EFFECTS OF OVERHEAD MIST IRRIGATION ON PRODUCTION OF FIELD VEGETABLE CROPS AT HIGH TEMPERATURES

By

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CHAPTER I

INTRODUCTION

A substantial portion of Oklahoma's farm income is derived from production of vegetables for processing and fresh market. Census figures show that 414 acres of tomatoes were harvested in Oklahoma in 1969. Considering the potential value of tomatoes at from one to three thousand dollars per acre, the economic contribution from tomatoes alone is obvious. The most important limiting factor for vegetable production in Oklahoma is climate, specifically the combination of high temperature and low relative humidity. Even though the tomato is a warm season crop, when day temperatures exceed 90°F. and night temperatures remain above 68°F. it will not produce at a level high enough to make it economical. Thus the crop must be planted early enough in the spring to allow all fruit to be set prior to the onset of high summer temperatures. In Payne County, Oklahoma, the mean date of the last killing frost is April 4 and the average high temperature in June is 90°F. (6). According to Thompson and Kelly (20) the tomato must have at least three and one half months of favorable growing season to be profitable. This leaves two choices for utilizing that time with the most favorable climate for tomato production in Oklahoma. The first is to start plants in a greenhouse prior to planting in the field and thus gain six to eight weeks or second, to lower the temperature in the summer. This study was designed to explore the latter possibility.

In this study tomatoes, leaf lettuce, and green peppers were selected because all have high potential value per unit area and are rendered unproductive or undesirable by high temperature conditions. These crops are popular and profitable in other areas of the nation but have enjoyed only limited success in this area. The tomato, *Lycopersicon esculentum* (20), is the number one processing vegetable crop in the United States and ranks next to the potato in total farm value. Lettuce, *Lactuca sativa* (20), is the most popular of the salad crops, and the farm value of the commercial crop is exceeded only by potatoes and tomatoes. Green pepper, *Capsicum annuum* (20), is widely grown; however, its economic importance is not as great as tomatoes or lettuce.

CHAPTER II

LITERATURE REVIEW

Effect of Irrigation on Soil and Air Temperature

It is possible to cool plants and soil with mist irrigation due to filtration of sun rays and absorption of heat by water. The increased water vapor in the air results in increased solar energy absorption by the atmosphere. This causes a corresponding reduction in the temperature of the plant and in transpiration (16). Benedict (2) was able to obtain "complete control of temperature to 80°F." at Van Buren, Arkansas by applying one tenth of an inch of water per hour by means of perforated pipe or rotating sprinklers. Van Den Brink and Carolus (21) increased relative humidity and decreased temperature 18°F. twelve inches above the soil surface by light irrigation with overhead sprinklers. Prashar (16) found that the temperature was lowered as much as 14°F. by means of overhead misting. In experiments conducted by Bible et al. (3) the plant stem temperature was lowered more than 16°F., and the yield of marketable tomatoes was increased by 50 percent when from three hundredths to six hundredths inch of water per hour was applied by means of overhead mist irrigation.

Effect of Temperature and Humidity on Tomato

The general opinion among many researchers is that high temperature and low relative humidity are the major factors contributing to a lack of fertilization and subsequent blossom drop in tomatoes (1, 9, 11, 18, 20, 22). Smith (18) listed extremely hot weather and low humidity among eleven possible causes of blossom shedding in tomatoes. Tests conducted in Oklahoma (18) showed that blossom drop was most severe either when moisture or humidity was low or when temperature was high. These conditions were most severe when accompanied by hot dry wind. Abdalla and Verkerk (1) reported on work done with tomatoes in the Netherlands in which a marked increase in flower shedding occurred when temperature was increased from 72°F. to 95°F. Lipton (12) reported that fruit set was significantly lower at temperatures greater than 86°F. if relative humidity was low. In his work relative humidity was the major factor since fruit set increased when temperature was held constant and relative humidity was increased. Cordner (9) identified high temperature as the principal factor limiting fruit set with low relative humidity and fluctuating soil moisture as contributing factors.

An exception to the theory of high temperature injury to tomatoes was reported in Texas by Johnson and Hall (11). Fruit set and development took place at temperatures often exceeding 110°F. in a shaded greenhouse provided the blossoms were sprayed with a sucrose plus urea plus parachlorophenoxy acetic acid solution. They concluded that high light intensity was more critical than high temperature if auxin is supplied. On the other hand, Moore and Thomas (14) found that with reduced light intensity and high temperature fruit set increased, but when temperature was suitable, light intensity had no apparent effect.

Work by Went (23, 24) and Went and Cosper (25) indicated that the critical factor limiting tomato fruit set and development was night temperature with the optimum being from 59°F. to 68°F. Went (23, 24) found that the size of inflorescence and flowers decreased with an increase in night temperature. He concluded that a decrease in sugar translocation at high night temperatures decreased root and top size and caused the plant to use all available sugar for growth leaving none for storage. Another conclusion presented by Cordner (9) was that overhead spray irrigation and fluctuating soil moisture reduced fruit set in tomatoes.

The above mentioned environmental factors result in a physiological malfunction within the plant which causes formation and development of an abscission layer and subsequent blossom drop. This droppage of blossoms is almost exclusively a result of a lack of pollination and/or fertilization. Burk (4), Smith (18), and Abdalla and Verkerk (1) observed an elongation of the style during periods of high temperature and low relative humidity, thus exposing the stigmatic surface to the drying action of the wind and as a result pollen grains either blew off the stigma or failed to germinate. Favorable environmental conditions must be present from pollination to fertilization which Verkerk (22) reported to be 48 to 72 hours at 60°F. night temperature. Abdalla and Verkerk (1) reported slower pollen tube growth at high temperature with poor pollen germination from flowers produced at high temperature. Those pollen grains that germinated failed to reach the ovary after 48 hours while pollen grains produced at normal temperature reached the ovary in as little as 24 hours. Smith (18) found that the temperature three days before full bloom anthesis had the greatest effect on flowering and that a time lag of three days exists between high temperature injury to the blossom and appearance of visible injury symptoms.

Effect of Temperature and Moisture on Lettuce

Leaf lettuce grown under high temperature conditions often develops a seedstalk before the plant is fully grown, resulting in an unmarketable product. High temperature appears to be the most important factor causing premature seedstalk formation and development in lettuce (13, 20). Janes and Drinkwater (10) were able to reduce seedstalk formation and development from 57 percent to 12 percent with light and frequent irrigation. They concluded that high soil temperature rather than air temperature causes seedstalk formation in lettuce.

Effect of Temperature, Moisture and Humidity on Peppers

Pepper is very similar to the tomato in climatic requirements; however, it may be more subject to injury from adverse conditions than the tomato (20). Temperature and humidity at the time of blossom development and fruit set have a market effect on yield. Unfavorable temperature and water supply are the basic factors causing drop of buds, blossoms and small fruit (20). Abscission usually takes place under conditions of high temperature and low relative humidity. Cochran (7) reported greater fruit set at temperatures from 60°F. to 70°F. than at 90°F. to 100°F. under greenhouse conditions. In the field a significant increase in fruit set was obtained when air temperature was lowered from 73.3°F. to 65.9°F. Cochran (7, 8) identified high moisture as being conducive to blossom formation and fruit set especially at temperatures from 60°F. to 70°F. Plants grown at 50°F to 60°F. or at 90°F. to 100°F. set no fruit regardless of soil moisture content. Under field conditions plants given high moisture by means of overhead irrigation did not set significantly different amounts of fruit than did plants receiving a "reasonably adequate" supply of water from rainfall. Cochran (7) reported a significant reduction in the percentage of blossoms that set fruit at 22 percent humidity compared to 80 percent humidity. wrinkle, contract Shriveling of the young ovaries indicated that blossom drop was probably caused by a water deficit at low humidity when the plants were transpiring rapidly. Drop of young buds occurred within 18 hours after exposure to low humidity followed by open flowers within the next 18 hours. Small immature fruits were the last to drop. Cochran (7) also found that the pepper will produce parthenocarpic fruit when exposed to 50°F. to 60°F. temperature at the time of anthesis. This was caused by a lack of fertilization resulting from slow pollen tube growth at low temperature.

CHAPTER III

MATERIALS AND METHODS

Experiment

Plants used in this experiment were direct seeded into two and one half inch peat pots, germinated under mist and grown in a greenhouse at approximately 67°F. Seeds were planted May 16, 1972, and transplanted to the field June 15 and 16. A second planting to be used in case of failure of the first was planted June 20, and transplanted to the field July 18. Data pertaining to lettuce were collected from the second planting. All other data were collected from the first planting. All plants received two applications of 500 ppm 20·20·20 fertilizer prior to transplanting. Varieties used were "Better Boy" tomato, "Big Green" lettuce and "Early California Wonder" pepper.

The land used for the experiment was a Kirkland silt loam left fallow in 1971 with weeds controlled by (flat circular plate) disking. The soil was tested by the Spurway method for major nutrients and soil reaction. Prior to planting an application of 2000 pounds per acre of hydrated lime was disked in. At transplanting 400 pounds of 10·20·10 fertilizer per acre was broadcast and watered in.

Weeds were controlled manually during the experiment.

The plants were transplanted by hand, watered individually then watered by overhead sprinklers. Tomatoes were spaced five feet between rows and two feet between plants; lettuce was spaced 18 inches by 18 inches; peppers were spaced 40 inches between rows and 18 inches between plants. Plots were 80 feet long. Three rows of each species were planted in each of three replications. Copy of original The replications were arranged end to end running at right angles to the prevailing wind. This provided a minimum amount of spray drift from one replication to another. A ten foot space was left between replications. Individual plots were randomized among the replications so that each species appeared in every possible location. Temperature at the time of transplanting was above 90°F. and some wilting was experienced; however, overhead misting kept plant stress to a minimum. Dead plants were replaced three days after the initial transplanting. The plants were given approximately 0.1 inch of water per acre by means of overhead sprinklers twice a day until they were established then once each day at 1:00 p.m. until the cooling treatments were started.

Each replication was divided into two parts, a misted and a non-misted portion. Twenty foot joints of standard two inch irrigation line were placed in the middle of the planting leaving approximately 17 feet on each side. The mist nozzles were installed on risers 18 inches high, one riser per 20 foot pipe joint.

Cooling and irrigation were accomplished with the same line. For irrigation, Rainbird 14600-TNT rotating sprinklers (15) with 1/8 inch, seven degree nozzles were installed on each riser. This provided an equal amount of irrigation water to all plots. Plants were irrigated when available soil moisture in the non-misted area dropped to approximately 50 percent. Approximately one inch of water was applied to bring the soil moisture up to field capacity. Cooling was accomplished by installing Rainbird 14V-LA-TNT rotating sprinklers (15) with 1/16 inch five degree nozzles on every second riser leaving 40 feet between sprinklers. Each sprinkler covered a radius of 17 feet at 20 psi.

Treatments consisted of automatic application of water during the hours when the temperature was expected to exceed 90°F. during the high temperature period. The water was automatically turned on for 10 minutes and off 20 minutes to accomplish the desired cooling effect. The cooling system was in operation from eight a.m. until eight p.m. beginning July 25. The duration of the daily treatment period was shortened as day temperatures became lower and was terminated October 1. Each sprinkler applied approximately 0.04 inch of water per hour. Within the mist treated area relative amounts of water were received by each plot as follows:

Treatment one received the greatest amount of water. The soil surface was waterlogged at all times during the day.

Treatment two received less water than number one. The soil surface stayed wet but not waterlogged.

Treatment three received less water than number two. The soil surface remained slightly damp.

Treatment four (control) received water only from rainfall and irrigation as needed. The soil surface remained dry between water applications.

Air temperature data were recorded by means of 24 hour thermographs set six inches above ground level. Two thermographs were placed in the mist treated area and two in the control area. All thermographs were covered with a plywood structure to protect from direct mist spray and sunlight. The two thermograph readings from each area were averaged to obtain the final temperature data. Soil temperature two inches deep and relative humidity were collected manually at 1:00 p.m. on selected days.

Tomatoes were harvested manually September 8, 15, 19, 22, 26, and 29. Fruits were sorted into salable and non-salable, then counted and weighed. Peppers were harvested August 31, September 16 and September 29. Fruits were sorted, counted and weighed. Salable fruits were graded in accordance with United States Department of Agriculture Standards for Grades. Lettuce from the second planting was harvested August 17 then counted and weighed. None of the lettuce was of marketable quality.

Tomato fruit set data were obtained by tagging ten clusters per treatment per replication. Plants were tagged July 25 and August 15 before any blossom in the cluster showed yellow color.

Data were analyzed to determine the effect of water treatments and harvest dates on total fruit yield and salable fruit yield. Data were subjected to analysis of variance and Duncan's new Multiple Range Test (17).

CHAPTER IV

RESULTS AND DISCUSSION

Effect of Intermittent Mist on Temperature

Misting reduced by 48 percent the number of days when air temperatures reached or exceeded 90°F. and the number of hours the temperature remained at 90°F. or above was reduced by 62 percent. Air and soil temperatures were reduced 2°F. and 7°F. respectively (Table I).

TABLE I

EFFECT OF INTERMITTENT MIST ON TEMPERATURE AND HUMIDITY

Treatment	Air Temperature Average High	Air Temperature Average Low	Average Soil Temp.	Days Temp. Reached 90°F.	Average No. of hours at 90°F. or Higher	Average Relative Humidity
Mist	84°F.	67°F.	75°F.	12	2.0	42%
Non Mist	86°F.	68°F.	82°F.	25	3.2	30%

The average high temperature of the non mist treated area was not as high as expected partly because of a cool front which moved across the state the last week in August bringing unseasonably cool temperatures. It is interesting to note that the difference between the intermittent mist area high and low was 17°F. while the difference between the high and low temperature in the non mist treated area was 18°F. This indicates that the damp soil surface had very little effect on air temperature during the hours of darkness. The night temperature of both the intermittent misted area and the non misted area fell within the range reported by Went and Cosper (23) as being optimum for tomato fruit set.

It is possible, due to the proximity of the misted and non misted areas, that some effect on the non misted temperature could have occurred. However, this effect was minimal since the average high temperature recorded for the non misted area was less than three degrees from that reported by the Stillwater Weather Station which is located approximately five miles north.

The most noticeable difference between treatments was the number of days when the temperature reached 90°F. or more and the length of time it exceeded 90°F. According to Abdalla and Verkerk (1) pollen produced at high temperature has a low germination rate and slow pollen tube growth rate even when the temperature becomes suitable. If this is the case, plants in the control plots should have produced considerably less viable pollen than did the mist treated plants. Production of less viable pollen presumably would result in reduced fruit set.

Effect of Treatments on Tomato Yield and Fruit Set

Water treatments significantly increased total number of fruit and total fruit weight (Figure 1). In both cases, total weight and total number, there is no significance between treatments one and two. Treatment three, however, resulted in a significantly higher yield than

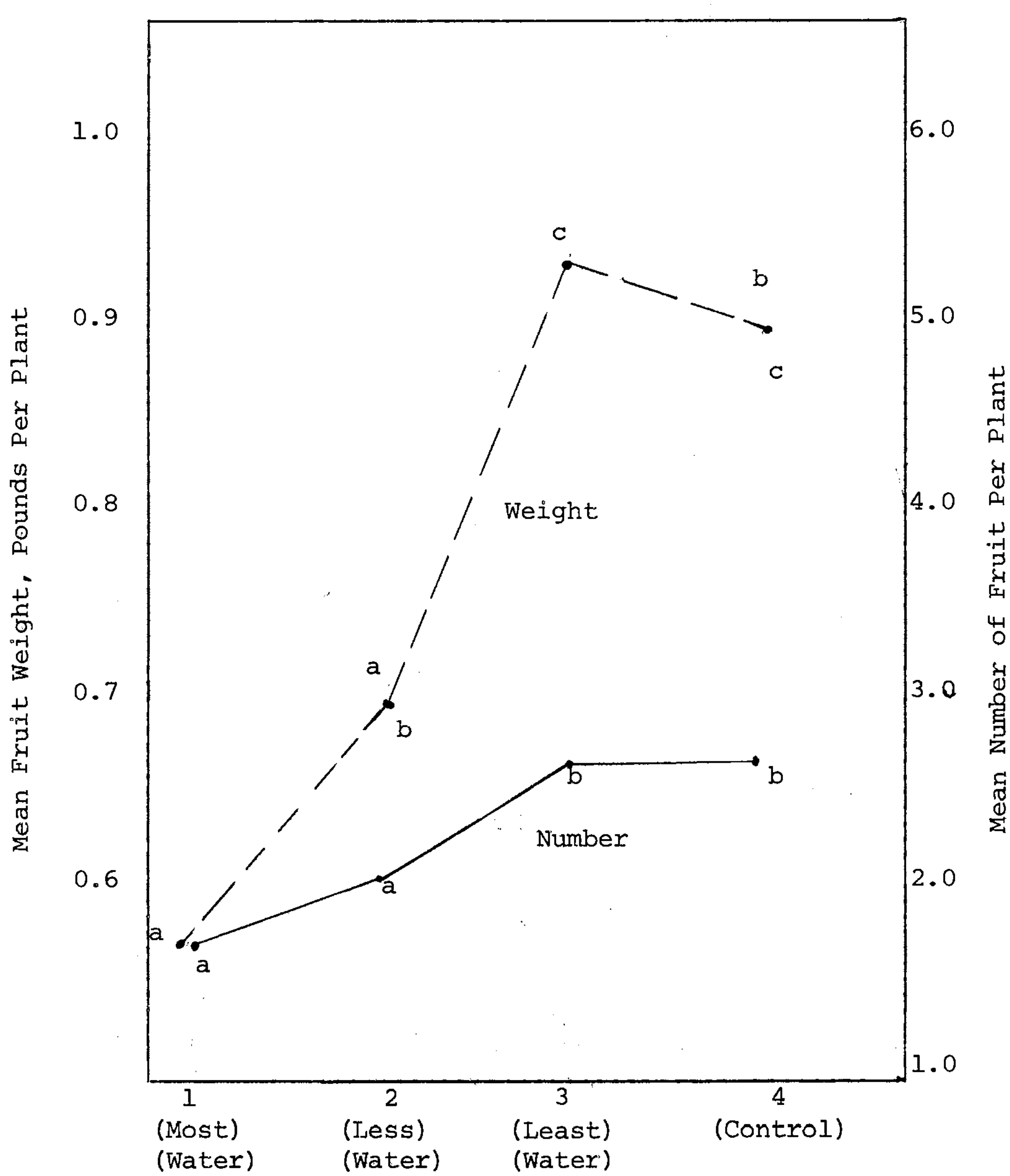

Figure 1. Effect of Water Treatments on Total Yield of Tomatoes

All points on the same line labeled with the same letter are not significantly different at the 1% level.

treatment two. There appeared to be no yield difference between those plants receiving a small amount of water regularly and those receiving water only from irrigation and rainfall. Treatment four produced a significantly greater number of fruit than treatments one or two but weight of fruit produced in treatment four was not significantly greater than treatment two. This suggests that fruit set may be more sensitive to water application than is fruit development. The effect of mist treatments on marketable fruit weight and number was not significant.

Date of harvest significantly increased weight and number of marketable tomatoes (Figures 2 and 3). The time interval between harvest dates was changed from once per week to twice per week as the crop came into full production. The change from seven day intervals (dates one and two) to the four day intervals (dates two and three) resulted in a significant decrease in total mean fruit weight and a significant increase in number and weight of marketable fruit. At the second harvest the total production was 1.09 pounds per plant of which 41 percent was marketable. At the third harvest, four days later, the total mean weight per plant dropped to 0.33 pounds per plant of which 58 percent was marketable. This represents a net decrease in total mean weight of marketable fruit of 0.26 pounds per plant at the third harvest; however, the mean percent weight of marketable fruit and total mean weight increased through the last harvest. At the final harvest 70 percent of the total weight of fruit was marketable. Percent marketable fruit by weight increased significantly from the third to the fourth harvest while the increase in percent marketable fruit by number was not significant until the sixth harvest. The temperature at the time of fruit set for the sixth harvest was from 75°F. to 85°F. while the

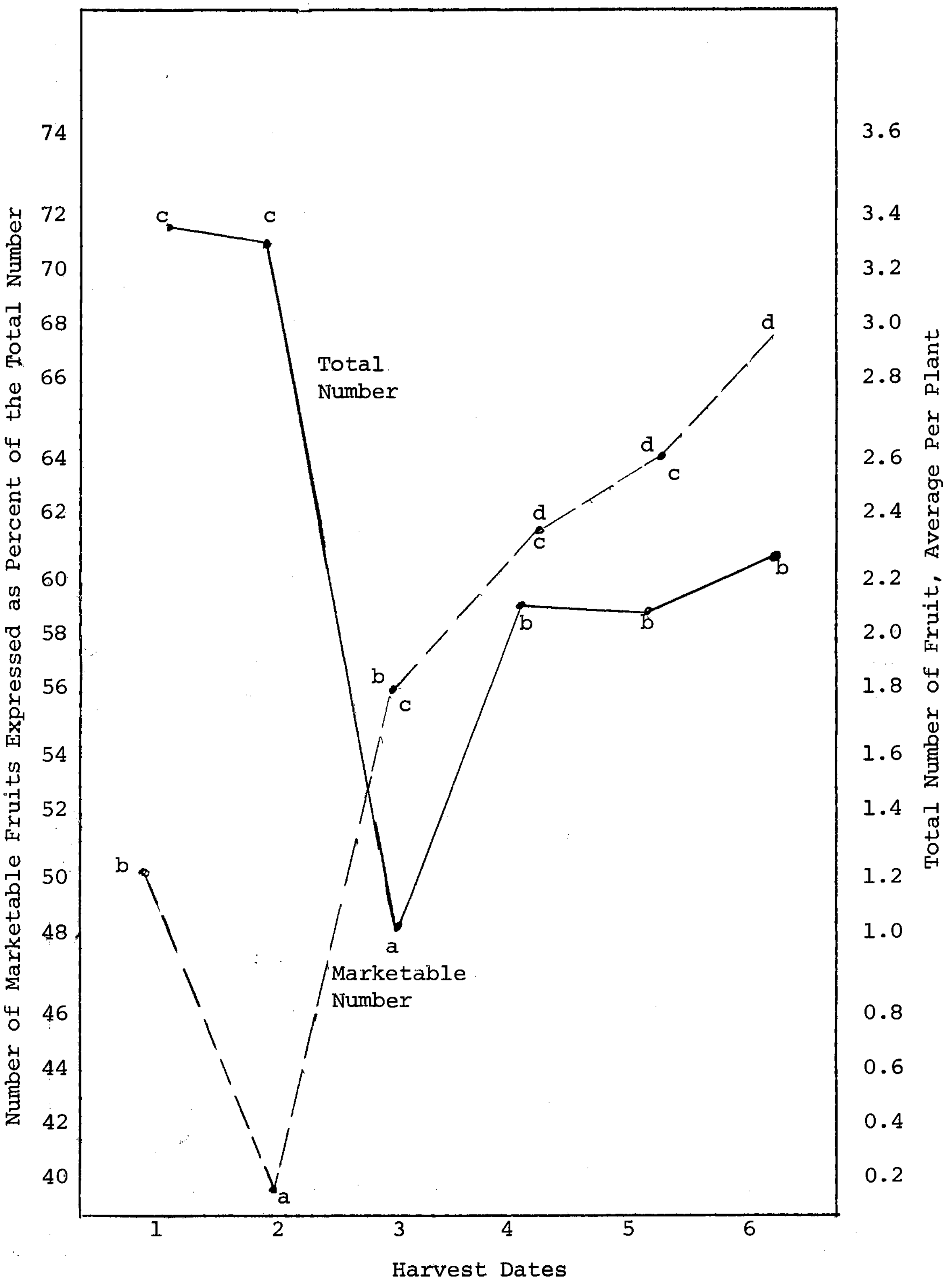

Figure 2. Effect of Harvest Date on Number of Marketable and Total Number of Tomatoes

All points on the same line labeled with the same letter are not significantly different at the 5% level.

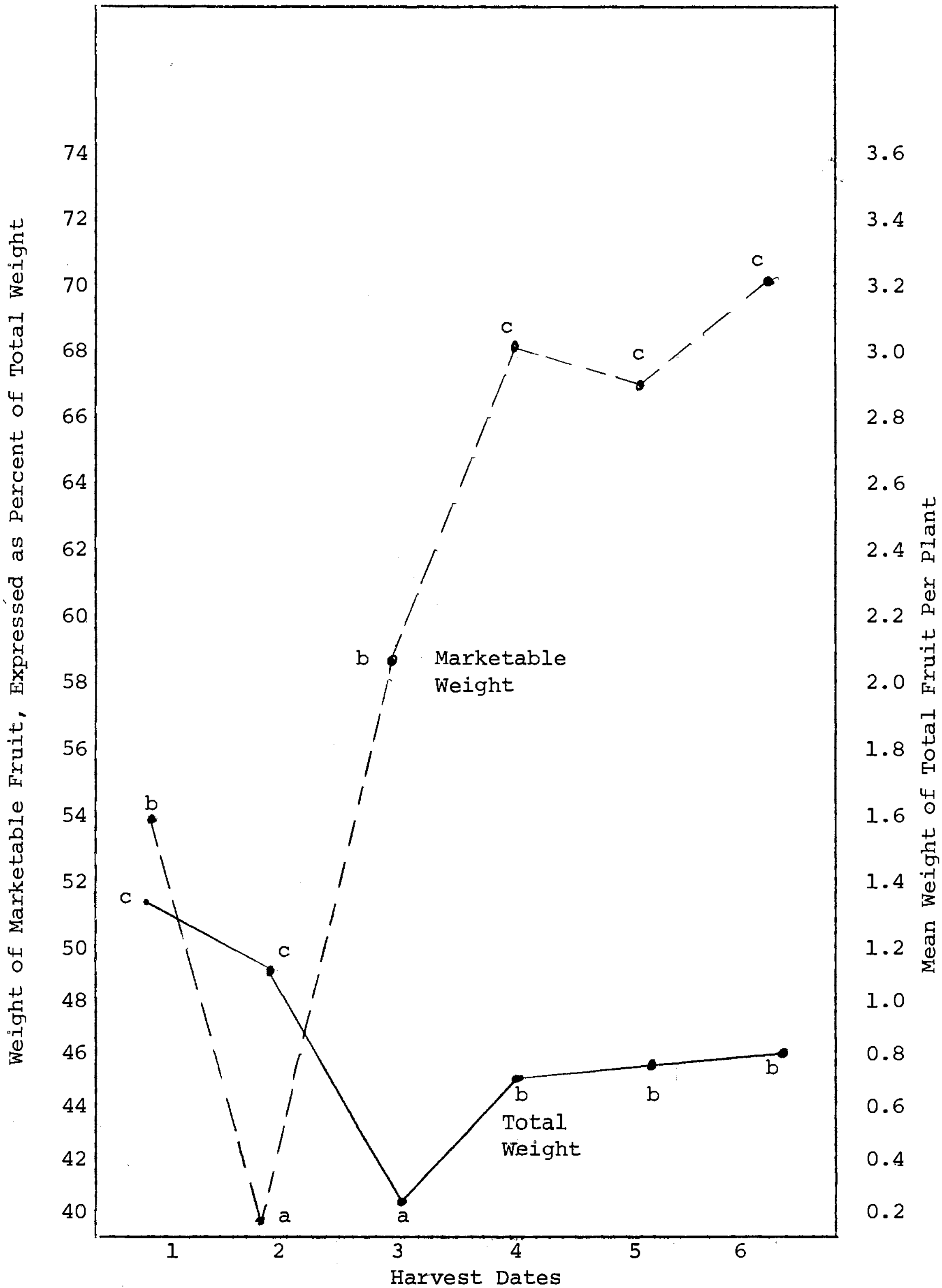

Figure 3. Effect of Harvest Date on Weight of Marketable and Total Weight of Tomatoes

All points on the same line labeled with the same letter are not significantly different at the 5% level.

temperature at set of the fourth harvest was from 87°F. to 97°F. This suggests an inverse relationship between temperature and mean number of marketable fruit without the same result with size of marketable fruit. ✓ The relationship between mean weight and mean number of total fruit indicates that harvest date had no appreciable influence on size of total fruit as it did on size of marketable fruit.

Misting increased tomato fruit set six percent and reduced the average high temperature 3°F. (Table II) A cool front brought rain and unseasonably low temperatures to the state during the last week in August. The period from July 25 to August 21, however, provided good test conditions. The high temperture range on the non misted area from July 25 to August 21 was 73°F. to 110°F. and in the misted area it was 80°F. to 102°F. (Table II) The reduced fruit set in the non misted area may be associated with the lower humidity which would cause excessive transpiration and stress within the plants.

TABLE II

EFFECT OF TEMPERATURE AND HUMIDITY
ON TOMATO FRUIT SET

Treatment	Date Tagged	Date Checked	Average Set	Average High Temperature*	Average Humidity*
Non Mist	July 25	Aug. 21	35.5%	89.4°F.	27.6%
Mist	July 25	Aug. 21	41.5%	85.8°F.	36.3%
Non Mist	Aug. 15	Sept. 1	66.9%	84.9°F.	
Mist	Aug. 15	Sept. 1	83.7%	85.1°F.	

*Average from date tagged to date checked

The outward characteristics of aborted blossoms observed in this work were the same as those reported by Smith (18) and Abdalla and Verkerk (1), namely yellowing pedicel and pistil, shriveled blossoms and development of the abscission layer. The aborting blossoms would easily fall when touched and could quite likely have been blown off by wind or knocked off by rain or irrigation water.

Effect of Treatments on Pepper Yield

Water treatments significantly increased weight and number of marketable peppers (Table III). However, water treatments had no significant effect on total weight or total number of fruits.

TABLE III

EFFECT OF WATER TREATMENTS ON WEIGHT AND NUMBER OF MARKETABLE PEPPERS

	(Most) (Water) Treatment 1	(Less) (Water) Treatment 2	(Least) (Water) Treatment 3	(Control) Treatment 4
Marketable Number	87.2% b	79.9% b	63.5% a	80.0% b
Marketable Weight	90.0% b	81.2% ab	70.8% a	81.1% ab

All means in the same line followed by the same letter are not significantly different at the 5% level. The figures represent marketable fruit by number and weight expressed as percent of the total fruit number and weight from combined replications.

It is interesting to observe that there was no significant difference either in mean number or mean weight of marketable fruit between plants receiving the greatest amount of water (Treatment 1) and those receiving comparatively small amounts (Control). Treatment 3 appears least satisfactory for pepper production.

Number of marketable and total number of peppers was significantly influenced by date of harvest (Table IV).

TABLE IV

EFFECT OF DATE OF HARVEST ON TOTAL AND MARKETABLE PEPPERS

Harvest Number	1	2	3
Marketable Number*	70.4% a	75.3% a	87.3% b
Total Number/Plant	1.1 a	2.1 b	1.9 b

All means on the same line followed by the same letter are not significantly different at the 5% level.

*Mean number of marketable fruit from combined replications expressed as percent of the total number.

The last harvest yielded a significantly higher number of marketable peppers than harvest one or two. The total yield from the first harvest, on the other hand, was significantly lower than harvest two or three. The total number doubled from harvest one to harvest two while the number of marketable fruit increased by five percent during the same period. The significant increase in marketable number from harvest two to harvest three and the relative stabilization of total number suggest that conditions during the early part of the harvest season were favorable for fruit set and unfavorable for fruit development while the opposite was true later in the season. Total weight and marketable weight showed no response to harvest date.

Fruit produced on plants in the mist treated area was generally of better quality than fruit from plants in the non misted area (Table V).

Marketable peppers were combined and graded in accordance with United States Department of Agriculture Standards for Grades. Over the three harvest dates an average of 59 percent of the fruit from the mist treated area graded number one or fancy, while the average from the non mist treated area was 49.6 percent.

TABLE V

GRADES OF MARKETABLE PEPPERS FROM MIST AND NON MIST TREATED AREAS

	Harvest Date	Adjusted[1] Marketable Production	Number Graded[2]	Percent Which Graded Number One or Fancy
Misted Area[3]				
	1	179	22	64%
	2	358	41	63%
	3	304	60	50%
Non Misted Area[4]				
	1	100	10	50%
	2	203	20	40%
	3	165	17	59%

[1]Adjusted to compensate for difference in number of plants
[2]Graded at least 10% of the fruit from the combined water treatment
[3]Consists of water treatments 1, 2, and 3
[4]Consists of water treatment 4 (Control)

Effect of Treatments on Lettuce

The lettuce crop was hampered severly by problems encountered during the course of the experiment. An infestation of cabbage loopers shortly after transplanting placed stress on the plants; however, the major problem was in keeping adequate moisture supplied to those plants not under the mist system. As a result, there were no significant difference in seedstalk formation, plant weight or quality. None of the lettuce produced was considered of marketable quality.

CHAPTER V

SUMMARY AND CONCLUSIONS

Temperature Control

Air temperature was reduced 2°F. by the application of 0.04 inches of water per hour from an overhead mist irrigation system. Soil temperature at a depth of two inches was reduced 7°F. and the number of days during the experimental period when temperature exceeded 90°F. was decreased by 48 percent. This particular arrangement of equipment shows considerable possibility; however, extensive rearrangement or redesigning would be needed to make it effective commercially. It may be possible that this type of operation could be used at night to reduce temperatures sufficiently to allow summer production of tomatoes.

Tomatoes

An inverse relationship was indicated between temperature and number of marketable fruit while the same did not occur with fruit size. No significant difference in yield was noted between plants receiving a small amount of water at 20 minute intervals and those receiving water only from rainfall and irrigation. Fruit set appeared more sensitive to water application than fruit development. Tomatoes are generally more responsive to date of harvest than to water as it was applied in these tests. A significantly greater amount of marketable fruit was produced when harvested twice rather than once per week. Date of harvest had no appreciable effect on fruit size when considering all fruit; however, date of harvest did appear to influence size of marketable fruit.

Peppers

Fruit quality, determined by United States Department of Agriculture Standards for Grades, was considerably better with fruit produced on plants in the mist treated area. Fifty-nine percent of the fruit from the combined treatments in the misted area graded U. S. number one or fancy compared to 50 percent from the non mist treated area. Harvest date did not have a significant influence on weight of marketable peppers and fruit number appeared more sensitive to water application than fruit weight. The total number of fruit was affected significantly only by harvest date. Total fruit weight showed no significant response to harvest date or mist.

Lettuce

The design of this experiment did not provide a means for adequate water application to the non misted lettuce; therefore, the data pertaining to lettuce were inconclusive.

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