Table 4. Foliar mineral concentrations (dry weight basis) of 'Starkrimson Delicious' trees on various rootstocks (overall means for 1984 through 1986).[z]

Interstock/ rootstock	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Mn ($\mu g \cdot g^{-1}$)	Zn ($\mu g \cdot g^{-1}$)
M.27 EMLA	2.74 a	0.18 a	1.30 a	1.29 a	0.39 a	126 a	67 a
P.2/KA313	2.58 b	0.19 a	1.36 a	1.01 b	0.36 a	52 c	58 b
P.22/KA313	2.57 b	0.19 a	1.29 a	1.11 b	0.37 a	66 b	64 ab
C.6/KA313	2.62 b	0.19 a	1.39 a	1.08 b	0.36 a	73 b	61 ab

[z]Mean separation within columns by Duncan's New Multiple Range Test (p = 0 .05). Each data value is the mean of 21 observations.

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Influence of Plastic Mulch and Type and Frequency of Irrigation on Growth and Yield of Bell Pepper

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Additional index words. Soil moisture, *Capsicum annuum*, trickle, sprinkler

Abstract. **A field study was designed to evaluate the effects of various irrigation methods, raised beds, and plastic mulch on yield and fruit quality of bell pepper (*Capsicum annuum* L.) Irrigation was scheduled on the basis of soil matric potential and monitored by Hg manometer tensiometers and soil moisture blocks. Trickle-irrigated plots were watered at soil matric potentials of −0.025 and −0.075 MPa, and sprinkled plots at −0.075 MPa. The combination of black polyethylene mulch and irrigation produced maximum yields, but frequency of irrigation had little effect on yield when peppers were mulched. High frequency trickle irrigation (irrigated 15×) and trickle irrigation of a lesser frequency (irrigated 5×) resulted in similar yields when peppers were mulched. The use of mulch without irrigation had a large effect on yield: yields from plots that were mulched but not irrigated were similar to yields from plots that were sprinkler-irrigated but not mulched. The percentage of marketable fruit was substantially reduced in the absence of irrigation or mulch, because of the high incidence of both solar injury and blossom-end rot.**

Proponents of trickle irrigation contend that trickle irrigation, because of the frequency of watering inherent in this system, results in a constant high soil moisture level that is nonlimiting to crop productivity. However, most studies comparing sprinkler and trickle irrigation have reported similar yields of various vegetable crops produced by the two systems (2, 7, 12). Nevertheless, slight differences in soil matric potential at even a relatively high level of soil moisture can result in marked differences in vegetable growth and yield (1, 3, 8, 10, 12). In spite of the large impact that small differences in soil moisture can have on plant growth and yield, many irrigation studies do not use soil matric potential as the basis for irrigation scheduling.

We more fully assessed the potential advantages of trickle irrigation for vegetable production in a humid area by examining frequency of irrigation and comparing trickle with sprinkler irrigation for bell pepper production using soil matric potential as the basis for irrigation. Integrated into the study were cultural practices common to pepper production that are often used in conjunction with trickle irrigation: black polyethylene mulch was compared with bare soil and raised beds were compared with level ground. Black plastic mulch is frequently used to conserve soil moisture, increase soil temperature, and control weeds (5). Raised beds are commonly used in pepper production to improve soil drainage and decrease disease incidence.

Irrigation studies were conducted during Summer 1985 at Cornell University's Long Island Horticultural Research Laboratory in Riverhead, N.Y. Bell peppers were grown

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Table 1. Effects of type and frequency of irrigation and mulch on early flowering, early and total yields, and individual fruit weight of 'Calwonder' pepper.

Irrigation	Mulch	Flowers[y] (No./plant)	Early[z] yield (t·ha^{-1})	Total[x] yield (t·ha^{-1})	wt/fruit (g)
Trickle 15×	Yes	6.9	10.8	40.4	121
Trickle 5×	Yes	6.5	11.9	42.6	128
Sprinkler	Yes	6.4	11.1	41.3	126
Sprinkler	No	4.4	8.7	36.7	129
No irrigation	Yes	6.7	10.2	38.3	121
No irrigation	No	4.3	3.2	24.1	94
Significance					
Trickle 15×/mulch > trickle 5×/mulch		NS	NS	NS	NS
Trickle/mulch > sprinkler/mulch		NS	NS	NS	NS
Sprinkler/mulch > sprinkler/no mulch		**	**	**	NS
Sprinkler/mulch > no. irrigation/no mulch		NS	NS	*	NS
Sprinkler/no mulch > no. irrigation/no. mulch		NS	**	**	**
No irrigation/mulch > no. irrigation/no. mulch		**	**	**	**
Main effect sprinkler		NS	na	na	na
Main effect mulch		**	na	na	na
Sprinkler × mulch		NS	**	**	**

[z] Flowers per plant at anthesis.
[y] Cumulative marketable and unmarketable fruit harvested through 16 Aug.
[x] Cumulative marketable and unmarketable fruit harvested through 10 Sept.
[NS,*,**] Not significant, significant at 5%, significant at 1%, respectively; na = not applicable since interaction was highly significant for these parameters.

on a Riverhead sandy loam soil. Fertilizer was broadcast and incorporated before transplanting 6-week-old transplants, at N, P, and K rates of 110, 100, and 90 kg·ha^{-1}, respectively. Nitrogen was applied at 30 kg·ha^{-1} by spreading along the edge of the plastic mulch about 2 weeks after transplanting. Appropriate pest control measures were taken throughout the season. Where required, raised beds (0.90 m wide and 0.12 m high) were shaped mechanically.

Black polyethylene mulch (1.20 m wide and 0.050 mm thick), underlaid with trickle irrigation hose, was installed before transplanting. A 0.4-mm biwall drip tubing (Chapin Watermatics, Watertown, N.Y.) was used. A pressure regulator and four pressure gauges in the irrigation system facilitated monitoring of water pressure and increased the accuracy of treatment applications. Shutoff valves for each plot allowed independent treatment applications.

Plots were separated by a 2-m buffer zone to limit the effects of neighboring sprinkler treatments and water movement between plots. Trickle or sprinkler irrigation lines were centered in the middle of double rows of plants in irrigated plots. Disregarding the wide buffer zone between plots, a double row configuration with plant spacing of 0.30 × 0.45 m equalled a population of 36,000 plants/ha. Plots were 7.5 × 1.4 m and contained 50 plants.

Soil matric potential was monitored at about 8 AM, 6 days per week by Hg manometer tensiometers (0.1 MPa standard design assembly, no. 655X1-B1M1, Soil Moisture Equipment Co., Santa Barbara, Calif.) in the irrigated plots and soil moisture blocks (no. 5201, meter no. 5910A, Soil Moisture Equipment Co.) in the unirrigated plots. Six to ten measurements of soil matric potential in the plant root zone at a depth of 0.15 m were averaged for each treatment or subplot treatment to schedule irrigation. Irrigation was applied when the soil matric potential reached a minimum of −0.025 or −0.075 MPa. There was an unirrigated treatment as well.

Before initiation of irrigation treatments, a relationship was established between soil matric potential and mass soil water content by means of pressure plate extraction (15 bar ceramic plate extractor, no. 1500, Soil Moisture Equipment Co.). Based upon this soil moisture characteristic curve, the rate of water delivery and the period of time for each irrigation were calculated for each treatment to restore soil moisture to field capacity (about −0.01 MPa soil matric potential).

'California Wonder' peppers were transplanted on 11 June onto raised beds and level ground with the plot configuration already described. Perforated, triple-chambered garden sprinkler hoses, 7 m in length, were used to provide irrigation in sprinkler-irrigated plots. Raised beds and black polyethylene mulch were added as variables. The experiment was arranged as a split-plot with four replications. Raised beds and level ground were two main plot treatments. The six subplot treatments were combinations of irrigation regime and mulch. Trickle-irrigated plots were watered at −0.025 and −0.075 MPa. Sprinkler-irrigated plots were watered only at −0.075 MPa. A sprinkler treatment at a minimum soil matric potential of −0.025 MPa was not included because it was not considered a feasible practice for commercial pepper production. All trickle-irrigated plots were mulched whereas mulch was a variable in sprinkler-irrigated plots.

Measurements of plant height and diameter of leaf canopy spread on 10 plants per plot were taken at three biweekly intervals beginning 18 July, and ending 15 Aug. The number of buds on 10 plants per plot that had reached anthesis by 24 July were counted as an indication of the potential for early fruit development and subsequent early yield. Cumulative yield as well as the percentage of unmarketable fruit exhibiting solar injury or blossom-end rot from 40 plants per plot were recorded throughout the season.

Statistical analysis was performed by analysis of variance to segregate the effects

Table 2. Effects of type and frequency of irrigation and mulch on the combined incidence of blossom-end rot and solar injury of 'Calwonder' pepper.

Irrigation	Mulch	Percent of total yield
Trickle 15×	Yes	8.3
Trickle 5×	Yes	7.1
Sprinkler	Yes	8.8
Sprinkler	No	5.4
No irrigation	Yes	10.4
No irrigation	No	24.8
Significance		
Trickle 15×/mulch < trickle 5 ×/mulch		NS
Trickle 5×/mulch < sprinkler/mulch		NS
Sprinkler/mulch < sprinkler/no mulch		NS
Sprinkler/mulch < no irrigation/no mulch		NS
Sprinkler/no mulch < no irrigation/no mulch		**
No irrigation/mulch < no irrigation/no mulch		**
Sprinkler × mulch		**

[NS,*,**] Not significant, significant at 5%, and significant 1%, respectively.

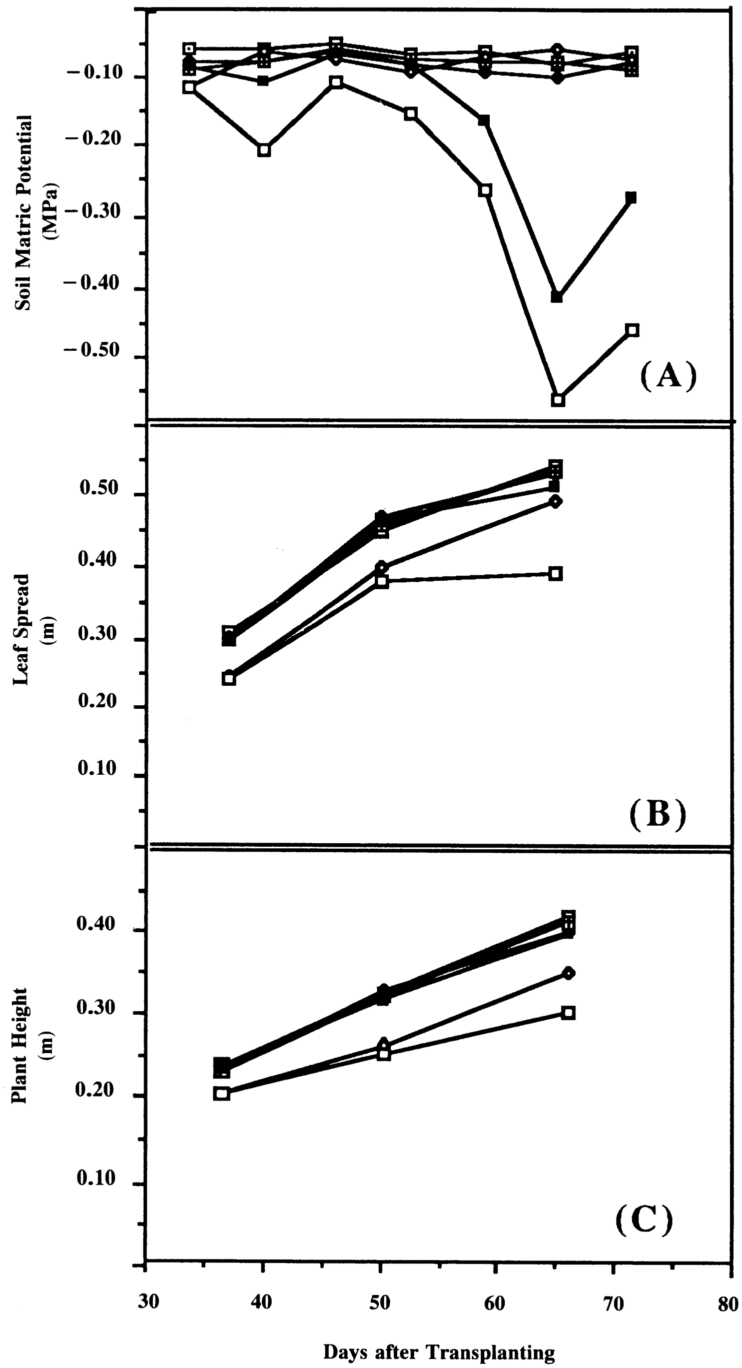

Fig. 1. Fluctuation of soil matric potential as influenced by irrigation and mulch (**A**). Leaf canopy spread (**B**) and plant height (**C**) of 'Calwonder' pepper as influenced by mulch and irrigation type and frequency. Trickle 15×/mulch (⊡); trickle 5×/mulch (♦); sprinkler irrigation/mulch (⊞); sprinkler irrigation/no mulch (◇); unirrigated/mulch (■); unirrigated/no mulch (□).

of the main and subplot treatments. Specific planned contrasts were then performed to establish significant treatment differences. Subplot treatments that were sprinkler-irrigated or unirrigated, both mulched and nonmulched, constituted a 2 × 2 factorial, examining the effects of sprinkler irrigation (irrigated at −0.075 MPa) and black polyethylene mulch. The presence of an interaction of sprinkler irrigation and mulch was determined and the simple effects of sprinkler irrigation and mulch were examined by contrasts of the means. When no interaction was present, the main effects of sprinkler irrigation and mulch were examined.

Split plot analysis of variance of every measured characteristic revealed no significant differences resulting from the main plot treatments of raised beds and level ground. Therefore, main plot effects were pooled for the determination of the subplot treatment effects.

Soil moisture levels in all but the unirrigated, nonmulched treatment were similar up to 9 weeks after transplanting (Fig. 1). The total precipitation from April through September was 578 mm. From the 5th week after transplanting, the unirrigated, nonmulched plots had decreasing soil moisture with a minimum level of −0.54 MPa. The unirrigated mulched treatment did not exhibit a drop in soil moisture until 9 weeks after transplanting, reaching a minimum of −0.35 MPa.

Plant height and leaf canopy spread increased over the season regardless of treatment (Fig. 1). Plant height and leaf canopy spread were similar for plants in the two trickle-irrigated treatments at all times of measurement. The comparison of trickle irrigation with sprinkler irrigation also showed no significant differences in plant height or leaf canopy spread. However, in sprinkler irrigated plots, plant height and leaf canopy spread showed significant ($p < 0.05$) positive responses to mulch at all times of measurement. In mulched plots, plant height and leaf canopy spread did not show a significant response to sprinkler irrigation. Leaf spread and plant height at 37 days were similar in sprinkler-irrigated and non-irrigated plots without mulch. However, at 65 days, there was a highly significant ($p < 0.01$) advantage to sprinkling. In the absence of irrigation, highly significant ($p < 0.01$) responses to mulch were observed for plant height and leaf canopy spread at all times of measurement. These results indicate a much larger growth response to mulch than to irrigation.

Earliness of flowering, as indicated by the number of flowers per plant that had reached anthesis by 24 July (Table 1), was not enhanced by the type of frequency of irrigation. The plants in the frequent trickle regime had been irrigated five times by the 24 July measurements, while those in the other irrigated regimes had been irrigated once. Flowering, however, was more advanced on mulched than on nonmulched plants.

Early fruit yield (Table 1) reflected the measurements of early flowering. All mulched plants had comparable yields regardless of any irrigation variable. Neither frequency nor type of irrigation influenced yields. However, early yield was higher in irrigated than in nonirrigated plots that were not mulched.

Total fruit yield was similar for high (15 times) and low (5 times) frequency trickle irrigation (Table 1). Total fruit yield was also similar under trickle and sprinkler management. The combination of any type of irrigation and mulch produced maximum yields. Irrigation of bare ground resulted in a 10% reduction of yield relative to mulched ground. Plots that were mulched but not irrigated yielded 10% less than those that were mulched and irrigated. Plots that were neither irrigated nor mulched yielded about 40% less than those that were irrigated and mulched.

Fruit were smallest and, therefore potentially least marketable, in the nonirrigated, nonmulched treatment (Table 1). There was a statistically significant, but practically unimportant difference in fruit weight between high and low frequency trickle irrigation.

Blossom-end rot was a common disorder during the early harvests, while solar injury predominated during the later harvests. Most striking was the high percentage of unmarketable fruit harvested from the nonirrigated, nonmulched treatment (Table 2). The wide fluctuations in soil moisture observed in the nonirrigated, nonmulched treatment (Fig. 1) probably contributed to the high incidence of blossom-end rot, while the exposure of fruit to direct sun, which resulted from reduced plant leaf cover (Fig. 2), probably contributed to the high incidence of solar injury late in the season. Irrigation, mulch, or the combination of the two markedly reduced both blossom-end rot and solar injury relative to lack of irrigation and mulch (Table 2).

Trickle or sprinkler irrigation worked equally well when application of water was based upon soil matric potential. However, in 1985, a moderately dry year, sprinkler irrigation, which saturated the soil over a wider area, maintained adequate soil moisture longer than trickle irrigation, and, therefore, required one less irrigation. It may be that the increased yields often reported to be due to trickle irrigation in humid areas are due to the cultural practices often accompanying the use of trickle, such as mulch and timely fertilizer and pesticide applications through the trickle system (9).

In this study, mulch without irrigation resulted in slightly higher yield than irrigation without mulch. Similar results have been observed with eggplant (9) and strawberry (11). Through the combination of irrigation and mulch maximized total fruit yield, the marginal gain was so small that only one or the other is likely to be economically advantageous.

Early flowering and early yield were increased by the use of mulch in both irrigated and unirrigated plots, just as in other vegetable crops (4, 6). Improved growth associated with mulched crops resulted from both the warming effect of mulch and the improved soil moisture retention by mulch (5). The pattern of soil moisture depletion (Fig. 1) suggests that in humid vegetable growing areas, maximum yields still may be obtained when irrigation is withheld in mulched peppers until quite late, even in a relatively dry season.

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Within-row Spacing Effects on Yields of Celery for Processing and Fresh Market

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Abstract. **Celery (*Apium graveolens* L.) cultivars, Camlyn, Tall Utah 52-70R (IMP.), Florida 2-14, and Clean Cut were grown at within-row spacings of 10, 20, or 30 cm during the winter seasons of 1984–85 and 1985–86 in commercial celery fields located near South Bay, Fla. Stalks were trimmed to 36 or 51 cm height to simulate fresh and processing celery yields, respectively. Cultivars responded similarly to within-row spacings for each measured variable. Untrimmed or trimmed to 51-cm-stalk weights per plant or per hectare were not different among cultivars. 'Camlyn' when trimmed to a 36 cm height had a lower stalk weight and a smaller stalk diameter than the other cultivars except when compared with 'Clean Cut' in the 1984–85 experiment. Untrimmed and trimmed stalk weights increased linearly per hectare and decreased linearly per plant as within-row spacings decreased from 30 to 10 cm. Stalk diameter decreased quadratically as within-row spacings decreased from 30 to 10 cm. Marketable petiole number per plant decreased linearly in the 1984–85 experiment and quadratically in the 1985–86 experiment as within-row spacings decreased. Celery stalks produced at 10-cm within-row spacing were too small for optimum economic fresh market returns, although they produced the highest marketable yield per hectare for a processing market. Plants from a 20-cm within-row spacing were optimum for fresh market celery.**

Celery is a major crop in Florida with production having encompassed about 3400 ha at a value of $42.8 million during the 1986–87 season (2). Plant spacings of 61 cm between rows and 17 cm within rows (4) are recommended to obtain optimum fresh market yields on muck soils of Florida. In a 2-year study, a reduction in between-row spacing from 71 to 61 cm resulted in an increase in fresh market celery yields (1). As within-row spacing increased from 15 to 20 cm, fresh market celery yield per hectare decreased in one year and no significant effects on yields was noted in another year (1). In another study (3) fresh market celery yields increased as within-row spacing decreased from 81 to 61 cm. A preliminary study re-

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