Using Air in Sub-Surface Drip Irrigation (SDI) to Increase Yields in Bell Peppers

D. Goorahoo[1], G. Carstensen[1], D. F. Zoldoske[1]*, E. Norum[1], and A. Mazzei[2].
[1]Center for Irrigation Technology (CIT), California State University, Fresno. 5370 N Chestnut Ave, Fresno, CA 93740. [2]Mazzei Injector Corp. 500 Rooster Drive, Bakersfield, CA 93307.
*Speaker: Tel.- (559) 278 2066. e-mail: david_zoldoske@csufresno.edu

Abstract: Root zone modification has long been a subject of interest among growers and researchers. Well-aerated soil is known to provide a generally better environment for root development and plant growth. Unfortunately, single purpose air injection systems have typically proven too costly for successful commercial application. With advances in subsurface drip irrigation (SDI) technology, that could change. The concept of aerating the irrigation water has the potential for the air to move with water within the root zone more generally and affect crop growth. In a pilot study, production trials featured injection of air into drip lines, so that the water applied had a volume of approximately 12 percent air. For air injection into the drip lines, a manifold was constructed using a Mazzei® differential pressure injector. Irrigations were conducted every seven days using reference Evapotransporation (Eto) information. The experimental plot was one-quarter acre. Soil cover over the drip line was five to six inches of sandy loam, and plant rows were 190 feet long. Treatments consisted of SDI with untreated water and SDI with 12 percent injected air. Treatment plots consisted of two rows per treatment, with four replications of each treatment. Harvest data for one growing season showed that bell pepper plants irrigated with the aerated water produced 33 percent more peppers, with 39 percent greater weight, than plants irrigated with non-aerated water. In addition to yield data, there was greater dry weight and larger root mass in those plants that had received aerated water. The major effect of the injected air was within the first 150 feet of the drip tape inlet. The small-plot results are sufficiently encouraging to justify further trials on a larger plot approaching commercial scale, where rows can extend as long as 680 feet.

Introduction: The spaces within a soil, known as soil pores, can be filled with liquid and/or gases. Physical, chemical, and biological soil characteristics that influence crop growth and yield depend on the relative proportions of these two phases within the root zone. For example, a soil that is well aerated will favor increased root respiration and aerobic microbial activity (Mengel and Kirkby, 1982). Conversely, in soils where the pores are filled with liquid, or waterlogged soils typical of poor drainage, anaerobic conditions prevail. These anaerobic conditions are produced when the oxygen (O_2) that is carried in the water is depleted.

Oxygen (O_2) is essential for root respiration. However, immediately after the roots have been surrounded by water they can no longer respire normally. The liquid impedes diffusion of metabolites such as carbon dioxide and ethylene. This causes the plant to be stunted because ethylene is a growth inhibitor (Arkin and Taylor, 1981). When air is injected into the water within the root zone, diffusion of ethylene and carbon dioxide away from the roots may be increased. This increased diffusion rate should result in improved growing conditions. Increased oxygen diffusion rates to the root have shown to increase nitrogen (N_2) fixation in legumes (Paul and Clark, 1989). Atmospheric O_2 concentrations greater than 20% have been found to increase N_2 fixation, but levels higher than 50% result in inhibition (Paul and Clark, 1989). The supply of available carbon and the supply of O_2 both have major effects on symbiotic fixation. The amount of adenosine triphosphate (ATP) generated using a given quantity of O_2 appears greater when carbohydrate is oxidized than when hydrogen (H_2) is oxidized (Arkin and Taylor, 1981). Plants use ATP as the major carrier of phosphate and growth energy. Furthermore, increased N_2 fixation can be attributed directly to an increase of atmospheric O_2 in the root zone. The first regions to suffer oxygen deficiency are the regions of highest metabolic activity, such as the zones of cell division and elongation at the end of the roots (Paul and Clark, 1989). Hence, adding air to the root zone could result in less stress overall on the plants.

Oxygen is also essential for most soil microorganisms. It has been estimated that in a fertile soil, microorganisms consume more O_2 than crop plants (Wolf, 1999). Hence, sufficient oxygen is important for soil processes such as Nitrification and Ammonification, which involves the *Nitrosomonas* and *Nitrobacter* species, respectively (Stevenson, 1982). Shortages of O_2 can lead to denitrification, whereby important amounts of nitrogen are lost for crop production as nitrate is reduced to volatile nitrogen compounds (Wolf, 1999). In addition, oxygen is also needed for large groups of soil fauna. These include a number of insects, nematodes, mites, spiders and earthworms, which improve the soil physical, biological and chemical properties.

Modifying root zone environments by injecting air has continued to intrigue investigators. However, the cost of a single purpose, <u>air-only</u> injection system, separate from the irrigation system, detracts from the commercial attractiveness of the idea. With the acceptance of subsurface drip irrigation (SDI) by commercial growers, the air injection system is at least potentially applicable to the SDI system. Unfortunately when air alone is supplied to the SDI system it emits as a vertical "stream" moving above the emitter outlet directly to the soil surface. As a consequence, the air affected soil volume is probably limited to a chimney column directly above the emitter outlet. Balancing the air/water relationships as well as changing soil temperature could affect growing conditions, yield, and time of harvesting particularly in locations with limited growing seasons. The concept of aerating the irrigation water increases the potential for the air to travel with water movement within the root zone more generally and affect crop growth.

Over the past several years, grower experience in Kern county, California, has shown a positive crop response to air added to the root zone via venturi injectors capable of aerating water with fine air bubbles. In related work, a grower reported that on a commercial test plot basis pepper yield increases were 12.8 percent and 8.1 percent for premium and processed bell peppers, respectively. The value of the increased yield is however partially offset by increased energy costs. The main objective of the current project was to determine the impact of air injected into water delivered through SDI on yield of bell peppers. Specific tasks were to evaluate the following: (1) crop response to non-aerated (control) and air injected drip tape irrigation system by measuring yield, size and root weight; (2) bell pepper crops grown on mulched and non-mulched plant beds; and, (3) correlation of crop yield and location down the row (i.e. distance from source of air injection).

<u>Procedure:</u> The experiment was conducted on research fields located at the Center for Irrigation Technology (CIT),California State University in Fresno, CA (Fresno county, San Joaquin central valley; elevation < 150 m, average annual rainfall < 300 mm). The soils are fine sandy loam with < 2% organic matter in the upper soil horizon. Field plots consisted of approximately 1/4 ac. of bell peppers with plastic film mulch and approximately 1/4 ac. without plastic film mulch. Within the half-acre experimental area there were 8 pairs of rows approximately 380 ft. long. Each pair of rows was in a bed configuration with beds and drip lines spaced 60-in. center to center. Alternate beds were irrigated with aerated and non-aerated water, respectively. The bell pepper plant rows were offset 12 in. from both sides of the drip tape. The 8ml drip tape, buried approximately six inches, was rated at 0.34 gpm per 100 ft. at 8 psi. Emitter spacing was 12-in. center to center.

Manifolds for each treatment were fitted with dual flowmeters, pressure gauges and pressure regulators. The aeration manifold was fitted with a Mazzei® (patented) injector gas inlet port, a throttling valve and setup to attach to a rotometer capable of measuring airflow rates up to 20 cubic feet per hour (CFH). The basic principle of the injector is as follows: as water under pressure enters the injector inlet, it is constricted in the injection chamber (throat) and its velocity increases. The increase in velocity through the injection chamber, according to the Bernoulli equation, can result in a decrease in pressure below atmospheric in the chamber. This drop in pressure enables air to be drawn through the suction port and be entrained into the water stream. As the water stream moves toward the injector outlet, its velocity is reduced and the dynamic energy is reconverted into pressure energy. The aerated water from the injector is supplied to the irrigation system. The fluid mixture delivered to the root zone of the plant is best characterized as an air/water slurry.

Pre-germinated bell pepper plants were planted on May 4, 2000 at a down-the-row spacing of 12 in. Plants were then monitored for growth vigor and overall growing conditions in order to carry out weeding and fertilizer applications. Monitoring parameters included number of dead or wilted plants, green color and canopy cover for assessing vegetative growth, and proportion of weeds in plots. Both mulched and non-mulched plots were subjected to the same irrigation schedule. An effort was made to maintain adequate levels of soil moisture for the specific needs of pre-germinated plants especially given the late planting date of May 2000 and the onset of relatively hot field conditions.

Early irrigations were made as needed to maintain a moist root zone. As the pre-germinated plants took root it was possible to schedule irrigation at 7-day intervals. Calculated run times were modified as needed to ensure the wetting front moved the 12 inches from the drip line to the plant in order to provide contact with the plant's root system. The Reference Evapotranspiration (Eto) was obtained from a California Irrigation Management Information System (CIMIS) station on the California State University, Fresno campus. The canopy factor was developed by field observations. The crop factor (Kc) was taken from the literature. A system efficiency of 80% was assumed. Air to water volume ratio in the fluid mixture supplied via the SDI had a mean value of 12% and a range of 11.0 to 13.5%.

The plots had a total of 8 rows, consisting of 4 receiving aerated water and 4 receiving non-aerated water. Rows 1, 2, 5 and 6 received aerated water and the others received non-aerated water. Rows 1 and 8 were considered as guard rows and were not involved in the test harvesting. Row 2 (aerated) and row 3 (non-aerated) were paired together and designated as "A" pair. Likewise, rows 4 & 5 were designated "B" pair and rows 6 & 7 were designated "C" pair. Using a table of random numbers, four 10-ft. sections of test rows were identified in each A, B, & C pair and harvested for data collection and analyses. These 12 sample plots were accepted only if there were similar numbers of plants in the aerated and non-aerated treatments. Harvest data was coded to identify location as a measure of distance from the source of air injection. Peppers were harvested three times during the growing season at 88, 116 and 168 days after planting. At the end of the final harvest, one aerated and one non-aerated plant from each of the twelve sample plots were examined for root and shoot (stem and leaves) mass. The representative plants were dug up, washed clean, separated into above and below ground portions, oven dried, and weighed.

Results and Discussion: Early observations revealed that a high percentage of plants were dying in the plastic film mulch plots. On closer inspection, the stalks seemed to be atrophied at the point where they emerge from the plastic mulch. Probable causes for this atrophy include root fungi, viral infection, mechanical action of the plant stalk rubbing against the plastic film, and sunlight reflection. Excess soil water because of the mulch preventing evaporation may also be a reason for death of plants. In any case, it was obvious that the mulched plots required a different irrigation regimen than the non-mulched plots. With a common manifold, this was impossible. Given the poor stand in the mulched plots and the inherent manifold restriction, the mulched plots were abandoned. The non-mulched plots exhibited a good stand and vigorous growth and were therefore used for the rest of this study.

Only saleable peppers within the 10-ft. section of rows were used in the data analyses. Saleable peppers were defined as those with no sunburn, no insect holes, and at least 50 grams. It was possible to harvest saleable peppers from all locations at 88, 116 and 168 days after planting, with the exception of the second picking at location in Row C, at 38ft from the inlet, for the plots receiving water only. Average weights (± standard deviation) for the aerated and non-aerated peppers were 103.7 (± 12.02) and 99.4 (± 11.49) grams, respectively. Based on a ***t-test*** statistic performed at the 95% probability level, there was no significant difference between mean weights of bell peppers from the aerated and non-aerated treatments. Weights of saleable peppers ranged from 50.57 grams (measured in Row B at 18ft from inlet line, to 285.51 grams (measured in Row A at 81ft from inlet line), for plants receiving water only, and from 50.55 grams to 440.81 grams (in Row A at 81ft from inlet line) for plants receiving both air and water. The lowest number of saleable peppers was obtained during the second picking, conducted 116 days after planting. The highest number of bell peppers from a given sample plot was 67 and this was obtained during the third picking of the aerated peppers at location 81ft from inlet line in Row A. When the three pickings were combined, the aerated plants had a production increase in both the number (**Figure 1**) and total weight (**Figure 2**). Because of the similarity in the mean weight of individual bell peppers from the aerated and non-aerated treatments, this production increase was due primarily to differences in the number of peppers from the different treatments. There were 212 more peppers, equivalent to a 33% increase, harvested from the aerated plots compared to plots that received only water (**Figure 1**). The aerated plants had a production increase of approximately 25.4 kg, a 39% increase, over the non-aerated plants (**Figure 2**). A paired *t-test* indicated that there was a significant difference, at the $p<0.01$ level, between the number of saleable peppers harvested from the aerated and non-aerated treatments at the various sampling locations. The mean total number (± standard deviation) of bell peppers harvested during the study from the aerated and non-aerated sample plots were 71.5 (± 19.0) and 54.25 (± 14.38), respectively.

Indexing the sections of rows harvested from supply manifold along the drip tape provided an opportunity to evaluate possible position effects. **Figures 3 and 4** show the distribution of the total quantity and total weight of bell peppers picked, respectively, as a function of distance from the supply manifold. Generally, there was increased production from the beginning of the row to a maximum value at the 81-foot location. Yield then decreased down the row to a minimum value at the 168 feet location. As indicated above, the difference in production was due mainly to number of peppers in each plot. An attempt was made to curve fit the total pepper count versus location data, in order to ascertain a model to describe a relationship between these two parameters (**Figure 5**). For the aerated irrigation treatment (**Figure 5a**), the relationship was best described by

$$y = 57.8 + 0.78x - 0.005x^2 \qquad \text{Eq.1}$$

where y is the total pepper count, and x is the distance (feet) from source. The non linear regression given by Eq.1 had an $r^2 = 0.54$ and was significant at the $p< 0.01$ level. For the water only treatment, there was no significant correlation between the total pepper count and distance (**Figure 5b**). The quadratic relationship between the total pepper count and distance from air injection source, given by Eq.1, instead of a linear relationship may be indicative of the fact that air and water are not the only factors influencing the bell pepper yields. Subsequent studies should therefore incorporate additional parameters such as pressure and velocity measurements along the drip tape. In addition, nutrient status of the soil in the harvested plots should also be monitored, especially since the fertilizers were added in the irrigation water. By incorporating these additional parameters, it may be possible to better describe any relationship between pepper yield and distance from the supply manifold.

The final part of this study involved examination of the dry weights of roots, stems and leaves of mature pepper plants. When the total root and shoot dry weights of the plant material from the twelve test plots were combined, it was found that: (1) the aerated plants had a root weight increase of 17.53 grams, equivalent to a 54% increase, over the water only plants (**Figure 6a**); and, (2) the aerated plants had a stem and leaf weight increase of 68.98 grams, equivalent to a 5% increase, over the water only plants (**Figure 6b**). More importantly, there was a significant difference ($p<0.001$) between the root dry weight: total plant dry weight ratio (R:P) for the aerated and non aerated treatments. The ratio, R:P, was calculated for each of the twelve locations using [root dry weight] ÷ [root dry weight + stem and leaves dry weight]. For the aerated plants, R:P ranged from 0.025 to 0.04 with a mean of 0.031 and standard deviation of 0.005. For the non-aerated plants, R:P ranged from 0.014 to 0.032 with a mean of 0.021 and standard deviation of 0.006. Assuming that water and nutrient availability were adequate for both the aerated and non-aerated plants, the increase in proportion of root mass in the aerated plants could be attributed to the air injection. Greater root mass is most likely associated with greater surface area of root material within the soil, thereby permitting the roots increased accessibility to water and nutrient supply. Ultimately, the plants can utilize the increased water and nutrients to produce more peppers.

Conclusion: The study showed that delivering aerated water to the plant root zone through subsurface drip lines resulted in a 33% increase in number, and a 39% increase in the weight of bell peppers produced. There were also significant increases in the dry weights of root and shoots from plants receiving aerated water as compared to plants receiving water only. These statistically significant results on a small plot (0.10 ac.) support reported results obtained on tests conducted on a commercial farm, and are sufficiently encouraging to justify follow-up fieldwork on larger plots. Special interest in the potential application of this air injection technology is the characterization of how the beneficial effect may vary with the length of drip lines. Hence, subsequent studies should attempt to monitor pressure and velocity changes along the drip system and correlate these with crop yield.

References:

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Figure 1: Total quantity of bell peppers picked during the study (All Plots)

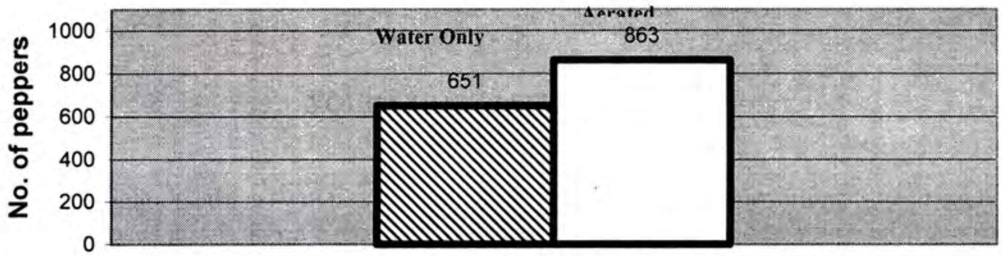


Figure 2: Total weight (grams) of bell peppers picked during the study (All Plots)

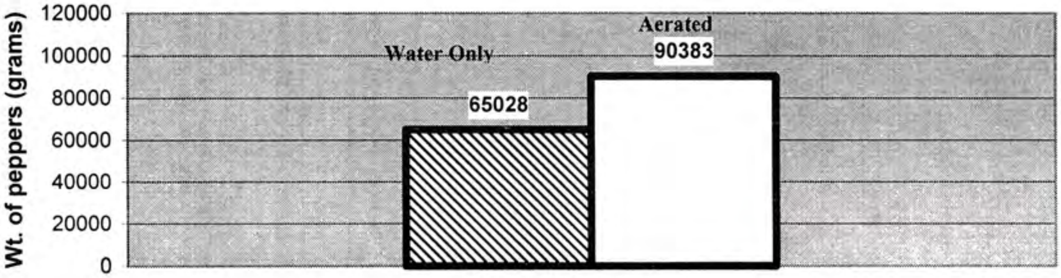


Figure 3: Quantity of peppers picked as a function of distance from supply manifold.

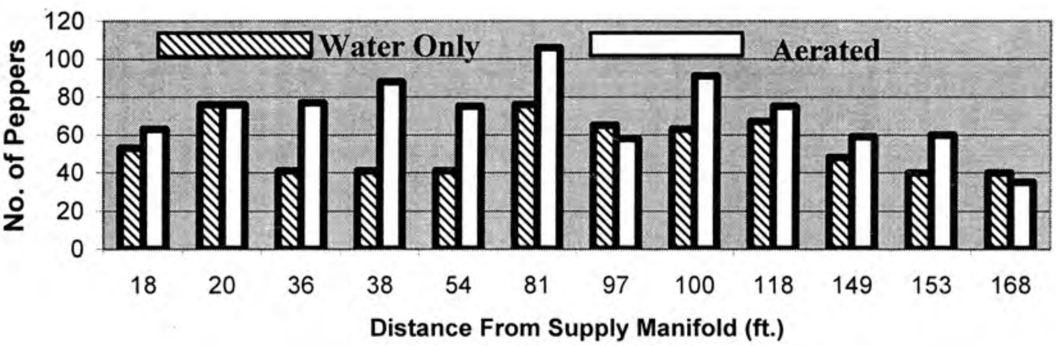


Figure 4: Total weight (grams) of pepper picked as a function of distance from supply manifold.

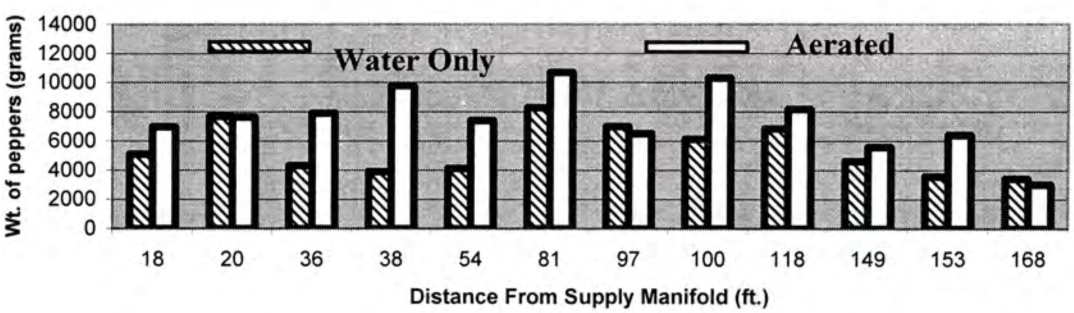
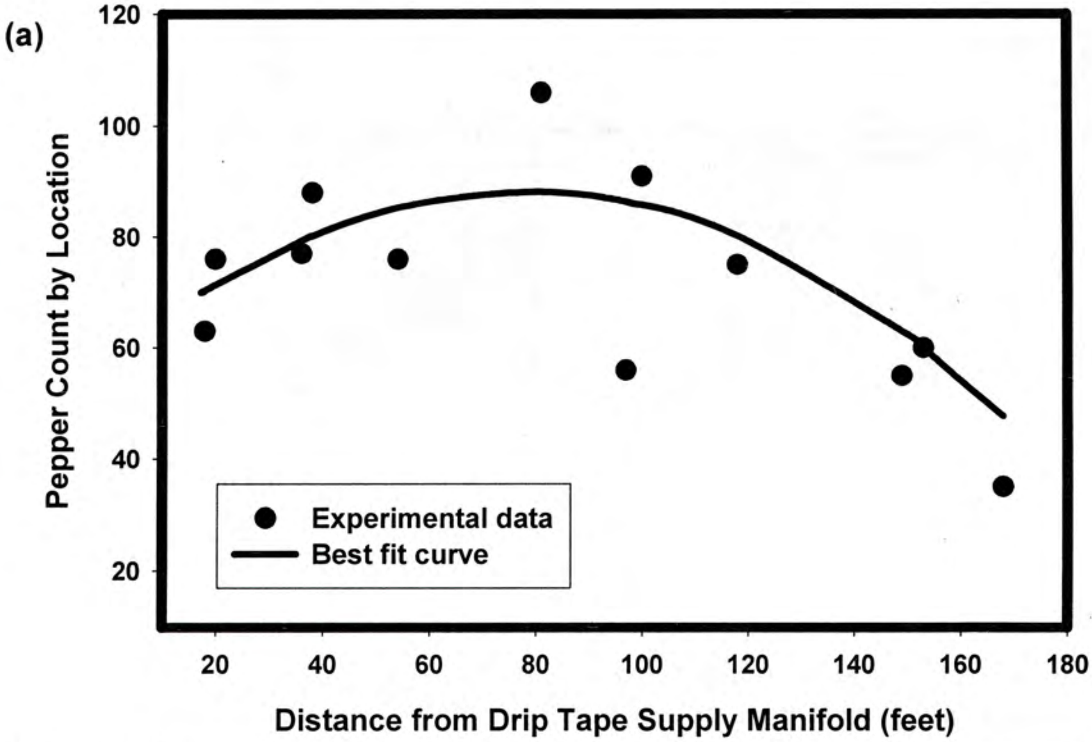


Figure 5: Peppers harvested by location for (a) aerated and (b) non-aerated irrigation water plots.



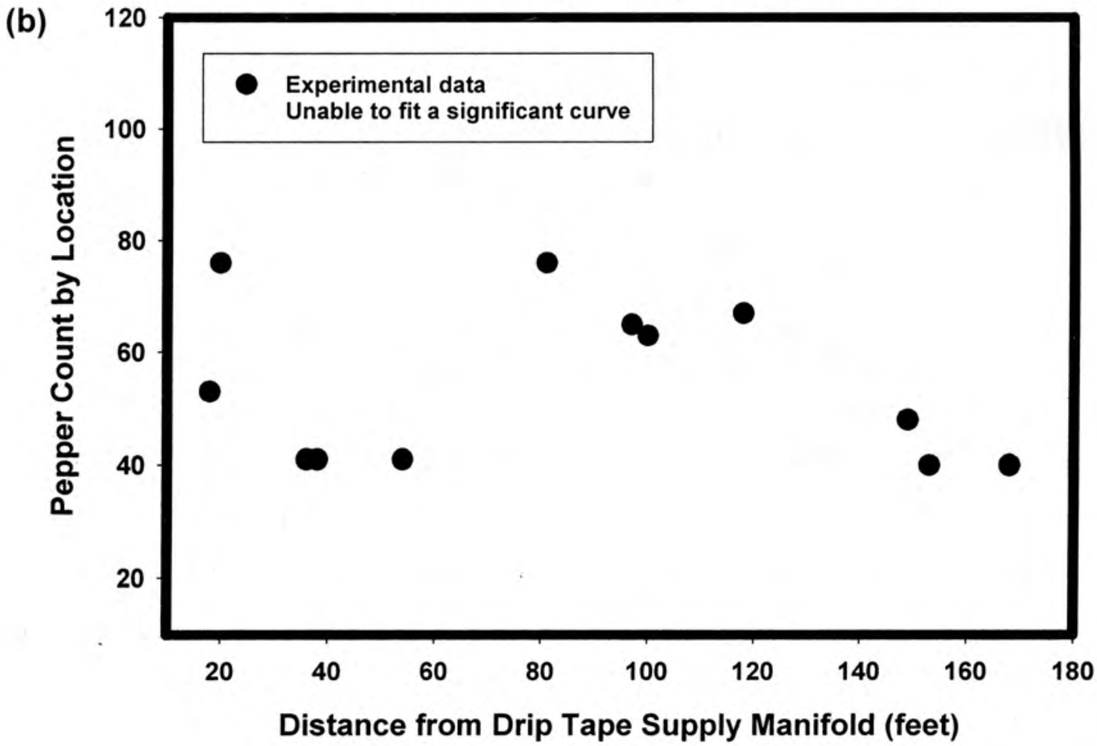


Figure 6a: Total dry weight (grams) of roots of mature bell pepper plants.

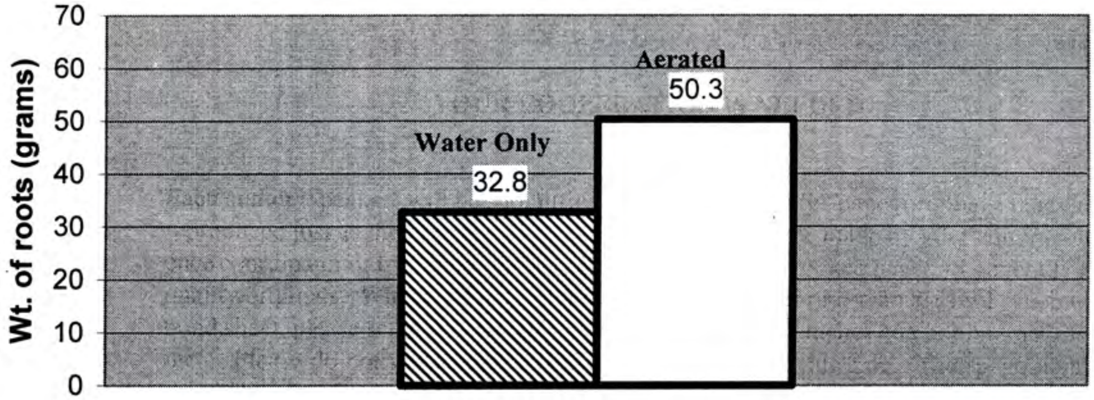


Figure 6b: Total dry weight (grams) of stems and leaves of mature bell pepper plants.