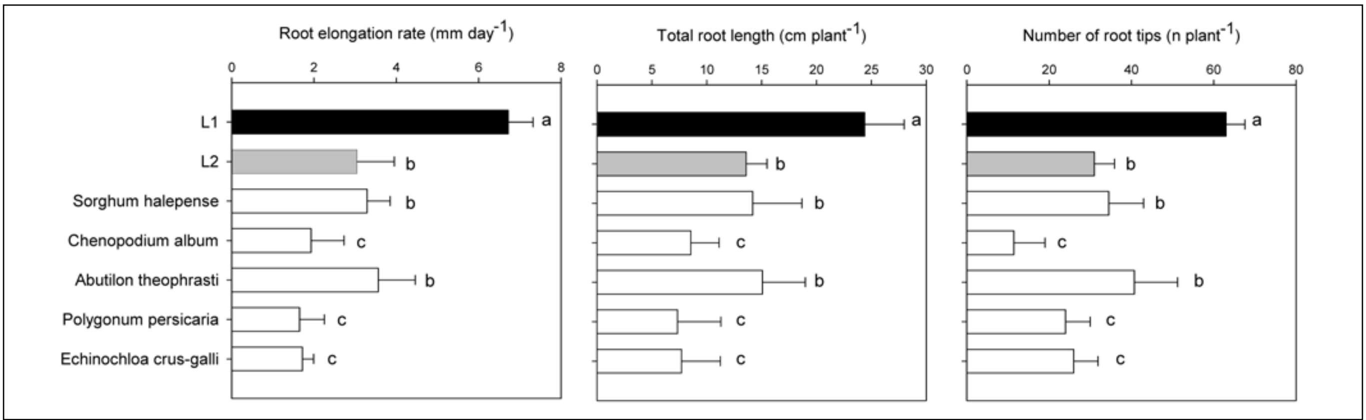

Figure 2. Root length density (cm cm^{-3}) of L1 and L2 sugar beet lines evaluated along the soil profile at 91, 152 and 212 days after sowing. The error bars represent the standard error of the mean. Means followed by different letter are significantly different (p<0.01)

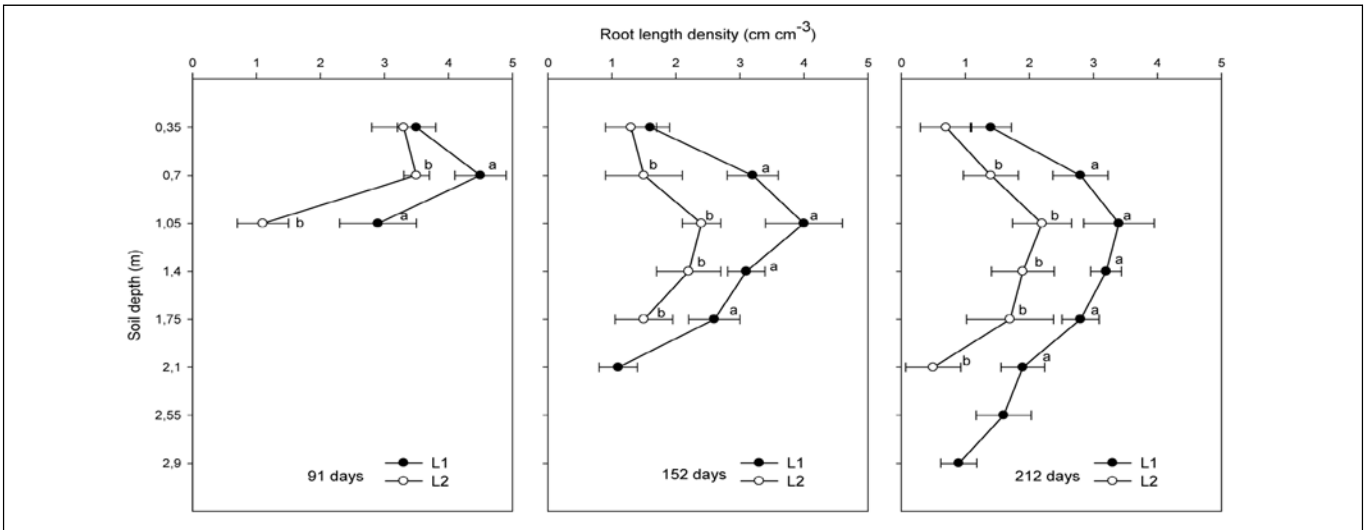

Table 1. Weed density and total weed vegetation in the check sub-plots not seeded with sugar beet (mean of four replicates) in the 3 years of experiment

Species	Family	Weed density plant m^{-2}	Total weed vegetation %
Sorghum halepense (L.) Pers.	Gramineae	4.5	30
Solanum nigrum L.	Solanaceae	3.7	25
Chenopodium album L.	Chenopodiaceae	2.2	15
Abutilon theophrasti Med.	Malvacee	0.9	6
Polygonum persicaria L.	Polygonaceae	0.9	6
Echinochloa crus-galli (L.) Pal. Beauv.	Gramineae	0.9	6
Cirsium arvense (L.) Scop.	Compositae	0.3	2
Euphorbia peplus L.	Euphorbiaceae	0.2	1.5
Anagallis arvensis L.	Primulaceae	0.1	1.0
Polygonum convolvulus L.	Polygonaceae	0.1	0.9
Polygonum aviculare L.	Polygonaceae	0.1	0.9
Senecio vulgaris L.	Compositae	0.1	0.8
Sonchus asper L. (Hill)	Compositae	0.1	0.7
Cynodon dactylon L.	Gramineae	0.1	0.7
Setaria viridis (L.) Pal. Beauv.	Gramineae	0.1	0.5
Medicago lupulina L.	Leguminosae	0.1	0.5
Convolvulus arvensis L.	Convolvulaceae	0.1	<0.5
Amaranthus retroflexus L.	Amarantaceae	0.1	<0.5
Stellaria media (L.) Vill.	Caryophyllaceae	< 0.1	<0.5
Taraxacum officinale Weber	Compositae	< 0.1	<0.5
Chaenorhinum minus (L.) Lange	Scrophulariaceae	< 0.1	<0.5
Conyza canadensis L.	Compositae	< 0.1	<0.5
Veronica persica Poiret	Scrophulariaceae	< 0.1	<0.5
Equisetum arvense L.	Equisetaceae	< 0.1	<0.5
Portulaca oleracea L.	Portulacaceae	< 0.1	<0.5
Papaver rhoeas L.	Papaveraceae	< 0.1	<0.5
Polygonum lapathifolium L.	Polygonaceae	< 0.1	<0.5
Artemisia vulgaris L.	Compositae	< 0.1	<0.5
Capsella bursa-pastoris L.	Cruciferae	< 0.1	<0.5
Setaria glauca (L.) Pal. Beauv.	Gramineae	< 0.1	<0.5
Sinapis arvensis	Gramineae	< 0.1	<0.5
Calystegia sepium (L.) R. Br.	Convolvulaceae	< 0.1	<0.5
Fumaria officinalis L.	Papaveraceae	< 0.1	<0.5
Alopecurus myosuroides L.	Gramineae	< 0.1	<0.5
Poa annua L.	Gramineae	< 0.1	<0.5
Avena fatua L.	Gramineae	< 0.1	<0.5
Matricaria chamomilla L.	Compositae	< 0.1	<0.5
Trifolium campestre Schreb.	Leguminosae	< 0.1	<0.5
Ammi majus L.	Umbrelliferae	< 0.1	<0.5
Total		**14.8**	

Table 2. Density and fresh weight of the weeds in the sugar beet plots and root and sugar yield in presence and absence of weeds. Means followed by different letter are significantly different (p<0.05)

			Root yield	
Breeding line	**Weed density**	**Fresh weed biomass**	**Weeded**	**Unweeded**
	plants m^{-2}	**g m^{-2}**	**t ha^{-1}**	
L1	3.1 b	626 b	59 a	71 a
L2	5.6 a	1132 a	46 b	62 b

Laboratory analysis

The root morphological traits total root length, root surface area and number of root tips of the two sugar beet lines and weeds were determined on eleven-day old seedlings grown in hydroponics following the procedures described by Stevanato *et al.* (2004) and Saccomani *et al.* (2009). *Solanum nigrum* L. was excluded from this analysis due to its low germination rate. Seedlings were grown on plastic tanks with an aerated solution containing 200 μM $Ca(NO_3)_2$, 200 μM KNO_3, 200 μM $MgSO_4$, 40 μM KH_2PO_4 and micro-elements (Arnon and Hoagland, 1940). The tanks were placed in a growth chamber at 25/18°C and 70/90% relative humidity with a 14/10 h light/dark cycle and nutrient solution was replaced daily. Root traits were determined by means of a scanner-based image analysis system (WINRHIZO Pro, Regent Instruments, Quebec, Canada).

Field analysis

Field trials were carried out in 2006, 2007 and 2008, using the methodologies described by Paolini *et al.* (1999) and Stevanato *et al.* (2006) to evaluate the weed parameters "weed density", "fresh weed biomass" and the sugar beet parameters "leaf area", "root length density" and "root yield". Treatments were arranged in a split plot design with sugar beet breeding lines as main plots and presence and absence of weeds as subplots, with four replications. The absence of weeds was obtained by weekly removing them manually. Check sub-plots without sugar beet were also included in each main plot for assessment of the potential weed flora in the field. Field surveys were carried out every 30 d, from May 15 to September 15 to determine the species composition and weed density (number of weeds per square meter). Leaf area and root length density were measured every each survey according to the procedures reported by Stevanato *et al.* (2006, 2010). Sugar beets and weeds were harvested in the middle of September to determine the root beet yield and the fresh weed biomass.

Data analysis

Data were subjected to analysis of variance using Statistica 9.0 package (StatSoft Inc., Tulsa, OK, USA). Fisher's Protected Least Significant Difference was calculated for mean comparison.

Results

Root morphological traits of the two sugar beet lines and the main weeds are reported in Figure 1. Significant differences ($p<0.01$) between L1 and L2 varieties were found for all the root traits evaluated. The most productive line (L1) was characterized by a significant higher ($p<0.01$) root elongation rate (+186%), total root length (+79%) and number of root tips (+103%) with respect to L2 and weeds. The root values of L2 were similar to those of *S. halepense* and *A. theophrasti* but significantly greater ($p<0.01$) than those of *C. album*, *P. persicaria* and *E. crus-galli*.

The two sugar beet did not significantly differed for emergence rate and leaf area development under field condition. As observed with minirhizotrons, L1 line showed, compared to L2, a greater ($p<0.01$) root length density in the soil profile below 0.35 m in all field surveys (Figure 2).

39 different weed species, belonging to 18 botanical families, were identified on check sub-plots not seeded with sugar beet (Table 1). These plots showed a total weed density of 14.8 plants m^{-2}. The most abundant botanical family was the grass family (*Gramineae*) with 8 species. The major weeds species, constituting 89% of total weed vegetation, are (mentioned in decreasing order of weed density): *Sorghum halepense* (L.) Pers., *Solanum nigrum* L., *Chenonopodium Album* L., *Abutilon theophrasti* Med., *Polygonum persicaria* L. and *Echinochloa crus-galli* (L.) Pal. Beauv.

Significant differences ($p<0.01$) were found between the two lines for the parameters "weed density", "fresh weed biomass" and "root yield" (Table 2). A significantly lower weed density ($p<0.01$) was found in plots cultivated with L1 characterized by greater development of root system with respect to L2 with low root development. Weed fresh weight on the plots cultivated with L1 was significantly lower ($p<0.01$) compared to that found in the L2 plots. The L1 line was more productive than L2 with and without weed competition.

Discussion

This study has revealed the superiority of the L1 sugar beet line with respect to L2 for the morphological traits root elongation rate, total root length, number of root tips and root length density strictly related to soil exploration, nutrient uptake and productivity, as previously demonstrated by Stevanato *et al.* (2010). Furthermore, L1 has evidenced a greater competitive ability against weeds with respect to L2 even if the two lines showed similar rates for seedling emergence and leaf apparatus development in the field. Therefore, the different competitiveness of the two lines should be directly related to the L1 root characteristics overall for their dominant role in water and nutrient acquisition. This is corroborated by numerous studies demonstrating that weed suppression ability of crops is correlated with root morphology attributes involved in nutrient uptake as reviewed by Casper and Jackson (1997). Particularly, Tilman and Wedin (1991) found that the competitively dominant species had high root biomass and nitrate uptake capacity and Fargione and Tilman (2006) showed that all the dominant competitors have high biomass / nitrogen, thin roots and high root length density at low soil nitrate concentrations.

The reduced root development of L2 might be caused by linkage drag associated with the introgression on its genetic background of a source of resistance to rhizomania (Rz2), originated from *Beta vulgaris* L. ssp. *maritima*, that seems to significantly limit root apparatus development (Stevanato *et al.*, 2008). The root morphological traits evaluated at the seedling stage are predictive of competitiveness against weeds. Sugar beet breeding for low input/organic farming requires the introgression of root characters allowing a rapid colonization of soil. The future development of this research will be to investigate the genetic base of these key traits to facilitate their incorporation through marker-assisted selection into commercial sugar beet varieties.

References

Arnon, D.I. and Hoagland, D.R. (1940) Crop production in artificial culture solution and in soils with special reference to factors influencing yields and absorption of inorganic nutrients. *Soil Science* 50: 463-483.

Bond, W. and Grundy, A.C. (2001) Non-chemicals weed management in organic farming systems. *Weed Research* 41: 383-405.

Callaway, M.B. and Forcella, F. (1993) Crop tolerance to weeds. In C.A. Francis and M.B. Callaway (ed.) *Crop improvement for sustainable agriculture*. Univ. Nebraska Press, Lincoln: 100-131.

Casper, B.B. and Jackson, R.B. (1997) Plant competition underground. *Annual Review of Ecology and Systematics* 28: 545-570.

Deveikyte, I. and Seibutis, V. (2006) Broadleaf weeds and sugar beet response to phenmedipham, desmedipham, ethofumesate and triflusulfuron-methil. *Agronomy Research* 4: 159-162.

Didon, U.M.E. and Boström, U. (2003) Growth and development of six barley (*Hordeum vulgare* ssp. *vulgare* L.) cultivars in response to a model weed (*Sinapis alba* L.). *Journal of Agronomy and Crop Science* 189: 409-417.

Fargione, J. and Tilman, D. (2006) Plant species traits and capacity for resource reduction predict yield and abundance under competition in nitrogen-limited grassland. *Functional Ecology* 20: 533-540.

Fofana, B. and Rauber, R. (2000) Weed suppression ability of upland rice under low-input conditions in West Africa. *Weed Research* 40: 271-280.

Gibson, K.D., Foin, T.C. and Hill, J.E. (1999) The relative importance of root and shoot competition between water-seeded rice and *Echinochloa phyllopogon*. *Weed Research* 39: 181-190.

Heidari, G., Mohammadi Nasab, A.D., Javanshir, A., Khoie, F.R. and Moghaddam, M. (2007) Influence of redroot pigweed (*Amaranthus retroflexus* L.) emergence time and density on yield and quality of two sugar beet cultivars. *Journal, Food, Agriculture and Environment* 3-4: 261-266.

Mason, H., Goonewardene, L. and Spaner, D. (2008) Competitive traits and the stability of wheat cultivars in differing natural weed environments on the northern Canadian Prairies. *Journal of Agricultural* 146: 21-33.

Paolini, R., Principi, M., Froud-Williams, R.J., Del Puglia, S. and Biancardi, E. (1999) Competition between sugarbeet and *Sinapis arvensis* and *Chenopodium album* as affected by timing of nitrogen fertilisation. *Weed Research* 39: 425-440.

Roumet, C., Urcelay, C. and Díaz, S. (2006) Suites of root traits differ between annual and perennial species growing in the field. *New Phytologist* 170: 357-368.

Saccomani, M., Cacco, G. and Ferrari, G. (1981) Efficiency of the first steps of sulfate utilization by maize hybrids in relation to their productivity. *Physiologia Plantarum* 53: 101-104.

Saccomani, M., Stevanato, P., Trebbi, D., McGrath, M. and Biancardi, E. (2009) Molecular and morpho-physiological characterization of sea, ruderal and cultivated beets. *Euphytica* 169: 19-29.

Sorgonà, A., Abenavoli, M.R., Gringeri, P.G. and Cacco, G. (2007) Comparing morphological plasticity of root orders in slow- and fast-growing citrus rootstocks supplied with different nitrate levels. *Annals of Botany* 100: 1287-1296.

Stevanato, P., Saccomani, M., Bertaggia, M., Bottacin, A., Cagnin, M., De Biaggi, M. and Biancardi, E. (2004) Nutrient uptake traits related to sugarbeet yield. *Journal of Sugar Beet Research* 41: 89-99.

Stevanato, P., Biancardi, E., Bertaggia, M., Tamino, G. and Saccomani, M. (2006) Competizione fra barbabietola da zucchero e specie infestanti in agricoltura biologica: Ruolo del sistema radicale. *Agroindustria* 5: 37-42.

Stevanato P., Trebbi, D., Bertaggia, M., Biancardi, E. and Saccomani, M. (2008) Apparato radicale e competitività della barbabietola da zucchero verso le malerbe. *Agroindustria* 6(3): 107-112.

Stevanato P., Trebbi, D. and Saccomani, M. (2010) Root traits and yield in sugar beet: Identification of AFLP markers associated with root elongation rate. *Euphytica* 173: 289-298.

Tilman, D. and Wedin, D. (1991) Plant traits and resource reduction for five grasses growing on a nitrogen gradient. *Ecology* 72: 685-700.

Turner, R.J., Davies, G., Moore, H., Grundy, A.C. and Mead, A. (2007) Organic weed management: A review of the current UK farmer perspective. *Crop Protection* 26: 377-382.

Vamerali, T., Saccomani, M., Bona, S., Mosca, G., Guarise, M. and Ganis, A. (2003) A comparison of root characteristics in relation to nutrient and water stress in two maize hybrids. *Plant and Soil* 255: 157-167.

Wilson, R.G., Miller, S.D. and Nissen S.J. (2001) Weed control. In: *Sugarbeet Production Guide*, 2001. University of Nebraska, Colorado State University, Montana State University, University of Wyoming, USDA Agricultural Research Service: 117-130.