J. AMER. SOC. HORT. SCI. 124(5):458–461. 1999.

Root Distribution and Yield of Direct Seeded and Transplanted Watermelon

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ADDITIONAL INDEX WORDS. seedling, roots, stand establishment, transplant, *Citrullus lanatus*

ABSTRACT. Transplanting generally results in more rapid stand establishment than direct seeding for cucurbit crops. A 2-year field study was conducted to examine the pattern of rooting of watermelon [*Citrullus lanatus* (Thunb.) Matsum. & Nak.] following usage of different planting methods, and to determine subsequent effects on crop yield. Root length was assessed by obtaining soil cores three times per growing season to a depth of 75 cm. Transplanted watermelons generally had greater root length density in the upper 30 cm of soil 4 to 7 weeks after planting (WAP). However, by 11 to 12 WAP root distribution was similar over the entire 75 cm soil profile for the two planting methods. Total marketable yields were comparable for direct seeded and transplanted watermelons during 1995, but transplanted watermelon yield exceeded direct seeded yield by 40% in 1996. In both years, 90% to 100% of the marketable yield of transplanted watermelons was obtained at the first harvest, compared to 0% to 55% for direct seeded watermelons. These findings suggest that rapid root proliferation of transplanted watermelons may be an important factor in their earlier establishment and increased early yields as compared to direct seeded watermelons.

Optimum vegetable crop production can only be accomplished if successful stand establishment is achieved first, as each plant contributes to total crop yield (Orzolek, 1991). Many vegetable growers across the United States use transplants to enhance stand establishment. Some advantages of using transplants as compared to direct seeding of crops include more efficient use of costly hybrid seed, avoidance of unfavorable environments such as cool soils, increased crop uniformity, and enhanced earliness of crop productivity (Liptay et al., 1982; NeSmith, 1994, 1997; Orzolek, 1991, 1996). Transplanted seedlings can experience check or shock under field conditions, however, their successful use depends largely on the ability of the plants to resume growth rapidly following transplanting (McKee, 1981a, 1981b).

While several studies have compared yields and above-ground growth of transplants and direct seeded cucurbit crops (Hall, 1989; NeSmith, 1993, 1994, 1997), few have examined root growth (Eigsti, 1971; Elmstrom, 1973). In fact, minimal research has focused on development of transplant root systems following planting and the role of seedling roots in stand establishment (Leskovar and Stoffella, 1995; Nicola, 1998). Rate of root proliferation has a direct influence on nutrient acquisition and subsequent crop yield (Barber and Silberbush, 1984). The type of root system developed for transplants can differ from that of direct seeded plants, particularly for crops having a prominent tap root (Elmstrom, 1973; Leskovar and Cantliffe, 1993; Leskovar and Stoffella, 1995; McKee, 1981a). Since roots and shoots are frequently in an equilibrium (i.e., growing and developing proportional to each other), any disturbance of this equilibrium can alter crop growth (Russell, 1977; Taylor and Arkin, 1981).

Numerous studies suggest that excessive root restriction of container-grown plants (i.e., transplants) can have pronounced effects on pre- and postplant morphology, physiology, growth, and development (NeSmith and Duval, 1998). Therefore, the objectives of this research were to quantify root distribution of transplanted and direct seeded watermelons (*Citrullus lanatus*) over two growing seasons under field conditions, and to determine the influence of the stand establishment methods on crop yields.

Received for publication 2 Nov. 1998. Accepted for publication 20 May 1999. This research was supported by state and Hatch Act funds allocated to the Georgia Agricultural Experiment Station. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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Materials and Methods

Experiments were conducted at Griffin, Ga., during 1995 and 1996 on a Cecil sandy clay loam (clayey, kaolinitic, thermic Typic Hapludult). On 26 May 1995 and 14 May 1996, 'Royal Sweet' watermelons were transplanted or direct seeded in the field in a randomized complete block design with four replications. Tillage preparation before planting consisted of chisel plowing to an approximate depth of 30 cm, disk harrowing, rototilling, and marking rows with a furrow opener. For direct seeded plots, three to four seeds were sown per hill by hand, and hills were thinned to a single plant after emergence. For transplanted plots, 4-week-old transplants grown in 50-cm^3 cells containing a commercial growing medium (Metro-Mix 300, W.R. Grace and Co., Cambridge, Mass.) were planted by hand. During greenhouse production, the transplants were watered daily and fertilized three times weekly with a water soluble fertilizer (20N–8.8P–16.6K plus micronutrients at a concentration of 200 $mg \cdot L^{-1}$ N; Peters Professional General Purpose Fertilizer, W.R. Grace and Co.). Minima/maxima greenhouse temperatures were 20 to 21/25 to 30 °C. Only natural light was used during transplant production, and its transmission into the greenhouse was ≤70% of sunlight. In the field, individual plot size was six rows wide by 9 m long. Row width was 1.8 m and in-row spacing was 0.9 m. Before planting, a 10N–4.4P–8.3K granular fertilizer was incorporated at 560 $kg \cdot ha^{-1}$. An additional application of N (as ammonium nitrate) at 78 $kg \cdot ha^{-1}$ was surface side dressed 4 weeks after planting. Weeds were controlled using a preplant application of ethafluralin [*N*-ethyl-*N*-(2-methyl-2 propenyl)-2, 6-dinitro-4-(trifluoromethyl) benzenamine] at an a.i. rate of 1.25 $kg \cdot ha^{-1}$ and hand weeding. Recommended insect and disease control measures were also used. Overhead-sprinkler irrigation was used to supplement rainfall (Table 1). The target water supply (rainfall plus irrigation) weekly was at least 4 cm. If there was not sufficient rainfall, irrigation was applied every 3 to 4 d (2 cm/application).

Watermelon roots were sampled at 4, 6, and 11 weeks after planting (WAP) in 1995, and at 5, 7, and 12 WAP in 1996. Samples were collected by taking soil cores (5 cm in diameter) with a tractor-

Table 1. Average maximum and minimum air temperatures, average soil temperature (at a 10 cm depth), and total rainfall in May, June, July, and August 1995 and 1996 in Griffin, Ga.

	Avg air temp (°C)							
	Max		Min		Avg soil temp (°C)		Total rainfall (cm)	
Month	1995	1996	1995	1996	1995	1996	1995	1996
May	28.2	29.1	15.3	15.4	21.9	22.9	4.7	5.7
June	29.0	30.7	16.9	17.8	24.2	25.9	7.0	3.4
July	33.3	32.0	20.3	19.7	26.5	27.8	5.7	11.8
August	31.6	30.3	21.0	18.9	26.4	26.7	12.8	3.6

mounted, hydraulic sampler to a depth of 75 cm. Sampling sites down the row were predetermined and marked. Thus, at each sampling the tractor was backed into the sample area without disturbance of future sampling areas. For each sample date, three cores were taken in the row of each plot between two plants. Sample locations were 15 cm to the side of each plant (two cores), and halfway between (45 cm) the two plants (one core). Samples were cut into 15 cm increments, placed in plastic bags, and stored in a freezer (–4 to –2 °C) until processing. Roots were separated from soil using a specially designed root washer (Smucker et al., 1982). A 6- to 8-min elutriation time was used, which is estimated to recover 97% of the roots for this textured soil according to Smucker et al., 1982. The washed roots were cleaned further of residue by hand, and were refrigerated until length assessments were made. Root lengths of the samples were measured with an image analysis system (AgVision, Decagon Devices, Pullman, Wash.).

Two harvests were made during 1995 (10 and 17 Aug.) and three harvests were made in 1996 (25 July, 6 and 16 Aug.). In 1995, only one undisturbed row was harvested, and in 1996 three undisturbed rows were harvested. Watermelons of each treatment were harvested when they were mature (brown tendril near stem, yellow color development on underside of fruit). Individual fruit were weighed separately and the number of fruit per plot was recorded. All data were subjected to analysis of variance and means were separated by least significant difference procedures.

Results

The two growing seasons did not differ greatly in average air and soil temperatures (Table 1). The amount of rainfall during June 1996 was only about half that of June 1995 The reverse was true for July of each year. While these rainfall patterns may have affected solar radiation received, they did not have a great influence on soil moisture since supplemental irrigation was used.

The main effect of depth of roots was significant ($P = 0.0001$) on all sampling dates in both years (Table 2). At 4 WAP in 1995 transplanted 'Royal Sweet' watermelons had greater root length ($P = 0.0833$) across all depths than direct seeded watermelons (Table 2, Fig. 1). However, there was no significant planting method by depth interaction for the first sampling date in 1995. Both direct seeded and transplanted watermelons had some roots down to 75 cm by 4 WAP. By 6 WAP in 1995, there was a significant planting method by depth interaction ($P = 0.0730$) for root lengths. The transplanted crop had 49% greater root length in the upper 15 cm of soil as compared to the direct seeded crop. Root length density was not different between the two planting methods at other soil depths 6 WAP. Root length distribution was not significantly different between transplanted and direct seeded watermelons at 11 WAP in 1995 over the entire 75 cm soil depth.

The main effect of planting method for root length was significant ($P = 0.0008$) at 5 WAP during 1996 (Table 2, Fig. 2). Transplanted watermelons had significantly greater root length throughout the first two soil depths on the first sampling date in 1996. Both transplanted and direct seeded watermelons had some roots distributed over the entire 75 cm soil profile, suggesting significant downward movement of roots for either stand establishment method. By 7 WAP in 1996, transplanted watermelons had significantly ($P = 0.0001$) greater root length than direct seeded watermelons at all sampling depths. The largest difference in root length occurred at the 30 cm soil depth, with the transplanted crop having more than 60% greater root length than the direct seeded crop 7 WAP in 1996. Near the end of the growing season in 1996 (12 WAP), root distribution was not significantly different for the two stand establishment methods. The direct seeded watermelon crop showed a substantial increase in root length at all depths from 7 WAP to 12 WAP in 1996.

Total watermelon yield was not different for the two planting methods in 1995; although all transplanted fruit were ready at the first harvest, whereas, only 55% of the direct seeded fruit were harvested on that date (Table 3). During 1996, total yields of transplanted watermelon were >40% more than direct seeded yields, with nearly 90% of the transplanted crop harvested on the first harvest date. There was no difference in average fruit weight between transplanted and direct seeded watermelons in either year (when there were fruit harvested for both treatments) with the exception of the second harvest in 1996.

Table 2. *P* values (probability > F) of main effects and interaction of planting method (PM) and soil depth (D) for root length density of transplanted and direct-seeded watermelons for sampling dates during 1995 and 1996.

	P value					
	1995			1996		
	Weeks after planting					
Effect	4[z]	6	11	5	7	12
PM	0.0833	0.0501	0.2522	0.0008	0.0001	0.8665
D	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
PM × D	0.4772	0.0730	0.3570	0.4227	0.1282	0.3256

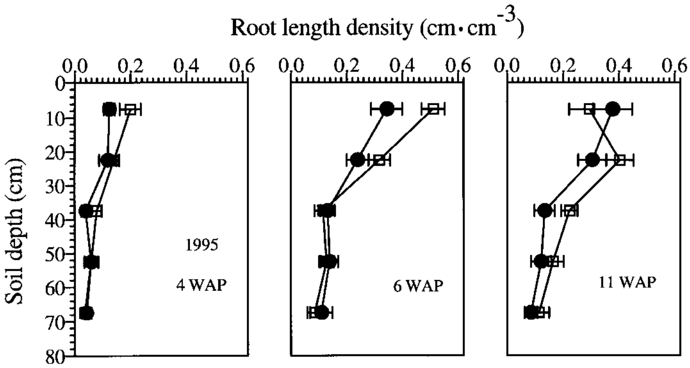

Fig. 1. Mean root length density and standard errors of transplanted (open squares) and direct seeded (closed circles) 'Royal Sweet' watermelons in 15 cm increments over a 75 cm soil depth during 1995. Data are for samples taken 4, 6, and 11 weeks after planting (WAP).

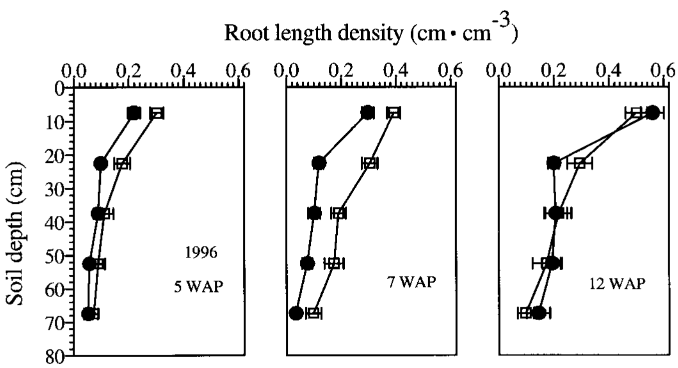

Fig. 2. Mean root length density and standard errors of transplanted (open squares) and direct seeded (closed circles) 'Royal Sweet' watermelons in 15 cm increments over a 75 cm soil depth during 1996. Data are for samples taken 5, 7, and 12 weeks after planting (WAP).

Discussion

Elmstrom (1973) indicated that roots of transplanted watermelon were more shallow, but more extensive than roots of direct seeded watermelon. Eigsti (1971) on the other hand reported that rooting patterns of triploid watermelons that had been transplanted or direct seeded were similar near maturity of the crop. Both of these studies were based on one time assessments of root systems. The data from the current experiment indicate that time of sampling of roots is very important in describing root distribution of transplanted and direct seeded crops and their possible differences.

In studies of root systems of direct seeded and transplanted pepper (*Capsicum annuum* L.), it has been shown that the root systems differ (Leskovar et al., 1990; Leskovar and Cantliffe, 1993). Transplanted peppers had greater root dry weights 50 d after planting (DAP) than direct seeded peppers, but between 50 and 70 DAP, roots of direct seeded pepper showed a higher relative growth rate (Leskovar and Cantliffe, 1993). The authors partitioned roots into tap roots, lateral roots, and basal roots. They indicated that most of the direct seeded roots were either tap root or laterals; whereas, transplanted roots were predominantly basal roots. Their samples were limited to the upper 20 cm of soil. While the current investigation of watermelon roots did not examine root types, the data show that both direct seeded and transplanted watermelons distributed roots over the entire 75 cm soil profile. Likely, growing watermelons in containers (transplants) modifies the tap root, but this modification apparently did not limit postplant rooting depth.

Early yields (i.e., first harvest) were greater for transplanted watermelons in both years, which has been reported previously for cucurbit crops (Elmstrom, 1973; Hall, 1989; NeSmith, 1993, 1994, 1997). The reason for less total yield of direct seeded watermelons in 1996 is not clear. Weather patterns could have affected pollinator activity and subsequent fruit set, but there was no measure or observance of this. When the watermelon yield trends of the current study are compared with root growth data, they depict that the greatest yield difference occurred in the year (1996) when the most pronounced difference in root proliferation between the treatments was observed. This suggests that more extensive rooting of transplants may be responsible, in part, for increased yields. Leskovar and Cantliffe (1993) suggested that the more extensive root growth of pepper transplants may have resulted in their superior yields as compared to direct seeded pepper.

Wien et al. (1993) concluded that increased plant growth of tomato (*Lycopersicon esculentum* Mill.) transplants grown using a plastic mulch, as compared to transplants without mulch, was a consequence of enhanced root growth and nutrient uptake early in the season for the mulched plants. A similar response may result from transplanting watermelons as opposed to direct seeding. It is plausible that rapid proliferation of transplanted roots in the upper soil depths allows these plants to acquire nutrients earlier. Hall (1989) reported that transplanted watermelon vines covered 40% to 50% of the plot area 1 month after planting, compared to only 10% vine coverage of direct seeded watermelon plots. Furthermore, Elmstrom (1973) hypothesized that increased yields for watermelon transplants as compared to direct seeded watermelons may be due to more extensive root growth of the transplanted crop early in the season, which allowed the transplants to better use water and nutrients. Tiessen and Carolus (1963) stated that root growth of transplants becomes very active within 3 d after transplanting, and that this rapid root growth affects nutrient uptake.

Table 3. Yield and average fruit weight for transplanted and direct-seeded 'Royal Sweet' watermelons on different harvest dates during 1995 and 1996 in Griffin, Ga.

	Harvest							
	First		Second		Third		All	
Planting method	Yield ($kg·m^{-2}$)	Fruit wt (kg)	Yield ($kg·m^{-2}$)	Fruit wt (kg)	Yield ($kg·m^{-2}$)	Fruit wt (kg)	Yield ($kg·m^{-2}$)	Fruit wt (kg)
				1995				
Direct-seeded	3.3 a[z]	9.6 a	2.7	6.2	---	---	6.0 a	8.0 a
Transplant	6.7 b	8.6 a	---	---	---	---	6.7 a	8.6 a
				1996				
Direct-seeded	---	---	2.9 a	10.9 a	1.4	9.4	4.3 b	10.4 a
Transplant	6.7	10.1	0.8 b	7.7 b	---	---	7.5 a	9.9 a

[z]Means within a column for a year followed by the same letter were not significantly different at $P = 0.05$.

Advanced physiological age of transplanted seedlings does not always cause increased early or total yields as compared to direct seeded crops (Cooksey et al., 1994; Leskovar and Cantliffe, 1993). Also, advanced physiological age of different aged transplants has been shown to have no yield advantage for cucurbit crops (NeSmith, 1993, 1994; Vavrina et. al., 1993). Thus, the simple fact that transplants are advanced physiologically does not insure they will have superior growth. Robbins and Pharr (1988) found that root restriction of cucumber (*Cucumis sativus* L.) caused an accumulation of starch in leaves of seedlings due to feedback from the root system. Perhaps such starch accumulation aids in transplanted seedlings supplying carbohydrates rapidly to roots once root restricting conditions are alleviated following field planting.

In conclusion, this research with transplanted and direct seeded watermelons has revealed that the root distribution patterns over time can be quite different for the two stand establishment methods. Although the distribution patterns were similar by the end of the growing season, increased root growth of transplants early in the growing season may provide advantages over direct seeding of crops.

Literature Cited

Barber, S.A. and M. Silberbush. 1984. Plant root morphology and nutrient uptake, p. 65–87. In: S.A. Barber and D.R. Bouldin (eds.). Roots, nutrient and water influx, and plant growth. Amer. Soc. Agron. Special Publ. 49.

Cooksey, J.R., B.A. Kahn, and J.E. Motes. 1994. Plant morphology and yield of paprika pepper in response to method of stand establishment. HortScience 29:1282–1284.

Eigsti, O.J. 1971. A comparison of mature triploid watermelon systems of roots and crown from direct field seeded plants and transplants. HortScience 6:288 (abstr.).

Elmstrom, G.W. 1973. Watermelon root development affected by direct seeding and transplanting. HortScience 8:134–136.

Hall, M.R. 1989. Cell size of seedling containers influences early vine growth and yield of transplanted watermelon. HortScience 24:771–773.

Leskovar, D.I. and D.J. Cantliffe. 1993. Comparison of plant establishment method, transplant, or direct seeding on growth and yield of bell pepper. J. Amer. Soc. Hort. Sci. 118:17–22.

Leskovar, D.I., D.J. Cantliffe, and P.J. Stoffella. 1990. Root growth and root–shoot interaction in transplants and direct seeded pepper plants. Environ. Expt. Bot. 30:349–354.

Leskovar, D.I. and P.J. Stoffella. 1995. Vegetable seedling root systems: Morphology, development, and importance. HortScience 30:1153–1159.

Liptay, A., E.F. Bolton, and V.A. Dirks. 1982. A comparison of field-seeded and transplanted tomatoes grown on a clay soil. Can. J. Plant Sci. 62:483–487.

McKee, J.M.T. 1981a. Physiological aspects of transplanting vegetables and other crops. I. Factors which influence re-establishment. Hort. Abstr. 51:265–272.

McKee, J.M.T. 1981b. Physiological aspects of transplanting vegetables and other crops. II. Methods used to improve transplant establishment. Hort. Abstr. 51:355–368.

NeSmith, D.S. 1993. Transplant age influences summer squash growth and yield. HortScience 28:618–620.

NeSmith, D.S. 1994. Transplant age has little influence on yield of muskmelon (*Cucumis melo* L.). HortScience 29:916.

NeSmith, D.S. 1997. A comparison of yields and yield components from different muskmelon (*Cucumis melo* L.) production systems. J. Veg. Crop Prod. 3:37–45.

NeSmith, D.S. and J.R. Duval. 1998. The effect of container size. HortTechnology 8:495–498.

Nicola, S. 1998. Understanding root systems to improve seedling quality. HortTechnology 8:544–549.

Orzolek, M.D. 1991. Establishment of vegetables in the field. HortTechnology 1:78–81.

Orzolek, M.D. 1996. Stand establishment in plasticulture systems. HortTechnology 6:181–185.

Robbins, N.S. and D.M. Pharr. 1988. Effect of restricted root growth on carbohydrate metabolism and whole plant growth of *Cucumis sativus* L. Plant Physiol. 87:409–413.

Russell, R.S. 1977. Plant root systems: Their function and interaction with the soil. McGraw-Hill, New York.

Smucker, A.J.M., S.L. McBurney, and A.K. Srivatava. 1982. Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. Agron. J. 74:500–503.

Taylor, H.M. and G.F. Arkin. 1981. Root zone modification: Fundamentals and alternatives, p. 3–17. In: G.F. Arkin and H.M. Taylor (eds.). Modifying the root environment to reduce crop stress. Amer. Soc. Agr. Eng. Monogr. 4.

Tiessen, H. and R.L. Carolus. 1963. Effect of different analyses and concentrations of fertilizer solutions on initial root growth of tomato and tobacco plants. Proc. Amer. Soc. Hort. Sci. 83:680–683.

Vavrina, C.S., S. Olson, and J.A. Cornell. 1993. Watermelon transplant age: Influence on fruit yield. HortScience 28:789–790.

Wien, H.C., P.L. Minotti, and V.P. Grubinger. 1993. Polyethylene mulch stimulates early root growth and nutrient uptake of transplanted tomatoes. J. Amer. Soc. Hort. Sci. 118:207–211.