Root Length Density and Yield Traits of Broccoli (*Brassica oleracea* L. var. *italica* Plenck) as Affected by Different Techniques of Seedling Growing and Transplanting

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Abstract

The research was carried out in Ofanto plain (southern Italy, Lavello, Basilicata region, 41°03'N, 15°42'E, 180 m a.s.l.), in order to study the response of broccoli ('Marathon F_1') both root length density (RLD) and yield traits as affected by: 1) different techniques of production of seedlings (volume containers equal to 13, 46, 90 and 180 cm^3), 2) different periods of transplant (24/08/2005 and 26/09/2005) and 3) different procedures of transplantation (with or without biodegradable container). A double rows lay out of planting, for a crop density of 2.94 plants m^{-2} was performed. The harvest started on 02.11.2005 and 12.12.2005, and ended after 30 and 45 days, respectively for the two transplantation times. Along with harvests, soil samples were taken at different positions (close to the plant, between the rows, between the doubled rows) and at different depths (0-20, 20-40, 40-60 cm) in order to measure RLD according to Newman's method (1966). The results showed that the RLD and the heads (corymbs) yield (as so as all the main yield components) were significantly influenced by: 1) the volume of containers, from 1.9 to 2.4 cm cm^{-3} and from 9.7 to 13.5 t ha^{-1}, respectively for the smallest and the largest container; 2) the time of transplant, with values of 2.4 , 1.9 cm cm^{-3} and 14.6, 10.9 t ha^{-1}, respectively, for the first and the second time; 3) the presence of the container at transplant, with values of 2.0, 2.3 cm cm^{-3} and 12.9, 13.5 t ha^{-1} for the transplant with and without container, respectively. Moreover, with reference to the RLD, were observed, as expected, a reduction with: 1) increasing distance from the plant (values from 3.3 to 1.3 cm cm^{-3}, respectively for samples collected near the plant and between the doubled rows) and 2) with increasing depth (values from 3.7 to 0.8 cm cm^{-3}, respectively for the 0-20 and the 40-60 cm layer).

INTRODUCTION

The root system has traditionally been associated with water and nutrient absorption and anchorage of the plant (Klute and Peters, 1991; Russel and Newbould, 1991). More recently increased interest in root hormonal biosynthesis, interaction of roots with mycorrhizal fungi and with organisms involved in symbiotic nitrogen fixation have amplified the importance of study plant root systems (Bowen and Rovira, 1991). Likewise, the productive performances are of fundamental importance not only for the development of the most appropriate strategies, agricultural and commercial, but even before that, for the success and spread of a crop.

In Italy Broccoli (*Brassica oleracea* L. var. *italica* Plenck) and cauliflower (*B. oleracea* var. *botrytis* L.) crops are grown on 17,637 hectares (http://www.agri.istat.it), of which the 66% are located in the South and almost 4,500 hectares are cultivated in Apulia and Basilicata regions. In Basilicata the cultivation is expanding and has the highest concentration in the Ofanto plain where the broccoli crop alone reaches about 400 ha. Crop planting is commonly made by using seedlings, at 3^{rd} - 4^{th} true leaf stage, previously grown into cell containers close to specialized nurseries. Cell size of containers is very important in order to obtain high quality of transplants (NeSmith and Duval, 1998); however, the agronomic response after crop transplanting can vary with the vegetable species used so much that in some case yield levels cannot be influenced by the volume of containers used for transplants production (Dufault and Waters, 1985).

The aim of this paper is to study the root length density (RLD) and the yield response of broccoli crop as affected by different techniques of seedling production as well as different periods and procedures of transplant.

MATERIALS AND METHODS

The research was carried out at Lavello (Basilicata region, 41°30'N, 15°48'E, 180 m a.s.l.), in open filed, on a sandy-silt soil (sand: 49.7%; silt: 28.3%; clay: 21.9%), having the following characteristics: pH 7.10; organic matter 1.58%; salinity 0.69%; total nitrogen 0.97%; $CaCO_3$ 31.06%; P_2O_5 588.20 ppm; K_2O 210 ppm; volumetric water content 30.4% at field capacity and 16.7% at wilting point; bulk density1.25 kg dm^{-3}. The soil was ploughed 40 cm-depth and uniformly rotated before pre-planting, fertilization realized by using 110, 220 and 160 kg ha^{-1} of N, P_2O_5 and of K_2O, respectively; during crop cycle further supply of N (200 kg ha^{-1}) was made. Watering was provided through a drip irrigation system with dripper lines 1.70 m apart and emitters (2-3 l h^{-1} water flow rate) spaced 0.30 m from each other.

The transplant of broccoli ('Marathon F_1') took place by using three-four-leaved seedlings and considering 3 factors: 1) different techniques of production of seedlings, i.e., by using containers (pots) having a volume equal to 13, 46, 90 or 180 cm^3; 2) different periods of transplant (24.08.2005, 26.09.2005) and 3) different procedures of transplant (seedlings with and without undergrounding container). All the pots used, cylindrical in shape, were made by biodegradable polyester 20% added of vegetable fibers.

Adopting a split-split plot design with three replications, a double rows layout of planting (0.40 m between rows, 0.30 m between plants on the row, 1.70 m between the doubled rows), for a crop density of 2.94 plants m^{-2}, was performed.

Besides, the different methods of seedlings bedding (with or without bio-degradable pots) were compared only in the first time of transplant.

At the end of each growing cycle soil cores were taken from the layers of 0-20, 20-40 and 40-60 cm depth to measure root length density (RLD) in three different positions with respect to the plant: close to the plant, between plants on the same row and between plants in the middle of double-row. The soil samples were dried at 60 °C in ventilated oven in order to preserve the conservation of roots. Later, after treating with Calgon (85% sodium hexametaphosphate + 15% sodium bicarbonate, at 10% on weight basis), repeated washing and separation by square mesh sieve of 0.2 mm, the root length was determined according to Newman method (1966). Root length was converted into RLD by means of the soil bulk density of 1.25 kg dm^{-3}.

The harvest of heads (corymbs) started on 2.11.2005 and 19.12.2005 and ended after 30 and 45 days, respectively, for the two transplant dates. At each harvest, fresh and dry weight of heads, both main (central) and secondary (lateral) ones, head mean weight, shoot and leaf dry biomass and harvest index, were assessed on samples taken from 8 m^2 from each plot. Besides, crop earliness was evaluated considering the time of the first harvest (number of days from transplant) and also by calculating the harvest mean time (HMT) according to the equation:

$$\text{HMT (d)} = \sum(y_1*d_1)\ldots.(y_n*dn)\ /Y$$

where "d_1" and "d_n" indicate, respectively, the days of the first and the last harvest; "y_1" and "y_n" indicate the yield for each harvest, and "Y" is the cumulative yield of all the harvests.

All collected data were processed by analysis of variance (ANOVA) using MSTAT-C ver. 2.0 software; among the sources of variation, transplant time (main plot) and transplant procedure (sub-plot) were considered as fixed factor while container volume (sub-sub-plot) was the random factor.

RESULTS AND DISCUSSION

The results showed that the RLD and the corymbs yield (as so as all the main morpho-productive traits) were significantly influenced by the container volume, the transplant time and the presence/absence of the container at transplant. Moreover, with reference to the RLD, were observed significant variations according with distance from the plant and with depth.

The RLD showed a higher value (0.01 P) of about 17% referring to the earlier time of transplant than the later, respectively 2.25 and 1.88 cm cm^{-3}. The container cell volumes adopted for the growth of seedlings showed RLD values of 2.26 and of 2.19 cm cm^{-3}, respectively for the larger containers (180 and 90 cc), not different from each other but higher (0.01 P) than that recorded for the smaller container, equal to 1.81 cm cm^{-3}, while the 46 cm^{-3} container has highlighted an intermediate value of 2.00 cm cm^{-3}. Moreover, regardless of the container cell volumes, the technique of transplant without biodegradable container showed a higher value (0.01 P) with respect to transplant with container, with average values, respectively, of 2.38 and 2.08 cm cm^{-3}. The position and the depth of sampling, as expected, showed values of RLD decreasing (0.01 P): the first, with increasing distance from the plant, the second, with the increase of depth. In particular, passing from drawing near the plant to the one on the row and to that in the middle of the double-row, were found respectively values of 3.06, 1.80 and 1.34 cm cm^{-3}, while passing from the layer 0-20 cm to 20-40 cm and to 40-60 cm depth were observed average values respectively of 3.56, 1.82 and 0.83 cm cm^{-3}. Significant, also, were the interactions of the container volume with the sampling depth and with the sampling position. In the first case (Fig. 1) the interactive effect is due to values of RLD increasing with the volume of the container only to the layer 0-20 cm depth, while those for the deeper layers were, respectively, not different between them. In the second case (Fig. 2), it was observed a similar pattern relatively both to the 0-20 and 20-40 cm depth layer.

With reference to the above-ground part of the plant all the measured parameters were significantly affected by transplant date, container size and transplant modalities (Table 1). In particular, early transplant significantly increased yield and average weight both of main and lateral heads; also the total dry biomass and the harvest index were higher in the first broccoli crop cycle, while corymb dry matter content (%) showed a lower value. The delay in transplant increased the crop cycle length prolonging significantly both the beginning of harvests and the HMT.

The container size positively influenced marketable yield, heads mean weight and total dry biomass of broccoli. The seedlings grown in 90 and 180 cm^3 pots reached the highest yields, equal to 13.8 and 3.8 t ha^{-1} on average, respectively, for the main and secondary heads. The decrease in the pot volume at 46 and 13 cm^3 reduced yields to 12.0 and 9.7 t ha^{-1} for the main heads and to 3.3 and 2.0 t ha^{-1} for the secondary ones. A similar trend was observed for the average weight of heads and the total dry biomass. The use of bigger pots improved also the crop earliness by anticipating the first harvest date and reducing the HMT values. However, the best results were achieved by 180 cm^3 pots which, respect to 13 cm^3 ones, anticipated of 9 days the beginning of the harvest and reduced of 13 days the HMT.

About transplant modalities, the undergrounding of the whole potted seedlings negatively affected yield both of main and secondary heads, mean weight and dry matter content of main heads, total dry biomass of crop and harvest index; moreover, significantly influenced crop earliness, delaying of 4 and 3 days the first picking of main and secondary heads, respectively, and the HMT.

CONCLUSIONS

Overall, the observation of the collected experimental data put in relevance the influence of the container cell volume adopted for the seedlings growth, which shows in most cases linear patterns, both referring to root system and shoot growth. Indeed, increasing volumes determined increase in RLD, marketable yield and mean weight, both for principal and secondary inflorescences, earliness, and total dry biomass. Similar results on pepper, both on root and shoot, are reported by NeSmith et al. (1992), on eggplant yield by Harmon et al. (1991) and on early yields of broccoli and cauliflower by Jones at al. (1991). Also the marketable yields of cabbage (White, 1980) and Chinese cabbage (Kratky et al., 1982) crops increased with higher container volume of transplants. On the contrary, a research conducted by Dufault and Waters (1985) showed that yields of broccoli and cauliflower crops were not affected by seedling container size. Whitwell and Crofts (1972) found an improving of earliness and a reduction of yields of cauliflower with the use of seedlings grown in large container cells than in small ones. Finally, as reported by Csizinszky and Schuster (1993) for cabbage, the effect of container cell size on yield and crop earliness can vary in relation to growing season.

The restriction of the root system in confined spaces has resulted in a different capacity for the plants, after transplant in open field, to develop adequate root systems and, consequently, to give rise to good productive performances. This response is also supported by the inverse relationship between the container cell volume with the timing of harvest, which shows how the initial stress is not recovered even from the point of view of time. Moreover, for many characters were no differences between the two containers of greater volume, while both gave different results as compared to those of lesser volume. It follows that the present experience has shown a critical volume for the growth of seedlings of broccoli between 90 and 46 cm^3.

Besides to container cell volume, the growth of the whole plant and its production have been affected positively both by the earliest time of transplant and by transplanting seedlings without biodegradable container. These conditions have promoted the growth of the plant, especially in the period immediately following the transplant; moreover, the others experimental treatments compared resulted in a gap that has not been recovered during the crop cycle, and that has resulted, for the above cited techniques, in values of RLD and yield higher and in a more marked precocity of harvest. On the average, with reference to vegetable crops widespread in the region, broccoli showed a RLD similar to muskmelon (Lovelliet et al., 2004), lower as tomato (Candido et al., 2005) and pepper (De Pascale et al., 2003).

Finally, the most appropriate choice relative to the volume of the container, the transplant timing and the transplant with biodegradable pot must necessarily take into account the overall economic balance of the crop and, in particular, with reference to the technical aspects examined here, the agronomic requirements and market of crops in precession and in succession, and the charge of a single plant when transplanted.

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Tables

Table 1. Effect of transplant time, container volume and transplant procedure on some morpho-agronomic traits of broccoli.

Treatments	Heads							Total dry biomass ($g\ m^{-2}$)	Harvest index
	Main ones					Secondary ones			
	Marketable yield ($t\ ha^{-1}$)	Mean weight (g)	Dry matter content (%)	HMT (d)	First harvest (d)	Marketable yield ($t\ ha^{-1}$)	Mean weight (g)		
Transplant time (1)									
Aug. 25th	14.4±0.5	461±11.1	8.1±0.1	81±0.8	75±1.0	3.7±0.4	66±3.7	597±12.3	0.22±0.01
Sept. 26th	10.3±0.6	321±14.8	9.0±0.2	101±1.5	92±2.3	2.8±0.2	54±2.6	506±24.6	0.16±0.02
	**	**	*	**	**	*	*	*	*
Container volume (cm^3) (2)									
180	14.1±0.9 a	423±18.1 a	8.6±0.1 a	87±1.9 d	76±1.5 c	3.6±0.3 a	63±3.2 a	624±18.1 a	0.19±0.02 ab
90	13.6±1.0 a	410±15.2 a	8.1±0.2 b	89±1.5 c	81±1.7 b	4.0±0.5 a	67±4.9 a	599±13.2 a	0.19±0.02 ab
46	12.0±1.0 b	380±16.0 b	8.7±0.3 a	92±1.7 b	86±1.9 a	3.3±0.4 ab	58±2.4 b	521±24.9 b	0.20±0.01 a
13	9.7±1.1 c	350±12.1 c	8.8±0.4 a	96±1.8 a	90±2.1 a	2.0±0.5 b	51±4.0 c	463±31.8 c	0.17±0.01 b
Transplant procedure(1)									
Without pot	14.0±0.5	419±15.6	8.4±0.1	87±1.4	78±1.8	3.8±0.4	65±3.1	616±12.0	0.19±0.02
With pot	12.9±0.4	405±16.0	7.9±0.2	90±1.3	82±2.2	3.0±0.3	61±3.3	587±13.4	0.17±0.01
	**	*	*	**	**	*	ns	**	*

(1) * = Significance at $P \leq 0.05$; ** = Significance at $P \leq 0.01$; ns = not significant differences.
(2) Means in each column followed by the same letters are different at $P \leq 0.05$ according to SNK Test.

Figures

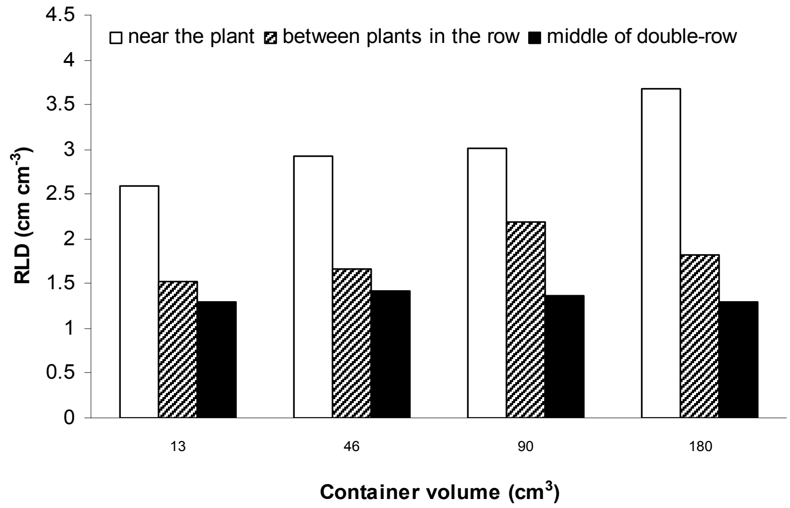

Fig. 1. RLD as affected by container cell volume and sampling position. (LSD≤ 0.01 P = 0.52).

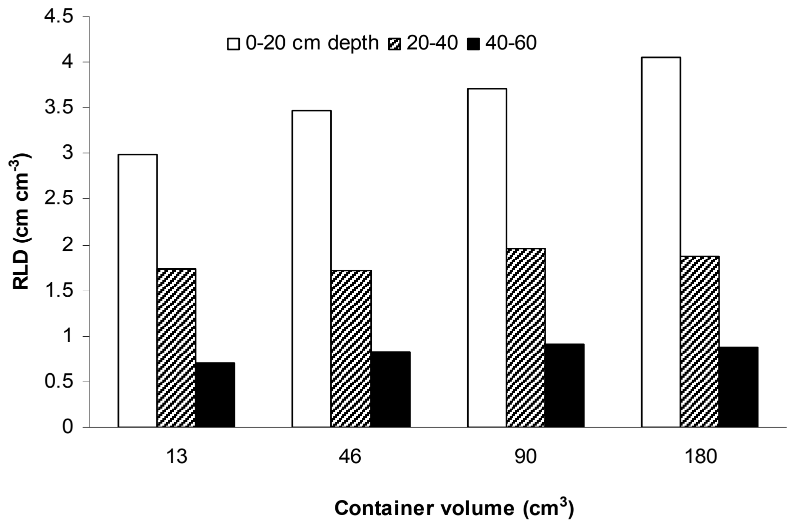

Fig. 2. RLD as affected by container cell volume and depth of sampling. (LSD≤0.05 P = 0.39).