Plant Density Effects on Single-head Broccoli Production

Lewis W. Jett¹, Ronald D. Morse², and Charles R. O'Dell³

Department of Horticulture, Virginia Polytechnic Institute and State University, Blacksburg, VA 24061-0327

Additional index words. *Brassica oleracea*, density, floret yield

Abstract. There is a strong consumer demand for single-head broccoli (*Brassica oleracea* L. var. *italica*) that yields more florets per unit weight than bunching broccoli. Two spatial arrangements (single vs. twin row) and five plant densities (10.8, 7.2, 5.4, 4.3, and 3.6 plants/m²) were examined for single-head broccoli production. Spatial arrangement had no significant effect on any measured attribute, although the twin-row arrangement resulted in less plant damage with each harvest. For exclusive production of quality, single-head broccoli with high yields of marketable florets, 3.6 plants/m² (46-cm within-row spacing) should be used.

Per capita consumption of broccoli has increased 330% since 1975 (Hamm, 1988). As a result, fresh-market broccoli hectareage has increased by ≈10% annually since the early 1970s (Karst, 1990). Production acreage has expanded to include nontraditional broccoli producing areas, where broccoli is viewed as an alternative to traditional agronomic crops (Hamm, 1992).

Virginia is one of several southeastern states that has promoted fresh-market broccoli as an alternative cash crop after researchers successfully identified an open-market window for fall bunching broccoli (Sterrett et al., 1990). Virginia has a suitable climate for fall broccoli production and is adjacent to large population centers, resulting in lower transportation costs for providing high-quality fresh broccoli to consumers (Borchers, 1979).

In Virginia, the initial effort was to duplicate production, postharvest, and marketing practices used successfully for California bunching broccoli production. In this system, several small heads are bunched together to make a single marketable unit. Because high plant densities are required for profitable production of bunching broccoli, direct seeding normally is practiced to minimize plant establishment costs. In hot, humid climates, such as those in Virginia, producing fall bunching broccoli requires seeding during stressful summer climatic and edaphic conditions, which may reduce seedling emergence (Elso et al., 1992; Jett and Welbaum, 1992). Because many broccoli growers are part-time vegetable producers, full effort is not given to proper seedbed preparation, precision seeding techniques,

mist irrigation of the seedbed, and over seeding and thinning are needed to achieve a desired plant stand. The combined effects of high soil temperatures, soil crusting, and poor cultural management practices have resulted in poor plant stand establishment and low broccoli yields for direct-seeded, fall broccoli crops in Virginia (Sterrett et al., 1990).

In 1988, horticulturists at Virginia Polytechnic Institute and State Univ., Blacksburg, conducted a survey of Virginia's master gardeners, who use many horticultural products, to determine consumer attitudes and preferences toward Virginia-grown broccoli. The survey respondents preferred (>90%) large-head broccoli that contains more florets and less stalk per unit weight, which in this paper is termed "single-head broccoli" to describe a single head that is equivalent in size to a bunch of broccoli (Relf et al., 1990). Because broccoli stalks are discarded in most homes and restaurants, commercial sales of packaged broccoli florets is increasing rapidly. In the near future, broccoli florets sales are projected to equal and perhaps exceed the standard pack (bunching broccoli) in volume (Coon, 1991; Karst, 1993; Klassen, 1993).

Producing single-head broccoli would require fewer plants per unit area and, thus, transplants could be used for field establishment, alleviating the problems of poor stand establishment. Broccoli production in Virginia and other southeastern states is located in areas with large commercial hectareage of transplanted row crops. Thus, equipment and grower knowledge are available for production of high-quality transplants. Also, most labor required for fresh-market broccoli production is devoted to harvesting (O'Dell et al., 1993). Because of a lower plant population, single-head broccoli likely would require fewer labor hours to harvest compared to high-density, bunching broccoli. Bacterial soft rot [*Pseudomonas marginalis* pv. *marginalis* (Brown) Stevens] often is a serious pathological problem, reducing broccoli yields in the southeastern United States (Canaday, 1992). Incidence of bacterial soft rot could possibly be reduced in the low-density, single-head

fields compared to the high-density, bunching broccoli production systems.

Much of the prior research investigating plant density of broccoli has focused on determining the greatest population density that produces marketable head sizes for either processing or fresh-market bunching broccoli (Cutcliffe, 1971, 1975; Chung, 1982; Palevitch, 1970; Zink and Akana, 1951). Westcott and Callan (1990) investigated the effect of plant population density on head weight and area yield of broccoli. They showed that modeling can predict a plant density that, based on knowing head weights for widely spaced plants at that site, achieves a specified head weight for any geographical region. The objective of this model was to achieve the highest plant density of broccoli that ensures a marketable head size for bunching broccoli production. This model does not take into account the compensational ability of individual broccoli plants to effectively use the ground area at each plant density. Producing single-head broccoli is based on exploiting the compensational ability of the individual broccoli plant to determine the plant population that optimizes floret yield, the consumer-preferred component of broccoli.

Given the potential production advantages and the strong consumer interest in single-head broccoli, the objectives of this research were to determine the feasibility of producing single-head broccoli and the optimal plant arrangement and spacing to maximize yield.

Materials and Methods

Experiments were conducted in 1990 and 1991 at the Virginia Tech Horticultural Research Farm, Christiansburg. Because 'Brigadier' (Petoseed Co., Saticoy, Calif.) produced medium to large heads in previous cultivar observation studies, it was selected for this experiment (C.R.O., unpublished). Uniform, 4- to 5-week-old, bare-rooted broccoli plants were hand-transplanted on 10 and 20 Aug. in 1990 and 1991, respectively. The soil, a Groseclose silt loam (pH 6.2), was fertilized with (in kg·ha⁻¹) 111N-22P-47K before transplanting, liquid 9N-19P-12K at 0.24 liter/plant at transplanting, and 55.5N-22P-47K 7 weeks after transplanting to coincide with floret initiation (Kowalenko and Hall, 1987). Foliar tissue samples were taken at the time of floret initiation for macro and micronutrient analysis. For broadleaf weed control, α,α,α-trifluor-2, 6-dinitro-*N,N*-dipropyl-*p*-toluidine (trifluralin) (0.6 kg a.i./ha) was double-disk-incorporated into the soil before transplanting. Supplemental overhead irrigation was used to deliver ≥25 mm of water per week.

To determine the optimal spatial arrangement for single-head broccoli production, plants were arranged in either single rows 61 cm apart, resulting in a more equidistant or square plant arrangement, or twin rows (30 cm apart and 122 cm center to center), resulting in a more rectangular planting arrangement. In 1990, four within-row spacings (WRS) were examined: 15, 30, 38, and 46 cm, resulting in 10.8, 5.4, 4.3, and 3.6 plants/m², respectively.

Received for publication 15 Apr. 1994. Accepted for publication 4 Aug. 1994. Mention of a proprietary product does not imply its approval to the exclusion of other products 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.

¹Graduate Assistant.

²Associate Professor.

³Extension Specialist, Vegetable Crops.

The following year, five WRS were examined: 15, 23, 30, 38, and 46 cm, resulting in 10.8, 7.2, 5.4, 4.3, and 3.6 plants/m² or 108,000, 72,000, 54,000, 43,000, and 36,000 plants/ha, respectively. For bunching broccoli production in Virginia and the southeastern United States, 10.8 plants/m² is optimal and is achieved by adhering to production practices such as seeding broccoli at double the final spacing and thinning to a desired stand (O'Dell, 1990). Traditional cultural practices for disease and insect control for broccoli production in Virginia were followed (O'Dell et al., 1993).

The design was a randomized complete block with three replications. Each plot was 4.6 × 6.1 m, and 20 plants per plot were harvested from the interior two rows. Harvesting was performed on alternate days starting the third week of Sept. 1990 or the first week of Oct. 1991, respectively.

United States grade standards for bunching broccoli state, "a single stalk may be considered equivalent to a bunch if it is approximately as large as other bunches in the lot" (U.S. Dept. of Agriculture, 1943). Because this definition is vague, preliminary studies were conducted to determine the head diameter that corresponded with the weight of a bunch of broccoli (≈560 g). Based on this study, broccoli that attained a head diameter of ≥20 cm was categorized as single-head broccoli. All broccoli heads were allowed to reach this target diameter, cut to 19 cm length, and trimmed of peripheral leaves at each harvest. If the heads were determined to be potentially unmarketable (i.e., too loose) before the next harvest, they were harvested and categorized as bunching broccoli. All harvested broccoli heads were evaluated subjectively for quality based on a scale from 1 (poor quality; unmarketable) to 5 (excellent quality). A harvest index was calculated as (total marketable head yield)/(total marketable head yield + waste) (Chung, 1982). Each year, floret yield was determined by randomly harvesting and weighing four replications of 10 to 14 bunches or single heads. The entire single head or bunch was weighed immediately after harvest, followed by separation and weighing the apical ≈9 cm of the head containing the florets. The remaining ≈10 cm of stalk was discarded. The floret percentage (total fresh weight/head or bunch) was multiplied by the fresh-market yield at each density to approximate area floret yield.

Results and Discussion

Palevitch (1970) noted that increasing plant population densities of processing broccoli from 4 plants/m² to 10 to 11 plants/m² increased yield, especially through using spacings approaching equidistant arrangements. In both years of our study, plant spatial arrangement had no significant effect on any measured variable. Therefore, all data are expressed with regard to spacing or plant density. Perhaps plant density was too low to be affected by arrangement approaching equidistance or the extent of limiting factors was too low to affect individual plant characteris-

tics over the plant density range studied. Despite the lack of spatial difference, the twin row arrangement, because of a greater spacing between the twin rows, produced less plant damage (i.e., leaf and stem breakage) with each harvest.

Leaf macronutrients and micronutrients concentrations were in the sufficient range, and for each nutrient, there were no significant differences among spatial arrangement or plant density (data not shown). Maintaining high fertility levels across all treatments minimized the chance that nutrient deficiencies might occur and limit single-head broccoli yield at the higher plant densities. Westcott and Callan (1990) also showed no N rate × plant density interaction for broccoli.

Spacing effects. Yields at 46-cm WRS (3.6 plants/m²) were the highest both years for exclusive production of high-quality, single-head broccoli, although the 38-cm spacing yielded equally well in 1990 (Table 1). There was no significant difference in quality among the WRS plant densities studied (data not shown).

In 1990 and 1991, head diameter, plant weight, and head weight increased as plant density decreased from 10.8 to 3.6 plants/m² (Table 2). Head weight increased by 232% in

1990 and 258% in 1991 as plant density decreased from 10.8 to 3.6 plants/m². However, as plant density decreased, total marketable crop yield (tonnes per hectare) decreased by 22% in 1990 and 12% in 1991 (Table 1). Thus, reducing plant populations by two-thirds for single-head broccoli production resulted in significant plant yield compensation, which translated into similar area crop yields.

Because our objective was to produce single-head broccoli, at the densest spacing (10.8 plants/m²), head weights, diameters, and yield are larger than what normally would be harvested at that spacing. Even so, average head diameter was ≤15 cm at the closest spacing and was categorized primarily as 2- to 3-stalk bunching broccoli. Because obtaining high-density broccoli stands by direct seeding has not been consistently achieved in Virginia and other southeastern states, transplanting may be the most successful technique to achieve a desired plant stand. However, the costs associated with producing and setting 108,000 plants/ha for bunching broccoli production probably would be prohibitive.

Decreasing plant density had no effect on the harvest index in 1990; however, in 1991, the harvest index was lowest at the two population extremes studied (10.8 and 3.6 plants/

Table 1. Plant density effects on total, single-head, and floret marketable yield.

Within-row		Marketable yield				
Density	spacing	Total		Single-head		Florets
(plants/m ²)	(cm)	t·ha ⁻¹	% ^z	t·ha ⁻¹	%	(t·ha ⁻¹)
1990						
10.8	15	22.7	87	0.7	3	12.6
5.4	30	20.5	97	9.0	43	12.2
4.3	38	18.5	91	11.0	58	11.3
3.6	46	17.7	89	11.0	70	10.9
Linear		*	NS	**	**	NS
1991						
10.8	15	19.4	92	0	0	10.7
7.2	23	18.7	100	0.5	3	10.4
5.4	30	18.8	100	4.9	25	10.8
4.3	38	16.8	100	7.9	46	10.0
3.6	46	17.0	97	12	71	10.8
Linear		NS	NS	***	***	NS

^zPercentage data are angular-transformed.

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 2. Harvest variables of broccoli as influenced by plant density (within-row spacing).^z

Density (plants/m ²)	Within-row spacing (cm)	Ht (cm)	Head diam (cm)	Plant wt (g)	Head wt (g)
1990					
10.8	15	51	15	400	241
5.4	30	50	19	676	404
4.3	38	51	20	774	488
3.6	46	51	21	964	560
Linear		NS	***	***	***
1991					
10.8	15	46	14	444	197
7.2	23	44	15	535	523
5.4	30	43	18	656	328
4.3	38	42	19	783	391
3.6	46	42	20	966	490
Linear		**	***	***	***

^zFor all variables measured, there were neither significant effects of spatial arrangement nor a spatial arrangement × within-row spacing interaction; the data reported are means of both spatial arrangements at each plant density.

NS, **, *** Nonsignificant or significant at $P \leq 0.01$ and 0.001, respectively.

m²) (Table 3). Allowing the broccoli plants at 46-cm WRS to mature to ≥ 20 cm head diameter did not result in a longer time interval for reaching 50% harvest, compared with the densest plant spacing (Table 3).

Floret yields. Single-head broccoli by definition yields a greater quantity of florets per unit weight than bunching broccoli. Random field sampling of Virginia-grown, single-head and bunching broccoli revealed that when only the florets were weighed, single-head broccoli was 65% florets (by weight) and bunching broccoli averaged 45% florets by weight. In 1991, the optimal spacing for producing single-head broccoli (46-cm WRS) produced floret yields as high as those obtained with the densest spacing used for bunching broccoli production (Table 1). The single-heads contain more florets per equivalent unit weight than bunching broccoli. Because more of what consumers desire is being provided, it is possible

that single-head broccoli could command a higher price per unit than standard bunching broccoli. Single-head broccoli also seems to offer distinct labor-saving advantages over bunching when broccoli is sold as packaged florets. With single-head broccoli, obtaining equal or even higher floret yields from fewer plants (36,000 plants/ha) probably would result in reduced harvest and floret-packaging labor costs, compared to the high-density (108,000 plants/ha) plant population needed for bunching broccoli. As broccoli production expands as an alternative crop in the southeastern United States to match the increase in fresh-market consumption, growers can consider producing single-head broccoli. The low plant density optimum (46-cm WRS) for high yields of single-head broccoli offers the grower stand reliability and potential economic advantages over using transplants to achieve the desired, uniformly spaced, plant density.

Table 3. Harvest index and time (days) to harvest 50% of the broccoli plants.

Density (plants/m ²)	Within-row spacing (cm)	Harvest index (%) ^{z,y}	Days to 50% harvest ^x
<i>1990</i>			
10.8	15	38.0	65
5.4	30	37.0	64
4.3	38	39.0	66
3.6	46	37.0	65
LSD _(0.05)		NS	NS
<i>1991</i>			
10.8	15	31.0	72
7.2	23	33.0	73
5.4	30	35.0	69
4.3	38	34.0	76
3.6	46	31.0	73
LSD _(0.05)		1.0	4

^xPercentage data are angular-transformed.

^yHarvest index: [(total marketable head yield)/(total marketable head yield + waste)]100.

^zDays from transplanting.

Literature Cited

- Borcher, E.A. 1979. Broccoli production in Virginia. *Vegetable Growers News* 7:15.
- Canaday, C.H. 1992. Effects of nitrogen fertilization on bacterial soft rot in two broccoli cultivars, one resistant and one susceptible to the disease. *Plant Dis.* 76:989-991.
- Chung, B. 1982. Effects of plant density on the maturity and once-over harvest yields of broccoli. *J. Hort. Sci.* 57:365-372.
- Coon, J. 1991. Broccoli boom creates demand for new types. *Amer. Veg. Grower* 36(9):44-46.
- Cutcliffe, J.A. 1971. Effects of plant population nitrogen, and harvest date on yield and maturity of single-harvested broccoli. *HortScience* 6:482-483.
- Cutcliffe, J.A. 1975. Effects of plant spacing on single-harvest yields of several broccoli cultivars. *HortScience* 10:417-419.
- Elson, M.K., R.D. Morse, D.D. Wolf, and D.H. Vaughn. 1992. High temperature inhibition of seed germination and seedling emergence of broccoli. *HortTechnology* 2:417-419.
- Hamm, S.R. 1988. Vegetables and specialties situation and outlook report. U.S. Dept. Agr. Econ. Res. Serv. TVS-245.
- Hamm, S.R. 1992. The U.S. supply of vegetables, p. 3-19. In: R.A. Lopez and L. Polopolus (eds.). *Vegetable markets in the western hemisphere*. Iowa State Univ. Press, Ames.
- Jett, L.W. and G.E. Welbaum. 1992. Osmotic and solid phase priming of broccoli seed, p. 73-81. *Proc. Natl. Symp. on Stand Establishment for Hort. Crops*, Fort Myers, Fla., 16-20 Nov. 1992.
- Karst, T. 1990. Vegetable consumption on rise. *Packer* January:3A.
- Karst, T. 1993. Value-added produce creeping up on bulk commodity sales. *Packer* December:1B.
- Klassen, P. 1993. In the green with broccoli. *Amer. Veg. Grower* 41:10-11.
- Kowalenko, C.G. and J.W. Hall. 1987. Nitrogen recovery in single- and multiple-harvested direct-seeded broccoli trials. *J. Amer. Soc. Hort. Sci.* 112:4-8.
- O'Dell, C.R. 1990. Improving broccoli stands. *Amer. Veg. Grower* 38:25-27.
- O'Dell, C.R., R.D. Morse, and P. Ramsey. 1993. Field seeded fall bunching broccoli production: A guide for Virginia farmers. Virginia Coop. Ext. Serv. Publ. 438-011.
- Palevitch, D. 1970. Effects of plant population and pattern on yield of broccoli in single harvest. *HortScience* 5:230-231.
- Relf, P.D., C.R. O'Dell, and M.M. Kushad. 1990. Virginia master gardeners reveal preferences in broccoli survey. *HortScience* 25:706.
- Sterrett, S.B., J.W. Mapp, and C.W. Coale. 1990. Feasibility of broccoli as a new enterprise—A systems approach. *HortScience* 25:638-641.
- U.S. Department of Agriculture. 1943. United States standards for broccoli. U.S. Dept. of Agr., Agr. Mktg. Serv., Washington, D.C.
- Westcott, M.P. and N.W. Callan. 1990. Modeling plant population and rectangularity effects on broccoli head weights and yield. *J. Amer. Soc. Hort. Sci.* 115:893-897.
- Zink, F.W. and D.A. Akana. 1951. The effect of spacing on the growth of sprouting broccoli. *Proc. Amer. Soc. Hort. Sci.* 58:160-164.