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Title: Irrigation and Plant Density Effects on Head Rot and Yield of Broccoli

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Effects of amount of applied water and frequency of irrigation on head rot and yield of three broccoli cultivars were evaluated in 1987 and 1988. Two irrigation frequencies were established with a line-source sprinkler system for 5.5 weeks during heading. The low-frequency experiment was watered once per week and the high-frequency experiment was watered three times per week with equal amounts of water. The amount of water applied decreased as the distance from the line increased.

Head rot was not affected by amount of water applied, but differences in head rot were apparent between years and between frequencies of irrigation. Incidence of head rot in 1988 was more than five times greater than in 1987 and was more than doubled under high-frequency compared with low-frequency irrigation. The amount of disease also varied among cultivars. Overall, OSU 86-3 had the greatest incidence of head rot (23.9%) followed by 'Citation' (13.7%) and 'Gem' (6.7%).

Yields were significantly affected by cultivar; 'Gem' and 'Citation' yielded higher than OSU 86-3. Response of yields to amount of water applied varied between years and frequencies, but generally, yields increased as the amount of water applied during head development increased until levelling off at 12 cm of water.

Within-row plant spacings from 15 to 30 cm and between-row spacing of 41 and 51 cm were employed to test the effect of spacing and population of two cultivars on head rot and yield of broccoli. Yields of 'Gem' increased linearly as the plant population increased, but yields of OSU 86-3 did not respond to the population increase. Changes in within-row spacing affected yields and head weight more than changes in between-row spacing. An inverse correlation existed between head weight and plant population. Incidence of head rot was not affected by planting density, but differed significantly between cultivars. The incidence of head rot was significantly higher for OSU 86-3 (28.8%) compared with 'Gem' (5.6%).

Irrigation and Plant Density Effects on Head Rot and Yield of Broccoli

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

IRRIGATION AND PLANT DENSITY EFFECTS ON HEAD ROT AND YIELD OF BROCCOLI

INTRODUCTION

Head rot, caused by the soft rot erwinia, *Erwinia carotovora* subsp. *carotovora*, is a common disease of broccoli (*Brassica oleracea* L. var. *italica*) in the Willamette valley of Oregon. The incidence and severity of head rot varies from field to field and from year to year, but occurs mainly during mild, moist weather conditions. To date, no chemicals have provided adequate control of this disease and only moderate levels of disease resistance have been identified in a few cultivars. Head rot development may be favored by irrigation and dense plantings because of microclimatic changes within the crop canopy, such as, increases in relative humidity and duration of dew periods, and decreases in temperatures. Yields are increased by increases in irrigation and planting density but may be offset by increases in disease. The purpose of this study was to determine the effects of amount of applied water and frequency of irrigation and planting density on head rot and yield of broccoli.

CHAPTER I. LITERATURE REVIEW

IRRIGATION

Effect on yield

Irrigation is an important component of crop production in areas where rainfall is limited or unpredictable during the growing season. Sprinkler and furrow irrigation is used extensively in the western United States where the majority of broccoli is grown (USDA, 1988). Research on broccoli response to irrigation has centered on the effects of soil-moisture stress at different stages of growth and the relationship between irrigation and fertilizer rates.

Massey et al. (1962) found that irrigation where soil moisture content never drops below 50% available moisture produces higher yields than no irrigation. Beverly et al. (1986) reported an increase in yield above 20 t/ha with increases in water as long as nitrogen was increased. Letey et al. (1983) found decreases in yield when water is applied to furrows in amounts of 30% more than that lost through evapotranspiration.

Lack of adequate water at certain periods of crop growth can severely affect yields while at other times plants can recover when adequate moisture is restored (Mauer, 1976). Broccoli is most sensitive to moisture stress during head initiation and enlargement (Singh and Alderfer, 1966). Mauer (1976) found that when moisture stress is imposed before head initiation and adequate water is present during and after head initiation, broccoli can recover with yields comparable to plants with no moisture stress imposed. In contrast, Singh and Alderfer (1966) stated that water stress imposed at any time during growth reduces yield. In their study, however, side shoots along with central heads were harvested, which may account for the differing conclusion with Mauer, who only harvested central heads.

Irrigation affects yields by influencing the size of individual heads. Mauer (1976) found an increase in head weight of 58% when broccoli was grown in soil with no less than 88% of available moisture compared with soil with no less than 32% of available moisture. Moisture stress imposed at head initiation negatively affects head weight and diameter (Singh and Alderfer, 1966; Mauer, 1976).

Other cruciferous crops respond similarly to irrigation and moisture stress. Cabbage is negatively affected by moisture stress imposed at any time, but especially during head formation (Singh and Alderfer, 1966). In experiments in which the amount and frequency of irrigation water applied to cabbage were varied, yields were higher when irrigating with 1.3 cm compared with 0.6 cm of water every 4 to 5 rainless days or 2.5 cm every 10 to 12 days (Janes and Drinkwater, 1959).

Cauliflower yields also increase with increases in applied water. Salter (1961) reported that frequent irrigation providing 14 cm of water over the season was necessary because withholding irrigation at any stage of cauliflower growth reduces yields. Salter

(1961) also found the greatest increase in yields occurs with the irrigation just before harvest. Cauliflower irrigated when less than 25% of the available soil moisture is depleted yields comparably to cauliflower irrigated to field capacity (Salter, 1959). Excessive irrigation reduces marketable yields compared with a normal irrigation (Nilsson, 1980).

Effect on foliar diseases

Irrigation, in its many forms, may influence the development of foliar diseases caused by fungal and bacterial pathogens. Foliar diseases are more often favored by sprinkler irrigation as opposed to other irrigation methods (Rotem and Palti, 1969). For example, Rotem and Cohen (1966) found the incidence of two tomato diseases, Stemphyllium blight and Xanthomonas blight, increases under sprinkler irrigation compared with furrow irrigation. Menzies (1954) reported an increase in the number and severity of bacterial diseases of beans in an arid climate when the crop was grown under sprinkler irrigation. Incidence of pear scab (Venturia pirina) doubled when the orchard was irrigated from above the canopy compared to irrigation at ground level (Sugar and Lombard, 1981). Some diseases, however, are not favored by the presence of moisture. The incidence of powdery mildew (Oidiopsis taurica) of tomato decreases under sprinkler irrigation compared with furrow irrigation (Rotem and Cohen, 1966).

Frequency of irrigation has a major influence on disease development (Rotem and Palti, 1969). Late blight of potatoes was more severe in plots receiving 8 to 11 overhead irrigations at 7 to 10 day intervals than in plots receiving 3 to 4 overhead irrigations at 21 to 28 day intervals (Rotem et al., 1962). Amount of water applied also influences diseases. The highest incidence of white mold (Sclerotinia sclerotiorum) in beans occurred with plants closest to the irrigation line which received the greatest amount of water (Miller and Burke, 1986).

Irrigation influences the microclimate of the plant canopy which may, in turn, influence disease. Sprinkler irrigation has a greater influence on the microclimate than do other forms of irrigation such as furrow or trickle irrigation (Rotem and Palti, 1969). Studies indicate sprinkler irrigation increases relative humidity, decreases foliar temperatures, and prolongs dew periods (Rotem and Palti, 1969; Crandall et al., 1971). Rotem and Cohen (1966) found monthly average temperatures in sprinkler-irrigated plots were 1 to 2° C lower and relative humidity was 3 to 5% higher than in furrow irrigated plots. Raniere and Crossan (1959) reported relative humidity in overhead irrigated tomato plots was 20% higher than in nonirrigated plots and the diurnal dew period was often 3 to 5 hours longer. As a result, the incidence and severity of tomato anthracnose increased. The extent of irrigation effects on the microclimate of the crop canopy is dependent on the surrounding environmental conditions at the time. The higher the temperature and the lower the relative humidity the more pronounced the effect of sprinkling (Rotem and Cohen, 1966).

The effect of irrigation on the host crop is also important to disease development. An increase in available soil water prior to infection may stimulate a flush of new growth providing succulent tissue for infection (Rotem and Palti, 1969). Soil moisture also influences the turgidity of a plant. Excess moisture can result in guttation, which favored some diseases because guttation of plant extracts from leaves provides a food source for pathogens. Infection rate and severity of a leaf spot of bentgrass, caused by *Helminthosporium sorokinianum*, increases in the presence of guttation fluid (Endo and Amacher, 1964).

Irrigation alone is not necessarily going to cause a disease outbreak. Most important are the interactions occurring between the environmental conditions created by irrigation, the predominant weather conditions, and the specific nature of the host and pathogen. During macroclimatic conditions extremely favorable or extremely unfavorable to disease, irrigation will not exacerbate a disease. When environmental conditions are marginal for disease development, however, irrigation may then be important by creating a microclimate favorable to disease (Rotem and Palti, 1969).

PLANT DENSITY

Effect on yield

Planting density has a major influence on broccoli yield and head size. Broccoli was originally grown at wide spacings to produce large central heads and numerous side shoots. Wide spacings also allowed for ease of mechanical cultivation. Spacings of 30 to 50 cm within-row and 0.75 to 1.0 m between-row were commonly recommended depending on the cultivar (Massey, 1962; Moore, 1952). Zink and Alderfer (1951) found when harvesting only the center heads, spacings of 20 cm within-row with double rows 33 cm apart and beds 1 m apart were optimal for the highest yield.

In anticipation of mechanical harvesting of broccoli, recent research has focused on the effect of planting density on yield of a single destructive harvest. It is difficult to make comparisons of actual yields between the following studies because of the differences in cultural methods used and the length of stalks of heads harvested. For example, Zink and Alderfer (1951) harvested and trimmed heads to stalk lengths of 20 cm or more while Cutcliffe (1971) trimmed stalks to a 15 cm length. Regardless, yields on an area basis increased as the plant population increased from 2 to 20 plants/m^2 (Zink and Alderfer, 1951; Cutcliffe, 1975; Salter et al., 1984; Chung, 1982). Higher yields were also obtained by planting in a square arrangement rather than a rectangular arrangement of the same number of plants (Palevitch, 1970). Thompson and Taylor (1976) found no significant difference between arrangements in a multiple harvest system.

Chung (1982) reported an asymptotic broccoli yield-plant density relationship with a levelling off at 20 plants/m^2 for the single harvest. In a multiple harvest system, Thompson and Taylor (1976) found yields levelling off at 10 plants/m^2. They also stated it was premature to define the yield-population relationship until a relationship between weights of heads and whole plants is established.

Head size is inversely related to planting density. As the plant population increases, especially when reducing the within-row spacing, head width and weight decreases (Zink and Alderfer, 1951; Palevitch, 1970; Cutcliffe, 1971). Chung (1982) found when increasing the population of 'Gem' broccoli from 2 to 23 plants/m^2, the head width was reduced almost by half. Cutcliffe (1975) reported an even greater reduction in the weight of 'Gem' broccoli heads. When the population increased from 4 to 24 plants/m^2, the weight of the average head decreased from 259 to 84 g. At these very high plant populations, head size may be too small to be marketable.

Plant population also influences time of maturity. Many studies indicate a delay in maturity, depending on the cultivar, at very close plant spacings (Zink and Alderfer, 1951; Cutcliffe, 1971). In contrast, Salter (1984) reported plants at high population densities mature earlier. This discrepancy may be because Salter used much larger populations, 50 to 100 plants/m^2, compared with the earlier studies.

Determination of the optimum planting density depends on the market requirements for head size and the broccoli cultivar planted.

Effect on foliar diseases

Changes in planting density may have direct and indirect effects on plant diseases. Increases in plant density directly affect disease incidence and severity by providing more plants available to infection and increasing the chance that inoculum will be intercepted by the host plant. Changes in planting density may indirectly affect disease by modifying the microclimate within the crop canopy. Increases in plant density more often than not provide a favorable environment for growth of a pathogen (Burdon and Chilvers, 1982). Close plant spacings tend to reduce air movement, increase relative humidity, lengthen dew periods, and decrease temperatures within the plant canopy all of which may affect disease development (Crandall et al., 1971; Burdon and Chilvers, 1982).

The following studies report increases in disease incidence as plant densities increased. Berger (1975) found an increase in Cercospora blight of celery in close compared with wide plant spacings and associated it with a modified microclimate. Grey mold of beans is most destructive where the rows are closest together or the stand of plants and growth of foliage is greatest (Campbell, 1949). Air movement is obstructed and the relative humidity within the foliarsphere increases, providing conditions favorable to grey mold infection. Blad et al. (1978) reported an increase in white mold in a dense compared with a sparse canopy of dry edible beans and determined the dense canopy was cooler and wetter, accounting for the differences in disease severity. Aerial stem rot of potatoes increased as plant population increased (Cappaert and Powelson, 1990). The duration of leaf wetness was longer in the dense compared with the sparse plant population providing free moisture for infection.

In general, there are few studies on the influence of planting density on disease. Yearly macroclimatic conditions can have an overriding influence on disease making field studies difficult. For example, grey mold of beans in Washington is most severe when wet weather is prevalent immediately preceding and during harvest but is almost nonexistent when the weather is dry (Campbell, 1949). In addition, changes in plant spacing may not be a viable alternative to other disease control measures when optimum yields are essential (Burdon and Chilvers, 1982).

BROCCOLI HEAD ROT

Bacterial soft rot of broccoli was first reported in England by Dowson and Dillon-Weston (1937) and has since been reported in Ireland (Ryan and Staunton, 1973), Australia (Wimalajeewa and Price, 1985), and the United States (Canaday et al., 1987). Water-soaked lesions develop on broccoli heads which may enlarge and eventually become soft, mushy tissue with a distinctly foul odor.

Wimalajeewa et al. (1987) isolated *Erwinia carotovora* subsp. *carotovora* and several *Pseudomonas* spp. from diseased heads, but did not consider any of these the primary pathogen because rotting occurred only when heads were injured and did not spread beyond injured tissue. A highly pectolytic strain of *Pseudomonas marginalis* was eventually determined by Wimalajeewa et al. to be the bacterial pathogen responsible for head rot. Canaday et al. (1988) reported both *E. carotovora* and *P. marginalis* to be responsible for this disease.

Because head rot occurs mainly during cool, moist weather conditions (Wimalajeewa et al., 1985; Canaday et al.,1987), disease control strategies have focused on cultural methods which provide unfavorable environmental conditions for disease development. No effective chemical control for head rot has been reported (Canaday et al., 1987) and only moderate levels of disease resistance in a handful of cultivars, such as 'Shogun', 'Green Defender', and 'Pirate' have been identified (Canaday, 1988).

CHAPTER II. SPRINKLER IRRIGATION EFFECTS ON HEAD ROT AND YIELD OF BROCCOLI

INTRODUCTION

Broccoli (*Brassica oleracea* L. var. *italica*) is commonly grown under sprinkler irrigation in the Pacific Northwest. For satisfactory yields, an adequate supply of water is especially important during head initiation and enlargement (Singh and Alderfer, 1966). Beverly et al. (1986) reported an increase in yield above 20 T/ha with an increase in water applied as long as nitrogen rates were increased. Letey et al. (1983) found, however, excessive water in amounts of 30% more than that lost through evapotranspiration decreased yield.

Although irrigation is essential for optimum yields, it may also create conditions favoring disease development (Rotem and Palti, 1969). Menzies (1954) reported an increase in the number and severity of bacterial diseases of beans in an arid climate when the crop was grown under sprinkler irrigation. In another study, the incidence and severity of tomato anthracnose increased under overhead irrigation (Raniere and Crossan, 1959). Increases in frequency of irrigation or amount of water applied have also increased the incidence of some diseases. Late blight (*Phytophthora infestans*) on potatoes was more severe on plots receiving 8 to 11 overhead irrigations at 7 to 10 day intervals than on plots receiving 3 to 4 overhead irrigations at 21 to 28 day intervals (Rotem et al., 1962). The highest incidence of white mold (*Sclerotinia sclerotiorum*) in beans occurred with plants closest to the irrigation line which received the greatest amount of water (Miller and Burke, 1986). Sprinkler irrigation increases relative humidity, decreases temperatures, and lengthens diurnal dew periods creating environmental conditions conducive to the development of many diseases (Crandell et al., 1971; Raniere and Crossan, 1959).

Head rot, caused by the soft rot erwinia, *Erwinia carotovora* subsp. *carotovora*, is a common disease of broccoli in the Willamette Valley of Oregon. The incidence and severity of head rot, however, varies from field to field and from year to year. Disease severity is highly influenced by the presence of free moisture on the surface of florets. Exact moisture requirements for initiation of head rot by *E. c. carotovora* have not yet been defined. With potato tubers, decay by this bacterium will occur under conditions of oxygen depletion. The accumulation of CO_2 or the presence of free water on the tuber surface is sufficient to induce anaerobic conditions, and in the presence of the pathogen, decay is initiated.

Alteration in the frequency and/or amount of water applied through sprinkler irrigation has been suggested as one way of modifying the microenvironment to achieve some disease control. The purpose of this study was to determine the effect of amount of applied water on head rot and yield of three broccoli cultivars.

MATERIALS AND METHODS

Field plots of broccoli were established in 1987 and 1988 at the North Willamette Experiment Station, Aurora, OR. Broccoli cultivars, 'Gem' and 'Citation', and the broccoli breeding line OSU 86-3 were double-seeded the last week of June into 3.8 cm cells containing a medium of peat, pumice, and shredded bark (1:1:2, v/v/v). One week later the plants were thinned to one plant/cell. Seedlings were fertilized weekly with a water soluble 20-20-20 fertilizer containing micronutrients. The seedlings were grown in an unheated greenhouse until transplanted to the field the last week of July.

The plot area consisted of a Willamette silt loam to which was applied trifluralin at 0.84 kg/ha, chlorpyrifos at 1.5 kg/ha, and a 10N-8.7P-16.7K fertilizer at 1120 kg/ha one week before transplanting, and propachlor at 4.5 kg/ha the day after transplanting. A diazinon drench at 1.1 kg/ha was applied twice for root maggot (Delia brassicae) control. An additional 168 kg/ha of N was applied as ammonium nitrate three weeks after transplanting. In 1987, Bacillus thuringiensis was applied to control cabbage loopers (Trichoplusia ni) the first week of September. A 10-row border of corn (Zea mays) was planted on May 25 at the perimeter of the plot area to reduce the influence of wind on the irrigation spray pattern.

In 1988, the methods were the same as the previous year with minor exceptions. Boron at 5.0 kg/ha was incorporated with the first fertilization. At the beginning of August, carbaryl was applied at

1.1 kg/ha to control western spotted cucumber beetle (Diabrotica undecimpunctata). Cabbage looper control was not necessary.

Each plot consisted of a four-row bed, 3.7 m long. Seedlings were spaced 24 cm apart within rows on 41 cm centers. All plots were sprinkler-irrigated and received equal amounts of water until the end of August, one to two weeks prior to head initiation. Then, two irrigation frequency experiments were established with a line-source irrigation system: the low-frequency experiment was watered once per week for 7 hr, and the high-frequency experiment was watered three times per week for 2.5 hr per irrigation. When rainfall occurred adjustments were made in the irrigation schedule. Amount of water applied decreased with an increase in distance from the irrigation line-source.

The line-source sprinkler irrigation system consisted of sprinkler heads placed on 60 cm risers (2 cm diam) spaced 12.2 m apart on an aluminum pipe (5 cm diam) placed in each frequency. In 1987, the plots were centered at 4, 6, and 8 m along one side of the irrigation line. Treatments were replicated six times. Catch cans placed at three distances from the line source were used to measure the amount of water applied. In 1988, water applied was measured after each irrigation from catch cans placed in each plot. Plots were centered at 2, 4, 6, and 8 m along both sides of the irrigation line. The design was a modified split-block design (Hanks et al., 1980; Miller and Burke, 1983). For the analysis of variance, cultivars were the main plots and amount of irrigation water applied was the subplot. In addition, in 1988 plots were planted on both sides of the irrigation line creating an additional factor, halves, analyzed as sub-subplots (Hanks et al., 1980). Amount of water applied at each distance could not be randomized due to limitations of the line-source irrigation treatment providing a continuous variable. The results were analyzed by analysis of variance to test cultivar and cultivar x irrigation interactions (Hanks et al., 1980). Regression equations tested for effects of irrigation.

Leaf wetness sensors were attached to tripods and placed in the center of 16 plots in the high-frequency irrigation experiment. Four sensors were placed at each of the four distances from the irrigation line. The sensors were connected to 21X microloggers (Campbell Scientific, Inc), which recorded the duration of leaf wetness from the time the irrigation regimes were established to the last harvest.

A strain of E. c. carotovora, isolated from a broccoli head with head rot symptoms in 1986, was used to inoculate the field plots. Inoculum was grown on King's B medium for 48 hours at 20-22°C. An aqueous cell suspension of Erwinia (10^6 cells/ml of water) was prepared and applied to the plots with a pressurized, backpack sprayer at four day intervals beginning at head initiation and ending prior to the second harvest. Broccoli heads were harvested three times in 1987 (September 28, October 6, and 12) and four times in 1988 (September 28, October 6, 13, and 18). Mature heads from the two center rows were harvested and the weight, width, total number of heads, and number of heads with symptoms of head rot and/or downy mildew were recorded.

In addition, a biological spray control experiment was established in 1987 under the high and low-frequency irrigations. Treatments included four isolates of *Pseudomonas flourescens*, *Erwinia herbicola*, and a control of no spray. Treatments were replicated six times and randomized under each frequency.

RESULTS

Head rot

The average incidence of head rot in 1988 was more than five times greater than in 1987 and significant differences in amount of head rot were apparent among cultivars (Tables II.1 and 2). Under both high- and low-frequency irrigation, OSU 86-3 had the highest percentage of head rot, followed by 'Citation' and 'Gem' (Tables II.3 and 4). Because significantly fewer heads were harvested from OSU 86-3 compared with 'Gem' and 'Citation', the number of heads with symptoms is also reported; 'Gem' had fewer heads with head rot than 'Citation' and OSU 86-3 in the low-frequency irrigation experiment (Table II.4), whereas, there was no significant difference between 'Gem' and OSU 86-3 in the high-frequency irrigation experiment (Table II.3). In 1988, under low-frequency irrigation the interaction of cultivar x irrigation x half was significant (Table II.2); on one side of the irrigation line the lowest incidence of head rot for OSU 86-3 occurred closest to the line, while on the other side of the line the plots farthest from the line had the lowest incidence of head rot. The other cultivars did not exhibit the same trend. In 1987, the incidence of head rot did not differ significantly among cultivars (Table II.5 and 6).

Increases in amount of water applied during head growth did not increase the incidence of head rot under the amounts tested. In 1987, the middle plots receiving 8.4 cm of water tended to have the most head rot, but differences were small, especially under low-

Table II.1. Analysis of variance for the incidence of head rot according to cultivar and irrigation treatments under high-frequency irrigation, 1988.

Source	DF	MS	F
Rep (R)	2	0.00596	
Cultivar (C)	2	0.88060	32.39 **
Error (C x R)	4	0.02719	
Irrigation (I)	3	0.01112	0.50 NV
Error (I x R)	6	0.02242	
C x I	6	0.03254	1.29 NS
Error (C x I x R)	12	0.02517	
Half (H)	1	0.17353	7.82 NV
Error (H x R)	2	0.02219	
C x H	2	0.06971	1.78 NS
Error (C x H x R)	2	0.03911	
I x H	3	0.04405	7.07 NV
Error (I x H x R)	6	0.00623	
C x I x H	6	0.03635	1.62 NS
Error (C x I x H x R)	12	0.02245	

[NS, **] Nonsignificant and significant at P=0.01.
[NV] Probability statements are not valid because treatments were not randomized.

Table II.2. Analysis of variance for the incidence of head rot according to cultivar and irrigation treatments under low-frequency irrigation, 1988.

Source	DF	MS	F
Rep (R)	2	0.01067	
Cultivar (C)	2	0.62203	36.81 **
Error (C x R)	4	0.01690	
Irrigation (I)	3	0.02408	4.48 NV
Error (I x R)	6	0.00538	
C x I	6	0.02229	2.29 NS
Error (C x I x R)	12	0.00974	
Half (H)	1	0.03196	2.63 NV
Error (H x R)	2	0.01213	
C x H	2	0.01540	1.45 NS
Error (C x H x R)	2	0.01341	
I x H	3	0.01419	3.16 NV
Error (I x H x R)	6	0.00449	
C x I x H	6	0.03838	2.96 *
Error (C x I x H x R)	12	0.01296	

[NS, *, **] Nonsignificant and significant at P=0.05 and 0.01, respectively.
[NV] Probability statements are not valid because treatments were not randomized.

Table II.3. Effect of broccoli cultivar on the incidence of head rot and downy mildew in 1987 and 1988 under high-frequency irrigation.

Harvest date/ Cultivar	Head rot				Downy mildew			
	Number of heads[z]		Percentage of heads		Number of heads		Percentage of heads	
	1987	1988	1987	1988	1987	1988	1987	1988
First harvest								
Gem	0.22 a[x]	0.00 a	2.95 a	0.00 a	0.06 a	0.29 a	0.62 a	2.85 a
Citation	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
OSU 86-3	0.06 a	0.00 a	0.69 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a
Second harvest								
Gem	0.56 a	1.33 a	5.75 a	14.69 a	2.67 a	3.29 a	35.11 a	35.02 a
Citation	0.33 a	0.92 ab	3.31 a	8.03 b	2.11 a	0.46 b	19.64 b	4.65 b
OSU 86-3	0.22 a	0.54 b	2.79 a	16.39 a	0.61 b	0.13 b	7.99 b	3.13 b
Third harvest								
Gem	0.28 a	1.54 b	10.88 a	35.59 b	1.61 a	2.08 a	40.26 a	65.35 a
Citation	0.11 a	3.42 a	2.01 a	48.10 b	0.61 a	0.75 b	19.68 ab	12.50 b
OSU 86-3	0.44 a	2.83 ab	5.74 a	79.71 a	0.83 a	0.38 b	10.43 b	10.21 b
Fourth harvest								
Gem	--	0.25 b	--	16.67 b	--	0.96 a	--	44.17 a
Citation	--	2.63 a	--	52.24 a	--	2.38 a	--	52.18 a
OSU 86-3	--	1.50 ab	--	46.73 a	--	0.50 a	--	16.81 b
Total harvest								
Gem	1.06 a	3.13 b	6.15 a	14.35 c	4.33 a	6.63 a	22.39 a	29.88 a
Citation	0.44 a	6.96 a	2.62 a	37.18 b	2.72 ab	3.58 b	15.39 a	18.40 ab
OSU 86-3	0.72 a	4.88 ab	5.13 a	52.41 a	1.44 b	1.00 b	9.46 a	10.12 b

[z] Average number of heads/plot.

[x] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.4. Effect of broccoli cultivar on the incidence of head rot and downy mildew in 1987 and 1988 under low-frequency irrigation.

Harvest date/ Cultivar	Head rot				Downy mildew			
	Number of heads[z]		Percentage of heads		Number of heads		Percentage of heads	
	1987	1988	1987	1988	1987	1988	1987	1988
First harvest								
Gem	0.17 a[x]	0.04 a	3.57 a	0.26 a	0.22 a	0.33 a	3.26 a	4.17 a
Citation	0.06 a	0.00 a	1.85 a	0.00 a	0.11 a	0.00 b	3.70 a	0.00 b
OSU 86-3	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 b	0.00 a	0.00 b
Second harvest								
Gem	0.39 a	0.08 b	4.46 a	0.80 b	3.00 a	2.88 a	30.56 a	33.10 a
Citation	0.33 a	0.58 a	2.91 a	5.20 ab	0.89 a	1.00 b	8.20 b	8.90 b
OSU 86-3	0.17 a	0.38 ab	1.85 a	9.30 a	0.22 b	0.25 b	2.74 b	4.10 b
Third harvest								
Gem	0.22 a	0.29 b	10.83 a	16.67 a	1.22 a	1.08 a	24.31 a	63.80 a
Citation	0.11 a	1.33 a	2.78 a	19.74 a	0.72 a	0.79 a	24.59 a	13.70 b
OSU 86-3	0.44 a	1.83 a	5.02 a	45.48 a	0.67 a	0.13 b	8.13 a	3.50 b
Fourth harvest								
Gem	--	0.04 a	--	1.39 a	--	0.46 a	--	22.92 a
Citation	--	0.50 a	--	17.01 a	--	0.96 a	--	35.57 a
OSU 86-3	--	1.04 a	--	41.04 a	--	0.54 a	--	18.40 a
Total harvest								
Gem	0.78 a	0.46 b	3.99 a	2.32 b	4.44 a	4.75 a	22.67 a	23.79 a
Citation	0.50 a	2.42 a	2.69 a	12.21 b	1.72 b	2.75 b	9.39 b	14.18 b
OSU 86-3	0.61 a	3.25 a	4.35 a	33.80 a	0.89 b	0.92 c	6.00 b	9.00 c

[z] Average number of heads/plot.
[x] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.5. Analysis of variance for the incidence of head rot according to cultivar and irrigation treatments under high-frequency irrigation, 1987.

Source	DF	MS	F
Rep (R)	5	0.00268	
Cultivar (C)	2	0.00594	2.75 NS
Error (C x R)	10	0.00216	
Irrigation (I)	2	0.01174	7.07 NV
Error (I x R)	10	0.00166	
C x I	4	0.00265	0.56 NS
Error (C x I x R)	20	0.00476	

NS Nonsignificant.
NV Probability statements are not valid because treatments were not randomized.

Table II.6. Analysis of variance for the incidence of head rot according to cultivar and irrigation treatments under low-frequency irrigation, 1987.

Source	DF	MS	F
Rep (R)	5	0.00822	
Cultivar (C)	2	0.00138	1.92 NS
Error (C x R)	10	0.00072	
Irrigation (I)	2	0.00989	3.03 NV
Error (I x R)	10	0.00326	
C x I	4	0.00068	0.20 NS
Error (C x I x R)	20	0.00337	

NS Nonsignificant.
NV Probability statements are not valid because treatments were not randomized.

frequency irrigation (Fig II.1). In 1988, regression equations failed to show a relationship between amount of irrigation water applied and the incidence of head rot (P>0.10) (Fig II.2).

In 1987, the difference in incidence of head rot between high- and low-frequency irrigation was small. Overall percentage of head rot under high-frequency irrigation was 4.6 compared with 3.7 under low-frequency irrigation. In 1988, however, the incidence of head rot was 34.6% under high-frequency compared with 16.1% under low-frequency irrigation. In addition, during the biological spray control experiment in 1987, large differences in the incidence of head rot were apparent between the high- and low-frequency experiments. No significant difference occurred between the control and any spray treatment, but the incidence of head rot was greater under high-frequency irrigation with 22.8% of the heads with head rot compared with low-frequency irrigation with 9.7% of the heads with head rot. The data from 1987 and 1988 suggests frequency of irrigation may be more important to the incidence of head rot than the amount of water applied at each irrigation.

Yield

Broccoli heads were harvested over a 3 to 4 week period. 'Gem' matured first, followed by 'Citation' and then OSU 86-3. Yields of the individual harvests reflect the differences in maturity (Tables II.7-10). Cultivar treatments affected yields (Tables II.11-14) with 'Gem' and 'Citation' yielding more than the OSU line. Yields were consistent between frequencies and years, except for the OSU line

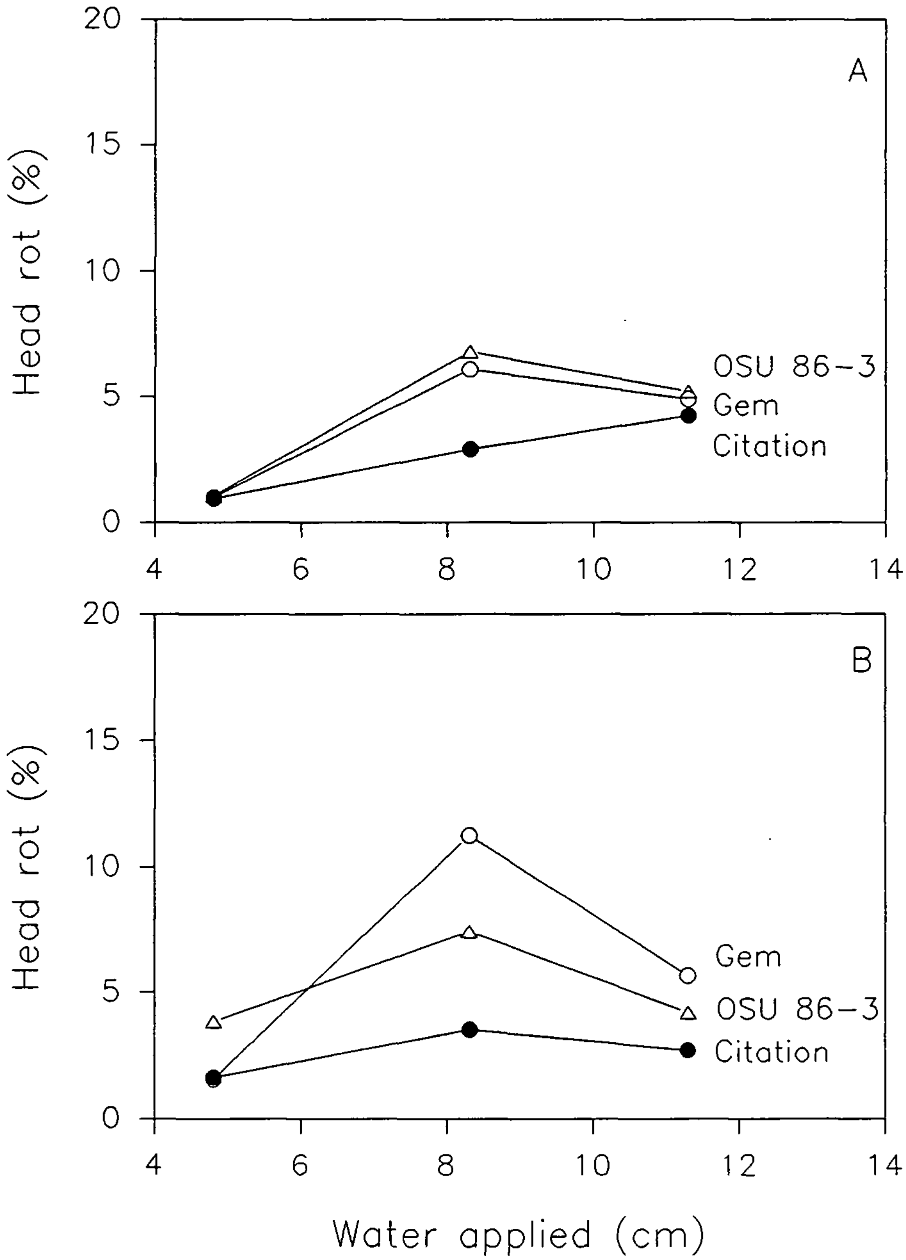

Fig. II.1. Effect of irrigation water applied during head development on the incidence of head rot under A) low-frequency and B) high-frequency irrigation in 1987.

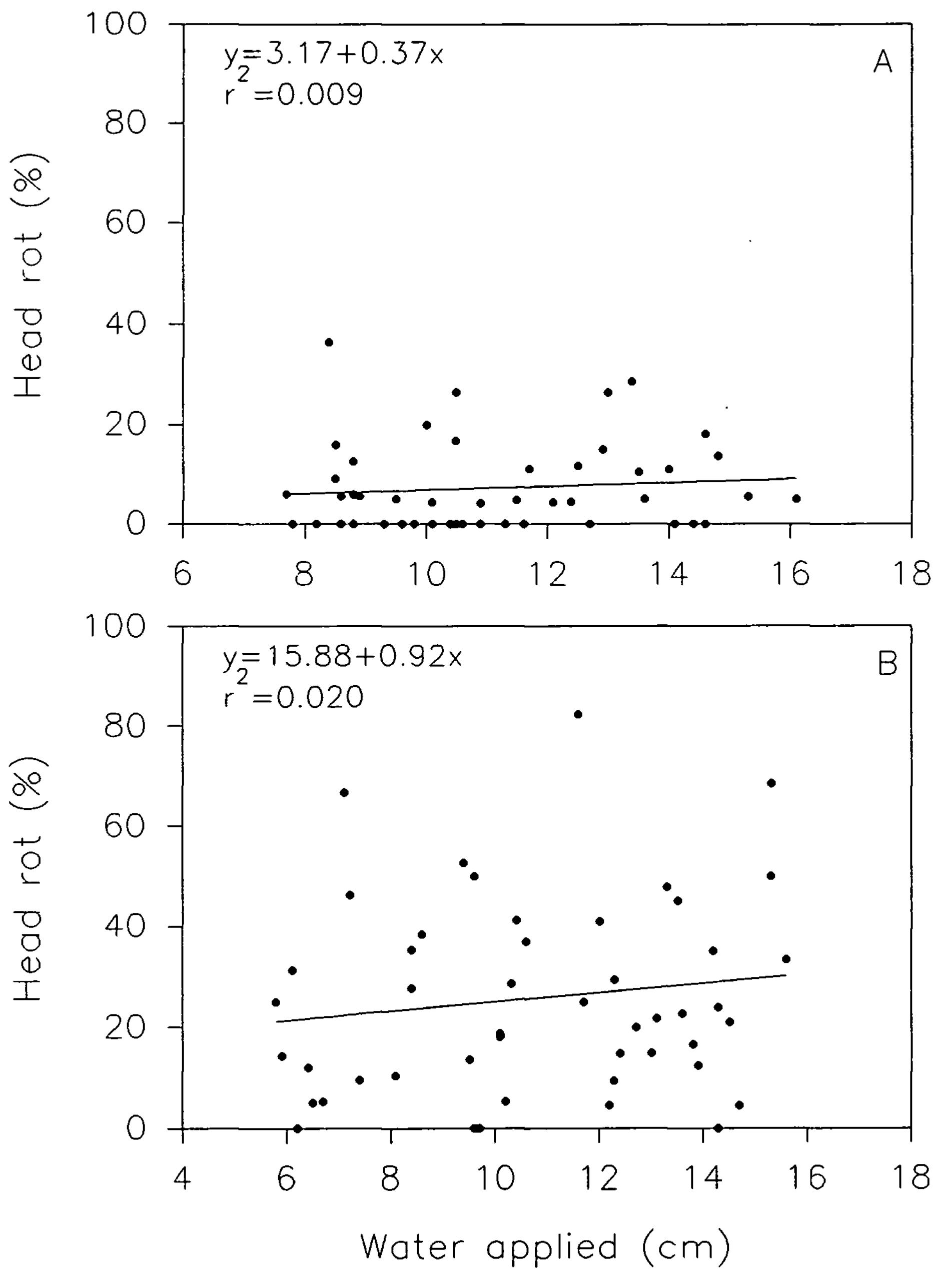

Fig. II.2. Regression of irrigation water applied during head development and the incidence of head rot under A) low-frequency and B) high-frequency irrigation in 1988. Only data from 'Gem' and 'Citation' is included due to the low yield of OSU 86-3.

Table II.7. Effect of cultivar on yield of broccoli under high-frequency irrigation, 1987.

Harvest date/ Cultivar	Yield (T/ha)	Number of heads	Head weight (g)	Head width (cm)
First harvest				
Gem	4.90 a[z]	7.1 a	233.9 b	10.85 b
Citation	3.36 a	3.9 b	282.1 a	11.99 a
OSU 86-3	0.74 b	0.9 c	282.8 a	11.49 ab
Second harvest				
Gem	7.31 b	9.0 b	285.4 a	11.99 a
Citation	10.70 a	11.2 a	327.3 a	12.90 a
OSU 86-3	6.27 b	6.6 c	321.9 a	12.38 a
Third harvest				
Gem	1.74 b	3.2 b	208.4 a	11.42 a
Citation	2.01 b	3.4 b	209.4 a	10.50 ab
OSU 86-3	4.50 a	7.9 a	204.1 a	9.76 b
Total harvest				
Gem	13.96 ab	19.2 a	250.4 c	11.25 b
Citation	16.07 a	18.5 a	295.5 b	12.13 a
OSU 86-3	11.51 b	15.4 b	258.7 a	10.91 c

[z] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.8. Effect of cultivar on yield of broccoli under low-frequency irrigation, 1987.

Harvest date/ Cultivar	Yield (T/ha)	Number of heads	Head weight (g)	Head width (cm)
First harvest				
Gem	5.60 a[z]	6.8 a	262.7 b	11.81 b
Citation	3.23 b	3.7 b	301.9 a	12.84 a
OSU 86-3	0.28 c	0.4 c	220.0 c	11.37 b
Second harvest				
Gem	7.81 b	9.8 a	274.7 a	12.09 a
Citation	10.26 a	11.3 a	305.7 a	12.87 a
OSU 86-3	6.78 b	7.7 b	299.5 a	12.51 a
Third harvest				
Gem	1.37 b	2.6 b	201.8 a	10.96 a
Citation	1.83 b	3.6 b	179.3 a	10.33 a
OSU 86-3	3.69 a	6.1 a	200.3 a	10.34 a
Total harvest				
Gem	14.79 a	19.3 a	259.4 a	11.73 b
Citation	15.32 a	18.6 a	278.2 a	12.27 a
OSU 86-3	10.74 b	14.3 b	254.0 a	11.48 c

[z] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.9. Effect of cultivar on yield of broccoli under high-frequency irrigation, 1988.

Harvest date/ Cultivar	Yield (T/ha)	Marketable yield (T/ha)	Number of heads	Head weight (g)	Head width (cm)
First harvest					
Gem	5.30 a[z]	4.99 a	7.1 a	242.9 a	10.92 a
Citation	0.58 b	0.58 b	0.7 b	282.5 a	11.19 a
OSU 86-3	0.12 b	0.12 b	0.2 b	247.5 a	11.11 a
Second harvest					
Gem	6.90 a	3.73 a	9.5 a	252.1 b	11.62 b
Citation	5.82 a	4.43 a	6.3 b	303.5 ab	12.02 b
OSU 86-3	3.06 b	2.41 a	2.9 c	373.6 a	13.03 a
Third harvest					
Gem	2.74 b	0.80 b	4.1 b	233.6 b	11.19 a
Citation	6.08 a	2.97 a	7.5 a	271.8 ab	11.97 a
OSU 86-3	3.79 ab	0.54 b	3.7 b	373.1 a	12.70 a
Fourth harvest					
Gem	0.52 a	0.12 b	1.4 a	121.0 a	9.17 a
Citation	2.67 a	0.53 a	4.6 a	181.2 a	10.10 a
OSU 86-3	1.22 a	0.20 b	2.3 a	179.0 a	9.61 a
Total harvest					
Gem	15.46 a	9.63 a	22.1 a	236.7 c	11.11 a
Citation	15.15 a	8.51 a	19.0 b	266.9 b	11.55 a
OSU 86-3	8.19 b	3.27 b	9.0 c	319.2 a	12.11 a

[z] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.10. Effect of cultivar on yield of broccoli under low-frequency irrigation, 1988.

Harvest date/ Cultivar	Yield (T/ha)	Marketable yield (T/ha)	Number of heads	Head weight (g)	Head width (cm)
First harvest					
Gem	7.24 a[z]	6.93 a	9.2 a	272.9 a	11.91 a
Citation	1.11 b	1.11 b	1.4 b	277.0 a	11.29 a
OSU 86-3	0.17 b	0.17 b	0.2 b	347.5	12.07 a
Second harvest					
Gem	6.01 b	3.56 b	8.5 a	234.3 c	10.96 a
Citation	8.65 a	7.16 a	9.2 a	316.5 b	12.12 a
OSU 86-3	3.72 c	3.04 b	3.3 b	385.1 a	11.88 a
Third harvest					
Gem	1.05 c	0.28 c	2.0 c	169.4 c	9.78 b
Citation	5.00 a	3.48 a	6.8 a	255.5 b	12.50 a
OSU 86-3	3.73 b	1.70 b	3.8 b	351.3 a	13.20 a
Fourth harvest					
Gem	0.32 a	0.13 a	0.8 b	129.4 a	9.79 ab
Citation	1.15 a	0.50 a	2.0 a	195.2 a	10.46 a
OSU 86-3	1.46 a	0.57 a	2.3 a	193.0 a	9.35 b
Total harvest					
Gem	14.62 a	10.90 a	20.5 a	242.5 b	11.38 a
Citation	15.90 a	12.25 a	19.3 a	279.2 b	12.03 a
OSU 86-3	9.08 b	5.48 b	9.5 b	330.4 a	11.95 a

[z] Means among cultivars within columns followed by the same letter are not significantly different at LSD=0.05.

Table II.11. Analysis of variance for yield, number, and head weight of broccoli according to cultivar and irrigation treatments under high-frequency irrigation, 1987.

		Yield		Number		Head weight	
Source	DF	MS	F	MS	F	MS	F
Rep (R)	5	4.8589		3.4519		2302.28	
Cultivar (C)	2	93.6678	6.42 **	74.6852	8.43 **	10370.35	5.14 *
Error (C x R)	10	14.5783		8.8630		2018.68	
Irrigation (I)	2	0.5949	0.07 NV	69.2407	7.51 NV	12470.11	10.73 NV
Error (I x R)	10	8.1133		9.2185		1162.35	
C x I	4	13.0626	3.23 *	14.6852	1.95 NS	4283.40	2.40 NS
Error (C x I x R)	20	4.0446		7.5296		1783.55	

[NS, *, **] Nonsignificant and significant at P=0.05 and 0.01, respectively.
[NV] Probability statements are not valid because treatments were not randomized.

Table II.12. Analysis of variance for yield, number, and head weight of broccoli according to cultivar and irrigation treatments under low-frequency irrigation, 1987.

		Yield		Number		Head weight	
Source	DF	MS	F	MS	F	MS	F
Rep (R)	5	3.4993		2.4296		2075.99	
Cultivar (C)	2	112.8742	24.57 **	131.4630	24.87 **	2903.06	1.78 NS
Error (C x R)	10	4.5941		5.2852		1630.23	
Irrigation (I)	2	147.2362	16.62 NV	82.4630	13.12 NV	30134.28	29.98 NV
Error (I x R)	10	8.8611		6.2851		1005.14	
C x I	4	6.5623	0.58 NS	6.4352	0.61 NS	461.11	0.21 NS
Error (C x I x R)	20	11.2436		10.5574		2222.59	

NS, *, ** Nonsignificant and significant at P=0.05 and 0.01, respectively.
NV Probability statements are not valid because treatments were not randomized.

Table II.13. Analysis of variance of broccoli yield according to cultivar and irrigation treatments under high-frequency irrigation, 1988.

		Yield		Marketable yield	
Source	DF	MS	F	MS	F
Rep (R)	2	9.7696		4.1794	
Cultivar (C)	2	405.4091	56.70 **	277.1699	54.77 **
Error (C x R)	4	7.1500		5.0605	
Irrigation (I)	3	47.3395	20.66 NV	0.6462	0.51 NV
Error (I x R)	6	2.2913		1.2638	
C x I	6	10.9984	1.28 NS	10.3198	2.60 NS
Error (C x I x R)	12	8.5691		3.9722	
Half (H)	1	77.3387	12.73 NV	57.7254	44.75 NV
Error (H x R)	2	6.0771		1.2899	
C x H	2	33.0571	36.68 **	11.6732	1.21 NS
Error (C x H x R)	2	0.9013		9.6563	
I x H	3	5.2085	1.56 NV	4.6348	0.63 NV
Error (I x H x R)	6	3.3283		7.3034	
C x I x H	6	6.7411	0.68 NS	8.6902	0.91 NS
Error (C x I x H x R)	12	9.8677		9.5217	

[NS, **] Nonsignificant and significant at P=0.01.

[NV] Probability statements are not valid because treatments were not randomized.

Table II.14. Analysis of variance of broccoli yield according to cultivar and irrigation treatments under low-frequency irrigation, 1988.

Source	DF	Yield MS	Yield F	Marketable yield MS	Marketable yield F
Rep (R)	2	12.3703		1.9148	
Cultivar (C)	2	315.6397	58.39 **	307.6477	89.48 **
Error (C x R)	4	5.4061		3.4382	
Irrigation (I)	3	16.9544	2.86 NV	0.5522	0.27 NV
Error (I x R)	6	5.9194		2.0137	
C x I	6	2.9851	1.32 NS	6.7794	2.12 NS
Error (C x I x R)	12	2.2639		3.1966	
Half (H)	1	26.1528	4.43 NV	0.1446	0.02 NV
Error (H x R)	2	5.9034		6.2534	
C x H	2	1.4992	0.20 NS	6.6083	0.68 NS
Error (C x H x R)	2	7.5360		9.6582	
I x H	3	11.1823	4.10 NV	2.4227	0.55 NV
Error (I x H x R)	6	2.7278		4.4335	
C x I x H	6	6.2985	1.90 NS	5.1683	0.59 NS
Error (C x I x H x R)	12	3.3075		8.7302	

NS, ** Nonsignificant and significant at P=0.01.

NV Probability statements are not valid because treatments were not randomized.

which yielded higher in 1987 than 1988 due to a loss in plant stand. Irrigation effects on yield were inconsistent regarding the amounts of water applied between the two irrigation frequencies. Yields increased as water applied increased from 4.8 to 11.3 cm for all cultivars under low-frequency irrigation in 1987 (Fig II.3A). However, an interaction occurred under high-frequency irrigation in 1987 (Fig. II.3). Yields were higher for 'Gem' under the low water regime (4.8 cm) compared with the high water regime (11.3 cm). 'Citation' had lower yields under the low water regime compared with the high water regime (Fig II.3B). Yields of the OSU line decreased as the water applied increased from the low to the high water regime. In 1988, an interaction between cultivar and half (Table II.13) occurred when 'Citation' yielded 4.6 t/ha less from one side of the irrigation line compared with the other. Yields of the other two cultivars were consistent between sides. Regression equations were fit to the water applied and yield data for 'Gem' and 'Citation' only, because of the extremely low yields of OSU 86-3 in 1988. Yields increased only slightly under low-frequency irrigation when water applied increased, whereas a quadratic equation fit the high-frequency data with yields levelling off at 12 cm of applied water (Fig II.4).

Marketable yield, measured in 1988 only, was total yield minus the yield of heads with head rot, downy mildew or both. Cultivar significantly affected marketable yield (Tables II.13 and 14). 'Gem' and 'Citation' had the highest marketable yield (Tables II.9 and 10).

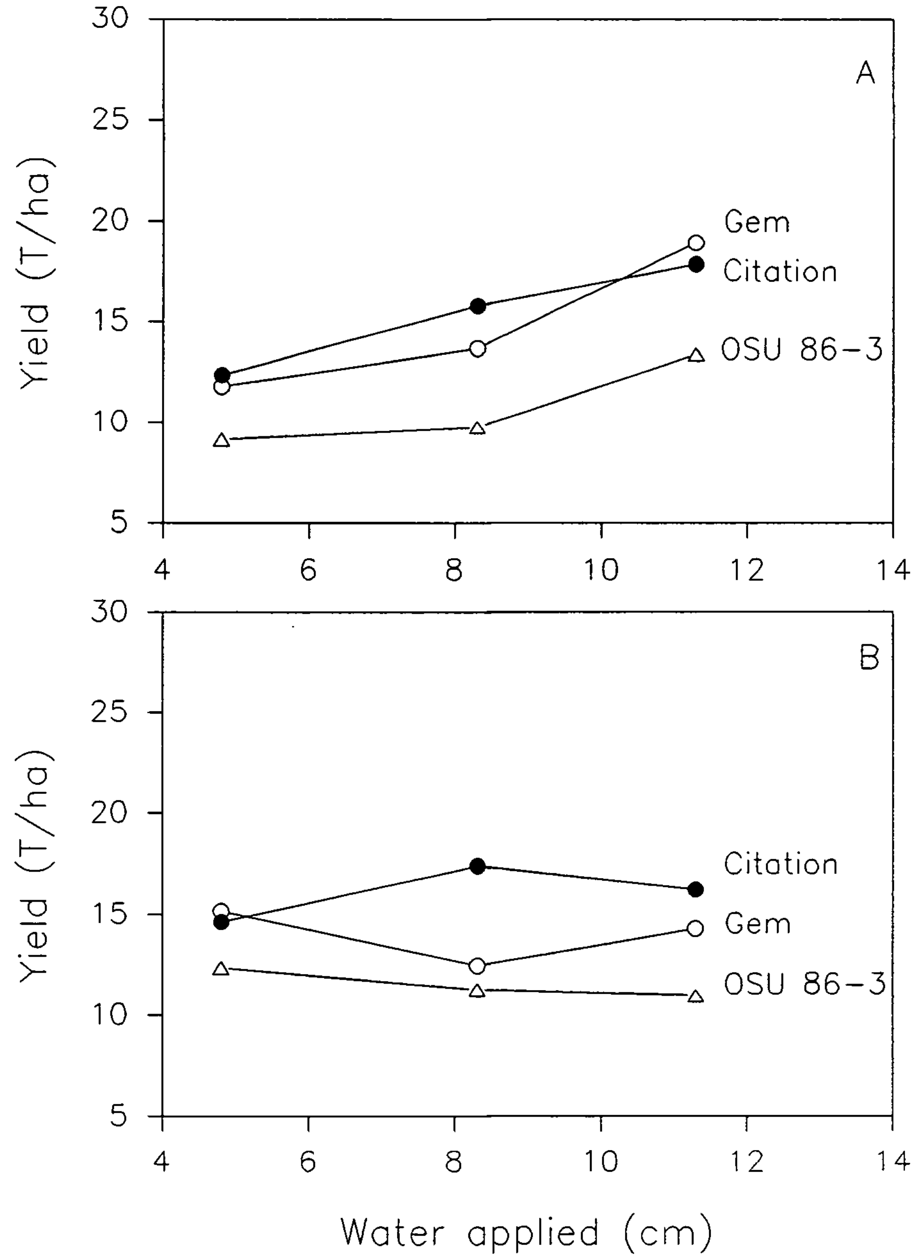

Fig. II.3. Effect of irrigation water applied during head development on the yield of three broccoli cultivars under A) low-frequency and B) high-frequency irrigation in 1987.

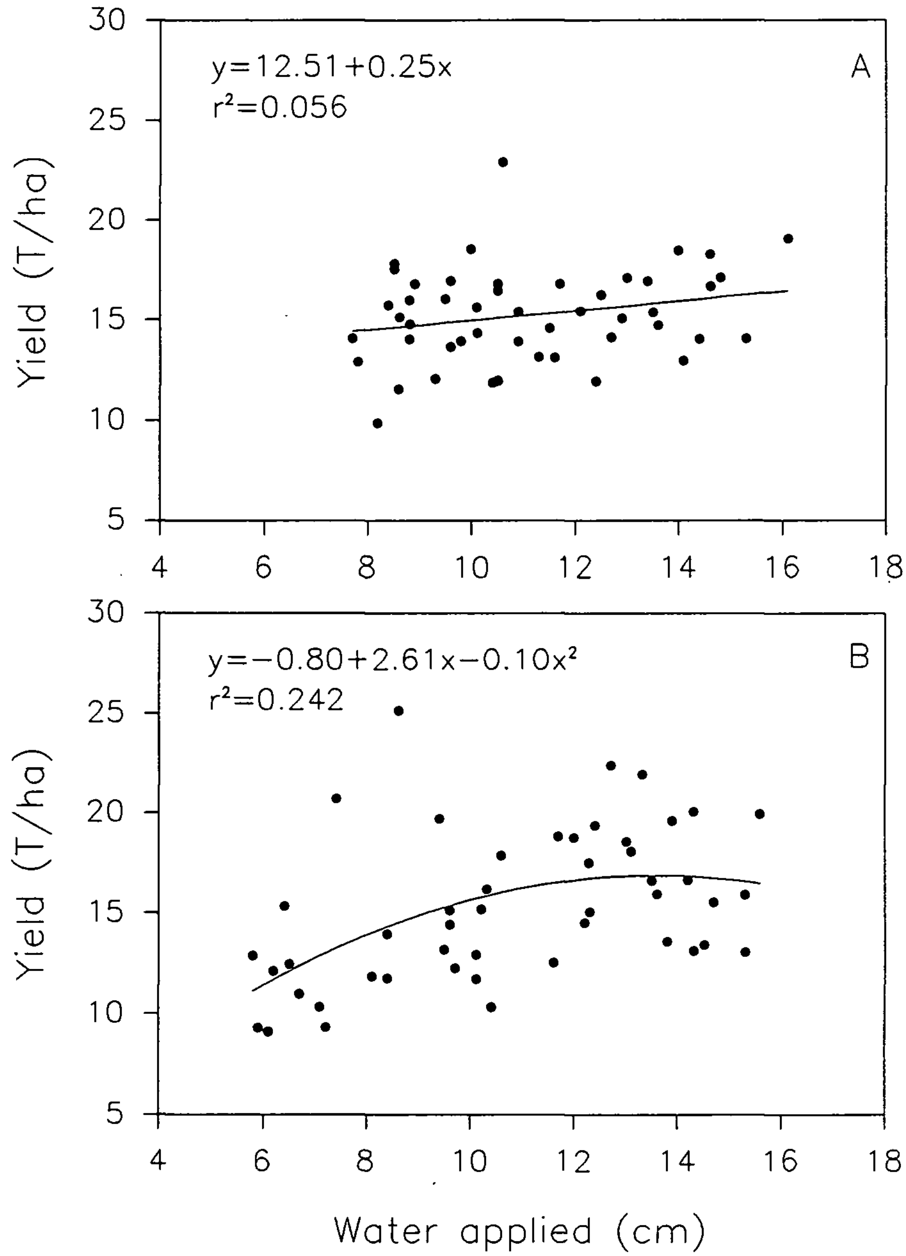

Fig.II.4. Regression of irrigation water applied during head development and yield under A) low-frequency and B) high-frequency irrigation in 1988. Only data from 'Gem' and 'Citation' is included due to the low yield of OSU 86-3.

More marketable heads were harvested during the first and second harvests compared with the third and fourth harvests. Marketable yields were slightly higher under low- compared with high-frequency irrigation. Incidence of downy mildew remained consistent between frequencies, whereas, the incidence of head rot under high-frequency irrigation was greater than under low-frequency irrigation (Tables II.1 and 2).

'Gem' and 'Citation' produced an equal number of heads (Tables II.7-10). OSU 86-3 produced fewer heads than did 'Gem' or 'Citation' in both years, but produced less in 1988. Number of harvested heads between 'Gem' and 'Citation' was consistent between years and irrigation frequencies.

Head weight was significantly different among cultivars (Tables II.15 and 16). 'Gem' consistently yielded the smallest heads regardless of irrigation frequency or year (Tables II.7-10). 'Citation' produced the largest heads in 1987 and the OSU line produced the largest heads in 1988. In 1987, head weight increased as the amount of water applied increased from 4.8 to 8.3 cm of water and then leveled off (Fig II.6). In 1988, regression models for head weight with only the 'Gem' and 'Citation' data were similar to the regression models for yield (Fig II.7 vs. Fig II.5). Under low-frequency irrigation, head weight did not increase significantly with increases in water, and the regression model did not fit ($P>.10$). Under high-frequency irrigation, a quadratic equation best fit the data with a levelling off of head weight at 12 cm of water applied.

Table II.15. Analysis of variance of number and weight of broccoli heads according to cultivar and irrigation treatments under high-frequency irrigation, 1988.

Source	DF	Number MS	Number F	Head weight MS	Head weight F
Rep (R)	2	4.8472		739.61	
Cultivar (C)	2	1120.4306	206.32 **	41835.96	61.63 **
Error (C x R)	4	5.4306		678.78	
Irrigation (I)	3	4.0138	1.53 NV	12509.21	8.36 NV
Error (I x R)	6	2.6250		1496.83	
C x I	6	5.0972	0.79 NS	2482.45	1.22 NS
Error (C x I x R)	12	6.4583		2036.46	
Half (H)	1	4.0138	0.23 NV	31766.86	86.64 NV
Error (H x R)	2	17.1806		366.63	
C x H	2	45.5972	7.28 *	2191.39	1.61 NS
Error (C x H x R)	2	6.2639		1358.52	
I x H	3	12.3843	2.07 NV	5623.75	8.09 NV
Error (I x H x R)	6	5.9953		694.83	
C x I x H	6	2.5231	0.24 NS	2049.92	1.27 NS
Error (C x I x H x R)	12	10.5509		1614.76	

NS, *, ** Nonsignificant and significant at P=0.05 and 0.01, respectively.
NV Probability statements are not valid because treatments were not randomized.

Table II.16. Analysis of variance of number and weight of broccoli heads according to cultivar and irrigation treatments under low-frequency irrigation, 1988.

		Number		Head weight	
Source	DF	MS	F	MS	F
Rep (R)	2	3.0139		308.88	
Cultivar (C)	2	873.3472	136.70 **	46817.96	21.73 **
Error (C x R)	4	6.3889		2154.86	
Irrigation (I)	3	3.6435	1.84 NV	11560.08	16.75 NV
Error (I x R)	6	1.9769		690.32	
C x I	6	3.2546	0.92 NS	1224.79	0.61 NS
Error (C x I x R)	12	3.5463		1995.59	
Half (H)	1	42.0139	81.76 NV	1587.77	1.31 NV
Error (H x R)	2	0.5139		1216.51	
C x H	2	0.6806	0.10 NS	4769.46	5.36 NS
Error (C x H x R)	2	6.806		889.88	
I x H	3	2.2361	0.32 NV	5177.40	3.84 NV
Error (I x H x R)	6	7.0694		1349.75	
C x I x H	6	5.5139	1.55 NS	1366.47	1.05 NS
Error (C x I x H x R)	12	3.5556		1299.70	

[NS, **] Nonsignificant and significant at P=0.01.
[NV] Probability statements are not valid because treatments were not randomized.

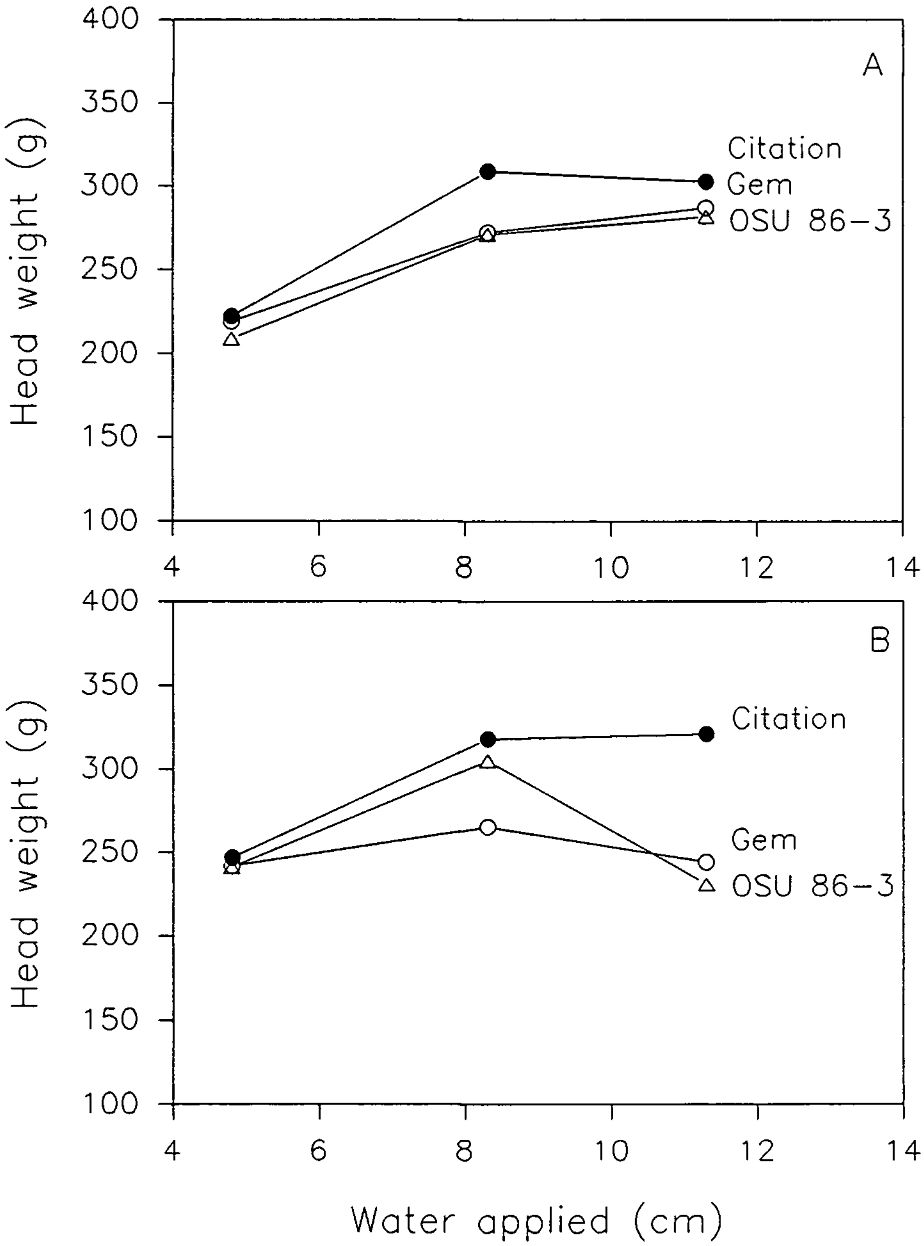

Fig.II.5. Effect of irrigation water applied during head development on the head weight of three broccoli cultivars under A) low-frequency and B) high-frequency irrigation in 1987.

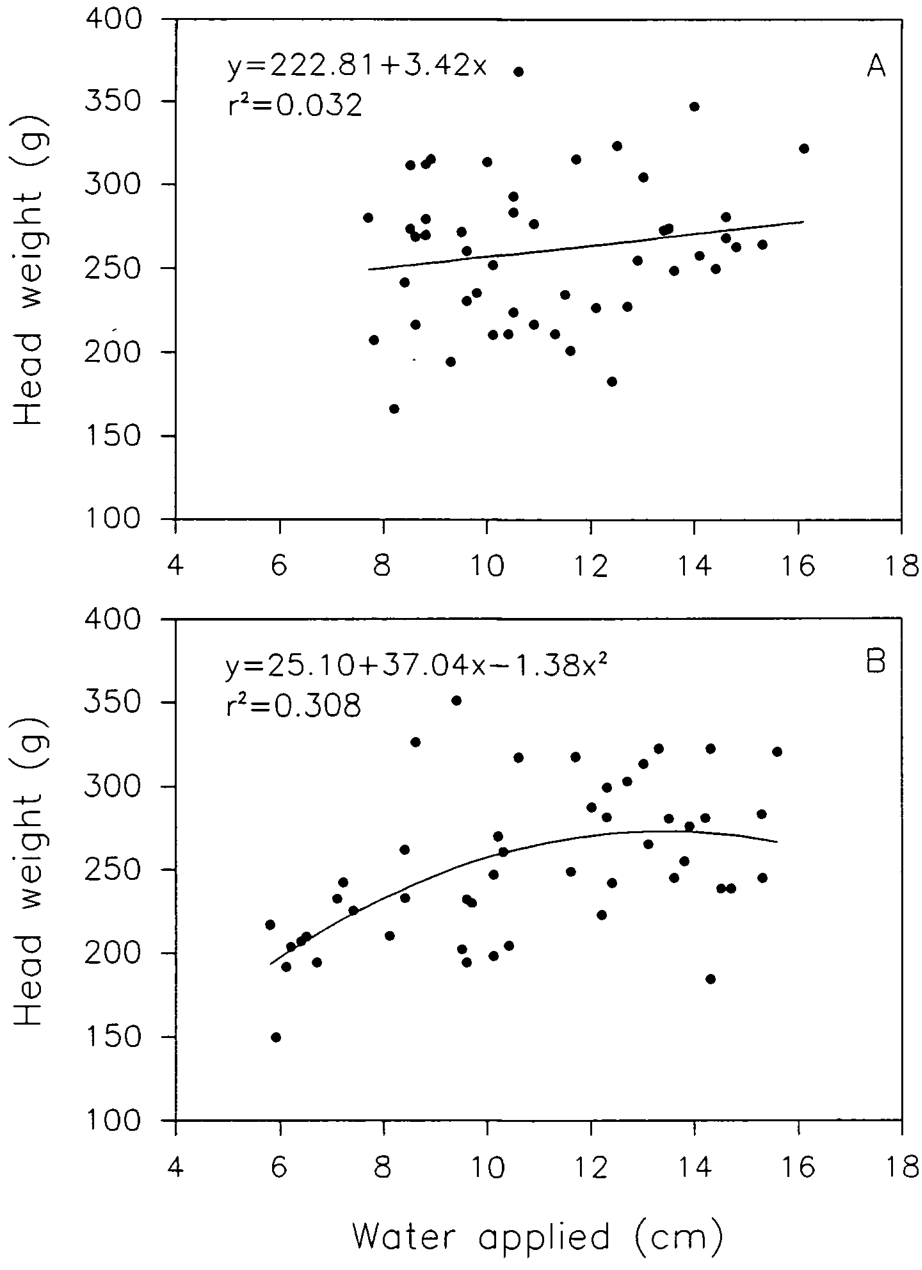

Fig.II.6. Regression of irrigation water applied during head development and head weight under A) low-frequency and B) high-frequency irrigation in 1988. Only data from 'Gem' and 'Citation' is included due to the low yield of OSU 86-3.

DISCUSSION

Head rot

Differences in amount of head rot among cultivars may have occurred because of differences in susceptibility or in climatic conditions that existed during head maturation. OSU 86-3 had the highest percentage of head rot, followed by 'Citation' and 'Gem', but head maturation did not occur at the same time. 'Gem' matured first followed by 'Citation' and OSU. Canaday et al. (1988) assessed the susceptibility of several broccoli cultivars and found 'Gem' to be quite susceptible. In this study, however, 'Gem' was the least susceptible. Canaday et al. (1989) also found an inverse correlation between the incidence of head rot and days to maturity. In our study, the longer the maturation period, the greater the incidence of head rot. The prevailing climatic conditions occurring at the time of maturation of each cultivar could explain some of the difference in the incidence of head rot. Most likely a combination of environmental and susceptibility factors is responsible.

When macroclimatic conditions are either unfavorable or extremely favorable for disease development, the influence of irrigation on the incidence of disease would be negligible, but within the window between favorable and unfavorable conditions, irrigation practices could influence disease development by modifying the plant microclimate (Rotem and Palti, 1969; Rotem et al., 1970). This macroclimatic influence could explain the large difference in incidence of head rot between the low- and high-frequency experiments in 1988 and the differences between years.

Temperature and rainfall data support the inference that differences in head rot incidence between years were associated with a variation in climatic conditions. Mild daily high temperatures- less than 22^{o}C- occurred more often and for longer periods from September 15 to October 15 in 1988 compared to 1987 (Fig IV.1). During this same period, 1.35 cm of precipitation was measured in 1987 compared with 3.35 cm in 1988.

The amount of water applied over the 5.5 weeks during heading did not affect head rot. Micrologger data indicate no relationship between amount of water applied and leaf wetness duration. Few studies have reported the effects of amount of water applied.

Frequency of irrigation was the most important factor affecting the incidence of head rot. Rotem and Palti (1969) suggest frequency of irrigation, other components being equal, has a major influence on disease development. Late blight (Phytophthora infestans) of potatoes was more severe on plots receiving frequent irrigations of 8 to 11 overhead irrigations at 7 to 10 day intervals than on plots receiving 3 to 4 overhead irrigations at 21 to 28 day intervals (Rotem et al., 1962).

Yield

Yields were equivalent between 'Gem' and 'Citation', whereas, yields of OSU 86-3 were significantly lower. In 1988, transplanted seedlings of OSU were smaller than the other two cultivars and may have been more susceptible to damage from cabbage maggot feeding.

'Gem' heads were slightly smaller than 'Citation' heads. The head weight of OSU 86-3 exceeded 'Citation' in 1988 because of a decrease in plant population, thus a decrease in competition for water, nutrients and space in the OSU plots.

Effects of amounts of water applied on yield under the two irrigation frequencies were inconsistent and difficult to assess. Several factors, such as wind, nozzle size and speed, can distort the irrigation spray pattern, thus, the irrigation gradient, accounting for some of the variability in yields. Also, the margin of irrigation regimes established varied between years and frequencies. Overall, yields are comparable to other studies. The irrigation and nitrogen management study by Beverly et al. (1986) recorded yields of 15 T/ha of broccoli when 280 kg/ha of N and 2.7 cm/wk of water was applied. In our study, yields of 15-16 T/ha were grown with the application of 280 kg/ha of N and an average of 2.4 cm/wk of water. Average yields of high- and low-irrigation experiments were similar which indicates irrigating only once per week would be adequate.

Line-source sprinkler irrigation systems for a continuous variable make statistical analysis of water effects difficult, but differences are usually large. Studies comparing results from a continuous variable to a randomized-block design reach the same conclusions (Bauder et al., 1975). Despite the design limitations, a line-source sprinkler system can be used effectively.

The lack of an efficacious chemical control for use on broccoli head rot makes irrigation management an important tool in controlling its incidence. Irrigating less than 3 times/week can reduce the incidence of head rot, but when macroclimatic conditions are favorable for head rot development, control of head rot is unlikely.

CHAPTER III. PLANT DENSITY EFFECTS ON HEAD ROT AND YIELD OF BROCCOLI

INTRODUCTION

Several studies indicate broccoli yields increase when plant populations increase from 2 to 20 plants/m^2, but response is dependent on the cultivar (Zink and Alderfer, 1951; Cutcliffe, 1975; Salter et al., 1984). Chung (1982) reported an asymptotic yield-plant density relationship with a levelling off at populations above 20 plants/m^2 for a single destructive harvest. In a multiple harvest system, Thompson and Taylor (1976) found yields levelling off below 10 plants/m^2. Planting in a square arrangement produced higher yields compared to a rectangular arrangement of the same number of plants (Palevitch, 1970). Higher yields were obtained by reducing the within-row rather than the between-row spacing (Cutcliffe, 1975).

Although yields per unit area increase as the plant population increases, broccoli head size decreases. Cutcliffe (1975) reported a 75% reduction in mean head weight when the population increased from 2 to 24 plants/m^2. Chung (1982) found that head width was reduced by almost half when 'Gem' broccoli populations increased from 2 to 23 plants/m^2.

High plant densities favor the incidence of a number of fungal and bacterial diseases by increasing the number of plants per unit area available for infection or by modifying the microclimate within the host canopy thereby providing a more favorable environment to disease development (Burdon and Chilvers, 1982). Ramularia leaf spot on sugar beets (Scott, 1969) and Cercospora blight of celery (Berger, 1975) were more severe in close-plant spacings compared with wide-plant spacings. Grey mold of beans was most destructive where the rows were closest together, or the stand of plants and growth of foliage were greatest (Campbell, 1949). Incidence of aerial stem rot of potatoes was greater in plantings with a dense canopy compared to a sparse canopy (Cappaert and Powelson, 1990). In several other studies, plant density had no effect on the disease incidence (Fritz and Honma, 1987; Strandberg and White, 1978).

Head rot of broccoli is a perennial problem in several production areas. Incidence of this disease, however, varies from field to field and year to year, but occurs mainly during mild, moist weather conditions (Wimalajeewa et al., 1985; Canaday et al., 1987). Two bacterial pathogens, Pseudomonas marginalis and Erwinia carotovora subsp. carotovora, have been reported as the causal agents, (Wimalajeewa et al., 1987; Canaday et al., 1988). To date, no chemicals have provided adequate control of this disease and only moderate levels of disease resistance have been identified in a few cultivars (Canaday, 1988). Disease control strategies have focused on cultural tactics that promote conditions unfavorable to disease. Dense plant populations provide favorable yields, but may also create conditions favorable for development of head rot. The purpose of this study was to determine the effect of plant density on head rot and yield of broccoli.

MATERIAL AND METHODS

Field experiments were conducted at the North Willamette Experiment Station, Aurora, OR, in 1987 and 1988. On 16 March, 1987, the broccoli cultivar 'Gem' was double-seeded into 3.8 cm cells filled with a medium of peat, pumice and shredded bark (1:1:2, v/v/v). One week later, seedlings were thinned to one plant per cell. Seedlings were watered as needed and fertilized weekly with a water-soluble 20-20-20 fertilizer with micronutrients. Plants were grown in an unheated greenhouse until planted to the field 4 weeks after seeding.

The plot area consisted of a Willamette silt loam to which was applied trifluralin at 0.84 kg/ha, chlorpyrifos at 1.5 kg/ha, and a 10N-8.7P-16.7K fertilizer at 1120 kg/ha 1 week before transplanting and propachlor at 4.5 kg/ha the day after transplanting. A diazinon drench at 1.1 kg/ha was applied twice for root maggot (Delia brassicae) control before and after transplanting. An additional 168 kg/ha of N were applied as ammonium nitrate 3 weeks after transplanting. In May, carbaryl at 1.1 kg/ha was applied to the plots to control flea beetles (Phyllotreta cruciferae).

Each plot consisted of a four-row bed, 4.6 m in length. The eight treatments of two between-row spacings (41 and 51 cm) and four within-row spacings (15, 20, 25, and 30 cm) formed a 2 X 4 factorial experiment. Treatments were replicated six times.

A strain of Erwinia carotovora subsp. carotovora, isolated from a broccoli head with head rot symptoms in 1986, was used to inoculate the field plots. Inoculum was grown on King's B medium for 48 hr at 20-22° C. An aqueous cell suspension (10^6 cells/ml) was prepared and applied to the plots with a pressurized, backpack sprayer at weekly intervals beginning at head initiation and ending the week of the second harvest. Plots were harvested on June 14 and 23. Mature heads from the two center rows of each plot were harvested, and the weight, total number of heads, and number of diseased heads were recorded.

In 1988, methods were similar to 1987 except as follows. The breeding line, OSU 86-3, as well as 'Gem', was planted. OSU 86-3 was seeded March 9 and 'Gem' was seeded March 23 to encourage heading at the same time. Seedlings were transplanted to the field April 26. The experiment included the same two between-row spacings (41 and 51 cm), but only three within-row spacings (15, 23 and 30 cm) forming a 2 x 2 x 3 factorial. The experimental design was a randomized block design and the twelve treatments were replicated five times. Plots were harvested four times in 1988 (June 27, July 5, 12, and 20).

Treatment effects were assessed by analysis of variance, and treatment means were compared by least significant difference (LSD). Regression coefficients were determined for yield and plant population and for head weight and plant population by fitting a simple linear regression model to these variables.

RESULTS

No head rot developed in 1987, whereas 17.5% of the broccoli heads harvested in 1988 had symptoms. Plant spacing, however, had no affect on disease incidence (Table III.1). In contrast, significant cultivar differences were apparent: 28.8% of the OSU 86-3 heads developed head rot compared to 5.6% of the 'Gem' heads by the end of harvest (Table III.2). Very little head rot occurred early in the season. Most of the disease occurred during the third and fourth harvests.

No interaction occurred between cultivar and plant spacings for total yields in 1988 (Table III.1) nor between within-row and between-row spacing for total yields in 1987 (Table III.3). In 1988, as both the between-row and within-row spacing decreased, yields increased (Table III.4). In 1987, only a decrease in within-row spacing significantly increased yields (Table III.5).

Yields generally increased as plant populations increased, but response depended on the cultivar. A linear equation was fitted to the population and total yield data for 'Gem' for both years (Fig. III.1). The two equations were similar for 1987 and 1988. One missing plot occurs each year. Yields were higher in 1987 than in 1988 due to a greater average head weight in 1987. Yields of OSU 86-3 did not respond significantly to differences in plant populations and failed to adequately fit a regression model, $y=13.1968+0.2049p$, ($r^2=0.04$). Although 'Gem' and OSU 86-3 did not respond similarly to differences in plant population, their overall yields did not differ

Table III.1. Analysis of variance of broccoli yield, productive plants, head weight, and head rot incidence according to spacing and cultivar in 1988.

Source of variation	DF	F-value			
		Yield[z]	Productive[x] plants	Head weight	Percent head rot
Replicates	4	0.27 NS	1.53 NS	1.06 NS	0.38 NS
Between-row spacing (B)	1	5.53 *	0.58 NS	0.92 NS	1.26 NS
Within-row spacing (W)	2	4.12 *	21.39 ***	9.15 ***	0.87 NS
B X W	2	1.67 NS	0.67 NS	0.44 NS	0.21 NS
Cultivar (C)	1	1.50 NS	25.91 ***	18.61 ***	75.68 ***
B X C	1	1.19 NS	3.02 NS	0.28 NS	0.36 NS
W X C	2	0.98 NS	1.22 NS	0.17 NS	1.44 NS
B X W X C	2	0.75 NS	1.04 NS	0.52 NS	0.25 NS
Error	44				

[z] Yield data analyzed with an error of only 41 degrees of freedom due to 3 missing plots.
[x] Percentage of plants producing heads.
NS, *, *** Nonsignificant or significant at P=0.05 and 0.001, respectively.

Table III.2. Effect of cultivar on the incidence of head rot of broccoli at each harvest in 1988.

Cultivar	Percent head rot[z] First	Second		Third		Fourth	
Gem	1.97	3.08	(3.00)	22.29	(5.33)	12.78	(5.56)
OSU 86-3	0.0	3.89	(3.84)	38.44	(24.69)	37.72	(28.77)
	NS	NS	NS	*	***	*	***

[z] Cumulative head rot incidence in parenthesis.
NS, *, *** Nonsignificant and significant at P=0.05 and 0.001, respectively.

Table III.3. Analysis of variance of broccoli yield, productive plants, and head weight according to spacing in 1987.

Source of variation	DF	F-value		
		Yield	Productive plants	Head weight
Replicates	5	0.55 NS	1.03 NS	0.49 NS
Between-row spacing	1	0.93 NS	0.02 NS	4.97 *
Within-row spacing	3	4.34 **	5.66 **	6.03 **
Interaction	3	0.10 NS	1.82 NS	0.58 NS
Error	35			

NS, *, ** Nonsignificant and significant at P=0.05 and 0.01, respectively.

Table III.4. Effect of between-row and within-row spacings on yield, percentage of productive plants and head weight and width in 1988.

Spacing (cm)	Yield (t/ha)	Productive plants (%)	Head weight (g)	Head width (cm)
Between-row				
41	16.69	80.5	217.6	10.3
51	14.83	78.0	230.1	10.7
	*	NS	NS	NS
Within-row				
15	17.36	67.9	189.1	9.8
23	15.40	76.0	225.4	10.5
30	14.71	93.8	257.0	11.2
LSD (0.05)	2.11	8.2	32.0	0.8

NS, * Nonsignificant or significant at P=0.05.

Table III.5. Effect of between-row and within-row spacing on yield, percentage of productive plants and head weight of broccoli in 1987.

Spacing (cm)	Yield (t/ha)	Productive plants (%)	Head weight (g)
Between-row			
41	17.7	81.9	217.3
51	16.5	82.2	250.5
	NS	NS	**
Within-row			
15	20.0	77.8	191.5
20	16.2	76.4	216.2
25	18.1	86.7	270.3
30	14.0	87.2	257.6
LSD (0.05)	3.5	6.9	42.7

NS, ** Nonsignificant or significant at P=0.01.

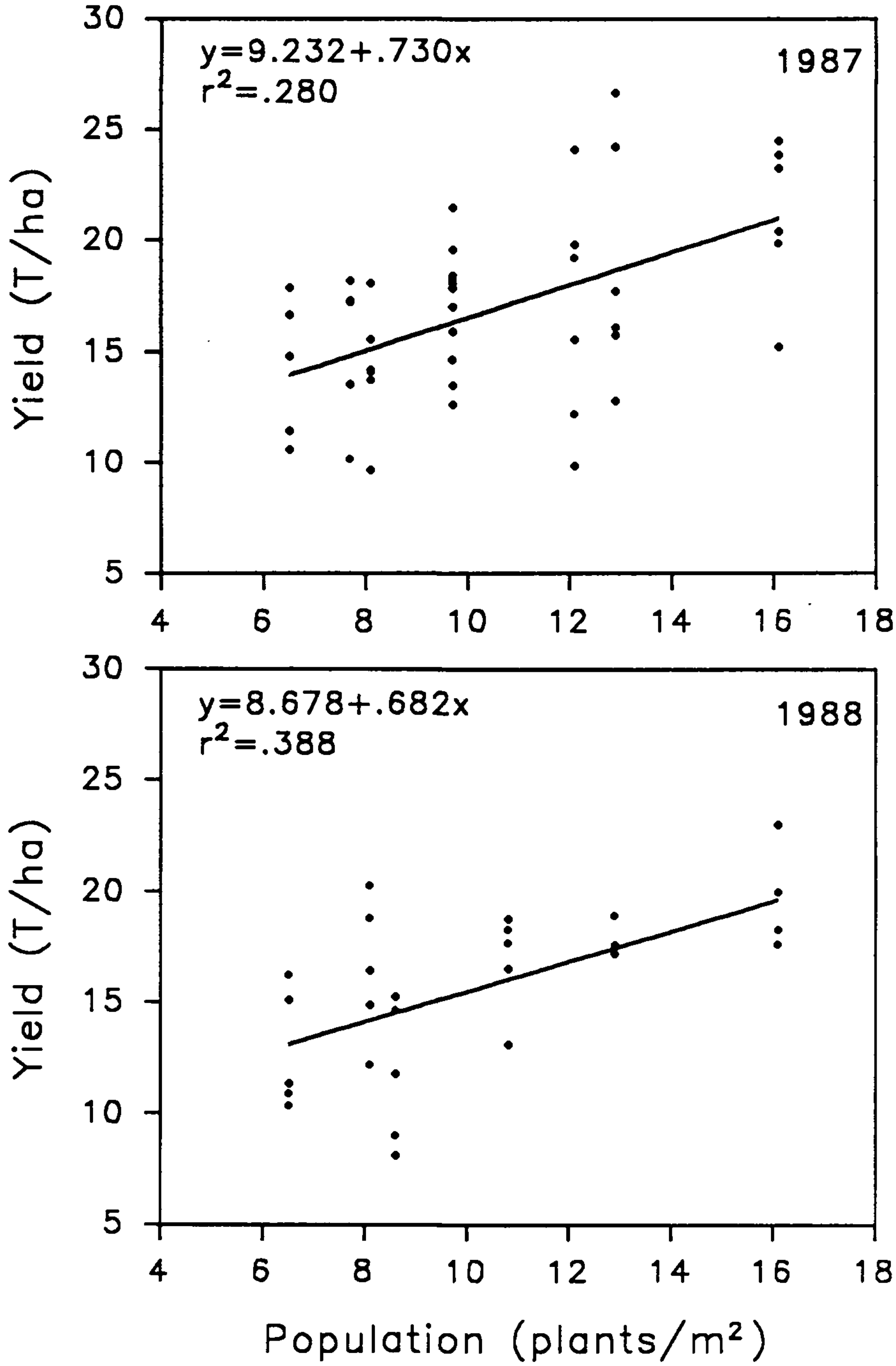

Fig. III.1. Effect of plant population on yield of the broccoli cultivar , 'Gem', in 1987 and 1988.

significantly (Table III.1).

An inverse relationship existed between head weight and plant population (Fig. III.2). The linear regression equations were similar for both years for 'Gem'; in 1987 the equation was $h=348.02-11.02p$ and in 1988 the equation was $h=287.00-8.68p$ where h=head weight (g) and p=plants/m^2. Head weight of the OSU line varied greatly as the population decreased and did not fit the model with an equation of $h=340.22-8.42p$ ($r^2=0.175$) as well as did 'Gem' in 1987 ($r^2=0.311$) and 1988 ($r^2=0.468$).

No interactions occurred between main effects for head weight in 1987 (Table III.3) or in 1988 (Table III.1). In 1987, the head weight of 'Gem' decreased significantly as both the between-row and within-row spacings were reduced (Table III.3). In 1988, only a decrease in within-row spacing decreased the mean head weight significantly (Table III.1).

Plant spacing also influenced the percentage of productive plants, the number of plants forming broccoli heads/total number of plants in each plot. Percentage of productive plants decreased as the within-row spacing was reduced in 1987 (Table III.5) and 1988 (Table III.4), but was not affected by between-row spacing. In 1988, the percentage of plants developing heads was significantly different

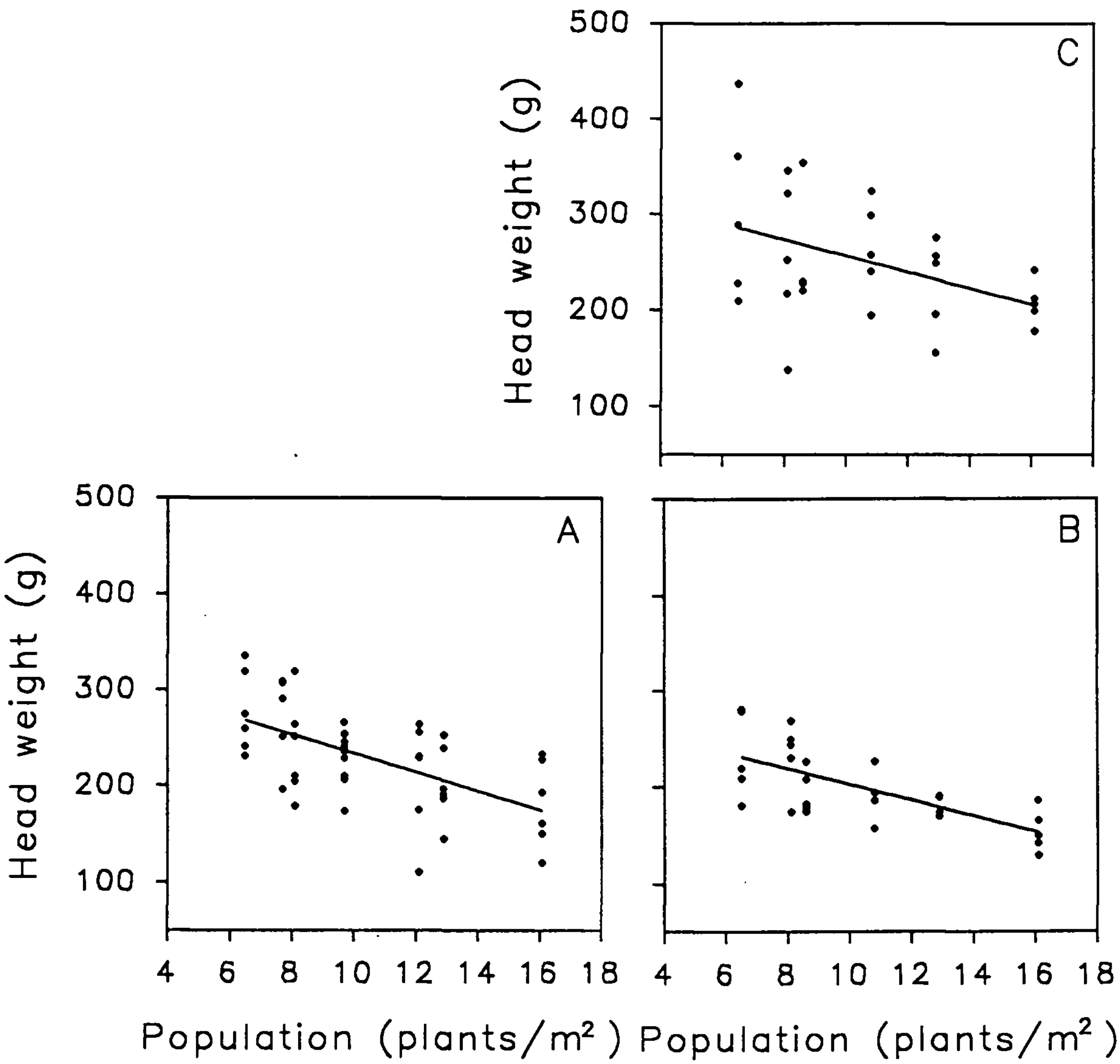

Fig. III.2. Effect of plant population on head weight of the broccoli cultivar, 'Gem', in A) 1987 and B) 1988 and C) the broccoli line, OSU 86-3, in 1988.

between the two cultivars (Table III.1). 'Gem' produced smaller heads, but more plants developed heads compared with OSU 86-3, which produced fewer, but larger heads (Table III.6).

Table III.6. Effect of broccoli cultivar on yield, productive plants, and head weight and width in 1988.

Cultivar	Yield (t/ha)	Productive plants (%)	Head weight (g)	Head width (cm)
Gem	16.32	87.7	195.84	10.5
OSU 86-3	15.35	70.8	251.86	10.5
	NS	***	***	NS

NS, *** Nonsignificant or significant at P=0.001.

DISCUSSION

Plant population had no affect on the incidence of head rot. The position of the broccoli head may explain, in part, the lack of a planting density affect on disease. In many cultivars, the broccoli head is above the canopy where it is exposed to warming and drying more than a head submerged within the canopy, and thus, not affected by modifications of the microclimate within the plant canopy.

Density-disease studies with other crops have had both similar and conflicting results. For example, Strandberg and White (1978) determined infection rates of celery leaf spot (Cercospora apii) were not influenced by population; Berger (1975), however, had reported close plant spacings favored celery leaf spot compared to wide spacings. Strandberg and White (1978) found an increase in plant spacing did not decrease the duration of leaf wetness enough to be unfavorable to the pathogen. In another study, the incidence of cabbage soft rot was not increased by increases in planting density (Frits and Honma, 1987).

The incidence of head rot was affected by cultivar treatments. It is difficult, however, to assess actual differences in cultivar susceptibility due to differences in time of maturity. OSU 86-3 was planted two weeks earlier in the greenhouse to encourage a similar maturation period with 'Gem', but the OSU line still matured two weeks later than 'Gem'. Canaday et al. (1988) has assessed cultivar susceptibility to head rot and found 'Gem' to be quite susceptible. In our field study less than 6% of 'Gem' heads developed head rot.

Differences in macroclimatic conditions during head maturation may explain differences in disease incidence. A 2°C increase in the maximum mean daily temperature occurred from a two week period prior to the last OSU 86-3 harvest compared with the two week period prior to the second harvest when most of 'Gem' was harvested. The higher maximum daily temperature occurring during the heading of OSU could account for the difference in disease incidence between the two cultivars. The average daily minimum temperature was the same, 11°C.

Canaday et al. (1988) reported disease pressure in the Southeastern United States is high when rainfalls are frequent and relative humidity is high. In Australia, disease occurrence was greatest during cool, moist weather conditions (Wimalajeewa et al., 1985). In our study, the highest incidence of disease occurred during the third and fourth harvests when the daily average maximum temperature was 26°C and the daily minimum was 11°C. Only a trace amount of rain fell, but irrigations occurred regularly.

Canaday et al. (1989) also reported an inverse correlation between the incidence of head rot and the days to maturity and head weight. The larger the heads or the longer the period from planting to harvest, the lower the incidence of head rot. These results are inconsistent with our study. OSU 86-3 produced larger heads and had a longer maturation period than 'Gem', but developed more disease. Most likely, a combination of susceptibility factors and environmental conditions was responsible for the difference in the incidence of head rot observed.

Increased yields and decreased head size with increases in broccoli populations have been reported in other broccoli population studies (Zink and Akana, 1951; Cutcliffe, 1975; Chung, 1982). An asymptotic relationship exists between populations from 2 to 100 plants/m^2 and yield, with a levelling off between 10 and 20 plants/m^2, but cultivar response may differ (Chung, 1982, Salter et al., 1984). The linear relationship observed for 'Gem' in our study of populations between 6.5 and 16.1 plants/m^2 are consistent with these findings. Studies suggest optimum planting densities between 10 and 20 plants/m^2 depending on the market requirements for head size. Very large plant populations increase yield but decrease head size to a point that may not be marketable. In Oregon, head size requirements for processing and fresh market are quite variable and buyer dependent.

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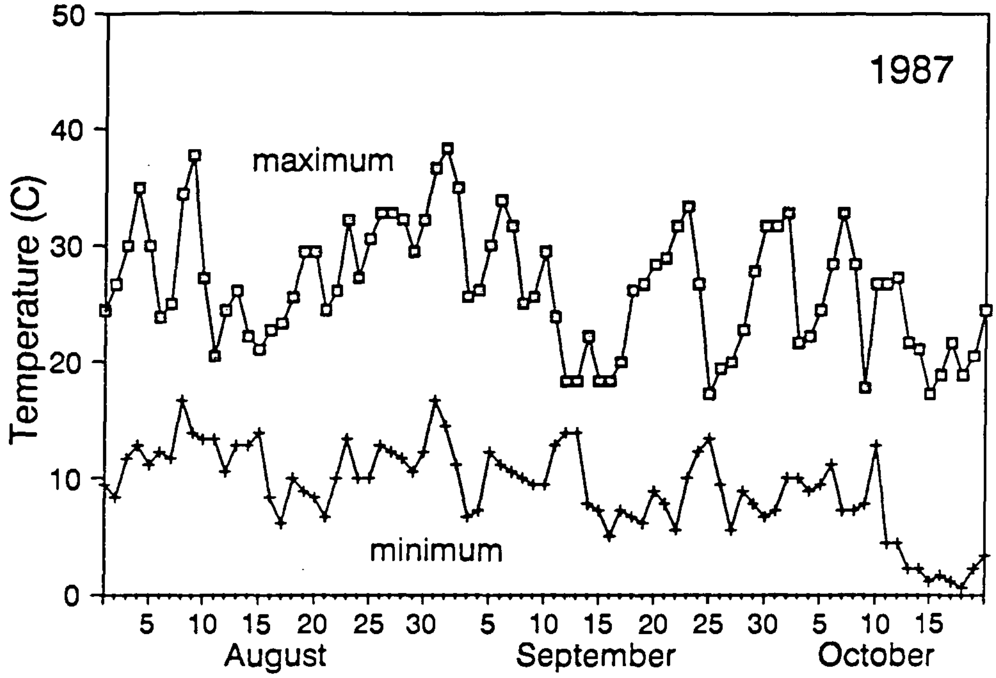
APPENDIX



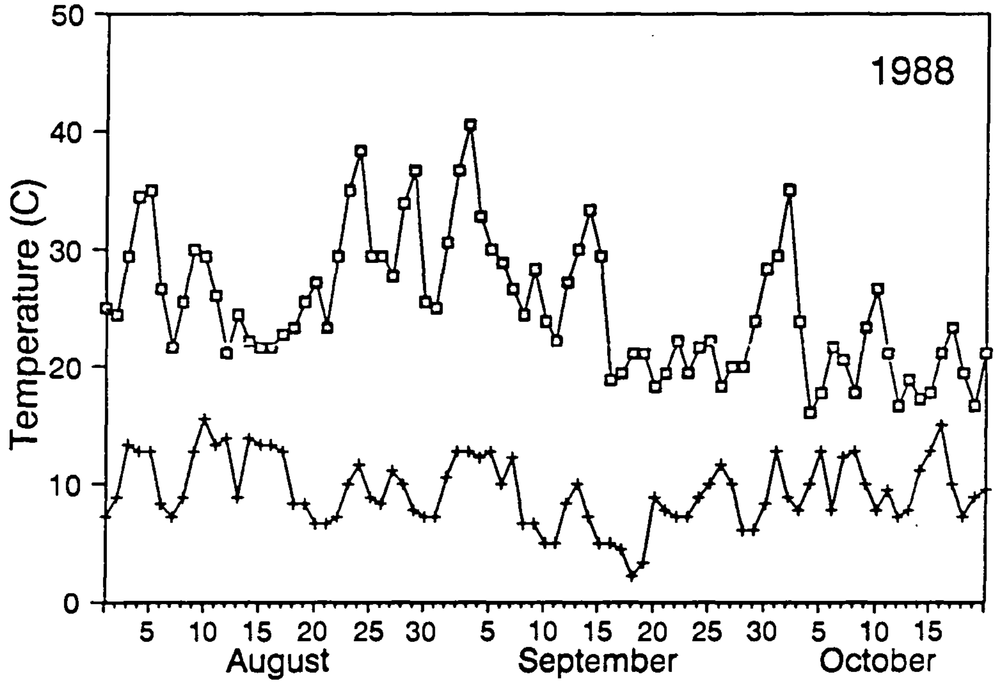


Fig. IV.1. Maximum and minimum temperatures during irrigation regimes.

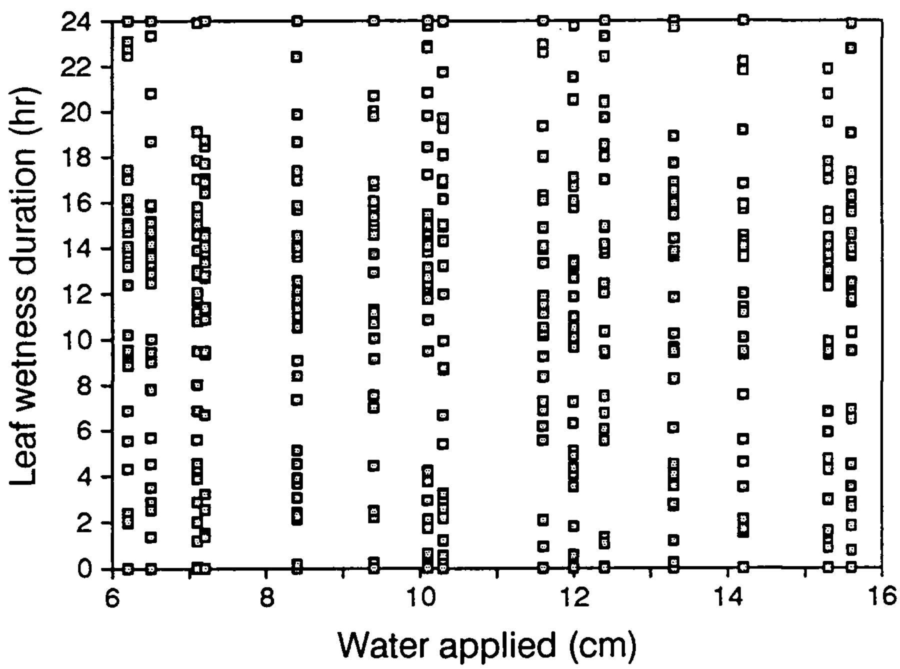


Fig.IV.2. Effect of water applied on leaf wetness duration. Each point represents a day from September 16 to October 18, 1988.

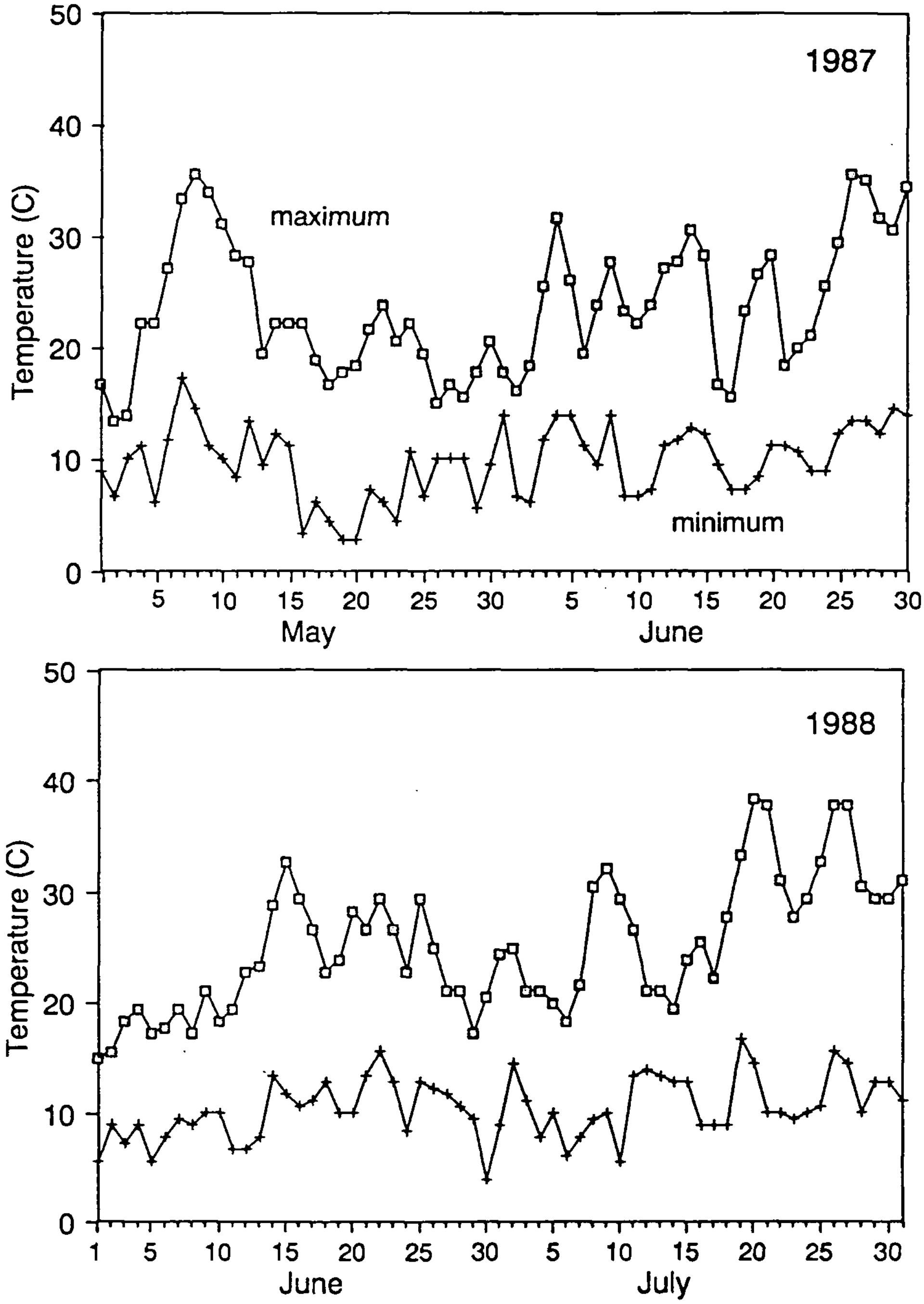


Fig. IV.3. Maximum and minimum temperatures during broccoli heading in plant density experiment.