EFFECTS OF IRRIGATION METHOD, PLASTIC MULCH, AND FERTILIZER RATE ON THE GROWTH, YIELD, AND DISEASE OCCURRENCE OF 'JET STAR' TOMATOES

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INTRODUCTION

Black polyethylene used as a soil mulch for growing vegetables has increased yields under certain conditions (5,7,18,20,24,28,52,54).

Drip or trickle irrigation of vegetables, especially in the arid desert lands in Israel, promoted higher yields and used less water than did conventional methods of irrigation (2,4,10,26,27,28,40,52).

Few studies in the literature have compared the combined effects of black plastic mulch and trickle irrigation on the fruit yield and disease occurrence on tomatoes.

This study was undertaken to study the effects of plastic mulch under three levels of soil fertilization as a possible way for vegetable growers to maximize yields, reduce plant and fruit diseases, and to use water efficiently using two irrigation methods--trickle irrigation and an overhead sprinkler system.

LITERATURE REVIEW

PRINCIPLES OF MULCHING VEGETABLES

Mulching vegetables to improve growth and production has been practiced for many years. A mulching material can be described as anything that can be spread on the ground to protect the roots of plants from heat, cold, or drought, or to keep fruit clean (16).

Synthetic mulches are used presently by many commercial vegetable growers. It is purchased in 3 or 4 feet widths. The thickness of the film is usually 1 to 1 1/2 mils (1 mil equals 0.001 inch). Most weeds cannot break through this thickness (16). Black film is usually preferred over clear film. Using clear film will result in higher soil temperatures under the film, but weeds have to be controlled by fumigation or selective herbicides prior to application of the film (16).

A mulch changes the soil and microclimate in which the plant is growing, especially when growing conditions are less than ideal. Mulch can help to alleviate plant stresses that result from weather conditions such as low rainfall, cool air temperatures, and cool soil temperatures (16).

Factors which influence the plant's response to mulching are the particular crop grown, time of year, type of soil, rainfall, and soil and air temperatures. Better growth and higher yields will result when mulches improve the environment in which a plant is growing (16).

Mulches create a physical barrier that control weeds (16,19,33,44,45), reduce evaporation, retain soil moisture (16,19,25,33,39,40), and reduce soil compaction (16).

More extensive than normal root systems have been noticed on plants that were mulched with black and clear plastic (16,37).

EFFECTS OF BLACK POLYETHYLENE MULCH ON YIELDS OF VEGETABLES

Many researchers have found that using black plastic mulch on tomatoes produced greater yields of fruit (5,12,15,19,22,25). However, some researchers have found black plastic to decrease fruit yields of tomatoes (44,45).

Black plastic mulches increase the soil temperature and hasten early plant development, especially when soil temperatures are less than ideal for plant growth. Sheldrake (57) proposed that the higher soil temperatures (3-5° F) that occur underneath black plastic may not cause the greater yields of vegetable crops. When measuring the CO_2 concentration in the microclimate surrounding muskmelon leaves, he found a 4-fold increase in CO_2 concentration, which he believed was a major factor contributing to an increase in growth and yield of fruit. Clarkson (14) found that average soil temperatures at soil depths of 1, 3, and 6" under black polyethylene mulch were usually 1 to 5° F higher than at comparative soil depths under nonmulched conditions. Using black polyethylene, Courter (16) found a 11.3° F increase in soil temperature under the mulch, as compared with bare soil. Takatori et. al. (59) observed a 3° F higher soil temperature underneath black plastic mulch. Fritschen and Shaw (23) reported that the 4 to 10° F higher soil temperatures under black plastic mulch may be explained by examining the effects of the plastic film. He states, "Black plastic film is not transparent to radiation. Therefore, the energy which passes through the film must be absorbed by one surface, conducted through the film, and re-radiated at the other surface. When the plastic film is placed on the ground so that the air movement underneath is restricted, a film of moisture condenses on the lower side of the plastic. The condensed moisture layer and the plastic film acting as a greenhouse, effectively trap long wave terrestrial radiation. The color of the plastic film, the "greenhouse effect", and the absence of evaporation from the plastic surface are the causes of the treatment temperature differences."

EFFECTS OF SYNTHETIC MULCHES ON SOIL FERTILITY AND YIELDS

Mulching soils with black plastic and clear plastic seem to retain nitrate-nitrogen and reduce the amount of leaching nitrates, thereby making more nitrates available to the crop for use (7,14). Liptay and Tiessen (40) found nitrate-nitrogen levels under polyethylene higher than in bare soil. Black and Greb (7) found that soil measured to a depth of 18" and starting from an initial nitrate-nitrogen level of 26 lbs/acre contained 140 lbs/acre of nitrate-nitrogen after 12 weeks when covered with black plastic while bare fallow soil contained 78 lbs/acre. Nitrate-nitrogen present in the 0-6" or 6-18" depths of soil under plastic cover was 32 or 15 lbs/acre greater than bare fallow soils sampled at the same depths. Soil temperature increases combined with excellent moisture conditions near the surface of plastic covered soils favored nitrate-nitrogen accumulation.

Everett (21) found that mulched tomato plants given a high fertilizer rate of 310-72-364 lbs of N-P-K/acre gave significantly lower yields compared to low and medium rates of 130-72-137 and 220-72-261 lbs of N-P-K/acre respectively.

Bryan and Dalton (10) reported in Florida that when fertilizer was incorporated into the soil and black plastic mulch placed on top, yields were as high with low fertilizer rates as yields from plots with high fertilizer rates banded on top of the bed. Tests in commercial fields showed a higher tomato yield and quality grade when fertilizer was incorporated into the bed and covered with black plastic than when it was banded on top of the bed.

EFFECTS OF SYNTHETIC MULCHES IN RELATION TO PLANT DISEASES

Researchers have found that virus, fungus, and nematode populations on tomatoes (35,62) and lettuce (31) mulched with black plastic were smaller than on plants grown on bare soil. Chalfant, et. al. (13) have found that film mulches did not affect the number of populations of nematodes and fungi. Halsey, et. al. (30) reported greater losses of tomato fruits when they were allowed to grow on sandy soil with no black plastic. Considerably less soil rot was found on tomato fruits that were mulched with black plastic, with the fruits resting on plastic.

PLANT DISEASES RELATED TO ATMOSPHERIC MOISTURE AND IRRIGATION PRACTICES

It is commonly observed that fungal pathogens need free water to sporulate and induce infection on plants. Menzies (42) states, "For a parasitic disease to develop to damaging proportions in a crop, the climate must not only be suitable for spore germination and infection, but must also permit sufficient sporulation for secondary infections. It is these secondary infections that lead to widespread damage to the crop. In general, free water must be present on the plant surface from 6 to 12 hours or more to permit infection, and a much longer time is necessary for secondary sporulation. In addition, many of these disease organisms depend on splashing water to loosen the spores from the infected plant surface and to spread them to other plants. Usually, the optimum temperatures for spore production, germination, and infection are lower than those normally prevailing during clear, summer weather."

One plant disease that is dependent of free water to permit infection is early blight (Alternaria solani). Early blight is a common problem in tomato and related plants. Rands (48) describes the symptoms of A. solani for tomato and related plants as a characteristic leaf spot disease, distinguished by the concentric markings or "target-board" appearance of the spot. The principal temperatures for spore germination and mycelial growth on favorable media fall within the following limits: minimum 1-3°, maximum 37-45°, optimum 26-28° C. This was also noted by Pound (47). Infection may occur through stomates or directly through the cuticle. The period of incubation varies from 48 to 72 hours. Primary infection may result from overwintered conidia or possibly from new conidia produced by overwintered mycelium.

Early blight ordinarily makes little development until the host has passed its period of greatest vigor and is being weakened by external conditions. Optimum spore production is dependent upon frequent rains aided by heavy dews. Climate and soil exert a controlling influence upon the development of the disease. In general, it becomes most serious when the season begins with abundant moisture which is followed by high temperatures unfavorable to the host plant but with sufficient moisture to insure maximum sporulation. Periods of continued drought check its spread completely. Therefore, the optimum conditions for an epidemic of early blight require relatively high temperatures alternating with moist periods in combination with a more or less weakened condition of the plant (4,48). Sanitary measures to be practiced include crop rotation and removal of plant debris (4).

It has been shown that the successful growth and infection of tomato plants by early blight can be attributed to the physiology of the plant (34). Horsfall and Heuberger (34) have found that the age of plant tissue is important. Early blight will not attack young plants that are growing vigorously that contain an abundance of young tissue. Once growth begins to slow down, old tissue begins to predominate, starting with lower leaves of the plant and progressing to the top. Good air drainage normally reduces the infestation.

Early blight also is more prevalent on plants that bear the largest number of fruits. These plants have a high yield-to-foliage weight ratio. Plants which carry fruit early in the season showed more disease than those carrying them late in the season. Also, if plants are deflorated, less disease develops. As disease increases, green fruit decreases and ripe fruit increases. Low nitrogen nutrition also tends to increase susceptibility to early blight. Plants that are given a high amount of nitrogen grow luxuriantly and fruit poorly. The young, green, succulent tissue does not contact the disease because of its vigorous growth (34,52).

Barratt and Richards (4) have shown that defoliation of the tomato plant by early blight precedes the maturing of the fruit by about 2 weeks. It was also found that the earlier the yield, the earlier the defoliation. occurred. It was confirmed as reported by Horsfall and Heuberger (34) that the greater the amount of fruit per leaf, the greater the amount and rate of defoliation. Plants that have a high available nitrogen supply mature more slowly than those with a limited nitrogen supply, and consequently, defoliate more slowly (4,60).

Rotem (51) found that a high soil moisture level, in which potted tomato plants were kept before inoculation with early blight, was associated with an increased susceptibility to early blight and also with a high yield-to foliage weight ratio, known as a predisposing factor for early blight.

Another disease that is accelerated by humidity and irrigation water is anthracnose (Colletotrichum phomoides). This disease causes rotting of ripening tomato fruits. Fulton (24) reported that as fruits approach maturity, anthracnose can readily gain entrance through wounded or unwounded mature fruits. Anthracnose does not attack young fruits that are wounded. Wounding of young fruits causes a corking of the surrounding tissues which effectively prevents further development of the fungus. Inoculation of young fruits produces typical lesions only on wounded areas. Lesions produce rapidly at 80° F. Anthracnose penetrates the cuticle of the fruit by means of a penetration tube which grows from the lower side of the appresorium (swollen tip of the hypha). The infection tube in green fruits swells slightly on contact with the cell wall, but remains latent between the cell wall and the cutin layer. As the fruits ripen, the fungus enlarges and produces swollen, inter- and intracellular hyphae in the hypodermis. Upon contact with the parenchyma cells, the fungus develops many fine hyphae which grow rapidly through the walls and cell contents. Microscopic cracks in the cuticle are not believed to be a factor in infection. The fungus may be transmitted with seed and the chief method of overwintering is from stromata on infected plant debris (36).

Raniere and Crossan (49) found that overhead irrigation increased the incidence and severity of tomato anthracnose. Relative humidity (RH) between noon and 6 p.m. was as much as 20% higher in irrigated plots for 5 days following irrigation. The diurnal dew period (duration of free moisture) was commonly 3-5 hours longer in irrigated plots during this time. It was concluded that the higher RH's and the longer dew periods in microclimates of irrigated tomato plots prolong spore viability and permit germination of _C. phomoides_.

Crossan and Lloyd (17) reported that plots receiving 4 irrigations totaling approximately 4 inches of water in a 30-day period had a significantly higher incidence of tomato anthracnose.

DRIP IRRIGATION--PRINCIPLES AND CONCEPTS

Drip or trickle irrigation utilizes the principle that a plant grows better under conditions of constant accessibility to moisture. Trickle irrigation "drips" the daily water requirement of a plant into the root zone constantly; thus the soil is kept at, or close to, field capacity (2). Trickle irrigation has many advantages, especially when used in arid regions. It promotes increased yields, usually more than double compared with sprinkler or furrow irrigation (27). With drip irrigation, only part of the soil surface is wetted, but at highly frequent intervals. The agricultural crop is located in this wetted zone (27). The soil surface does not "seal" as it would with furrow irrigation. Sealing would result in a large restriction of water penetration into the soil (29).

During sprinkler or furrow irrigation, there is a rapid change in the plant's root zone from saturation to field capacity, followed by a gradual change from field capacity to a minimum water content before the next irrigation (27). Soils which are furrow irrigated compact easily from foot traffic during harvest. Drip irrigation improves water penetration and avoids soil compaction between plant rows (29). Also, the soil no longer serves as a "reservoir" for water. The water that is leached below the root zone is returned back to the root zone by constant dripping of the irrigation system (27). Drip irrigation can be used if the soil structure is poor because the soil does not have to hold water between irrigations since the water is constantly replenished. The soil thus acts as a support for plant roots and as a structure to constantly receive the irrigation water (27).

DRIP IRRIGATION IN RELATION TO YIELD AND FRUIT QUALITY

Irrigating tomatoes with drip irrigation has increased yields compared with sprinkler or furrow irrigation. Bower, et. al. (8) noticed that when soil-water tension in the root zone was maintained below 0.2 bar, the yield of marketable 'Tropic' tomatoes was 17% greater than when tension was maintained below 0.4 or 0.6 bar. At all 3 tensions, yields and total amounts of irrigation water required under trickle irrigation did not differ significantly from yields and water required under basin irrigation. Bryan, et. al. (11) noted that drip irrigation resulted in better control of soil moisture, uniformity of growth, and higher yields of mulched and unmulched tomatoes than overhead irrigation. Locascio and Myers (41) observed that yields of 'Walter' tomatoes increased 290% using trickle and overhead irrigation compared with non-irrigated plots. Yields increased 380% using trickle irrigation plus supplemental fertilizer as compared with non-irrigated, non-fertilized plots. Rudich, et. al. (54) noted that drip irrigating tomatoes during the period of fruit set and fruit development was found to increase yield levels by 53 metric tons/ha compared with non-irrigated plants. Irrigation applied only during the period of fruit development had a favorable influence on yield as well as on the efficiency of water utilization. However, irrigation during fruit development had an unfavorable influence on the lowering of fruit quality; i.e. total soluble solids, acidity, viscosity, and vitamin C. Stall and Bryan (58) found that tomato packers and growers in Dade County, Florida agreed that the total marketable fruit from fields using drip irrigation ranged 5 to 10% higher than those using overhead irrigation. They also agreed that a higher percent of larger and smoother fruit was produced when drip irrigation was used. Goldberg and Shmueli (28) observed that yields of bell peppers, a close relative to the tomato, were all greater with trickle than with sprinkle irrigation.

MATERIALS AND METHODS

On March 15, 1979, tomato Lycopersicon esculentum Mill. 'Jet Star' seeds were seeded in a growing medium of 1:1:1 peat:perlite:vermiculite (Jiffy Mix) in the Kansas State University Horticulture Research Greenhouses, Manhattan, Kansas. On April 3, they were transplanted into 5 cm "Jiffy" peat pots into the same 1:1:1 medium.

During the last week in April, the plants were taken to the Ashland Horticulture Farm of Kansas State University to be hardened off outside. On May 9 and 10, the plants were transplanted to the field in a Sarpy fine sandy loam soil.

The study consisted of a split-split plot experimental design. There were two main irrigation systems used: a) overhead, and b) trickle, each measuring 12.8m x 14m. Main plot treatments were a) mulch, and b) no mulch. Three rows contained black plastic and 3 rows contained bare soil. There were 6 sub plots per main plot. Each sub plot was 3.7m x 3.7m and each contained 18 plants. They were spaced 1.8m between rows and 61cm between plants in the row. Two of the 6 sub plots were given a low rate of fertilizer equal to 24.5kg N/ha and 36.7kg P/ha. Two were given a medium rate of fertilizer equal to 48.9kg N/ha and 73.3kg P/ha. Two were given a high rate of fertilizer equal to 97.8kg N/ha and 146.5kg P/ha. The medium rates were the recommendations from the Kansas State University Soil Test Reports. The low rate of fertilizer was obtained by dividing the medium rate in half and the high rate was obtained by doubling the medium rate. The soil test report indicated that the soil contained a high amount of K, so none was added. The fertilizer was broadcast onto each sub plot, the trickle irrigation tubing was put down, and the black plastic mulch was laid on the proper sub plots by a plastic mulch laying machine before the plants were transplanted. The plants were then planted through the mulch by making a hole with a bulb planter, extracting a core of soil, and placting each plant in the hole and covering it. Insecticides were applied as needed, but no fungicides were applied at any time throughout the study.

The overhead irrigated plot was irrigated by a 76 mm diameter aluminum irrigation pipe known as a "perforain". A well pump supplied water to the field.

The trickle irrigated plot was irrigated by 'Viaflow' porous-plastic, trickle irrigation tubing placed 5 cm to the side of the tomato plant stems. The water "weeped" out of the tubing at a constant rate of 3.8 l per minute. Three rows had the trickle tubing underneath the black plastic and the other 3 rows had the trickle tubing on bare soil. The tubing ran the entire length of each row, which was 3.7 m.

The delivery system came from well water pumped into a 4164 l steel water tank. At the bottom of the tank, a steel 19 mm pipe was inserted with a valve at the end so the water could flow out by gravity. Attached to the filter outlet was a 12.7 mm diameter PVC pipe which ran for 60.9 m underground to the corner of the field.

A piece of 12.7 mm diameter PVC pipe, 3.5 m long, was attached to the line to serve as a standpipe to regulate the water pressure. Estes and Ferguson (20) state that one should multiply the maximum desired pressure (4-6 psi) by 2.31 or have 71 cm per psi needed to determine the height of the standpipe. It has been reported that 'Viaflow' trickle tubing should carry water at a pressure between 4-6 psi.

Determining when to irrigate was achieved by using soil tensiometers placed at 30.5 cm depths. Tomato plants should be irrigated when the soil moisture tension becomes greater than 30 centibars (54). Both the trickle and overhead irrigated plots were irrigated when the tensiometers read between 20-30 centibars.

The heights of all the tomato plants were taken on June 9, 1979 and recorded after the tomatoes grew in the field for 1 month. Harvest dates were July 2, 9, 13, 18, 21, 24, and 30; and August 2, 6, 11, 16, and 29, with peak harvest at about August 6. On each harvest date, all tomatoes at the "breaker" stage to the red ripe stage were picked and graded into the following quality characteristics and disorders for each sub-sub plot of 18 plants:

1. Total number of fruit/plant
2. Total marketable weight of fruit/plant
3. Percent Cull fruit (less than 5 cm in diameter)
4. Percent fruit with Anthracnose

A foliar disease rating of Alternaria solani (early blight) was taken to compare the percent diseased leaves occurring in the overhead-irrigated plots and the trickle-irrigated plots. The rating was done on a scale of 0-10; 0 = no diseased leaves, 10 = 100% diseased leaves. There were 5 ratings taken at 10 day intervals from July 22 to August 31.

The study was terminated on August 31, 1979. At this time, 3 plants per unit were cut off at the base of the plant, the fruit removed, the mean fresh weights were recorded, and the means calculated.

The data was statistically analyzed by the use of the Statistical Analysis System (SAS), a computer system for data analysis at the Kansas State University Computing Center (3).

RESULTS

Using trickle irrigation, 40% less water was used to supply an equivalent reading on tensiometers in the plant row as compared with overhead irrigation. Although statistical comparisons were not determined between the overhead and trickle blocks, in most instances a trend toward major differences was observed between these 2 irrigation methods. Plants that were irrigated by overhead irrigation tended to have shorter initial plant heights (Table 1), yielded slightly more fruit (Table 2), tended to produce more marketable fruit (Table 3), tended to have greater fresh weights (Table 6), and tended to have fewer diseased leaves per plant (Table 7) at peak harvest and throughout the season (Figure 1) than plants irrigated by trickle irrigation.

There was a distinct advantage in using plastic in the overhead irrigation block. Plants mulched with black plastic and irrigated by overhead irrigation yielded significantly more total fruit (Table 2), produced more marketable fruit (Table 3), and had significantly less anthracnose on the fruit (Table 5) than unmulched plants. Plastic mulch, when used with both overhead and trickle irrigation, provided better growth. Plants that were mulched with black plastic in both overhead and trickle plots had significantly greater initial plant heights (Table 1), significantly greater amounts of diseased leaves during peak harvest (Table 7), and produced more cull fruits (Table 4) than unmulched plants. During peak harvest and throughout the season, although no statistical comparisons were made, a greater amount of diseased leaves occurred in the trickle irrigated plots (Table 7). Plants irrigated by overhead irrigation increased sharply in the amount of diseased leaves after the peak harvest date (Figure 2).

Plants given a high rate of fertilizer showed less percentage of diseased leaves than plants given low and medium rates when they were irrigated by overhead irrigation during peak harvest (Table 7). Plants that were given a high rate of fertilizer, trickle irrigated, and mulched with black plastic had significantly taller initial plant heights than plants given low and medium fertilizer rates (Table 1).

It was shown that plants receiving a high amount of fertilizer when mulched gave a significantly greater total number of fruit as compared with plants receiving a low amount of fertilizer which were unmulched (Table 2). Also, plants mulched with black plastic and given a high amount of fertilizer had a greater weight of marketable fruit than unmulched plants given a low rate of fertilizer (Table 3).

The results were probably influenced by the existing weather conditions during the summer of 1979. Rainfall could have influenced the response of several variables studied, since total summer rainfall and rainfall amounts at one time were excessive (Appendix Figure 1).

DISCUSSION

In a general comparison between two irrigation systems, plants irrigated by overhead irrigation seemed to have shorter initial plant heights. This was probably due to less water being available to the plant after the soil had dried and before the next irrigation was applied (Table 1). Overhead irrigated plants tended to yield greater numbers of fruit (Table 2) and more marketable fruit (Table 3), probably because the plants were grown on soil that had good drainage and could be cultivated easily. The trickle irrigated plots were growing in an area of lower elevation. Thus, the plants received more water draining from all areas of the field. The water tended to accumulate in this area and the soil became "waterlogged". There was standing water in the field at times, and the plant roots could have become oxygen-starved. It was also observed that the final plant fresh weights seemed to be larger than trickle irrigated plants. A general observation that fewer diseased leaves seemed to be observed in the overhead irrigated plants could have been because of non-humid conditions around the plants, as was with the trickle irrigated plants (Figure 1) due to wet soil conditions.

Overhead irrigated plants which were mulched with black plastic yielded significantly more total fruit (Table 2) and produced more marketable fruit (Table 3) than unmulched plots, probably because of soil temperatures underneath the mulch being higher than in unmulched treatments. This agrees with reports by several others (14,16,23,59). Also, soil nitrogen may not have tended to leach through the soil under black plastic as fast as through unmulched soil as observed by others (7,10,12,21,40). Significantly fewer instances of anthracnose were found on overhead irrigated, mulched plants (Table 5). The fruits were not resting on the soil, hence the pathogen which can overwinter in the soil could not penetrate through the fruit as easily, as demonstrated by Fulton (24). Most plant responses to mulch occurred in overhead irrigated plots, probably becasue of better drainage on the soil. Tillage was better accomplished in the overhead irrigated plots, because tillage could be done closer to the plants. With trickle irrigated plots, it was not possible to till as close to the plants for fear of breaking the trickle tubing.

Plants that were mulched with black plastic and irrigated by both overhead and trickle irrigation had significantly greater initial plant heights (Table 1), possibly due to higher soil temperatures under the mulch, as observed by others (14,16,23,59) or higher soil moisture under the mulch, as other researchers have noted (16,19,25,33,39,40). Mulched plants also had significantly greater amounts of diseased leaves during peak harvest (Table 7) and produced more cull fruits than unmulched plants, in which similar findings by other researchers could not be found.

Disease development increased throughout the season, probably due to the large amounts of rainfall to splash and transmit spores. The primary foliar disease observed throughout the season was early blight (Alternaria solani) with a few cases of Septoria leaf spot. The third observation of the percentage of diseased leaves was taken on August 7, which corresponded to the date of the peak fruit harvest.

The vegetable grower is interested in controlling diseases up to the point of peak harvest. After this time, fruit yields decrease and plant diseases start to occur more frequently as the plants start to senesce and weaken. It then may no longer be economical for the grower to control plant diseases. It is for this reason that the peak harvest date was presented. During peak harvest, although no statistical comparisons were made, there appeared to be a greater amount of diseased leaves occurring in the trickle irrigated plots (Table 7). The soil was waterlogged, which contributed to a heavy infestation of early blight which concurs with other reports published (34,52).

The foliar disease ratings of diseased tomato plant leaves having early blight seemed to be greater for trickle irrigation throughout the season due to the saturated soil conditions (Figure 1). Agrios (1) states that conidia of early blight can be spread by splashing rain and is more prevalent on plants under stress, caused by unfavorable environmental conditions. However, plants irrigated by overhead irrigation increased sharply in the amount of diseased leaves after the peak harvest date (Figure 2). One possible explanation for this sharp rise could be because the overhead irrigated plots received more water on the leaf surfaces from rain plus irrigation. Trickle irrigated plots only received water on the leaf surfaces when it rained and not by irrigation. Plants given a high rate of fertilizer showed less percentage of diseased leaves than plants given low and medium rates when they were irrigated by overhead irrigation during peak harvest (Table 7). This occurrence could have been due to these plants receiving improved nutrient levels throughout the study. Agrios (1) states that plants receiving a balanced nutrition of required elements are more capable of protecting themselves from new infections and limiting themselves to existing infections. Also, it has been shown that plants with a high available nitrogen supply mature more slowly than those with a limited nitrogen supply, and consequently, defoliate more slowly. An abundance of nitrogen retards maturation of plants directly by stimulating vegetative growth. Abundant rainfall allows a greater utilization of nitrogenous fertilizers and thus results in a slower maturation of the plant and a slower growth of early blight, as was observed by Barratt and Richards (4). This can be seen for the peak harvest date in Table 7 in plants receiving high fertilizer rates. However, the continued heavy rainfall provided an ideal environment for an increase in infection from early blight, and so the fourth and fifth observation dates of plants given high fertilizer rates in Figure 2 showed a sharp increase in early blight.

One possible way to delay the attack of early blight would be to add nitrogen to determinate varieties of tomatoes at transplanting time to delay maturity. Care should be used to not force the plant into a vegetative condition. Tomato growers may justify the cost of fertilizers if, by providing the plants with adequate nutrition, the plants will be more healthy. In this study, under overhead irrigation, plants receiving high amounts of fertilizer had significantly less foliar diseases present. Healthy plants would reduce the cost of chemical sprays to control plant diseases. Plants that were given a high rate of fertilizer in trickle irrigation and mulched with black plastic had significantly taller initial plant heights than plants given low and medium fertilizer rates (Table 1), probably due to the greater amount of fertilizer the plant had available. Fertilizer in the unmulched plots probably tended to leach through the soil at a faster rate, which has been observed by Black and Greb (7).

Plants that were given a high fertilizer rate when mulched gave a significantly greater total number of fruit (Table 2) and a greater weight of marketable fruit, (Table 3) as compared with fruit recieving a low amount of fertilizer which were unmulched. This could be due to the tendency of the fertilizer not to leach as fast under the mulch as in bare soil.

The 1979 growing season was relatively wet. The total cm of rainfall for May, June, July, and August were 6.96, 7.85, 14.10, and 7.42. This is shown in Appendix Figure 1. These rainfall amounts were large, and they occurred quite regularly throughout the season, hence, the results reported for tomato were influenced by rainfall, making it difficult to detect large differences in yields and foliar diseases in both the trickle irrigated plots and the overhead irrigated plots. If rain was the limiting factor, there may have been differences in both irrigation systems.

Field plot design when conducting trickle irrigation experiments is sometimes difficult. Field plot locations should be selected very carefully. In this study, the trickle irrigated plots were slightly lower in elevation than the overhead irrigated plots. The topography of the land, as well as the soil type should be known before choosing the area to be planted. It would be difficult to obtain accurate data if 1 plant row was irrigated by trickle and the adjacent row irrigated by a different system. Water from 1 row would flow into the other row giving bias to the results. Thus, the different irrigation methods must be separated into blocks. Also, in this study, there was no pump to carry the water to the field. Therefore, the field plot was designed to place the main water line in close proximity to the water tank. This took advantage of the water flowing down to the field by gravity.

Further studies should be made growing fresh market tomatoes with trickle irrigation and black plastic mulch under a wide variety of climatic conditions to see if there could be any benefits for vegetable growers who receive a high amount of annual rainfall, but with an unpredictable distribution of annual rainfall. If a grower raises fresh market tomatoes in a humid region of the U.S., it would be to his advantage to use trickle irrigation because rainfall might not come during the critical periods needed for the growth of the tomato. Rudich, et. al. (54) observed that when trickle irrigation was applied during the period of fruit set and fruit development, the irrigation increased yields dramatically by maintaining a low level of plant stress. If the grower in the humid region uses trickle irrigation, higher yields will offset the cost of the system.

SUMMARY

This study was undertaken to study the effects of plastic mulch under 3 levels of soil fertilization as a possible way for vegetable growers to maximize yields, reduce plant and fruit diseases, and to use water more efficiently, using 2 irrigation methods--trickle irrigation and an overhead sprinkler system. Using trickle irrigation, 40% less water was used to supply an equivalent reading on tensiometers in the plant row as compared with overhead irrigation.

Plants that were irrigated by overhead irrigation tended to have shorter initial plant heights, yielded slightly more total numbers of fruit, tended to produce more marketable fruit, tended to have greater fresh weights, and tended to have fewer diseased leaves per plant at peak harvest and throughout the season than plants irrigated by trickle irrigation.

Plants mulched with black plastic and irrigated by overhead irrigation yielded significantly more total fruit, produced more marketable fruit, and had significantly less anthracnose on the fruit than unmulched plants. Plastic mulch, when used with both overhead and trickle irrigation, provided better plant growth. Plants that were mulched with black plastic in both overhead and trickle plots had significantly greater amounts of diseased leaves, had greater initial plant heights during peak harvest, and produced more cull fruits than unmulched plants.

During peak harvest and throughout the season, although no statistical comparisons were made, a greater amount of diseased leaves occurred in the trickle irrigated plots. Plants irrigated by overhead irrigation increased sharply in the amount of diseased leaves after the peak harvest date.

Plants given a high rate of fertilizer showed less percentage of diseased leaves than plants given low and medium rates when they were irrigated by overhead irrigation during peak harvest. Plants that were given a high rate of fertilizer, trickle irrigated, and mulched with black plastic, had significantly taller initial plant heights than plants given low and medium fertilizer rates.

It was shown that plants receiving a high amount of fertilizer when mulched gave a significantly greater total number of fruit and a greater weight of marketable fruit as compared with plants receiving a low amount of fertilizer which were unmulched. The results were probably influenced by the existing weather conditions during the summer of 1979. Rainfall could have influenced the response of several variables studied, since total summer rainfall and rainfall amounts at one time were excessive.

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Table 1. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the height of 'Jet Star' tomato plants measured one month after transplanting.

Irrigation Method		Plant Height in cm Fertilizer Rate[1/] Low	 Medium	 High	 $\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 42.4	Mulch	45.5b[z]	44.7b	45.3b	45.1b
	No Mulch	40.0a	39.9a	39.4a	39.7a
	$\overline{X}$ Fertilizer Treatment	42.8a	42.3a	42.3a	
Trickle $\overline{X}$ = 46.0	Mulch	46.5kl	47.8l	52.8m	49.0j
	No Mulch	41.6ij	42.6ij	44.8jk	42.7i
	$\overline{X}$ Fertilizer Treatment	41.6i	45.2i	48.8j	

1/ Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

z Mean separation by Duncan's multiple range test, 5% level.

Table 2. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the total number of fruit per plant.

Irrigation Method		Mean Fruit No./Plant Fertilizer Rate[1/] Low	Medium	High	$\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 43	Mulch	46ab[z]	47b	51b	48b
	No Mulch	34a	42ab	41ab	39a
	$\overline{X}$ Fertilizer Treatment	40a	45b	46b	
Trickle $\overline{X}$ = 36	Mulch	36i	33i	38i	36i
	No Mulch	37i	40i	33i	37i
	$\overline{X}$ Fertilizer Treatment	37i	37i	36i	

[1/] Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

[z] Mean separation by Duncan's multiple range test, 5% level.

Table 3. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the total marketable weight of fruit in kg per plant.

Irrigation Method		Mean Mkt. Wt. of Fruit in kg/Plant — Fertilizer Rate[1/] Low	Medium	High	$\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 5.3	Mulch	5.6ab[z]	5.6ab	6.5b	5.9b
	No Mulch	4.2a	5.1ab	5.2ab	4.8a
	$\overline{X}$ Fertilizer Treatment	4.9a	5.3ab	5.8b	
Trickle $\overline{X}$ = 4.5	Mulch	4.4i	4.1i	4.7i	4.4i
	No Mulch	4.0i	5.4i	4.2i	4.5i
	$\overline{X}$ Fertilizer Treatment	4.2i	4.7i	4.4i	

[1/] Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

[z] Mean separation by Duncan's multiple range test, 5% level.

Table 4. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the % cull fruit harvested per plant.

		Mean % of Cull Fruit/Plant			
		Fertilizer Rate[1/]			
Irrigation Method		Low	Medium	High	$\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 7.4	Mulch	9.6b[z]	10.3b	7.3ab	9.1b
	No Mulch	4.9a	7.4ab	4.9a	5.7a
	$\overline{X}$ Fertilizer Treatment	7.2a	8.9a	6.1a	
Trickle $\overline{X}$ = 7.1	Mulch	9.0jk	8.0ijk	9.7k	8.9j
	No Mulch	5.9ijk	5.5ij	4.4i	5.2i
	$\overline{X}$ Fertilizer Treatment	7.5i	6.7i	7.0i	

1/ Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

z Mean separation by Duncan's multiple range test, 5% level.

Table 5. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the % anthracnose on fruit harvested per plant.

Irrigation Method		Mean % Anthracnose/Plant: Fertilizer Rate[1/] Low	Medium	High	$\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 22.2	Mulch	20.2ab[z]	14.9b	21.1ab	18.8a
	No Mulch	25.8a	26.5a	24.4a	25.6b
	$\overline{X}$ Fertilizer Treatment	23.0a	20.7a	22.8a	
Trickle $\overline{X}$ = 21.6	Mulch	19.6i	18.5i	23.4i	20.5i
	No Mulch	20.7i	23.8i	23.3i	22.6i
	$\overline{X}$ Fertilizer Treatment	20.2i	21.2i	23.4i	

1/ Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium - 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

z Mean separation by Duncan's multiple range test, 5% level.

Table 6. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the fresh weight per plant of mature tomato plants with fruits removed.

Irrigation Method		Mean Fresh Wt. in kg/Plant, Fertilizer Rate[1/] Low	Medium	High	$\bar{X}$ Mulch Treatment
Overhead $\bar{X}$ = 9.1	Mulch	9.7ab[z]	6.5a	10.5b	8.9a
	No Mulch	8.0ab	10.0ab	10.0ab	9.3a
	$\bar{X}$ Fertilizer Treatment	8.8ab	8.3a	10.3b	
Trickle $\bar{X}$ = 6.4	Mulch	5.2i	5.8i	7.2i	6.1i
	No Mulch	4.7i	8.2i	7.3i	6.7i
	$\bar{X}$ Fertilizer Treatment	4.9i	7.0j	7.3j	

[1/] Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

[z] Mean separation by Duncan's multiple range test, 5% level.

Table 7. The interaction of fertilizer rate and black plastic mulch under two irrigation systems affecting the % foliar disease rating of leaves per plant when observed during peak harvest.

Irrigation Method		Mean % Foliar Disease Rating of Leaves/Plant: Fertilizer Rate[1/] Low	Medium	High	$\overline{X}$ Mulch Treatment
Overhead $\overline{X}$ = 20.4	Mulch	20.6ab[z]	31.7c	16.1a	22.8b
	No Mulch	20.0ab	15.6a	18.2ab	17.9a
	$\overline{X}$ Fertilizer Treatment	20.3b	23.6c	17.2a	
Trickle $\overline{X}$ = 31.0	Mulch	27.8ij	43.8i	32.5jk	34.7j
	No Mulch	30.6jk	25.0i	27.8ij	27.8i
	$\overline{X}$ Fertilizer Treatment	29.2i	34.4j	30.1i	

1/ Low = 24.5 kg N/ha and 36.7 kg P/ha

Medium = 48.9 kg N/ha and 73.3 kg P/ha

High = 97.8 kg N/ha and 146.5 kg P/ha

z Mean separation by Duncan's multiple range test, 5% level.

Figure 1. The interaction of irrigation method and observation time on the foliar disease rating of 'Jet Star' tomato plants.

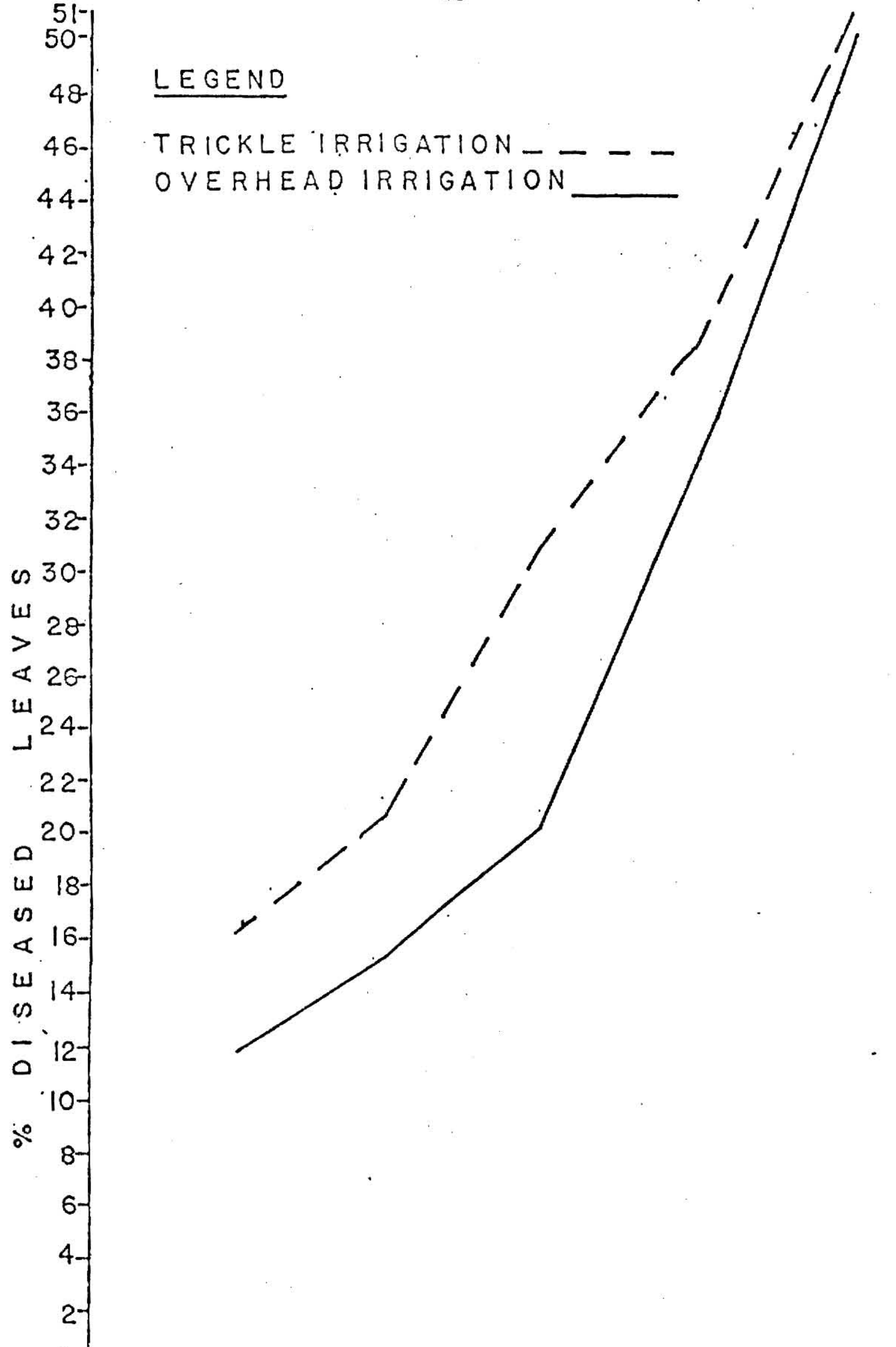
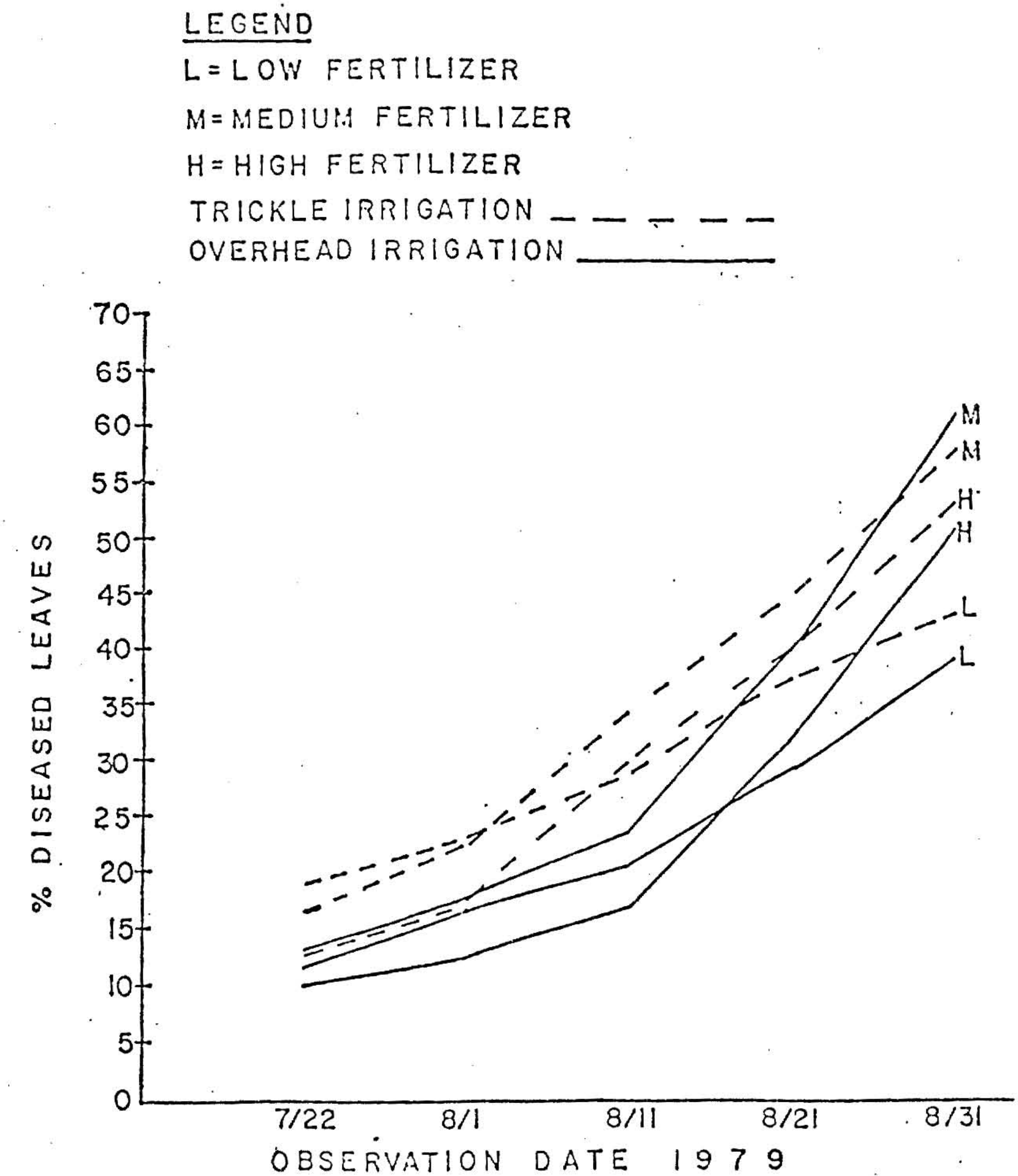

LEGEND
TRICKLE IRRIGATION
OVERHEAD IRRIGATION
% DISEASED LEAVES
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
51
7/22
8/1
8/11
8/21
8/31
OBSERVATION DATE 1979

Figure 2. The interaction of fertilizer and irrigation method on the foliar disease rating with time on 'Jet Star' tomato plants.


LEGEND
L = LOW FERTILIZER
M = MEDIUM FERTILIZER
H = HIGH FERTILIZER
TRICKLE IRRIGATION
OVERHEAD IRRIGATION
% DISEASED LEAVES
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
7/22
8/1
8/11
8/21
8/31
M
M
H
H
L
L
OBSERVATION DATE 1979

APPENDIX

Table 1. Amounts of water applied per hectare.

Amounts of water applied per hectare were calculated as follows:

1. For the trickle irrigation system:

gallons/hour x No. of hours = gallons applied to plot

$$\frac{\text{No. of gallons applied to plot}}{\text{plot in ft}^2} \times \frac{x}{43{,}560}$$

= No. of gallons applied/acre

gallons/acre x 3.78 l/gal = liters/acre

liters/acre x 2.47 ha/acre = liters/hectare

2. For the overhead irrigation system:

1 acre = $(208.7\ \text{ft})^2$

but 208.71 ft x 12 in/ft = 2,504.52 inches

hence, $(2{,}504.52\ \text{in})^2/\text{acre} = 6{,}272{,}620.4\ \text{in}^2/\text{A} = C$

If C x L = cubic inches/acre, where L = linear inches applied to an acre

then 1 linear inch H_2O/Acre = 6,272,620.4 in^3 H_2O/acre

1 gallon = 2,785.42 cubic centimeters (c.c.)

1 cubic inch = 16.387 c.c.

hence, $\frac{3{,}785.42\ \text{cc/gal}}{16{,}387\ \text{cc/cu in}}$ = cubic inches/gallon

$$\frac{\text{cubic inches/acre}}{231\ \text{cubic inches/gallon}} = \text{gallons/acre}$$

$$\frac{\text{gallons/acre x plot size in sq ft}}{43{,}560\ \text{sq ft/acre}} = \text{gallons/plot}$$

gallons/acre x 3.78 l/gal = liters/acre

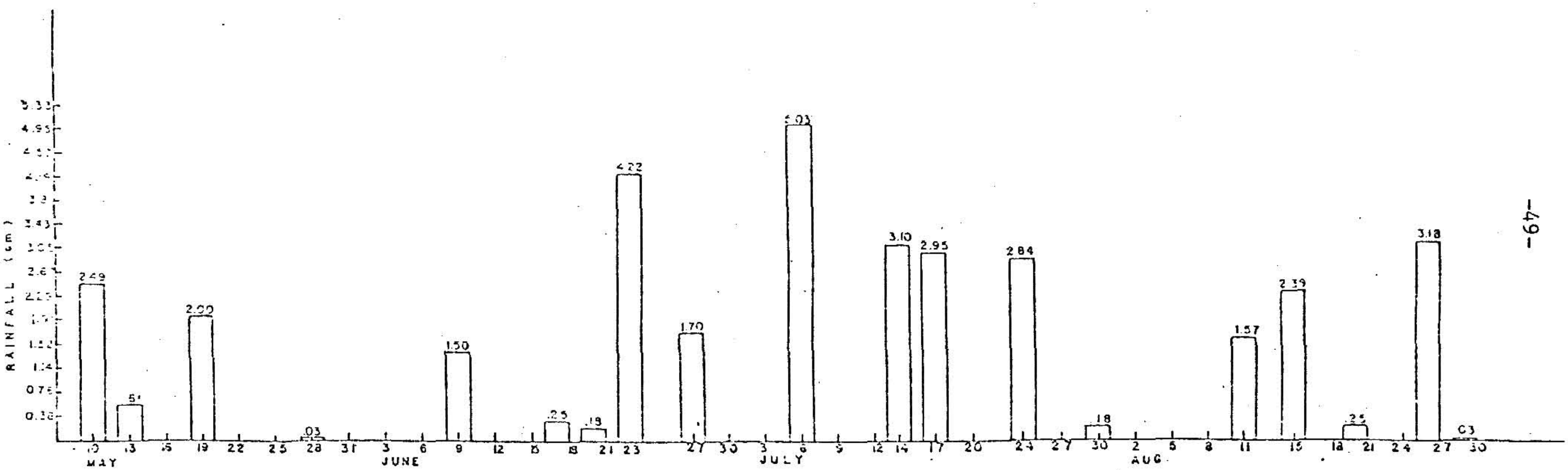
liters/acre x 2.47 ha/acre = liters/hectare

Figure 1. Three day total rainfall data at Manhattan, Kansas from May 9 to August 31, 1979.

ILLEGIBLE DOCUMENT

THE FOLLOWING DOCUMENT(S) IS OF POOR LEGIBILITY IN THE ORIGINAL

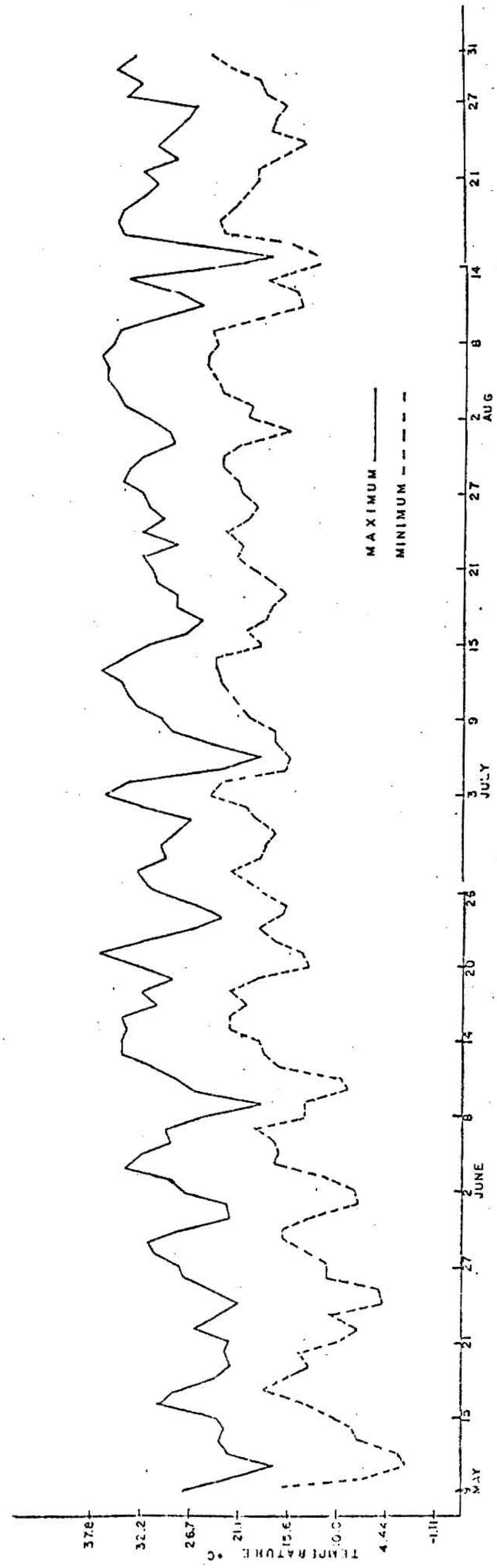
THIS IS THE BEST COPY AVAILABLE



<u>Total cm of rainfall/month</u>

May	6.96
June	7.85
July	14.10
August	7.42

Figure 2. Daily maximum and minimum temperatures at Manhattan, Kansas from May 9 to August 31, 1979.


TEMPERATURE °C
37.8
32.2
26.7
21.1
15.6
10.0
4.44
-1.11
9 MAY
15
21
27
2 JUNE
8
14
20
26
3 JULY
9
15
21
27
2 AUG
8
14
21
27
31
MAXIMUM
MINIMUM

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VITA

Carl Joseph Cantaluppi, Jr. was born on October 9, 1954 in Tuxedo Park, New York. He graduated from Lakeland Regional High School in Wanaque, New Jersey in 1972. He then entered Delaware Valley College of Science and Agriculture, Doylestown, Pennsylvania, where he received a B.S. degree in Horticulture in 1976. He then worked during the period of time from May 1976 to June 1978 as a produce buyer for Safeway Stores, Inc. in Maryland, a vegetable grower in Pennsylvania, and as a roadside market manager, also in Pennsylvania. In September 1978, he enrolled at Kansas State University to obtain a M.S. degree in Horticulture. In December 1979, he received a M.S. degree and decided to pursue a Ph.D. degree in Horticulture at the University of Minnesota.

EFFECTS OF IRRIGATION METHOD, PLASTIC MULCH, AND FERTILIZER RATE ON THE GROWTH, YIELD, AND DISEASE OCCURRENCE OF 'JET STAR' TOMATOES

BY

CARL JOSEPH CANTALUPPI, JR.

B.S. (Horticulture), Delaware Valley College
of Science and Agriculture, 1976

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Horticulture
Kansas State University
Manhattan, Kansas

1980

Using trickle irrigation, 40% less water was used to supply an equivalent reading on tensiometers in the plant row as compared with overhead irrigation. Plants irrigated by overhead irrigation tended to have shorter initial plant heights, yielded slightly more total numbers of fruit, tended to produce more marketable fruit, tended to have greater fresh weights, and tended to have fewer diseased leaves per plant at peak harvest and throughout the season than plants irrigated by trickle irrigation. Plants mulched with black plastic and irrigated by overhead irrigation yielded significantly more total fruit, produced more marketable fruit, and had significantly less anthracnose on the fruit than unmulched plants. Plants mulched with black plastic in both overhead and trickle plots had significantly greater amounts of diseased leaves during peak harvest, produced more cull fruits, and had greater initial plant heights than unmulched plants. During peak harvest and throughout the season, although no statistical comparisons were made, a greater amount of diseased leaves occurred in the trickle plots. Plants irrigated by overhead irrigation increased sharply in the amount of diseased leaves after the peak harvest date. Plants given a high rate of fertilizer showed less percentages of diseased leaves than plants given low and medium rates when they were irrigated by overhead irrigation during peak harvest. Plants that were given a high rate of fertilizer, trickle irrigated, and mulched with black plastic, had significantly taller initial plant heights than plants given low and medium fertilizer rates. It was shown that plants receiving a high amount of fertilizer when mulched gave a significantly greater total number of fruit and a greater weight of marketable fruit as compared with plants receiving low rates of fertilizer which were unmulched.