data suggest this is probably due to a reduction in the number of floral buds that break and/or a decrease in bloom concentration, which may lead to pollination inefficiency, rather than to a direct effect of insufficient chilling on the inherent fruit-setting capacity of the flower. Although the plants were young and in pots, budbreak response to chilling and percent fruit set were similar to mature field-grown plants. Thus, there is no evidence to suggest that insufficient chilling produces inherently weak flowers.

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Feasibility of Broccoli as a New Enterprise—A Systems Approach

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Abstract. An interdisciplinary systems approach was used to explore the potential of fall, fresh-market broccoli as a new enterprise for eastern Virginia. Thirteen cultivars were evaluated in three plantings. Crop value was estimated at each harvest based on weekly market prices. The market window was open from mid-October until late November, with production of 160 cartons/ha, each at 11 kg. However, production of 120 cartons/ha narrowed the window to 2 weeks. Yield of some cultivars exceeded 160 cartons/ha in the first planting; yield of others was below the target production in the second planting. Low yield and low prices during most of the harvest period for the second planting suggests that the optimum harvest season ends in mid- to late November. Problems with poor plant establishment must be addressed before growers can fully capitalize on potential of broccoli as a new enterprise.

Vegetables are frequently considered a viable option for diversification by agricultural

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producers. The decision to evaluate a new horticultural enterprise requires the careful consideration of many factors. Grower interest is essential, as is grower willingness to address the specific needs of a new crop. Concurrent evaluations of trends in per capita consumption, potential demand for the commodity, condition of the market windows, seasonal patterns of production, and possible competition need to be completed (Bauer et al., 1987; Runyan et al., 1986;

Sterrett et al., 1989). There are several additional concerns that also must be addressed. Vegetable production is labor intensive and often requires specialized equipment, skilled production management techniques, and unique postharvest handling to produce and maintain the quality product needed to be competitive in the marketplace (CAST, 1984; Kline et al., 1986). The interdisciplinary approach includes the evaluation of the production feasibility and the economic and marketing potential to establish a realistic assessment of new enterprise combinations (Sterrett et al., 1989).

This study focuses on the production feasibility of fall broccoli as a new enterprise for eastern Virginia. In addition to growers' interest, other factors that were involved in the selection of broccoli for evaluation as a new enterprise included an increase of 330% in per capita consumption of broccoli since 1975 (Harem, 1988), the possible extension of the existing harvest window in Virginia to expand existing marketing opportunities, the possibility that fall broccoli production would fit into the production schedules of currently grown vegetable commodities (potatoes, snap beans, etc.), the proximity of five major terminal markets within a 970-km radius, and the development of a regional farmers market by the state of Virginia that will require a more-diverse product mix.

To estimate potential yields and product quality, as well as determine the potential harvest season, replicated yield trials with 13 cultivars were planted 10 Aug. (week 31), 19 Aug. (week 33), and 10 Sept. (week 36) 1987 on a Bojac sandy loam soil (coarse-loamy, mixed thermic Typic Hapludult) at the Eastern Shore Agricultural Experiment Station, Painter, Va. Three-row plots were 7.6 m long, with 0.6 m between rows and 0.1 m between seeds within the row (26,700 seed/ha). Fertilizer (112N-49P-93K, kg-ha⁻¹), B (1.1 kg-ha⁻¹), and α,α,α -trifluoro-2,6-dinitro-N,N-dipropyl-p-tolu-

Table 1. Yield, plant population, marketable heads, head diameter, and head weight of broccoli planted 10 and 19 Aug. 1987.

Main effect	Yield (cartons/ha) ^z		Established plants ^y (%)	Marketable heads (%)	Head diam (cm)	Head wt (g)
	10 Aug.	19 Aug.				
Cultivar (C) ^x						
Southern Comet	185	83	28	79	8.1	232
Green Top	180	53	22	73	8.6	276
Galaxy	178	110	25	92	9.7	250
Symphony	156	94	33	78	8.7	204
Green Comet	155	98	29	83	8.9	214
Brigadier	152	52	25	76	6.3	235
Premium Crop	147	48	30	59	7.5	216
Green Valiant	144	53	33	57	5.1	211
Embassy	142	33	34	55	5.5	196
Green Belt	102	12	26	41	3.7	204
Green Duke	94	62	17	98	7.9	230
Emperor	89	111	28	73	9.2	199
Futura	53	25	15	60	5.9	174
Waller-Duncan (P = 0.05)	50	38	6.7	27.7	1.8	46
Plantings (P) ^w						
10 Aug.	137		28	93	7.2	227
19 Aug.	64		25	49	7.4	214
Significance	**		*	**	NS	*
Interaction (C × P)	**		NS	NS	NS	NS

^x11-kg cartons.^yPercent of plants established from 26,700 seeds sown/ha.^wMean of four observations.^zMean of 52 observations.

Fig. 1. Average minimum, maximum, and median price of broccoli from Atlanta, Baltimore, Boston, New York, and Philadelphia markets combined (1983-87). Prices are adjusted 20% to reflect wholesale commission and terminal charges. Cost of production is based on (A) 122 cartons/ha, each weighing 11 kg, or (B) 162 cartons/ha and assumes that slurry ice is available at harvest.

idine (trifluralin) (0.56 kg a.i./ha), were incorporated before planting. Seeding depth was 15 mm. To encourage germination, irrigation was applied to the 10 Aug. planting in four 13-mm increments between 11 and 14 Aug. The 19 Aug. planting was irrigated in three 6- to 13-mm increments between 21 and 27 Aug. The harvest period for the first planting was 30 Oct. (week 44) to 1 Dec. (week 48), while that of the second planting was 24 Nov. (week 47) to 9 Dec. (week 49). Data were tested by analysis of variance procedure, with mean separation within planting date by Waller-Duncan ($K = 100$) (SAS Institute, 1985).

Several cultivars in the first planting exceeded 120 cartons/ha (Table 1), which is

considered an average commercial yield in southern Virginia. (O'Dell et al., 1989). Substantially lower yields for all cultivars were noted for the second planting. 'Emperor', 'Galaxy', and 'Green Comet' had the highest yields, although the yield of no cultivar exceeded 111 cartons/ha. The third planting (10 Sept.), deliberately scheduled late to determine the end of the planting and harvesting window, produced no marketable heads.

Several studies have shown a linear increase in marketable yield with increased plant populations, although head weight is reduced (Chung, 1985; Cutcliffe, 1975; and Dufault and Waters, 1985). However, the plant density associated with maximum re-

turn over production costs may vary with planting date (Chung, 1985). In this study, stand establishment of the heat-tolerant 'Embassy' accounted for only 34% of the sown seed (Table 1). Plant stand establishment for high-yielding 'Galaxy' and 'Southern Comet' was between 2.5% and 31%, while the stand of low-yielding 'Green Duke' and 'Futura' was between 15% and 20%. Plant establishment must be improved if broccoli, particularly direct-seeded broccoli, is to be grown commercially in eastern Virginia. Plant establishment was significantly correlated with both yield ($r = 0.50$) and number of marketable heads/ha ($r = 0.62$). The low plant populations may be attributed, in part, to heat stress during and immediately after germination. Daily maximum air temperatures at Painter, Vs., frequently exceeded 32°C during the fall broccoli planting season (19 days in July and 16 days in August). Elson and Morse (1989) have shown that germination of broccoli seed was inhibited with constant soil temperatures exceeding 36°C. Plant establishment problems and subsequent low yields have also plagued the research plots and commercial plantings in southern Virginia (O'Dell et al., 1989).

In addition to marketable yield, quality is important in establishing and maintaining marketing opportunities (O'Dell et al., 1989; Runyan et al., 1989; Sterrett et al., 1989). The loose, more open-head type of 'Southern Comet', 'Green Comet', and 'Galaxy' detracted from the visual quality of these cultivars. While both 'Green Belt' and 'Green Valiant' produced high-quality, tight, uniform heads with fine beading, yields for the first harvest were 102 and 144 cartons/ha, respectively. The quality standards used in this trial are those adapted for broccoli in Virginia, as based on the USDA grade "fancy" for broccoli (USDA, 1943).

Fig. 2. Estimated net value of broccoli cultivars based on average weekly prices at terminal markets and \$478/ha + \$2.83/carton production, harvest, and marketing costs. Cultivars include 'Green Top' (GT), 'Southern Comet' (SC), 'Galaxy' (GA), 'Symphony' (SY), 'Brigadier' (BR), 'Premium Crop' (PC), 'Green Comet' (GC), 'Embassy' (EB), 'Emperor' (EM), 'Green Valiant' (GV), 'Green Duke' (GD), 'Green Belt' (GB), and 'Futura' (FU).

Table 2. Integration of harvest maturity on estimated value of 'Galaxy', 'Green Top', and 'Green Valiant' broccoli in planting 1.

Harvest No.	Week	Price ^a (\$/carton)	Marketable yield (%)			Estimated market value (\$/ha)		
			Galaxy	Green Top	Green Valiant	Galaxy	Green Top	Green Valiant
1	43	6.97	37.4	0	0	437	0	0
2	44	8.93	39.1	32.2	0	612	461	0
3	45	9.90	17.0	41.9	0	281	719	0
4	46	8.93	2.8	19.0	6.4	38	317	75
5	47	8.02	2.4	15.1	28.2	31	73	324
6	48	7.34	1.3	1.8	65.5	16	24	679
Total ^b		...	---	---	---	1415	1594	1375

^aAverage of three terminal markets, adjusted to 80% of median price.

^bTotal = estimated market value over all harvests.

For cultivars with an average head diameter < 90 mm, up to four heads can be included per bunch without exceeding the maximum bunch diameter of 210 mm (8.5 inches). To meet the above criterion with four heads per bunch, the minimum average head weight is 195 g (14-count carton). Of the cultivars tested, only 'Futura' failed to meet the minimum head weight (Table 1). All other cultivars met both the bunch weight and bunch diameter criteria, based on average head weight and diameter. However, thick stems and short internodes noted for several cultivars detracted from the overall appearance.

Temperature influence on product quality and the potential length of the harvest period must also be considered. Average day-night temperatures exceeding 24°C have been associated with loose bud structure, uneven bud development, and premature flowering (O'Dell et al., 1989). Based on the 30-year average for Painter, Va., the average day-night temperature during August and early September could exceed 24°C (National Oceanic and Atmospheric Administration, 1987), thereby restricting the potential harvest period of high-quality broccoli. Quality can also be adversely affected by exposure to freezing temperatures late in the harvest season. The risk of freeze damage in late plantings can be minimized by harvesting

before the date associated with 50% probability of first occurrence of temperatures below -4.4°C (O'Dell et al., 1989). The date of 50% freeze probability for Painter, Va., occurs on 4 Dec. (week 49) (Tinga and Bailey, 1967). The target production period for this growing area appears to be about mid-October to late November. High temperature constraints at planting may limit the possibility of production before week 42, while increased risk of frost during week 49 would curtail production in December.

A market window analysis was completed using selling prices from Atlanta, Baltimore, Boston, New York, and Philadelphia terminal markets. For each market, the selling prices were discounted 20% to adjust for wholesale commission and terminal market charges. Average maximum, minimum, and median prices for 14-count cartons of broccoli were calculated using quotes for 1983 through 1987 (Federal-State Market News Service, 1987). Since similar trends were noted for the five markets, the combined data are shown in Fig. 1. The market window was considered "open" when the average minimum adjusted price exceeded the cost of production (Runyan et al., 1986).

Estimates of grower costs are based on either 122 or 162 cartons/ha (300 or 400 cartons/acre). While the average yield in southern Virginia was 120 cartons/ha in 1987 (P.

Ramsey, personal communication), yields >162 cartons/ha should be feasible with appropriate management practices (O'Dell et al., 1989). Estimates include production, shipping-point marketing, transportation costs, and the costs associated with packing and icing, assuming slurry ice facilities are available. Marketable yield and economic costs for harvesting, packing, and transportation will vary with specific situations.

As shown in Fig. 1, the market window for fall broccoli should be open until week 48, provided the average yield equals or exceeds 162 cartons/ha. However, with an average yield of 122 cartons/ha, the market window narrows to about weeks 46 and 47. The market window could also be expanded by the identification of specific marketing niches in marketing channels other than terminal markets (Green and Schuck, 1988; Runyan et al., 1986). A more-detailed analysis of potential marketing and economic factors would be needed to ensure successful implementation of broccoli as a new enterprise for eastern Virginia.

The economic analysis included crop value and grower cost, based on cultivar yield. The crop value was calculated using 80% of the average price quoted from the three closest terminal markets—New York, Philadelphia, and Baltimore. Grower cost included \$478/ha production costs and \$2.83/carton harvest, icing, and shipping-point marketing costs (P. Ramsey, personal communication). Estimated net return varied greatly with cultivar and planting date (Fig. 2). The negative returns from the second planting reflect the significantly lower plant population, the lower yield, fewer marketable heads (Table 1), and the notably lower market value during most of the harvest period (weeks 47-49, Fig. 1).

Since crop value is a function of market price and yield, those cultivars that yield during periods of greater demand (higher prices) produce the greatest return. While the yield of 'Galaxy' and 'Green Top' was similar, the lower price for the first harvest resulted in a lower estimated net return for the early maturing 'Galaxy' than for 'Green Top', which matured 1 week later (Table 2). The late maturity of 'Green Valiant' (weeks 47 and 48) resulted in an estimated net return of 68% of that of 'Green Top', even though the yield of 'Green Valiant' was 80% of 'Green Top'. For both plantings in this study, lower yield and declining prices resulted in lower net return for the late-maturing cultivars. Additional studies are needed to refine cultivar selection and planting schedules to meet market demands and maximize net return.

Economic feasibility of direct-seeded fall broccoli on the Eastern Shore depends on cultivar selection and cultural practices that ensure adequate plant populations, acceptable product quality, and improved marketable yield. The problem of low plant populations from direct seeding must be addressed before the potential of broccoli as a new enterprise in eastern Virginia can be fully assessed. Perkins-Veazie and Cantliffe (1989) reported improved germination of cabbage with seed covers

of peat-vermiculite or calcined clay when soil temperatures exceeded 30C. Additional cultural and economic evaluations are needed to assess the feasibility of using transplants as an alternative production method. Based on the available marketing, production, and economic information, fall broccoli has potential as a new enterprise for Virginia, provided the average yield exceeds 160 cartons/ha and the harvest season ends before the first week in December (week 48).

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Scheduling Irrigations for Carrots

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Additional index words. *Daucus carota*, water use efficiency, crop coefficients

Abstract. A 3-year irrigation scheduling study on carrots (*Daucus carota* L.) was conducted at the Colorado State Univ. Horticulture Research Center near Fort Collins to determine the irrigation schedule that produced the best combination of high water use efficiency and marketable yields with the least amount of water and fewest irrigations. This study used an irrigation scheduling program developed by the U.S. Department of Agriculture/Agricultural Research Service with crop coefficients calculated for carrots. Maximum carrot production and water use efficiency were obtained when the scheduling program simulated a 30-cm rooting depth at planting, increasing linearly to 60 cm in 75 days. Best yields and water use efficiency were attained by irrigating whenever 40% of the available water in the root zone had been depleted. The computer program for irrigation scheduling is available on diskette from the authors.

In arid land, the amount and timing of irrigation for many crops is still largely left to the judgment of the irrigator. Since water represents an essential and often costly input for carrot production, the purpose of this study was to develop an irrigation scheduling program for carrots that would aid irrigators in deciding when and how much water to apply.

by the moisture level of the soil or plant. Soil moisture may be determined by feel, gravimetric sampling, gypsum blocks, tensiometers, or neutron probes (Donahue et al., 1977). Water stress level in the plant may be determined by infrared thermometers (Jackson, 1982), pressure bombs (Tyree and Hammel, 1972), or ultra-microphones that sense breaking capillaries (Hanan, 1987). The problem with all of these methods is that they require visits to each field, and, when many fields and crops are involved, this can be time-consuming and costly.

The desired irrigation schedule should produce high carrot yields and high water use efficiencies (WUE) while minimizing the number of irrigations and total depth of water applied. Water use efficiency is defined as the yield of carrots (in kilograms per hectare) produced for each millimeter of water applied, including rain. Irrigation scheduling variations were evaluated on replicated small plots. The scheduling treatments were modified each year, based on the previous year's results.

Our irrigation scheduling approach was to

maintain a daily soil water budget using the Penman equation as modified by Jensen (1969). Daily crop water use or evapotranspiration (E_c) was calculated by multiplying the reference E_o by crop coefficients based on crop and stage of growth (Kincaid and Heermann, 1974). The equation used was: $E_c = K_c E_o + K_e (0.9 - K_c) E_o$, where: E_c = daily evapotranspiration; E_o = potential evapotranspiration for reference crop (alfalfa); K_c = crop coefficient determined by the stage of growth and soil water depletion ($K_c = K_{co} K_d$); K_{co} = ratio of E_c for crop in question, when soil water is not limiting and soil surface evaporation is negligible, to the reference crop E_o ; K_d = stress factor that drops below 1.0 as soil water is depleted; K_e = coefficient taking on the values of 0.8 for the first day, 0.5 for the 2nd day, 0.3 for the 3rd day, and 0.0 for subsequent days, following rainfall or irrigation.

This model calculates daily water deficit using 1) water-holding capacity of the soil, 2) current assumed rooting depth, 3) amount of effective rain, and 4) the calculated E_c .

Fig. 1. Crop coefficient curves for irrigation scheduling of carrots before effective cover. The dashed line (1985-1987) represents the coefficients assumed for the 3-year field study. The revised curve (solid line) duplicates the irrigation treatment that gave highest yield and best water use efficiency in each of the three years.

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