Planting Systems Influence Growth Dynamics and Quality of Fresh Market Spinach

Daniel I. Leskovar¹ and Larry A. Stein

Texas Agricultural Experiment Station, Texas Agricultural Extension Service, Department of Horticultural Sciences, Texas A&M University, 1619 Garner Field Rd., Uvalde, TX 78801

Frank J. Dainello

Texas Agricultural Extension Service, Department of Horticultural Sciences, Texas A&M University, College Station, TX 77843

Additional index words. *Spinacea oleracea*, mulch, plant density, root growth, shoot growth, within-row spacing

Abstract. The objective of this work was to determine the effect of within-row plant spacing and mulching on growth, quality, and yield of an experimental semi-savoy spinach (*Spinacea oleracea* L.) genotype 'Ark-310' to produce a high quality fresh market product. Within-row spacings were 15 and 25 cm, and mulching treatments were bare-soil and black polyethylene mulch. Plants were destructively sampled weekly (1995–96) or bi-weekly (1997–98) for leaf area (LA), leaf number, leaf dry weight (LDW) and root dry weight (RDW) measurements. Plants grown on plastic mulch at 25-cm spacing had greater LA, LDW, and RDW than when grown at 15-cm spacing on mulch or bare-soil. Leaf number and specific leaf area (LA/LDW) were less affected by either spacing or mulching. The amount of soil on harvested leaves was lower on plants grown on plastic mulch in both years. In one year, total yields (MT/ha⁻¹) were 42% higher at 15-cm than at 25-cm plant spacing, while mulch increased yields by 20%, independently of plant spacing. These effects were not evident in the year with higher rainfall (1997–98).

Spinach is a popular salad vegetable providing significant amounts of vitamin A, vitamin C, calcium and iron. In southwest Texas, ≈2500 ha of fresh market spinach are planted in the fall, accounting for 10% of the total U.S. production. However, fresh market spinach production has declined since 1987 (J. Peña, personal communication). Low market prices, use of disease-susceptible cultivars, low yields and lack of maintenance of quality, such as cleanliness, color, and texture, are factors contributing to this decline. Most fresh-market spinach grown in Texas is a savoy leaf type resulting from an increase in growth of parenchyma tissues between leaf veins. It is hand-harvested by cutting leaves just above the growing point and field-packing into wooden bushel baskets. This practice is ineffective in maintaining a high quality final product able

to compete with either bunched root-cut or bagged baby leaf spinach and/or other loose-head salad vegetables such as lettuce. Therefore, there is a need to develop spinach production systems for improved yield while maintaining preharvest quality. This parallels the advent of new, fresh market genotypes being developed by the Univ. of Arkansas and characterized by slow growth, dark green color, superior pack-out appearance, and partial resistance to fungal diseases such as white rust (*Albugo occidentalis*) and blue mold (*Peronospora farinosa* f.sp. *spinaciae*).

Plant population and mulching have pronounced effects on growth and yield of many vegetable crops. However, few studies on plant spacings have been conducted in spinach. Bradley et al. (1975) and Osborne (1966) reported higher yield of canned spinach at lower bed or in-row spacing. Advantages of using plastic mulch as a component of intensive production systems has been documented with cucurbits and solanaceous crops but not with leafy vegetables (Lamont, 1993). The aim of this study was to determine if plant density and mulching affect plant growth dynamics, product cleanliness, quality, and yield of an experimental fresh market spinach genotype established by transplanting.

Materials and Methods

An experimental semi-savoy spinach genotype 'Ark-310', developed by the Univ. of Arkansas for superior leaf quality charac-

teristics, was used in this study. Transplants were grown by Peterson Brothers Nursery, San Antonio, Texas. Seeds were placed in 13-cm³ peat pots containing 33% peat, 33% vermiculite, and 33% washed sand media on 4 Sept. 1995 and 24 Sept. 1997. Transplants were watered and fertilized according to Peterson's standard nursery practices. They were hand-transplanted on a Uvalde silty clay loam (fine-silty, mixed, hyperthermic Aridic Calciustoll) soil at the Texas Agricultural Experiment Station (TAES), Uvalde on 13 Nov. 1995 and 3 Dec. 1997. Plants were grown on 8-m raised (15-cm-high) beds with 1.93 m between beds, with four rows spaced 25 cm apart in the bed. In-row spacing treatments were 15 and 25 cm, representing a plant population of 138,169 and 82,901 plants/ha, respectively. Mulching treatments were bare-soil vs. black polyethylene mulch.

Plant water requirements were supplied using a drip irrigation system. Two drip tubes per bed were positioned at the soil surface in 1995 and at 10-cm depth in 1997. A Typhoon ultra light tape of 0.25-mm wall thickness (Netafim Irrigation, Austin, Texas), with emitters spaced every 30 cm, delivered a flow rate of 340 L·h⁻¹ per 100 m of bed at 55 kPa. Total rainfall during the study was 101 and 141 mm in 1995–96 and 1997–98, respectively. An additional 17 and 95 mm of water were supplied between 8 Dec. and 25 Jan. 1996, and between 3 Dec. and 2 Mar. 1998, respectively. Fertilizer was applied through the drip system (50N–40P–130K kg·ha⁻¹) using potassium nitrate, phosphoric acid, and urea. Metalaxyl fungicide, [(2, 6-dimethylphenyl)-N-(methoxyacetyl) alanine methyl ester] (25.1% a.i.), at 1.04 L·ha⁻¹ was applied preplant through the drip system. Weed control between beds and pest control were performed as needed.

Three plants per replication were destructively sampled ten times at weekly intervals from 13 Nov. until 16 Jan. 1996 and eight times at bi-weekly intervals from 4 Dec. until 17 Mar. 1998 (the 1st through the 8th sampling week). Roots were excavated with a shovel in an area 15 × 15 cm, with the plant in the center of the square, to a depth of 30 cm. Soil-root samples were gently shaken to remove the adhering soil and washed by soaking in water using a 20-L container. Leaves >2 cm long were counted and leaf area was determined using a digital image analysis system (DIAS; Decagon Devices, Pullman, Wash.). Plants were oven-dried at 65 °C for 5 d and leaf and root dry weights were determined.

Spinach plants were harvested from a 7.6-m² section per plot on 25 Jan. 1996 and 18 Mar. 1998, cut at the hypocotyl base and weighed. Ten random plants per replication were selected to collect soil attached to individual plants. They were washed on filter paper, and the amount of soil was collected, dried and weighed.

A randomized complete-block design with four replications of four rows 8 m long was used. Leaf number, leaf area (LA), leaf dry weight (LDW), root dry weight (RDW), specific leaf area (SLA = LA/LDW), yield, and the amount of soil/plant were subjected to

Received for publication 28 Dec. 1999. Accepted for publication 10 Apr. 2000. We thank R.W. Sprague, J.C. Ward, and K.G. White for assistance in the field; T.E. Morelock, Univ. of Arkansas, for providing the experimental spinach genotype; and J. Parsons and Peterson Brothers Nursery for providing transplants. Mention of a trademark, proprietary product or vendor does not constitute a guarantee or warranty of the product, nor does it imply approval or disapproval to the exclusion of other products or vendors that may also be suitable. 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.

¹E-mail address: d-leskovar@tamu.edu

analysis of variance and means were separated by LSD at $P \leq 0.05$ (SAS Institute, Cary, N.C.).

Results and Discussion

Growth components. In the 1995–96 experiment, LA of transplants grown on plastic mulch was greater than that of those on bare soil 21 d after transplanting (DAT), reaching a plateau after 49 DAT (Fig. 1A). This increase was greater at the 25-cm than at the 15-cm spacing. Black plastic mulch increases soil temperature, surface temperature, and maintains higher soil moisture by suppressing soil water evaporation in comparison with bare soil (Ham et al., 1993). Spacing did not affect LA on plants grown on bare soil (Fig. 1A). In

the second experiment, LA increased linearly up to 55 DAT, thereafter LA increased more for transplants at the 25 cm than at the 15 cm spacing, a response more evident under black mulch (Fig. 2A).

Leaf number per plant was unaffected by mulching or spacing (Fig. 1B), increasing linearly from 8 to 16 between 7 and 35 DAT in 1995, followed by a slow increase thereafter. Similar trends were measured between 16 and 83 DAT in the 1997–98 experiment, with the greatest increase for transplants under mulch at 25-cm spacing (Fig. 2B). Zink (1965) reported that the number of spinach leaves increased constantly from emergence to harvest when grown in California during spring.

Leaf dry weight increased constantly with time (Fig. 1C). The slope (b_1) was 42% greater for transplants grown on mulch (1.36, $r^2 = 0.97$) than on bare soil (0.96, $r^2 = 0.98$) at 0.25-m spacing. Relative growth rates (dry weight basis) were not significantly different among treatments in either year, with a maximum and similar value of $0.037 \text{ g} \cdot \text{g}^{-1} \cdot \text{day}^{-1}$ at 21 and 41 DAT in 1995 and 1997, respectively. In 1997–98, LDW increased constantly between 23 and 83 DAT, the increase was significantly greater for transplants grown at 25-cm spacings (Fig. 2C). Specific leaf area (SLA) was generally unaffected by planting systems in 1995 and 1997, except that plants spaced 25 cm on mulch had significantly higher values 49 DAT ($147 \text{ vs. } 81 \text{ cm}^2 \cdot \text{g}^{-1}$) than did bare-soil plants spaced 25 cm in 1995. Pooled across all treatments, SLA decreased from 162 to $66 \text{ cm}^2 \cdot \text{g}^{-1}$ between 7 and 70 DAT. Young expanding leaves were thinner, but leaf thickness increased with plant maturity.

Root dry weight (RDW) in 1996 increased slowly between 7 and 42 DAT; thereafter, RDW of plants on mulch increased more rapidly than did that of plants on bare soil (Fig. 1D). At 70 DAT, RDW of plants spaced 25 cm on mulch averaged 1.7 g vs. 1 g for plants grown at 15 cm on mulch or bare soil (Fig. 1D). In 1997–98, root growth of transplants was greater at 25-cm than at 15-cm spacing, irrespective of mulch (Fig. 2D). In addition to root growth differences associated with plant spacing and mulching, spinach genotype may also influence root growth. Leskovar and Black (1994) noted that total RDW for ARK 88-354 and ACX 5044 genotypes established by direct seeding were 0.275 and 0.173 g per plant, respectively, 116 d after seeding.

Quality and yield. Plants on plastic mulch at 15-cm spacing had 52% and 56% less soil on the leaves than did plants harvested from bare soil in 1996 and 1998, respectively (Fig. 3A). Averaged across both spacings, mulch decreased the amount of soil by 68% in 1998. Fresh market spinach with a savoy leaf type is more prone to hold soil particles in leaf vein regions than is a processing smooth leaf type. During the 1998 season there were 25 rainfall events, four of them delivering 50 mm just prior to harvesting. One of the advantages of plastic mulch was to provide a cleaner product, since soil splashing to the leaves was minimized. Soil accumulation on the leaves because of wind, splashing, and/or harvesting can be further reduced by increasing plant population, as noted in the first experiment.

In 1996, yields were 42% higher at the closer plant spacing (Fig. 3B). Mulch increased yields by 20%, a response that was independent of plant spacing (Fig. 3B). However, yields did not respond to either plant population or plastic mulch in 1998. In processed spinach, Bradley et al. (1975) reported a yield increase when in-row spacing decreased from 7.6 to 5.1 cm. Osborne (1966) also noted a yield increase of processed spinach by spacing plants at 2.5 cm instead of 5.1 cm. In our study, the maximum fresh market yield occurred when the ground area per plant was 375 cm^2 . In processing spinach established by direct

Fig. 1. (A) Leaf area, (B) leaf number, (C) leaf dry weight, and (D) root dry weight of 'Ark-310' spinach transplants as affected by mulching (bare soil vs. black polyethylene mulch), and in-row plant spacing (15 cm vs. 25 cm), Uvalde, Texas, 1995–96.

Fig. 2. (A) Leaf area, (B) leaf number, (C) leaf dry weight, and (D) root dry weight of 'Ark-310' spinach transplants as affected by mulching (bare soil vs. black polyethylene mulch), and in-row plant spacing (15 cm vs. 25 cm), Uvalde, Texas, 1997–98.

Fig. 3. Spinach (A) amount of soil content and (B) yield of 'Ark-310' spinach transplants as affected by mulching (bare soil vs. black polyethylene mulch), and in-row plant spacing (15 cm vs. 25 cm), Uvalde, Texas, 1996 and 1998. Vertical bars represent a mean [$n = 40$ (A) and $n = 4$ (B) $\pm$ SE].

seeding, maximum yield was reported at 65 cm² ground area (Bradley et al., 1975).

In summary, the rates of increase in leaf area, and leaf and root dry weight were greater for plants spaced at 25 cm, with vegetative growth being enhanced by mulch in both years. Leaf number, which increased constantly up to 25 leaves, and leaf thickness were generally less responsive to differences in planting systems. Mulch significantly reduced soil content after harvest, particularly under conditions of heavy rains in 1998. Mulch increased yield in one of two seasons, especially at 15-cm spacing. Apparently, for a root-cut or loose leaf spinach product, yield efficiency and quality of 'Ark 310' spinach may be further improved by combining high plant density with efficient irrigation and fertilization programs under mulch and drip. However, the technical feasibility of producing a fresh root-cut spinach with those intensive production systems must be justified economically.

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