MULCHING AS A MEANS OF PRODUCING VEGETABLE CROPS UNDER A LIMITED WATER SUPPLY

by

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1 May 84
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To Nora, Paco, and Marcela.

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ABSTRACT

The effect of five mulch treatments (barley and wheat straw) on the soil and plant water relations of tomato, pepper and cantaloupe plants was compared with the control, unmulched treatment during the summer of 1983. Also, the effect of mulch on soil temperature and plant yield was evaluated. Plantings were made in moist soil which had been flood irrigated to saturation three days before planting. The main objective for using the mulch was to reduce evaporation from this initial irrigation, and therefore have more available water for plant use. Plants in two mulch treatments received limited amounts of water through a drip system; plant growth in the remaining treatments depended on rainfall.

All mulch treatments produced higher yields than the non-mulched control in all vegetables studied. This resulted from improved plant and soil water, and temperature regimes.

INTRODUCTION

A common problem shared by people living in arid and semiarid regions of the world is the lack of adequate amounts of water for agricultural purposes. These arid regions represent approximately 32% of the world's total arable land (16). In these areas the amount and distribution of rainfall determines the type of agricultural practices that can take place. The variability of rainfall is the greatest hazard to crop production. Another characteristic is that rain comes in a few heavy showers of short duration, causing considerable runoff, therefore creating a cycle with alternating wet and dry seasons. The season of the year at which precipitation occurs has a considerable effect on rainfall efficiency; due to its high evaporative demand the warm-season rainfall is usually less efficient than that of the cool season.

All the environmental constraints imposed on the dry farming regions have a direct, negative effect on the social, economic and nutrition conditions of people living in these regions. Therefore the concern for finding an adequate technique for improving the conditions may be done through these improvement of soil water storage use and conservation that will permit the introduction of new food crops as well as an increase in yields. This will ultimately diversify the nutritional patterns and improve the standard of living for those people who live in regions where the lack of water imposes severe limitations on agricultural production.

The approach undertaken in this study was the development of a technique using the concept that mulching is the practice of placing a moisture or heat barrier over the top of the soil. Such a concept is possibly as old as agriculture itself, and in practice is aimed to have a beneficial effect on soil water use and conservation, erosion control, soil temperature moderation, weed control, and increased water infiltration. The greatest effects of mulching for agriculture in dry regions are: soil water conservation and temperature moderation. Therefore, this study was conducted with the following objectives: (a) to test a method of using organic mulch (barley and wheat straw) as a medium for reducing soil water evaporation and temperature while producing vegetables under limited water supply; (b) to measure the effect of different mulch arrangements on soil and plant water status, as well as some plant physiological parameters; and (c) to observe the performance of these vegetables under this method and determine which ones are best adapted to the environmental conditions of Tucson, Arizona.

LITERATURE REVIEW

Inadequate moisture supply is a major factor limiting crop yields in arid and semiarid regions of the world. Any development which increases the efficiency of water use will have an important influence on crop productivity and consequently on the welfare of people living in those regions, which represent approximately 32% of the world's total arable land area (16).

One approach that has great potential for improving the efficiency of water use in agriculture is the use of mulches. Oke (41) defines mulching as the practice of placing a moisture or heat barrier over the top of the soil. The same author stresses the role of mulching as a means of conserving soil moisture by reducing evaporation. Mulch may also be used to reduce soil warming or to prevent excessive cooling, depending on the mulch used and the time of the year (36, 63). The traditional mulch consists of a well-aereated, and consequently poor-conducting surface cover Different materials have been used as mulches; these include hay, straw, leaf litter, moss, wood chips, sawdust, and gravel. More recently artificial mulches have become common, including foil, plastic films, paper, and aluminum foil. In spite of the fact that some of them are effective in reducing evaporation and in preventing weed growth, they are not generally applicable to most field crops.

Evaporation of soil water under field conditions takes place as a series of drying cycles interrupted by precipitation or irrigation. Bond (6), and Lemon (38) pointed out that after wetting, evaporation may be characterized by three stages. The first is the constant-rate stage; the soil surface is wet and water flows primarily in the liquid state. The second stage is one of rapidly decreasing evaporation rate and the drying soil begins to assume a major controlling role. The third stage is characterized by a very slow but relatively constant water loss in which water movement through the dry surface layer of soil is primarily by vapor diffusion (6).

In studying these stages, it has been pointed out that the greatest water loss occurs during the constant-rate stage (2, 38). Therefore, the greatest potential for decreasing evaporation loss is by an external treatment such as with mulches, during the constant-rate stage when the soil surface is wet. This line of reasoning is very important when mulches are being used, since the effectiveness of the practice depends strongly on the initial available soil water that is intended to be conserved for utilization by growing plants.

The practice of soil surface treatment by the use of some type of mulch is probably as old as agriculture itself. As early as 1907, scientific evidence of the benefits of mulching was provided by several researchers (34). The mechanism of the evaporation of water from soils has been the subject of much controversy over a long period of time. This is especially true from the point of view of the practical significance of water losses by evaporation and methods for controlling or reducing such losses.

The effect of vegetative mulches in reducing evaporation has been studied by many researchers (17, 23, 27, 43, 48). For instance, in experiments with isolated soil columns (48), water losses were compared on four summer days for the following treatments: (a) columns were exposed to sun and wind, (b) shaded from the sun with an opaque screen, and (c) shaded from sun and wind and mulched with 4 tons of wheat straw per hectare (t/ha). The relative evaporation losses for those treatments were:

(a) bare soil exposed to sun and wind shaded, 100%

(b) bare soil shaded from sun, 64%

(c) bare soil sun and wind shaded, 47%

(d) mulched with wheat straw mulch, 27%

These results indicate that straw mulch reduced evaporation by 73% while shading reduced it by 36%. Therefore, it was concluded that half of the effect of the mulch was produced by obstructing solar radiation from directly contacting the soil surface.

In a similar field study (48), 4.5 tons per hectare of straw mulch was effective in reducing evaporation during a period of frequently recurring rains but was relatively ineffective when rains were few and scattered. The same view has been supported by other researchers (23, 48, 57).

Under field conditions after a rain, there is a period in which the soil moisture becomes adjusted to field capacity. If the soil is covered with mulch, the rate of drying immediately after a rain is greatly reduced and the period of soil-moisture adjustment is prolonged. It can be concluded that the cumulative value of evaporation control will be greater if the rains are frequent. On the other hand, if the rains are not frequent, the moisture saved by the mulch will depend on the amount of rain.

Results obtained by Vincent-Chandler (59) using cane-trash mulch in Puerto Rico showed that the average monthly losses of water by evaporation from bare soils and mulched soils were 5.4 and 2.3 cm, respectively. In other studies (32, 51), favorable effects on plant height, yield, and evaporation control were found for sugar cane and cowpea crops. These beneficial effects were attributed to better soil moisture and temperature regimes with mulching (32,52,60).

Soil Temperature

Mulches may either increase or decrease soil temperature. Loose dry material, such as straw or wood chips, act as insultation and protect against high temperatures. Light-reflective mulches, such as white paper or aluminum foil, can reflect sunlight and thus decrease soil temperature. Soil mulched with those materials is about 3 to 5 C cooler than bare soil (9). The temperature-stabilizing effect of mulches is due to insulation, heat absorption, and shading. The reduction in soil temperature attained by mulching appears to increase nutrient availability and to provide a better environment for root growth, and ultimately improve the performance of plants.

Soil temperature is an important edaphic factor that has profound influence on plant growth through its direct and indirect effects on several soil and plant phenomena (22, 52). The same authors conducted a field study with forage maize to characterize the diurnal and seasonal variations in soil temperatures due to different soil covers. They found that during early growth stages of the crop, straw mulch alone, and straw covered with a sheet of transparent polyethylene, lowered maximum soil temperatures by 11 and 4 C, respectively, in the top 20 cm. Mulching brought the soil temperature within the optimal range of 26 to 31 C. They also found that straw mulching significantly increased forage yield.

For certain plants, especially in arid and semiarid regions, excessive soil temperatures can be detrimental. Mulching offers a way of overcoming the negative effects of high temperatures during the summer growing season. This is usually achieved by providing a layer of 10 to 15 cm of mulch on the soil surface. The large quantities of heat from the sun are reflected or absorbed by the mulch, and little is transmitted down to the soil because of the insulating properties of the mulch. Mulches of plant material reduce soil temperatures by the combined effects of radiation interception and evaporative cooling (1, 59). The amount of mulch plays a very important role; it is generally accepted that the thicker the mulch the more soil temperatures are reduced.

McCalla and Duley (39) found that a heavy straw mulch of 4 t/ha reduced the temperature in the top 2-1/2 cm of soil by as much as 17.7 C during the summer. Their research also showed that a thinner layer of mulch (1 to 2 t/ha reduced soil temperatures by 3 to 6 C at 2-1/2 cm depth, and 2 to 4 C at 10 cm depth.

Numerous studies have been conducted to determine the influence of mulches on soil temperatures (42, 45, 46, 47, 61). In particular, Gurnah and Mutea (25) conducted an experiment in which soil temperatures under coffee plants mulched with grass, clear polyethylene either slightly raised soil temperatures or lowered it; and black and clear polyethylene greatly increased soil temperatures.

Duley and Kelly (11) studied the effect of mulch covers on the intake rate of rain by soil. They compared water intake rate of a surface covered by straw and wheat stubble, with that of a bare, cultivated soil surface. The initial water intake rate was high for both treatments, and the rate remained high for the mulched plots, but fell rapidly on the cultivated plots. They concluded that the cultivated plots had a compacted layer about 3 mm thick which had been formed by the impact of falling rain drops. This surface compaction did not occur on mulched plots. Similar results have been reported by other investigators (12, 23, 33).

Another important aspect of mulching is the selection of effective mulch material. Unger and Jessie (58) compared wheat grain sorghum and cotton residues for determination of their relative usefulness in conserving water. Their results showed that wheat straw was about twice as effective as grain sorghum and more than four times as effective as cotton stalks for decreasing evaporation. They attributed these differences to the physical nature of the residues (hollow, pithy, and woody), which affected their specific gravity and hence their thickness and surface coverage when applied at identical rates by weight. They concluded that it required 18 t/ha of sorghum and more than 32 t/ha of cotton residues to decrease evaporation to levels obtained with 8 t/ha of wheat straw.

Plant and Soil Water

The driving force for transpiration is the difference in vapor pressure of water within the leaf and the atmosphere beyond the boundary layer. The upper pressure gradient is influenced primarily by two factors: humidity and temperature (49).

In studying the availability of soil water for plant growth, Slatyer (53) pointed out that the degree to which an internal water deficit develops within leaves depends on the gradient of water potential within the plant. Strong evidence indicates that these gradients depend on the degree of stomatal closure. This important feature has been considered as one way in which a plant can withstand periods of moisture stress. Timely closure of stomata leads to lower transpiration rates (37). If the stomata are closed or nearly closed, resistance to transpiration can be very high; if they are open, resistance is relatively low.

Understanding how environmental factors influence transpiration and CO_2 absorption of a plant growing under field conditions is a difficult assignment (49). This is because at any given time, many environmental factors interact with each other, influencing the evaporation and diffusion process: for instance, increasing leaf temperature promotes evaporation considerably and diffusion slightly, eventually causing the stomata to close.

The factors that control the stomatal mechanism have been reviewed extensively. It is well known that under conditions of non-water stress, stomatal aperture is controlled mainly by light, relative humidity, CO_2 concentration, K^+ content, and abscisic acid (ABA) (8, 29, 49).

Stomata of most plants open at sunrise and close in darkness. Under this sequence, CO_2 needed for photosynthesis diffused into the leaf during the daytime. Therefore, light intensity affects not only the rate of stomatal opening but also the aperture size. Low concentrations of CO_2, due to its removal during photosynthesis by parenchyma and mesophyll, cause stomata to open in light.

Conversely, certain succulent plants native to hot, dry conditions act in a different way. Stomata of these plants, denominated CAM (crassulacean acid metabolism), open at night. They fix CO_2 into organic acids in the dark, and their stomata close during the daytime. This is a recognized mechanism for conserving water.

The water status of the plant strongly controls stomata opening and closing. Stomata appear to be highly sensitive to changes in water potential. As water stress increases, stomata of most plants close. However, this is not a universal phenomenon since in some plants, leaf-water potential has to be very low (high water stress) before stomata closure begins (8, 29, 44). Based upon these observations, the concept of the need for a critical threshold value before closure of stomata has been developed. The validity of this concept is difficult to generalize for all plants; however, a range from -12 to -16 bars has been defined as the range of critical threshold values. For instance, several studies have compared maize and sorghum for stomata behavior under water stress. Whether the plants were growing in the field or in an artificial environment, the stomata in maize began to close earlier than those in sorghum leaves as water stress developed. From this evidence, one can conclude that the threshold water potential for closure was usually lower (more negative) in sorghum than in maize (50, 56). Obviously this mechanism is not triggered by a single factor, so other factors such as osmotic adjustments, as well as water stress intensity and duration, can change this threshold range.

High temperature (30 to 35 C) also affect stomatal closing. This is an indirect effect caused by water stress or a rise in respiration rate (8, 44). Whenever stomatal closure occurs, photosynthesis and transpiration are reduced, since the stomatal apertures serve as entry valves for CO_2 and release valves for water (8, 10, 44).

Relative humidity has a considerable effect on evaporation, and therefore on the water requirement of crops. Constant temperature changes and atmospheric humidity affect transpiration by modifying the vapor pressure gradient from leaf to air. Relative humidity in dry regions tends to be low (5 to 30%) around mid-day. Low humidity, combined with high temperatures, increases the difficulties of supplying an adequate amount of water to plants (35, 55).

Transpiration also plays an important role in cooling the leaf. Evaporation of water is a powerful cooling process that contributes to reduce leaf temperature and maintenance of metabolic processes that otherwise would be adversely affected by high temperatures.

Vertical Mulch

Vertical mulch has been used (13) for increasing water movement into packed soils, raising the level of soil oxygen, changing soil physical properties, increasing root penetration, and for soil erosion control. A vertical mulch permits water to move into the soil more readily and to greater depths than by wetting downward from the soil surface.

Gardner (20) pointed out that vertical mulches were a good approach for partially overcoming the high water losses during the "constant rate phase" of soil water evaporation as discussed by several soil scientists (2, 20, 38).

Fairbourn and Gardner (13) found that vertical mulch treatment on a level soil surface saved 30 to 40% more of the applied water than a furrow treatment. The same authors (14) studied vertical mulches in microwatersheds at the Central Great Plains station at Arkon, Colorado. They found that soil water evaporation was the lowest on the micro-watershed with vertical mulch as a result of greater concentration and deeper infiltration of the applied water. They also observed an increase in soil water storage. This was the major factor responsible for the 37 to 150% increase in grain sorghum yield from the vertical mulched micro-watershed when compared with the yield from the unmulched micro-watershed.

In summary, the use of vertical mulches offers the potential for increasing and stabilizing yields in arid to semiarid regions by improving the infiltration rate and water storage capacity of the soil, and thereby increasing water availability for plant growth.

MATERIALS AND METHODS

Field research for this study was conducted from May 1983 to November 1983 on the University of Arizona Campbell Avenue Farm in Tucson, Arizona. Three recommended vegetable crops for the Tucson area were planted on May 8 and 10 (Table 1).

Table 1. Vegetable crop, cultivar, and plant density.

Crop	Cultivar	Plant Density
Tomato	Early Girl	1 plant/50 cm
Pepper	Bell pepper	1 plant/50 cm
Cantaloupe	Top Mark	1 plant/50 cm

Plantings were made in moist soil which had been flood irrigated to saturation (10-12 cm of water) three days before planting. The tomatoes (Lycopersicon esculentum) and peppers (Capsicum annuum) were transplanted by hand. These transplants were 15 days of age. Cantaloupe (Cucumis sativus) was direct seeded by hand.

The experimental design used in this study was a complete randomized block. The plots consisted of 5 rows 10 meters in length and one meter spacing between rows.

The mulch material consisted of a mixture of barley and wheat straw which had previously been baled. The mulch was placed in the corresponding treatments on the day of planting. The mulch treatments were applied to reduce moisture loss from this initial water application. Five mulch treatments were compared with the control, unmulched treatment (Fig. 1).

The first mulch treatment was designated as "vertical" (VE). A trenching machine was used to dig a vertical trench 12 cm wide and 30 cm deep. The distance between trenches was 1 m. Bales of barley straw were cut in sections approximately 10 cm wide and then hand-placed in the trench to give a continuous layer of mulch to the bottom and length of the trench. Approximately 5 cm of the mulch protruded above the soil surface to keep the infiltration route open. A row of seedlings, or seeds, was placed approximately 10 cm on each side of the mulch. No other treatment required a trench.

The second mulch treatment was designated as the "horizontal-plus-drip" (HPD) because a 12 cm layer of mulch was placed over the flat ground covering 100% of its surface. This treatment had plastic drip lines placed beneath the mulch to provide supplemental water as needed during critical stages of plant growth. The planting in this treatment was done by opening a narrow space through the straw until the soil surface was exposed to facilitate both planting and seedling emergence.

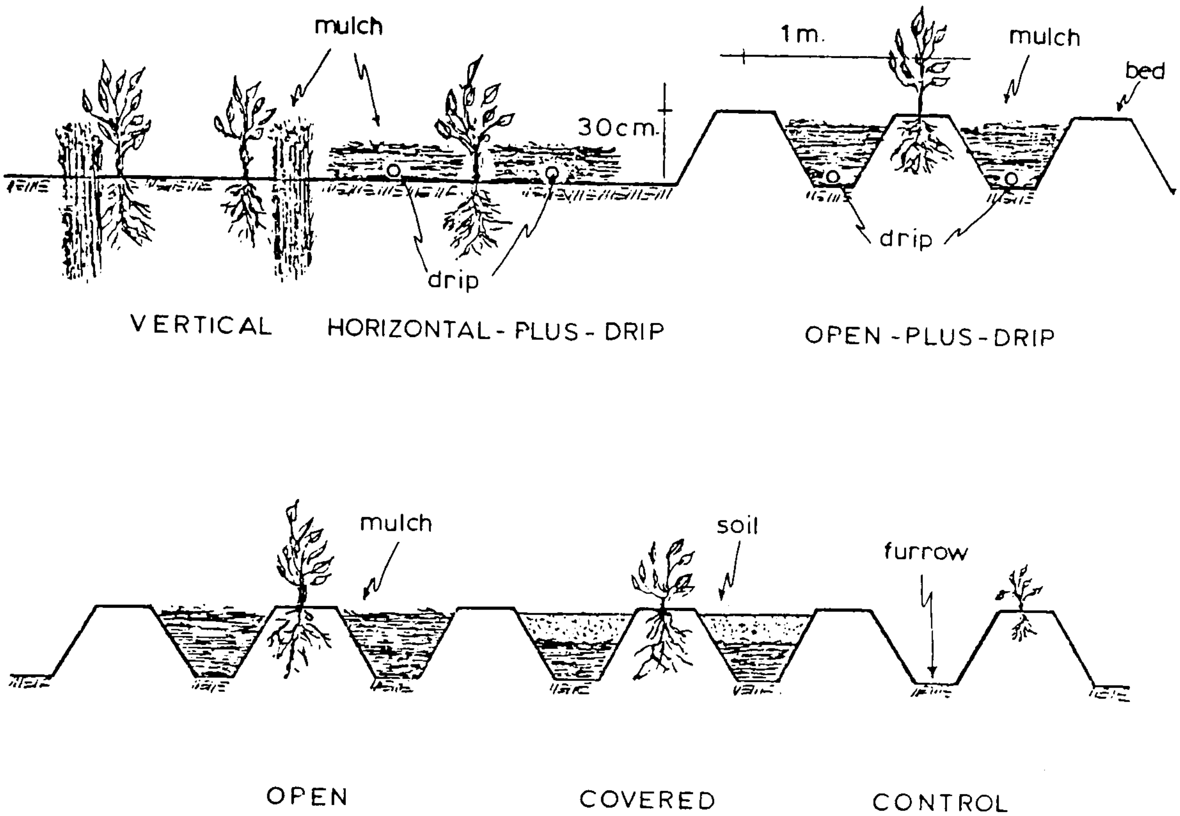


Fig. 1. Diagram showing the arrangement of the mulch material in the different mulch treatments.

The third treatment was called the "open-plus-drip" (OPD) and consisted of depositing straw in the bottom of furrows that were spaced 1 m apart. The mulch in this treatment covered approximately 50% of the soil surface. The seeds and seedlings were planted on the top and center of each bed. As in the horizontal treatment, a plastic drip line was placed beneath a 12 cm layer of straw mulch.

The fourth treatment was designated as "open mulch" (OP). This treatment had the same features as the open-plus-drip except that no drip line was placed under the straw.

The fifth treatment was called "covered mulch" (CO) and consisted of a modification of the open mulch treatment. In this case, a layer of soil approximately 10 cm thick was placed on top of the layer of straw. This produced a level surface over the entire plot.

The sixth and last treatment was the control. The plots in this treatment were furrowed in the same way as the open-plus-drip, open mulch, and covered mulch treatments; however, the control had no drip line nor mulch.

The sequence followed in placing the various straw mulches was based upon the concept of having moisture in the soil before mulch application and then observing the relative effect of the various treatments on soil moisture retention and plant growth. Consequently after construction of the beds, the entire field was flood irrigated, then after three days of drying, the mulch was placed according to the requirements of each treatment.

The drip system consisted of bi-wall, black plastic lines which had a main chamber with inner orifices and a secondary chamber with an outer orifice. Orifices were 30 cm apart. These bi-wall lines were connected to a central water supply line of white plastic PVC 1.3 cm diameter that in turn was connected to a 1890 liter steel water tank. The tank was placed on a steel frame 1.5 m high. Thus, the water flowed through the drip system by gravity. No other source of energy was used to operate the drip system.

A Li-Cor model CI-1600 steady-state porometer was used to monitor transpiration (ug cm^{-2} s^{-1}), diffusive resistance (s cm^{-1}), relative humidity (%), leaf temperature (C) and ambient temperature (C). The usefulness of this instrument in recording physiological and climatological parameters was first described by Beardsell, Jarvis, and Davidson (4). The porometer readings were taken concurrently with measurements of leaf water potential and soil moisture. One fully expanded leaf was measured from four plants in each treatment. Porometric measurements were recorded from 12 noon to 3:00 p.m.

Soil moisture depletion was evaluated with a Campbell Pacific Nuclear Corporation model 503 neutron probe at 30 cm depth. For this purpose, twelve access tubes 60 cm long were installed. Of these twelve tubes, six were located to monitor soil moisture changes in the six mulch treatments in the plots containing the pepper plants and the other six in plots with cantaloupe plants. During the installation of the tubes, soil samples were taken for the determination of water content using the gravimetric method. Those data, together with soil bulk-density, formed the basis for the field calibration of the neutron probe. Water status of plants was determined by measuring the leaf water potential (ψ_L) and osmotic potential (ψ_π). These determinations were made using Merrill 73-13 chamber psychrometers (Merrill Specialty, Inc., Logan, Utah) and a Wescor MJ-55 microvoltimeter. Leaf samples were collected directly in the field from 12 noon to 3:00 p.m. One leaf disc, approximately 5 mm in diameter, was placed in the psychrometer's chamber and equilibrated in a water bath (27 C) for a period of 4 to 5 hr. Determinations of ψ_L were made using fresh tissue (leaf disc) after the corresponding equilibration time. On the other hand, ψ_π values were determined after the chambers, containing the tissue, were frozen in liquid N_2 for 15 seconds and equilibrated overnight before obtaining the readings. Turgor pressure (ψ_P) was calculated by the difference of ψ_L and ψ_π.

Fresh weight of fruit was obtained at non-regular intervals due to the different growth patterns of the plant species studied. However, for each crop, the fruit was harvested when it reached a marketable size.

Soil temperatures were measured with soil thermometers inserted to a depth of 12 cm. Meteorological data were obtained from the University of Arizona Campbell Avenue Farm weather station located approximately 500 meters northwest of the experimental site (Table 2, Fig. 2).

Table 2. Precipitation distribution at Campbell Avenue Farm during the experimental period. -- Planting dates were May 8 and 10. Tucson, Arizona, 1983.

Month	Day	Rain (mm)	Total Rainfall per Month (mm)
May		0	0
June		0	0
July	8	0.1	
	11	8.6	
	13	5.5	
	21	2.7	
	22	0.5	
	25	0.2	
	27	4.3	21.9
August	1	1.2	
	2	0.5	
	5	3.0	
	7	1.0	
	9	13.9	
	10	16.5	
	11	9.6	
	15	3.0	
	16	11.4	
	17	15.4	
	19	3.0	
	29	6.0	85.0
September	7	3.5	
	14	1.7	
	16	2.2	
	20	8.6	
	23	0.7	
	26	6.3	
	27	1.0	
	29	14.2	
	30	29.7	68.3
October	3	143.5	
	4	5.0	148.5
			323.7

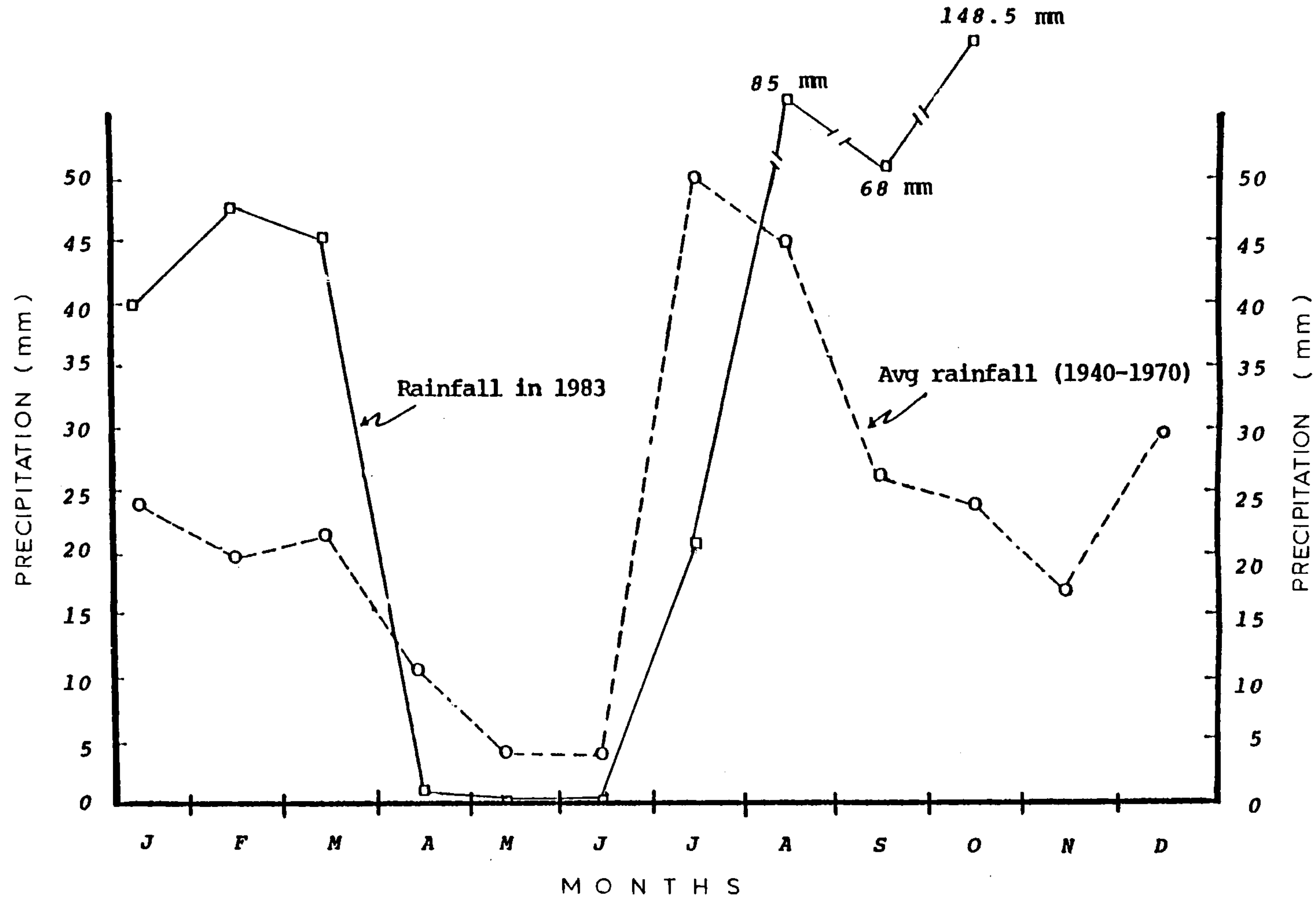


Fig. 2. Rainfall distribution in 1983 and for the 30-year average (1940-1970) at Campbell Avenue Farm, Tucson, Arizona.

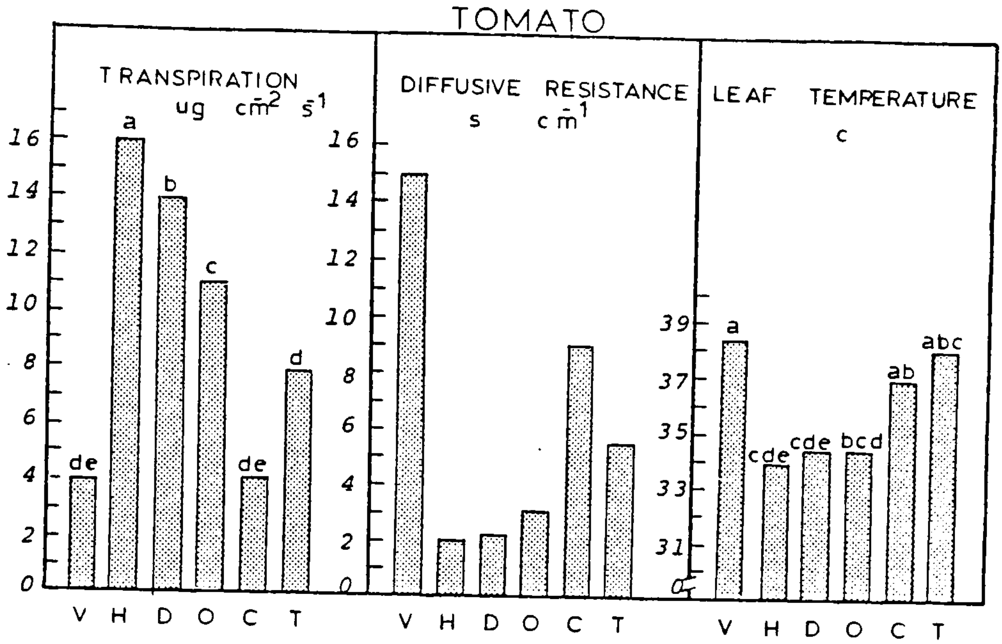
RESULTS AND DISCUSSION

Porometry

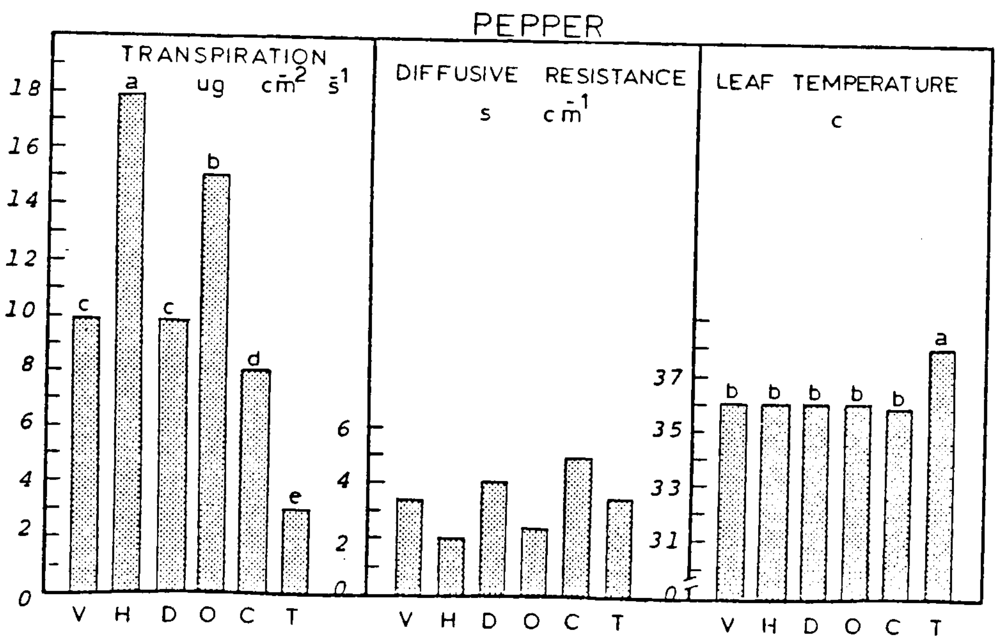
Results and discussion of the parameters measured with the porometer are presented in sequential order. Results for all vegetables evaluated on each particular date will be grouped accordingly.

The first porometer readings were taken on June 4, 1983, 26 days after tansplanting (DATP). Differences in transpiration (T), diffusive resistance (DR), and leaf temperature (LT) were evident among treatments in tomato as well as pepper plants. Consequently water stress started to develop.

Trends for T, DR, and LT in the tomato plants are shown in Fig. 3a. Transpiration for plants in the horizontal mulch treatment exhibited the highest value of 16.1 ug cm^{-2} s^{-1}, followed by open-plus-drip, open, control, vertical, and covered mulch 14, 10.9, 7.9, 4.1 and 3.9 ug cm^{-2} s^{-1} of water being transpired, respectively. The analysis of variance indicated significant differences in transpiration among treatments. Only the vertical and covered-mulch treatments had corresponding values that were similar, but different from the others. Letters on the bars in all figures indicate that values followed by the same letter are not



a.



b.

Fig. 3. Transpiration, diffusive resistance, and leaf temperature in plants at 26 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

significantly different at the 5% level according to the SNK test.

Diffusive resistance values shown in Fig. 3a indicated that the horizontal-plus-drip, open-plus-drip, and open-mulch treatments had the lowest DR to water losses. This is expected since there is an inverse relationship between transpiration rates and stomatal diffusive resistance. On the other hand, DR values were higher in the vertical and covered-mulch treatments.

Leaf temperatures indicated that tomato plants in the treatments with the highest transpiration rates had lower temperatures. Plants in the horizontal-plus-drip mulch treatment had an average LT of 33.8 C as opposed to 38.3 C for plants in the vertical mulch treatment. This significant difference of 4.5 C is related to the cooling effect of transpiration. The same response has been found by other researchers (28).

Values of transpiration and diffusive resistance in tomato plants were correlated with leaf temperature (Table 3). A high negative correlation (-0.95) was found between T and LT, which indicates that higher rates of transpiration reduced leaf temperatures. Also, DR was correlated positively with LT (0.94) since an increase in DR resulted in a decrease in T, causing LT to raise.

Table 3. Relationships between leaf temperature, transpiration, and leaf diffusive resistance in tomato plants grown under different mulch treatments. -- Tucson, Arizona, 1983.

		Correlation Coefficients (r) for Leaf Temperature (C)						
	DATP:	26	48	66	103	126	138	159
Parameter	Date:	Jun 4	Jun 26	Jul 14	Aug 20	Sept 12	Sept 24	Oct 15
Transpiration (ug cm^{-2} s^{-1})		-0.95*	-0.43	-0.79	-0.72*	-0.93*	-0.61	-0.18
Diffusive Resistance (sec cm^{-1})		0.94*	0.62	0.48	0.22	0.72	0.83*	0.56

* Statistical significance at 5% probability.

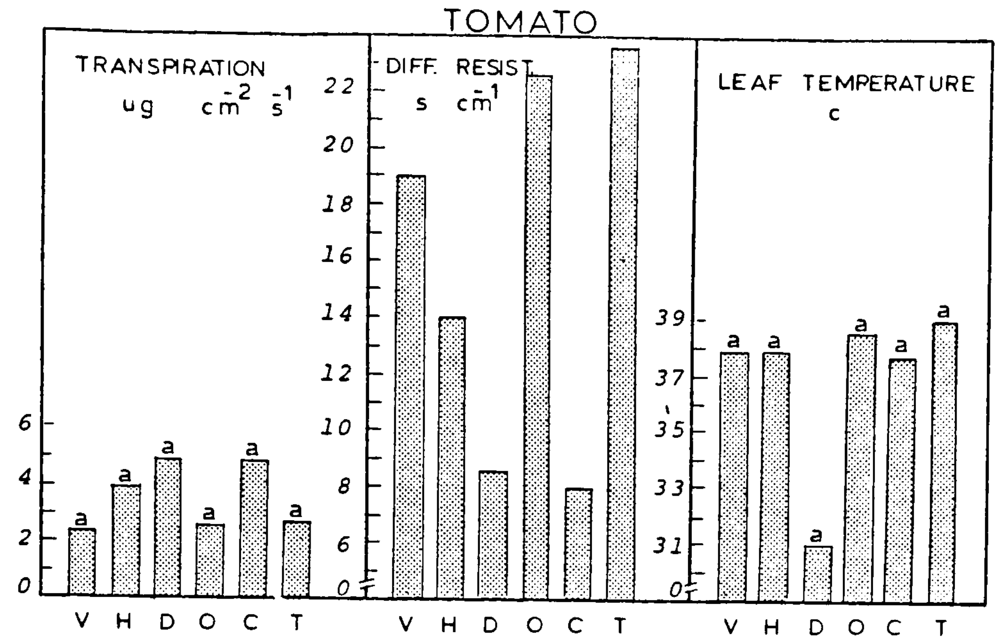
The analysis of data recorded 26 DATP (June 4), for pepper plants, indicates similar trends as those obtained for tomato plants (Fig. 3b). Significant differences in T existed among treatments: the horizontal-plus-drip treatment had the highest value, followed by the open-mulch treatment, 17.9 and 15.0 ug $cm^{-2}s^{-1}$, respectively. On the other hand, pepper plants in the control had the lowest rate in T: 3.5 ug $cm^{-2}s^{-1}$. Diffusive resistance values varied; however, this variation was not of the same order of magnitude as that obtained in tomato. This might be associated with differences in stomatal sensitivity to water stress between these species. Leaf temperature differences among treatments were less conspicuous. However, as it is shown in Fig. 3b, pepper plants in the control had a significantly higher leaf temperature.

The correlation coefficients for LT, T and DR are shown in Table 4. It was found that LT and T were inversely correlated (-0.79). Also, a high positive correlation (0.96) was found for LT and DR. Thus, these observations on peppers were similar to those on tomatoes. The climatological conditions prevailing at the time porometric measurements were made were as follows: air temperature 37.5 C, humidity 12.7%, and precipitation 0 mm.

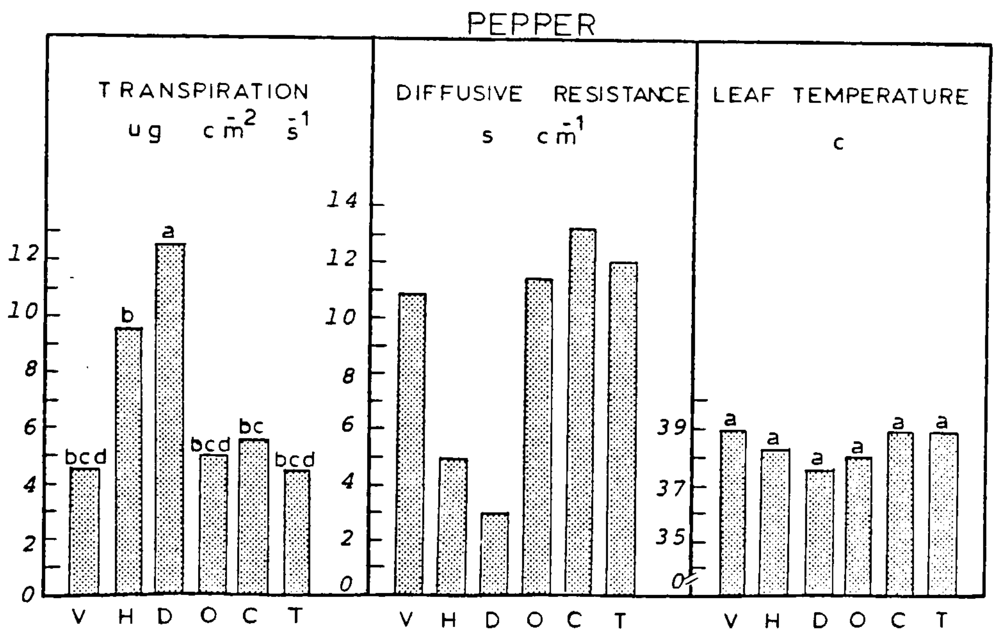
The second set of measurements was taken on June 26 (48 DATP). Even though soil moisture differences existed among treatments, no significant differences were found in T rates in tomato plants, Fig. 4a. When T rates at 48 DATP are compared to the ones at 26 DATP, it is noticeable that T values remained within the same range in the vertical and covered mulch treatments and that T values decreased for the horizontal, drip and open treatments. This indicates that plants that had the highest transpiration rates at 26 DATP were more sensitive to reductions in T at 48 DATP. One factor associated with this phenomenon was the low atmospheric humidity prevailing at the time of the readings (7.4%). As might be expected, stomatal apertures generally increase with increasing relative humidity. Guard cell turgor, and thereby stomatal aperture respond extremely rapidly to changes in relative humidity, and the rate of transpiration changes correspondingly. There is an advantage for the plant in having such a tight coupling between stomatal aperture and atmospheric moisture content.

A nonsignificant negative correlation (-0.43) and a nonsignificant positive correlation (0.62) were found on June 26 between LT and T, and LT and DR, respectively (Table 3).

The same physiological parameters measured in pepper plants are shown in Fig. 4b. An overall reduction in T rate occurred in all treatments, except the control, which slightly increased T rates as compared to values at 26 DATP. Signifi-



a.



b.

Fig. 4. Transpiration, diffusive resistance and leaf temperature in plants at 48 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

cant differences were found among treatments on this particular date. For instance, treatments vertical, open, covered, and control had T values between 4 and 6 ug $cm^{-2}s^{-1}$, respectively, while treatments horizontal and covered-plus-drip had T values of 9.5 and 12.5, respectively. The overall trend of transpiration seemed to be related to the soil moisture availability in each mulch treatment; as can be observed in Fig. 14, the treatments with higher soil moisture content had plants with higher rates of transpiration. Leaf temperature responses were not significantly different among all treatments (Fig. 4b).

Porometric measurements for the cantaloupe plants were taken for the first time at 48 DAP (Fig. 5). Cantaloupes were started from seed in the field as opposed to tomato and pepper, which were transplanted seedlings. Therefore, measurements were not taken until fully-expanded leaves were available.

Differences noted in T rates among the cantaloupe plants 48 DAP were not statistically significant. However, plants sampled in the horizontal mulch plot had a T value twice as great as those sampled in the control plot. The observed T rates were highly affected by their corresponding DR values. As might be expected, lower DR values caused higher T rates in this plant species. Differences in LT

Table 4. Relationships between leaf temperature, transpiration and leaf diffusive resistance in pepper plants grown under different mulch treatments. -- Tucson, Arizona, 1983.

		Correlation coefficients (r) for Leaf Temperature (C)						
	DATP:	26	48	66	103	126	138	159
Parameter	Date:	Jun 4	Jun 26	Jul 14	Aug 20	Sept 12	Sept 24	Oct 15
Transpiration (ug cm^{-2} s^{-1})		-0.79*	-0.82	-0.91*	-0.43	-0.97*	-0.61	-0.30
Diffusive Resistance (sec cm^{-1})		0.96*	0.74	0.81*	0.18	0.91*	0.83*	0.38

Table 5. Relationships between leaf temperature, transpiration, and leaf diffusive resistance in cantaloupe plants grown under different mulch treatments. -- Tucson, Arizona, 1983.

		Correlation Coefficients (r) for Leaf Temperature (C)				
	DAP:	48	66	103	126	189
Parameter	Date:	June 26	July 14	Aug 20	Sept 12	Oct 15
Transpiration (ug cm^{-2} s^{-1})		-0.91*	-0.57	-0.89*	-0.72*	-0.58
Diffusive Resistance (sec cm^{-1})		0.75	0.40	0.96*	0.69	0.69

* Statistical significance at 5% probability

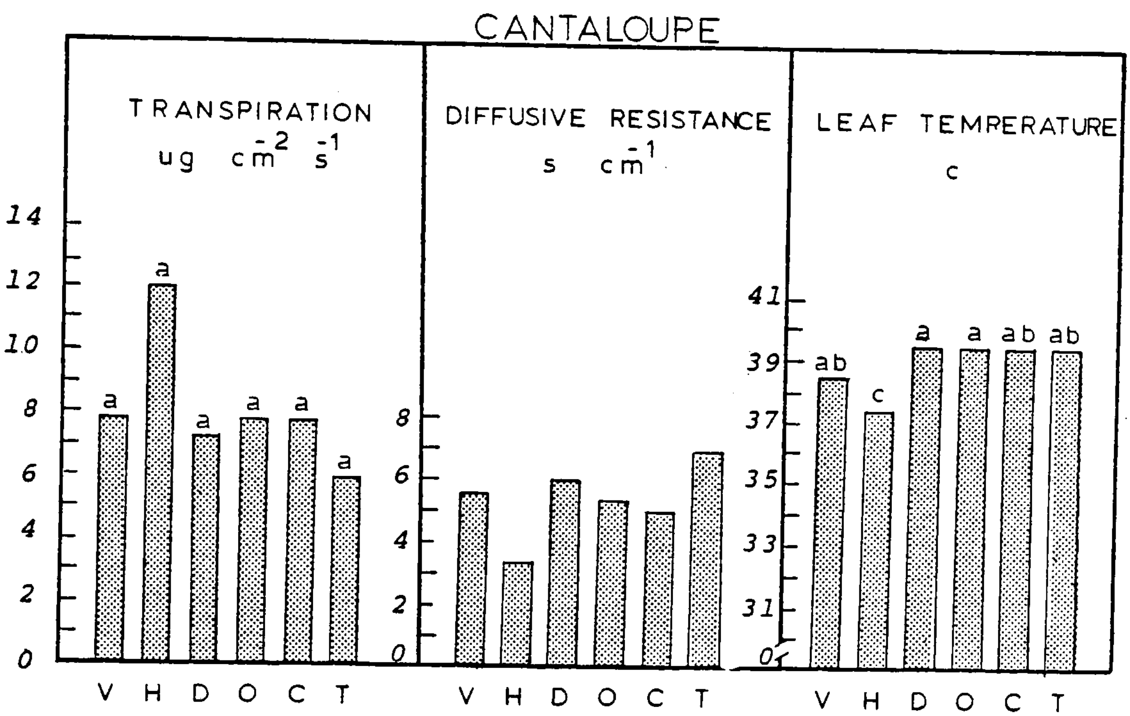
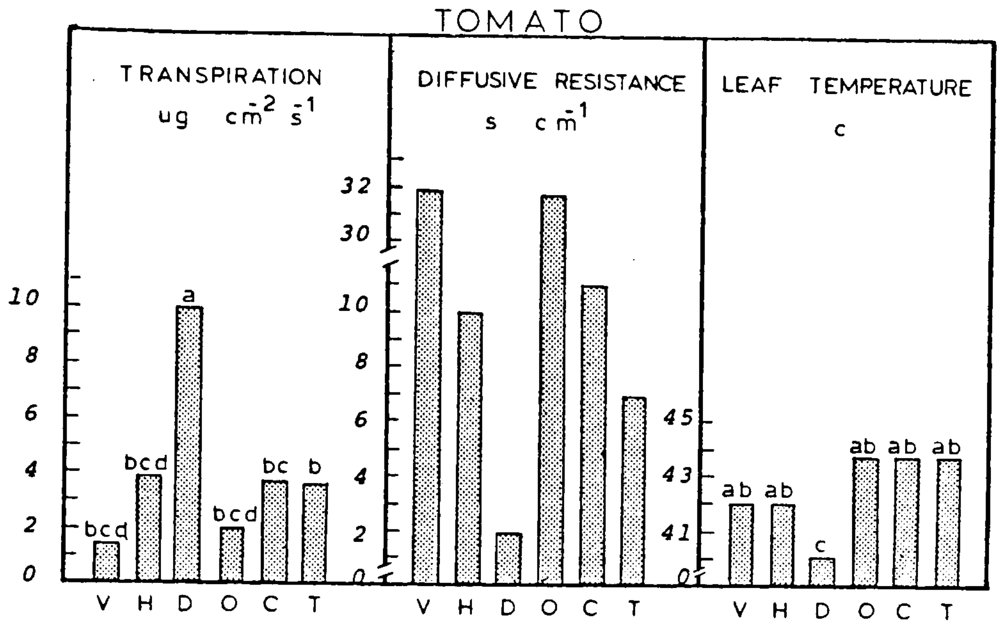


Fig. 5. Transpiration, diffusive resistance and leaf temperature in cantaloupe plants at 48 DAP. -- Key for treatments: V (VE) vertical; H (HPD) horizontal plus drip; D (OPD) open plus drip; O (OP) open; C (CO) covered; and T (CT) control.

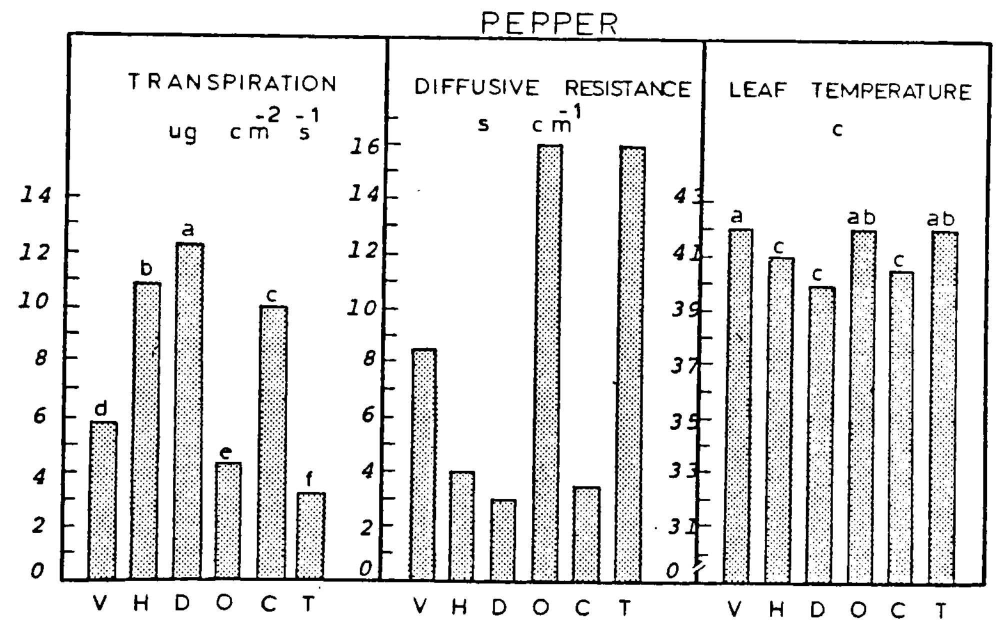
among cantaloupe plants were significant. Cantaloupe plants in the horizontal mulch treatment had lower LT values and had numerically higher rates of transpiration.

The analysis of porometric data obtained from the tomato and pepper plants at 66 DATP is shown in Figs. 6a and 6b. Transpiration trends observed in tomato plants (Fig. 6a) indicated that significant differences among treatments did exist. Plants in open-plus-drip treatment had the highest T value (10.1 ug cm^{-2} s^{-1}). The tomato plants in all other treatments were within the range of 1.4 to 3.7 ug cm^{-2} s^{-1}. Also pepper plants in the open-drip had the highest (12.3 ug cm^{-2} s^{-1}) transpiration values. The other treatments had T values ranging from 3.5 to 11.0 ug cm^{-2} s^{-1}. Concomitantly T rates were inversely related to DR. The lowest LT (40.2 C in drip) corresponds to the highest transpiration rate. Therefore, lower LT appear associated with the cooling effect of transpiration.

Greater differences in T at 66 DATP were observed among pepper plants than among tomato plants (Figs. 6a and 6b). Transpiration rates in horizontal-plus-drip and covered mulch treatments had the highest values: 10.7 and 12.3 ug cm^{-2} s^{-1}, respectively. However, plants in the vertical, open and control treatments had transpiration rates of 5.8, 4.1 and 3.1 ug cm^{-2} s^{-1}, respectively. By this time the soil water content (Fig. 14) was below the wilting point in all treatments except the horizontal-plus-drip treatment, which



a.



b.

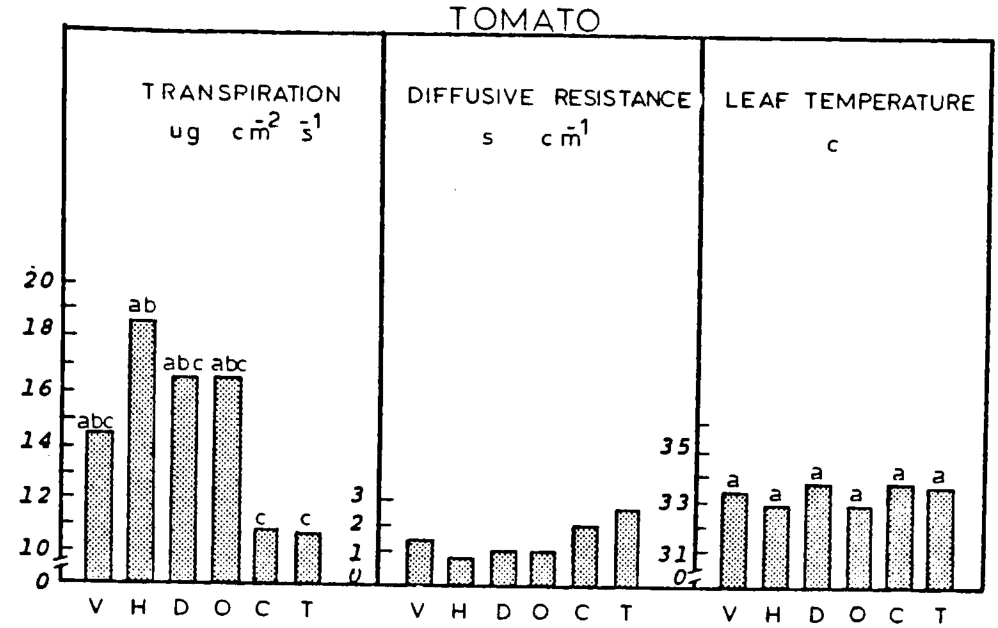
Fig. 6. Transpiration, diffusive resistance, and leaf temperature in plants at 66 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

maintained a water level above FC. It is interesting to note that the water applied through the drip system 63 DATP, and the first rain of the season (14 mm) at 65 DATP reduced the rate of evaporation in treatments HPD at 66 DATP. Hence, soil moisture in this treatment remained above field capacity at 66 DATP.

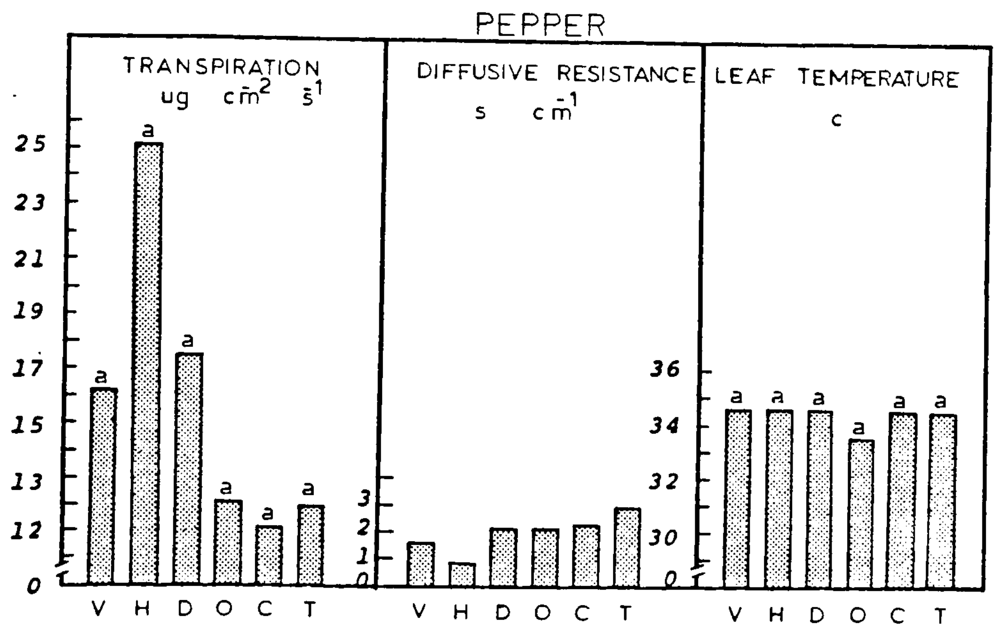
Diffusive resistance highly controlled the rate of transpiration in pepper plants (Fig. 6b). High DR values resulted in lower T rates and vice versa. Also, LT values followed the trend found in tomato plants: plants with higher T rates had the lowest leaf temperatures. Plants in the horizontal-plus-drip, vertical, and covered treatments consistently had temperatures 2 C lower than plants in the other treatments.

The physiological parameters measured were correlated. All parameters demonstrated significant correlations; for example, LT was negatively correlated (-.91) with T (Table 4). Oh the other hand, LT was positively correlated to DR (.81). Again, this trend indicated that LT was dependent on T and DR.

Data collected 103 DATP (August 20) and 126 DATP (September 12) in tomato plants are shown in Figs. 7a and 8a, respectively. Significant differences in T rates among treatments were found on both dates. The treatments with the highest T values at 103 DATP were: horizontal-plus-drip,

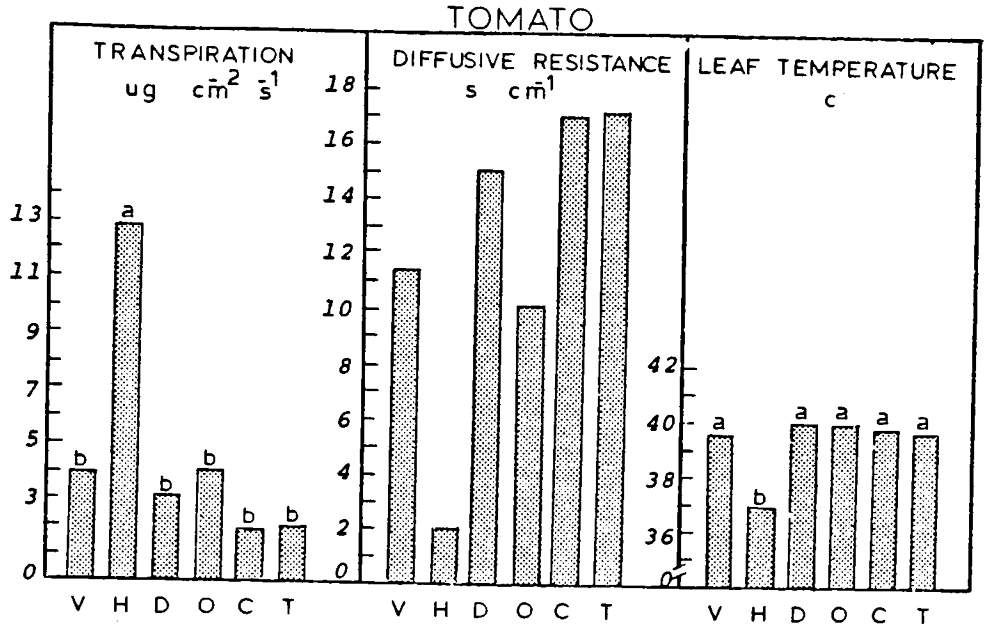


a.

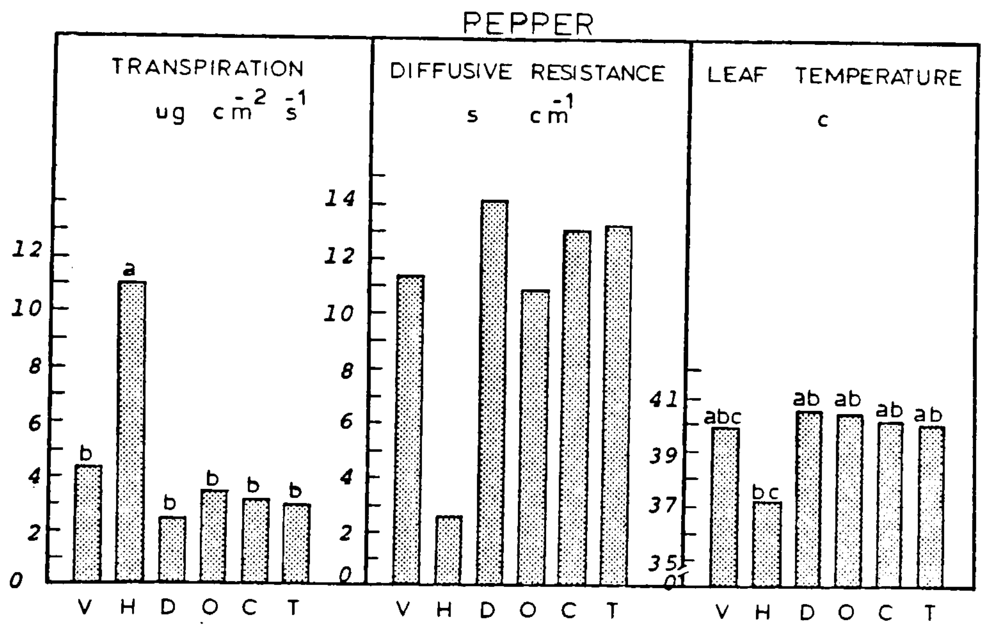


b.

Fig. 7. Transpiration, diffusive resistance, and leaf temperature in plants at 103 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.



a.



b.

Fig. 8. Transpiration, diffusive resistance, and leaf temperature in plants at 126 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

open-plus-drip, open, and vertical, their corresponding values were 19.5, 17.6, 17.4 and 15.4 ug cm^{-2} s^{-1} (Fig. 7a), while the covered and control treatments had T values of 11.9 and 11.8 ug cm^{-2} s^{-1}, respectively. Generally, higher soil moisture levels provided more water for transpiration; consequently plants in those treatments had higher T rates. Values of DR 103 DATP were very low, ranging from 1.1 cm^{-1} in the horizontal-plus-drip treatment to 2.7 cm^{-1} in the control. No significant differences in LT were found. The range in LT varied from 33 C in the horizontal-plus-drip to 33.8 C in the covered (Fig. 7a).

An overall increase in DR occurred in tomato plants from 103 to 126 DATP except in the horizontal-plus-drip treatment, which remained basically unchanged. This increase in DR resulted in an overall reduction in T rates. The horizontal-plus-drip treatment had a T value of 12.8 ug cm^{-2} s^{-1}, which was significantly different from the other treatments which were within a range of 2 to 4 ug $cm^{-2}s^{-1}$ (Fig. 8a).

The relationship between soil moisture content and transpiration in the horizontal-plus-drip treatment observed at 103 DATP changed at 126 DATP. Even though T rates were significantly higher in the horizontal-plus-drip, this was not associated with the highest soil-moisture level. A possible explanation for this may be the fact that plants in this treatment were more vigorous and had better developed root systems that made them more efficient in extracting soil moisture.

As soil moisture becomes depleted, soil-water-tension increases, resistance of water movement through the rhizosphere increases, and water absorption tends to lag behind transpiration. This results in reduced leaf-water potential, stomatal conductance, transpirational cooling, and elevated canopy temperatures (7, 21). Even though no significant differences in LT were found in tomato plants 103 DATP, the prolonged stress reduced transpiration and this in turn resulted in an overall increase of 6 C in LT at 126 DATP. However, the significantly higher T rates in treatment horizontal-plus-drip at 126 DATP resulted in a 4 C increase in LT as compared to 6 C in the other treatments (Figs. 7a and 8a).

The relationship between LT and T as well as DR in tomato plants is presented in Table 3. Leaf temperature and transpiration demonstrated highly negative significant correlation, -.72 and -.93 at 103 and 126 DATP, respectively. The values for LT and DR on the same dates were also negatively correlated but at a non-significant level: -.22 and -.72.

Similar general trends were found in pepper plants. As shown in Figures 7b and 8b, an overall increase in DR rates from 103 to 126 DATP was coupled with a decrease in T rates. An overall increase occurred in LT at 126 DATP, with an average increase of 5 C.

An analysis of the data collected from cantaloupe plants at 103 and 126 DAP indicated trends in T, DR and LT similar to those obtained from the pepper plants on the same dates. Transpiration values among treatments were significantly different at 103 DAP (Fig. 9); however, due to an overall increase in DR at 126 DAP (Fig. 10), T rates were greatly reduced. This resulted in no significant differences among treatments for T rates. The reduction in transpiration rate resulted in an overall increase in leaf temperature among treatments at 126 DAP, with an average increase value of 5 C.

The last two sets of porometric measurements in tomato, pepper, and cantaloupe were taken at 138 and 159 DATP. All of the measurements at 138 DATP were greatly influenced by the flood irrigation which was applied 133 DATP (Fig. 14). As shown in Figure 11a, the higher availability of soil water resulted in an overall increase in transpiration in tomato plants, with an average T value of 18 ug $cm^{-2}s^{-1}$, as compared with an average of 4.5 ug $cm^{-2}s^{-1}$ at 126 DATP (before irrigation). The absence of differences in T rates at 138 DATP is attributed to the high soil moisture availability in all treatments. In a similar manner, T rates

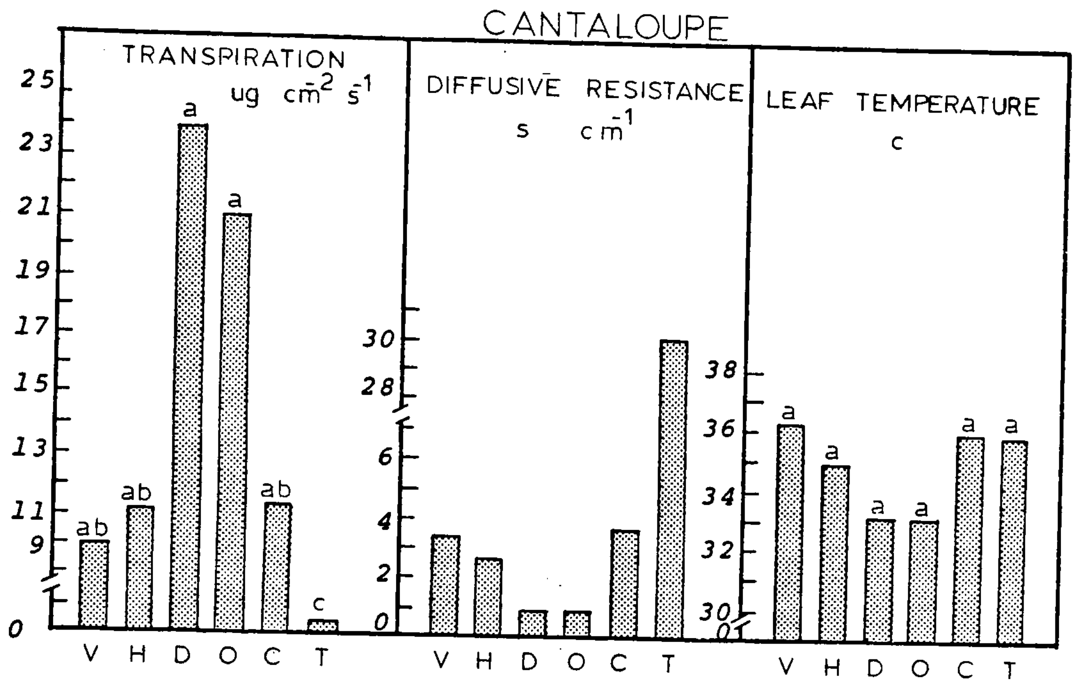


Fig. 9. Transpiration, diffusive resistance, and leaf temperature in cantaloupe plants at 103 DAP. -- Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

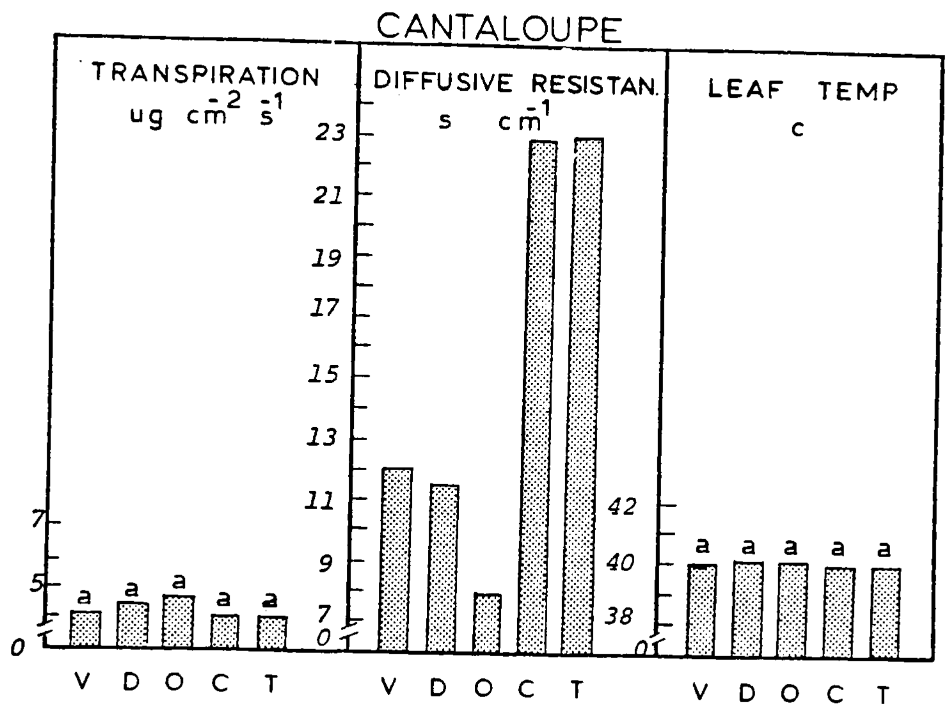
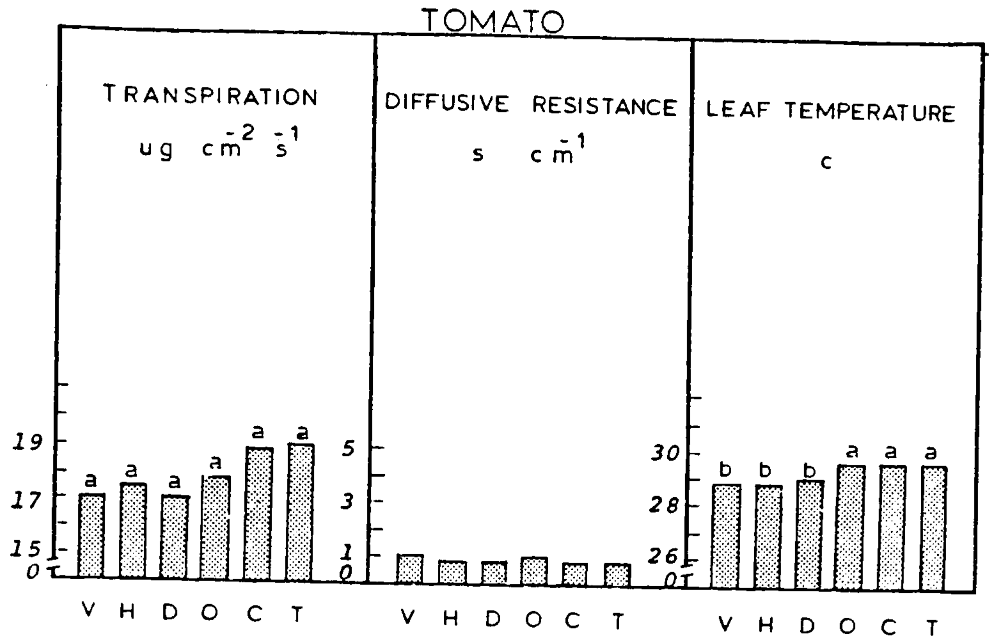
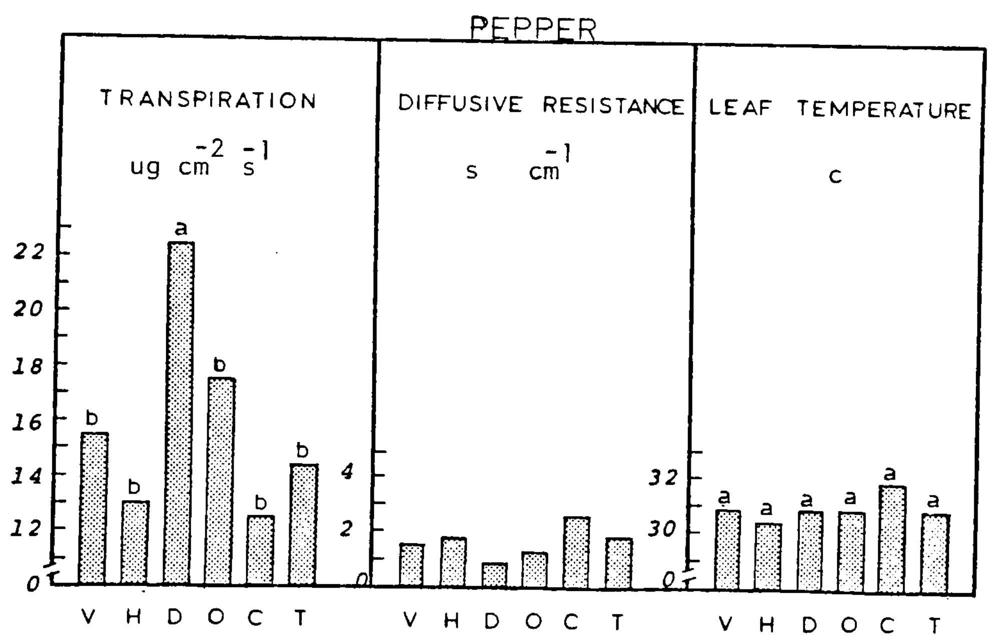


Fig. 10. Temperature, diffusive resistance and leaf temperature in cantaloupe plants at 120 DAP. -- Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.



a.



b.

Fig. 11. Transpiration, diffusive resistance, and leaf temperature in plants at 138 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP)open; C (CO) covered; and T (CT) control.

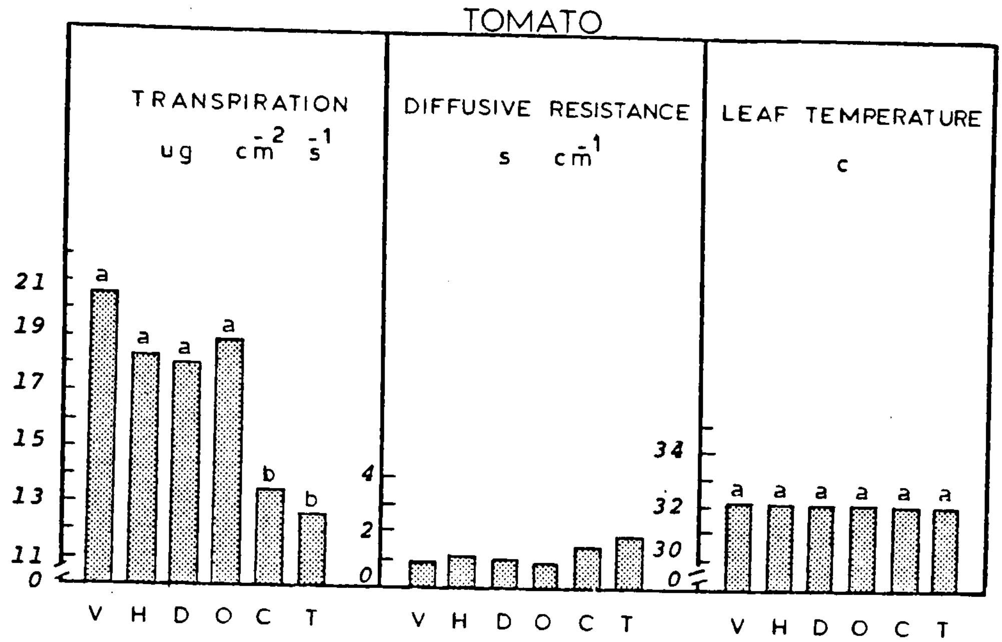
of the pepper plants increased from 126 to 138 DATP (Figs. 8b, 11b). These figures also indicate an overall reduction of 10 C in leaf temperature for both plant species. The reduction in temperature was significantly correlated with diffusive resistance (.83) in tomato and pepper plants (Tables 3 and 4). No porometric data were collected on cantaloupe plants at 138 DAP.

The last set of T, DR and LT measurements obtained from tomato, pepper, and cantaloupe plants at 159 DATP is shown in Figures 12a, 12b, and 13, respectively. These observations were greatly influenced by the 190 mm rainfall which occurred between 143 and 147 DATP. In spite of the significant differences among treatments (Fig. 12a), transpiration rates in tomato plants at 159 DATP remained similar to the values obtained at 138 DATP (Fig. 11a). A similar pattern was observed for pepper plants (Figs. 11b and 12b).

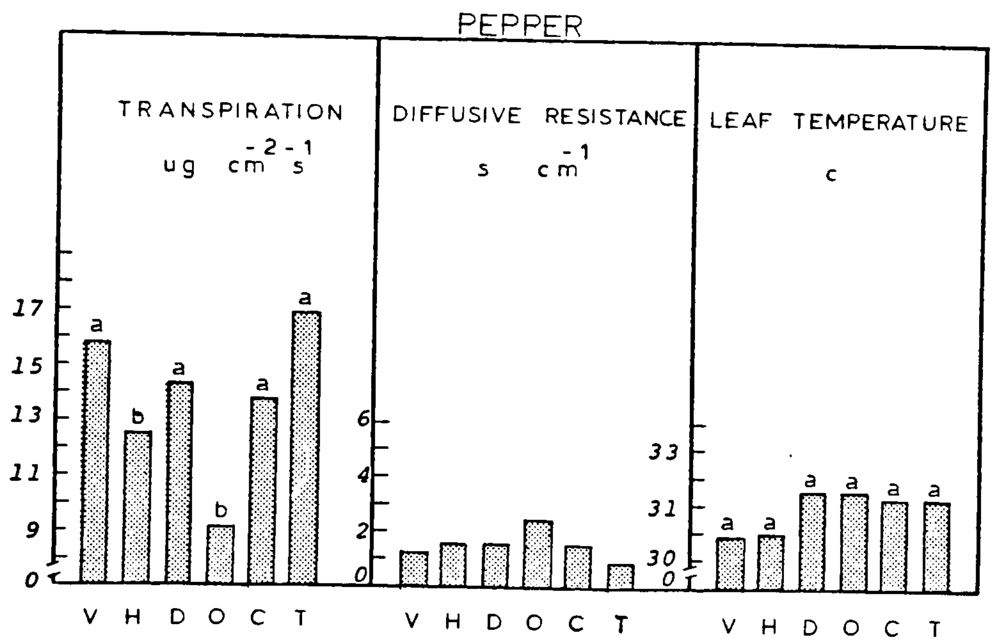
Cantaloupe plants also showed significant differences in transpiration rates at 159 DATP (Fig. 13). The trends observed 11 days after the rain indicated that the mulch was effective in retaining soil moisture (Fig. 14), and this in turn caused differences in transpiration rates.

Soil Moisture

The soil phase in which this study was conducted corresponds to Agua fine sandy loam, which is classified as



a.



b.

Fig. 12. Transpiration, diffusive resistance, and leaf temperature in plants at 159 DATP. -- (a) Tomato; and (b) Pepper. Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

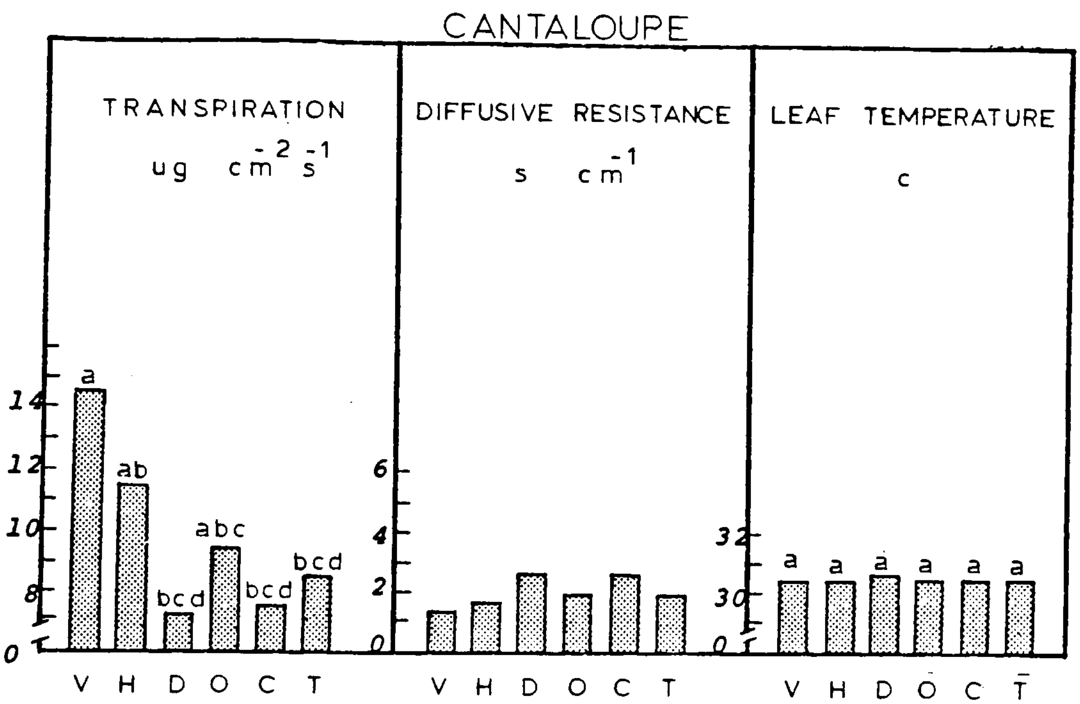


Fig. 13. Transpiration, diffusive resistance and leaf temperature in cantaloupe plants at 159 DAP. -- Key for treatments: V (VE) vertical; H (HPD) horizontal-plus-drip; D (OPD) open-plus-drip; O (OP) open; C (CO) covered; and T (CT) control.

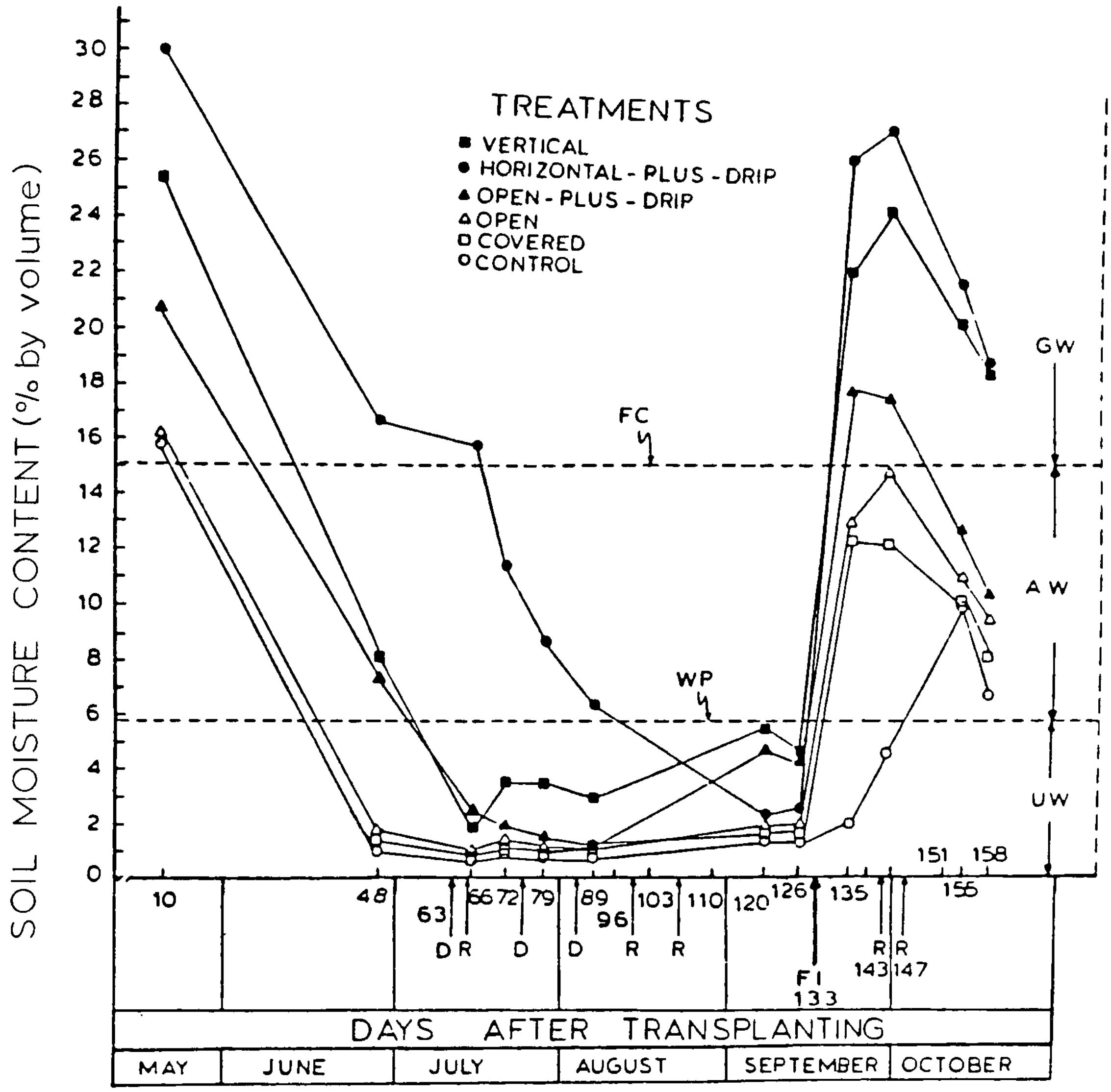


Fig. 14. Soil moisture content at 30 cm (% by volume) for different mulch treatments. -- Dates for drip irrigation (D), flood irrigation (Fl), rainfall (R), levels of moisture at field capacity (FC), wilting point (WP), available water (AW), gravitational water (GW), and unavailable water (UW).

being coarse-loamy over sandy, mixed (calcareous) thermic typic torrifluent.

The texture in the surface 30-cm layer is fine sandy loam (clay 12%, silt 29% and sand 59%). Below the 30-cm depth, this soil is described as being stratified coarse sand and gravelly sand. The percentage of water at field capacity (FC) and permanent wilting point (WP) is 15.3% and 5.9%, respectively.

The presence of the coarse sand and gravel below the first 30 cm of soil becomes a great disadvantage for dry-land farming since these materials hold less water than the fine sandy loam layer on the surface. Therefore, the water storage capacity of this soil is very limited. In this particular type of soil, when the advancing water front encounters coarse materials, the downward movement of water will stop until the upper layer of soil becomes nearly saturated. Hence, the soil overlying a coarse sand or gravel subsoil must become very wet before water will move down through the large pores of the subsoil (19). In this way, the overlying soil can hold up to two and three times as much as it would if the coarse subsoil were not present. However, under the high evaporative demand during the hot summer months, water losses due to evaporation are very high and the water stored in the first foot of soil is soon depleted.

Given the soil characteristics described above for the experimental site, it is reasonable to say that the mulch treatments tested were subjected to high levels of water stress. This allowed the development of a suitable environment to study the effects of mulching in retaining soil moisture and measuring its effects on plant growth and development.

Soil water content at planting time (3 days after the first flood irrigation) was essentially uniform for all treatments since the field was flood irrigated with approximately 8 to 10 cm of water. The first neutron probe (NP) readings were taken on May 18, which was 10 days after transplanting (DATP). These readings were used to develop the calibration curve that relates the soil moisture content determined by the gravimetric method with the NP readings obtained in the field. Therefore, these data will be considered as the first set of soil water measurements.

The amount of water expressed as percentage by volume stored in the soil through time is shown in Fig. 14. It is evident that differences in soil water content among mulch treatments existed by May 18 (10 DAP). These variations are assumed due to the mulch acting as a barrier, reducing water evaporation from the soil. This assumption seems reasonable since the factors (air temperature, relative humidity, precipitation, radiation, wind) involved in evapotranspiration were acting uniformly on all treatments. This includes plant water extraction since the growth stage within each treatment was the same and plant-water-stress had not developed.

It is important to recognize that the data obtained on different dates are the result of the combination of the prevailing environmental conditions which occurred during the time each set of data were collected. Therefore, plant-soil relationships may be altered in different ways, making it necessary to analyze and interpret each set of data according to the environmental conditions under which the data were collected.

Soil moisture was depleted at different rates for the different mulch treatments. As can be seen in Fig. 14, soil moisture differences among treatments are evident at 10 DATP. The soil in the horizontal-plus-drip mulch treatment had 30% moisture which is above FC. This water is held at a potential greater than -1/3 bar (15.3% moisture), and it will drain freely from the soil by the force of gravity within a 2 to 3 day period. However, water levels 10 DATP were still above FC, which indicates a very slow downward movement of water due to the presence of coarse materials below the 30 cm soil surface layer (Fig. 14). All treatments retained less water than the horizontal-plus-drip, especially the open, covered, and control which by this date had already reached field capacity.

In interpreting the soil moisture data obtained 10 DATP, it can be said that the manner in which the mulch was arranged for each treatment showed its effectiveness for moisture conservation, since no other external source of moisture (i.e., rain) influenced the treatments. One of the most noticeable effects occurred in the covered-mulch treatment, in which soil water was lost at the same rate as the open-mulch in spite of the layer of soil layed on top of the mulch. This is believed due to differences in soil and mulch temperatures and spectral reflectance which had an effect on the evaporation rate of the covered-mulch.

This interpretation is supported by temperature data collected 48 DAP. A TM 8-band radiometer (30) was used to measure temperature in band 8 or Far-Infrared with a wavelength range of 10.4 to 12.5 um. This instrument is widely used in remote sensing studies related to crop, soil, and water temperatures, as well as solar spectral reflectance (31).

The results obtained from soil and mulch temperatures, and reflectance measurements are shown in Table 6. Soil surface temperatures varied from 63.3 C for the soil on top of the mulch (covered-mulch) to 60.4 C for the soil surface in the control. On the other hand, the mulch temperatures were 51.7 C and 53.7 C in the horizontal-plus-drip and open-mulch treatments, respectively. Hence, the average

Table 6. Spectral reflectance in four wavelength ranges, and temperature of soil and mulch taken with the Tm 8-band radiometer 38 days after planting.

Material	Percentage of Spectral Reflectance				
	Band 1, blue (.45-.52 m)	Band 2, green (.52-.60 m)	Band 3, red (.63-.69 m)	Band 4, infrared (.76-.90 m)	Temperature C (10.4-12.5 m)
Dry soil in covered mulch treatment	14.28	17.71	23.02	28.14	63.3
Dry soil in control treatment	13.82	17.63	23.23	28.55	60.4
Mulch in horizontal plus drip treatment	25.72	35.52	49.19	63.09	51.7
Mulch in open treatment	24.27	35.06	50.49	64.56	53.7

temperature of the straw mulch on the surface was 9.1 C lower than that of the plots with soil on the surface.

The reflectance values for the soil-covered plots were approximately half that of the reflectance values recorded for the mulch-covered plots. Therefore, an inverse relationship between reflectance and temperature was established: the lower the reflectance, the higher the temperature. This was due to more solar energy being absorbed and transmitted down into the soil as compared to that of the mulch. Coefficients of simple correlation for reflectance and temperature in mulch and soil surfaces were -.97 and -.90, respectively. The reduced availability of energy and lower surface temperature combined to reduce evaporation rates in plots which were covered with the organic mulch.

Similar results have been obtained when the surface albedo is altered (41). It has been determined that the surface albedo, which is the ratio of the amount of radiation reflected by a body to the amount indicent on it, is a fundamental surface property that can be modified easily by simple surface treatments. For instance, Stanhill (54) applied a surface dressing of magnesium carbonate (white powder) and increased albedo by 100%, thereby doubling the short-wave reflection and approximately halving the solar input. The temperature in the treated plot was reduced 5 C (from 33 to 28 C) below that of the control.

The combination of factors mentioned above might have caused a strong temperature gradient, providing enough heat to be transmitted through the layer of soil to the underlying mulch and therefore causing the water to evaporate at a rate similar to the open and control treatments. This fact imposes a disadvantage for the covered-mulch. It is unfortunate that soil temperatures above and beneath the mulch in the covered-mulch treatment were not measured. More extensive research is needed to determine the radiation budget, and how it is affected by different soil and mulch arrangements.

The second soil moisture measurements were made 48 DATP. The same trend in soil moisture changes among treatments was found. Using the same soil moisture percentages for FC and WP as shown in Fig. 14, it can be observed that the moisture levels dropped considerably between 10 and 48 DATP.

Plant-available water is the portion of stored soil water that can be absorbed fast enough by plant root to sustain plant growth. It is defined as the weight percentage of total soil moisture held with a water potential between -.3 and -15 bars (5, 16). However, conflicting views are found in the literature regarding the limits for available soil water: one view holds that soil moisture is equally available over the whole range from FC to WP, while the opposing view contends that plant growth is adversely affected as soon as the soil moisture stress is increased. beyond a certain level, long before the WP is reached (3). It is now widely agreed that other factors can modify the ability of the plant to use water at different soil moisture levels, for example, soil salinity and environmental conditions such as high temperature, low relative humidity, high wind velocities, and increased light intensities. Each of these factors may cause transpiration rates in excess to water uptake.

The data obtained 48 DATP indicate that the mulch in the horizontal-plus-drip treatment retained the highest moisture level, approximately 17% which is close to FC. The open-plus-drip and vertical treatments had 7 and 8% moisture content, respectively. These two treatments kept moisture levels within the range of available water. On the other hand, the open, covered, and control had reached a level below the WP and had approximately 3% moisture. There are indications in the literature that certain plants are capable of depleting water from the soil to levels much lower than the WP. For instance, wheat plants with well-developed root systems were capable of absorbing water at tensions greater than -26 bars (18, 26, 53).

It is assumed that plants that can extract soil moisture below WP absorb water at levels that do not allow them to maintain high vegetative growth rates. This in turn adversely affects their yield and fruit quality (3).

Some plants, when placed under high water stress, can reduce their physiological processes to a survival level for periods of several weeks and then can recover after irrigation or rainfall provides more favorable conditions to reinitiate growth. Consequently, in considering the amount of water available to plants in arid conditions, the WP may be of little significance as the lower limit of soil moisture. The results obtained in this study support this view, since plants in most of the treatments grew for a period of 8 to 10 weeks under soil moisture contents well below the conventional WP level (Fig. 14). Therefore, the lowest limit of availability will depend on the species involved and on the prevailing conditions.

The third soil moisture readings were taken 66 DATP (Fig. 14). The soil moisture content for all treatments except the horizontal-plus-drip were considerably below the WP. No rain fell at the experimental site through this 2-month period (Fig. 2), hence plant water stress started to to develop, making it necessary to apply supplemental water through the drip system previously installed under the horizontal-plus-drip mulch and open-plus-drip treatments. Water was applied using an average of 3 liters per plant. It is important to emphasize that water was applied 3 days before the third soil moisture readings were recorded. However, two days after the drip irrigation took place, the first rainfall of the season (14 mm) occurred. In this way, the soil-water content for the horizontal-plus-drip and open-plus-drip treatments, at this particular date, include the water applied through the drip system plus the 14 mm of water from rainfall.

As might be expected, the horizontal-plus-drip treatment, which covers the entire soil surface, suppressed water losses more effectively than the other treatments. This efficiency is primarily due to the mulch acting as a barrier to reduce evaporation, and to a much lesser degree to the water applied through the drip system, since this supplemental water did not increase soil moisture content appreciably and differences among treatments remained basically unchanged from 48 to 66 DAP.

The full ground coverage of the horizontal-plus-drip mulch prevented evaporation more effectively than did the open-plus-drip treatment that received the same water input. On the other hand, the open, covered, and control treatments had the lowest soil moisture content. The vertical mulch treatment was intermediate in its water content due to a faster infiltration rate of rain water into the trenches containing the mulch.

The 4th, 5th and 6th soil moisture readings were taken at one-week intervals; these were 72, 79, and 89 DATP, respectively. The moisture content in the horizontal-plus-drip treatment decreased from about 11% on July 20 (72 DATP) to 6% on August 6 (89 DATP). This was the first time that the water content in this treatment approached the WP. The water status for the other treatments remained essentially unchanged. The drip system was used to provide water twice, at 76 and 86 DATP, for the horizontal-plus-drip and open-plus-drip treatments. The amount of water applied was approximately 6 liters per plant.

It is important to emphasize that by this time the evaporative demand was extremely high (mean maximum and minimum temperatures during July were 40 C and 21 C, respectively). This made the use of the drip system a high priority in order to maintain plant physiological processes at a minimum level since water stress was high. The mulch treatments can only reduce evaporation, not prevent it entirely.

There was an interruption in soil moisture recordings due to failure of the NP from 89 to 126 DATP. Hence, the 7th readings were recorded on September 7, which was 120 DATP. At this time, the moisture level of all treatments was below WP. The treatments with the highest moisture content were the vertical and the open-plus-drip (Fig. 14). One possible explanation for this is that 15 days before the readings were taken, a 30 mm rain infiltrated into the trench in the vertical treatment faster than in the other treatments. This was the first time that the water content in the horizontal-plus-drip treatment reached a level below WP. A contributing factor was the high transpiration rates of plants in this treatment (Figs. 7a, 7b, 8a, 8b). Plants in this treatment were more vigorous than in the other treatments. On the other hand, soil water content remained basically unchanged for the last 10 weeks for the covered, open-plus-drip and control treatments. By September 12 (126 DATP) the soil moisture in all treatments was essentially the same as it was at 120 DATP, consequently plant water-stress was at its highest level of the season.

Normally by this date some short summer rain storms would help to reduce plant water stress; however, in the summer of 1983 rainfall distribution was not favorable for plant growth (Fig. 2). In order to keep the plants alive, a flood irrigation of 6 to 8 cm was applied on September 19 (133 DATP) over the entire test site. This was the first time the experiment was flood irrigated since the flood irrigation applied for plant establishment.

The effect of the irrigation was measured two days later, as can be observed in Fig. 14 for September 21 (135 DATP). The soil moisture content increased steeply for all treatments except the control, which increased gradually. These data show a differential response to water uptake for the mulch treatments studied. For instance, the horizontal-plus-drip and vertical mulched plots attained moisture levels of 27 and 22%, respectively, while the open-plus-drip had approximately 18%. The other group of treatments included the open and covered, which had a soil moisture content between FC and WP. The exception to this trend was the control treatment, which had a moisture level below the WP. It was concluded that this was due to water runoff and a low infiltration rate. Runoff was prevented more effectively by the presence of mulch, especially in the horizontal-plus-drip treatment.

It is difficult to assess the effectiveness of the flood irrigation as the single factor responsible for the increase in soil water content and subsequent plant recovery. A possible explanation is that approximately 10 days after irrigation took place (143 DATP), a rainstorm dropped 190 mm during a 4-day period. Therefore, this precipitation masked the medium and long-term effect of the irrigation.

Finally, as shown in Fig. 14, the heavy storm (approximately 45% of the total summer rainfall) resulted in a high soil moisture level by September 30 (145 DATP). The last two sets of moisture readings at 155 and 158 DATP (October 12 and 15) indicated two general trends with steady decrease in moisture: first, the horizontal-plus-drip and vertical treatments formed a group which had 27 and 25%

moisture, respectively. These levels were above FC. Secondly, the open-plus-drip, open covered and control formed another group with 10, 9, 8 and 7% moisture, respectively. These levels were within the range of available water.

Plant Water Stress

The first measurements of leaf water potential (ψ_L), osmotic potential (ψ_π), and turgor pressure (ψ_P) were obtained 89 DATP (August 6). The values obtained from the tomato plants are presented in a sequential basis in Figs. 15 and Tables 7, 8, 9, 10, and 11. The trends observed indicated differences in ψ_L among treatments; for example, at 89 DATP the treatment with the highest water content or the least negative ψ_L value was the open-plus-drip (OPD) with -8.2 bars, followed by open (OP), horizontal-plus-drip (HPD), control (CT), vertical (VE), and covered (CO), with -9.6, -13.0, -14.0, -14.3, and -15.8 bars, respectively. According th Hsiao's classification of plant water stress (29), plants are midely stressed when tissue ψ_L is reduced by several bars, moderately stressed when tissue ψ_L is reduced by more than a few bars but less than 12 to 15 bars, and severely stressed when tissue ψ_L is reduced by more than 15 bars. Therefore, it can be concluded that plants in treatments OPD and OP were mildly stressed as compared to plants in the other treatments, which in turn were under moderate stress.

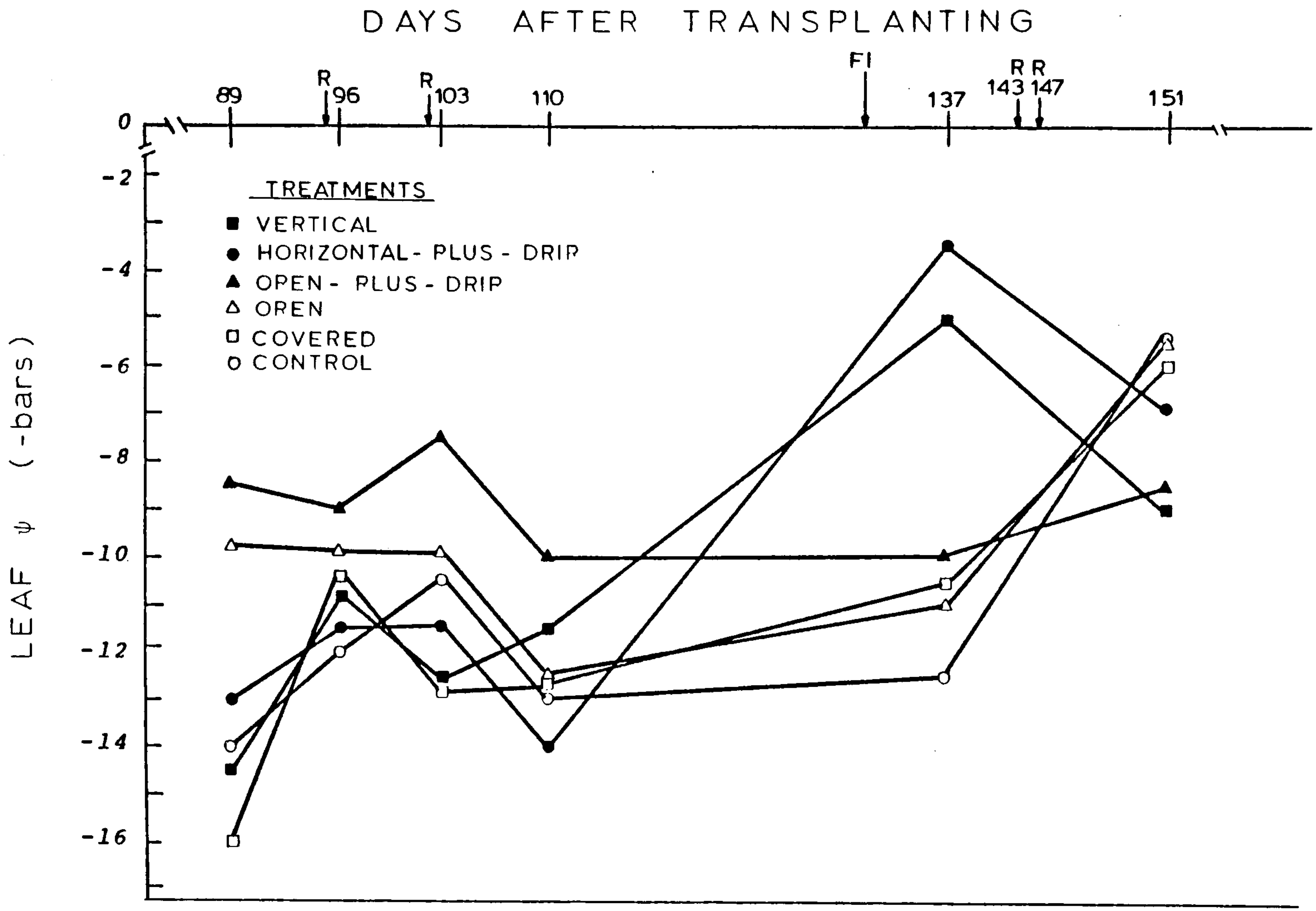


Fig. 15. Leaf water potential for tomato plants under different mulch treatments. -- Tucson, summer 1983.

Table 7. Leaf potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of tomato plants under different mulch treatments at 89 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	14.3	14.4	-0.1
Horizontal-plus-drip	13.0	13.1	0.1
Open-plus-drip	8.2	10.0	1.8
Open	9.6	9.8	0.2
Covered	15.8	15.8	0
Control	14.0	13.8	-0.2

Table 8. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressure (ψ_P) of tomato plants under different mulch treatments at 96 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	10.6	9.9	-0.7
Horizontal-plus-drip	11.3	11.4	0.1
Open-plus-drip	8.9	9.0	0.1
Open	9.5	10.0	0.5
Covered	10.3	12.0	1.7
Control	12.0	13.1	1.1

Table 9. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of tomato plants under different mulch treatments at 103 DATP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	12.2	11.4	-0.8
Horizontal-plus-drip	11.5	11.8	0.3
Open-plus-drip	7.5	7.3	0.2
Open	9.8	9.5	-0.3
Covered	12.6	14.1	1.5
Control	9.7	8.9	-0.8

Table 10. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of tomato plants under different mulch treatments at 110 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	11.4	11.1	-0.3
Horizontal-plus-drip	14.9	15.0	0.1
Open-plus-drip	9.5	10.4	0.9
Open	12.0	12.2	0.2
Covered	11.7	11.9	0.2
Control	11.8	11.9	0.2

Table 11. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of tomato plants under different mulch treatments at 137 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	4.8	10.8	6.0
Horizontal-plus-drip	3.7	8.0	4.3
Open-plus-drip	10.2	11.6	1.4
Open	10.9	11.3	0.4
Covered	10.4	11.8	1.4
Control	10.9	11.0	0.1

Changes in ψ_L are concomitant with changes in the component potential of ψ_π and ψ_P. A decrease in any one of these potentials is accompanied by a concurrent decrease in all the others. Because of cell turgidity, the absolute changes in ψ_π are of lower magnitude than the changes in ψ_L or ψ_P, but the relationship is not necessarily linear, nor the same for tissues of a different history (62). As a result of these relationships, any process correlated with ψ_L will also be correlated with ψ_π and ψ_P, although the regression coefficients may differ.

The response of the ψ_L components at 89 DATP is shown in Table 8. The observed values indicated that a reduction in ψ_L was accompanied by a reduction in ψ_π. It can also be observed that the highest ψ_P value (1.8) was associated with the highest ψ_L(-8.2) in the OPD treatment. In cells, ψ_P is positive or zero; hence the slight negetiave values of ψ_P shown in Table 7 are due to errors in measuring the plant water status and/or possible psychrometer contamination.

Differences in ψ_L among treatments in tomato plants at 96 DATP were of lower magnitude than those observed at 89 DATP. The observed trend (Fig. 15) indicates an overall increase in ψ_L. Values in treatments OPD and OP remained unchanged (-8.9 and -9.5 bars, respectively), but all the other treatments approached levels of moderate stress between -10.3 and -12.0 bars. As shown in Table 9, an overall increase in ψ_π and ψ_P was observed between 89 and 96 DATP. The increase in ψ_L and its components was due to a slight increase in soil water content caused by a 30-mm rain 93 DATP.

Psychrometric readings at 103 DATP indicated that treatments OPD and OP still had the highest ψ_L, and as shown in Fig. 15, the other treatments changed only 1 or 2 bars from the readings observed at 96 DATP. Values of ψ_π and ψ_P for 103 DATP are shown in Table 9. It can be observed that treatments VE, HPD and CO reduced their ψ_π values as compared to those observed 96 DATP. On the other hand, ψ_π values were actually higher in treatments OPD, OP and CT. This indicates that plants in the control treatment were able to temporarily use the rain water in a very efficient way. Changes in ψ_P also occurred, with an overall tendency for lower values at 103 DATP.

Differences in ψ_L among treatments were evident at 110 DATP. It is interesting to note that treatment OPD still had plants with the highest ψ_L (-9.5 bars) followed by treatment VE (-11.4 bars), which more effectively increased its soil-water content (Fig. 14) after the rainfall received 100 DATP. It is also interesting to note that the treatments with the highest soil water content had plants with the highest ψ_L (Figs. 14 and 15, and Table 10). However, there is one exception in which the treatment HPD has high soil moisture but at the same time it has the lowest ψ_L (-14.9

bars). This could be attributed to the higher transpiration rates in this treatment and therefore the faster soil-water depletion rates, as shown in Fig. 14.

The field was flood irrigated at 133 DATP due to severe plant water stress. Four days later (137 DATP), the greatest increase in ψ_L was recorded in treatments HPD (-3.7 bars) and VE (-4.8 bars), which in turn had the highest values of ψ_π and ψ_P, as can be observed in Table 12. The other treatments remained basically unchanged as compared to values obtained 110 DATP. The main conclusion that can be drawn from the readings obtained after irrigation is that the differences in ψ_L and its components were highly associated with differences in soil moisture content as a result of the mulch treatments. As observed in Figs. 14 and 15, all the treatments that had the highest soil moisture contents also had the highest values of ψ_L.

The last psychrometric measurements in the tomato plants were made 151 DATP. The results shown in Fig. 15 were mainly influenced by the occurrence of a rain storm that supplied an additional 190 mm of water five days before the ψ_L measurements were taken. The trends observed indicated two general patterns. First, it is observed that ψ_L in treatments HPD and VE at 151 DATP became lower than those at 137 DATP. Second, treatments OPD, OP, CO and CT attained greater ψ_L values as compared to those at 137 DATP. This lack of a well defined pattern in ψ_L is certainly associated with the pattern of soil moisture content shown in Fig. 14. Hence, a logical explanation for the patterns observed in ψ_L is that the soil in treatments HPD and VE was completely saturated, while the soil water content in the other treatments was between field capacity and wilting point. This created greater differences in ψ_L and its components at 137 DATP. However, at 151 DATP all treatments tended to have similar ψ_L values. It is interesting to note that treatments CO, OP and CT, which had the lowest ψ_L values at 137 DATP (-10.4, -10.9 and -10.9 bars, respectively) gradually acquired higher ψ_L values at 151 DATP: -5.9, -5.4 and -5.3 bars, respectively.

Values of leaf water potential and its components in the pepper plants are shown in Fig. 16 and Tables 12, 13, 14, 15, and 16. The results presented do not include data for plants in the control treatments, since the survival rate for this treatment was zero. Measurements of ψ_L indicated that by 89 DATP, the treatments with higher soil moisture content, VE and HPD (Fig. 14) resulted in slightly higher ψ_L values as compared to the other treatments. However, at 96 DATP (Table 13), all treatments had acquired higher ψ_L and ψ_π except treatment VE, which was severely stressed (-17.1 bars). The reason for this increase in ψ_L was an increase

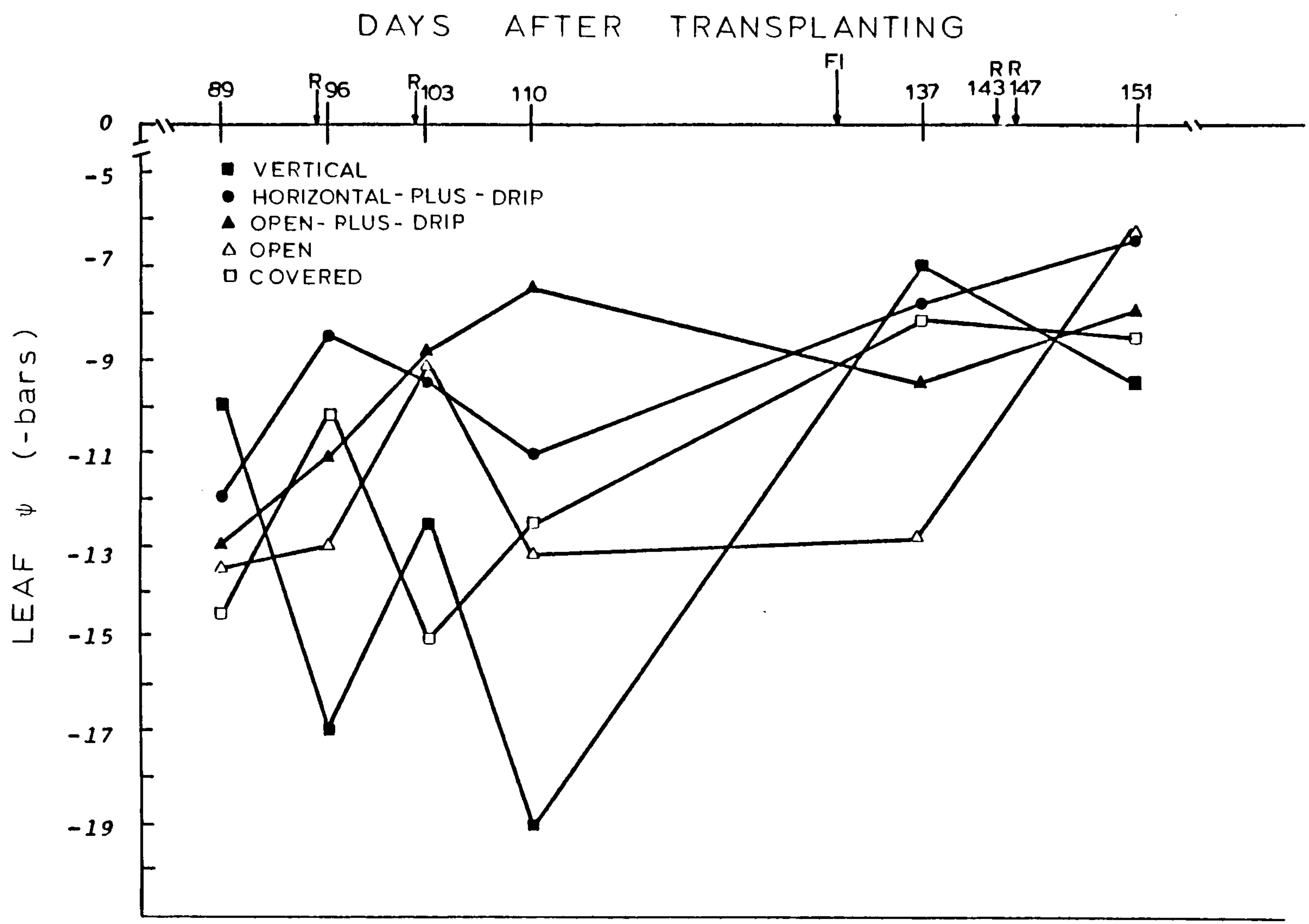


Fig. 16. Leaf water potential for pepper plants under different mulch treatments. -- Tucson, Summer 1983.

Table 12. Leaf potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of pepper plants under different mulch treatments at 89 DATP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	9.7	9.9	0.2
Horizontal-plus-drip	12.4	12.6	0.2
Open-plus-drip	13.4	13.8	0.4
Open	14.5	14.6	0.1
Covered	14.4	16.2	1.8
Control*	-	-	-

* No plants.

Table 13. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of pepper plants under different mulch treatments at 96 DATP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	17.1	16.9	-0.2
Horizontal-plus-drip	8.5	8.6	0.1
Open-plus-drip	11.2	11.8	0.6
Open	12.9	13.4	0.5
Covered	9.7	11.3	1.4
Control*	-	-	-

* No plants.

Table 14. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of pepper plants under different mulch treatments at 103 DATP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	12.5	12.7	0.2
Horizontal-plus-drip	9.9	12.3	2.8
Open-plus-drip	8.6	9.6	1.0
Open	9.2	10.4	1.2
Covered	15.1	15.4	0.3
Control*	-	-	-

* No plants.

Table 15. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of pepper plants under different mulch treatments at 110 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	18.9	18.7	-0.2
Horizontal-plus-drip	11.0	13.2	2.2
Open-plus-drip	7.3	7.5	0.2
Open	13.3	14.5	1.2
Covered	12.3	12.1	-0.2
Control*	-	-	-

* No plants.

Table 16. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of pepper plants under different mulch treatments at 138 DATP.

Mulch Treatment	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	7.0	12.8	5.8
Horizontal-plus-drip	8.6	16.5	7.9
Open-plus-drip	9.6	15.3	5.7
Open	12.6	16.8	4.2
Covered	7.4	15.4	8.0
Control	12.2	15.4	3.2

in soil moisture following the 30-mm rain, which occurred at 93 DATP.

Another rain occurred about at 100 DATP. This resulted in an increase in ψ_L for treatments OPD, OP, and VE, with -8.6, -9.2 and -12.5 bars, respectively. However, at 103 DATP (Table 14), treatments HPD and CO tended to have a lower ψ_L value than at 96 DATP. This suggested the existence of differences in soil water depletion among treatments due to differences in plant water extraction capabilities of the plants' root system. It is interesting to note that even though soil water content for all treatments except HPD had been below the wilting point ever since 39 DATP (Fig. 14), plants maintained high ψ_L, ψ_π and ψ_P values (Table 14). On the other hand, at 103 DATP, treatments VE and CO were moderately stressed.

The greatest differences in ψ_L values in pepper plants were found 110 DATP (Fig. 14). These differences were attributed to differential plant growth and root development. For instance, even though the soil moisture trends shown in Fig. 14 indicated that the VE treatment had the highest soil moisture content, this did not result in the highest ψ_L. It was concluded that the small root system developed at that time by plants in the VE treatment did not favor water uptake and consequently ψ_L had the lowest value (-18.9 bars). On the other hand, plants in treatments OPD were more vigorous, this fact, coupled with a soil moisture content similar to the VE, resulted in an increase in leaf water potential (-7.3 bars), as shown in Fig. 16 and Table 15. Intermediate values of ψ_L in the other treatments indicated moderated levels of water stress.

As previously described for tomato plants, water was applied by flood irrigation at 133 DATP. Therefore, measurements of plant water status at 137 DATP were markedly influenced by the increase in soil water content. The data obtained are shown in Fig. 14 and Table 16. As expected, a general increase in ψ_L occurred after irrigation. A substantial increase in ψ_L and its components occurred in plants in treatments VE, HPD and CO, while ψ_L in treatments OP remained unchanged, and decreased in treatment OPD. The lack of a consistent, well-defined relationship between soil water content and ψ_L in the different mulch treatments is the result of differences in water uptake and use by the plants, as well as differences in soil moisture content caused by the various mulch treatments.

The last measurements of plant water status at 154 DATP were taken approximately 5 days after the occurrence of a 190 mm rain storm. The trends observed indicated that the treatments that had the lowest ψ_L at 137 DATP (OPD and OP) tended to increase their ψ_L values by 154 DATP, especially the OP. This suggested a more gradual and better use of the water by the plants grown under these treatments. Treatments VE and CO, by 154 DATP, tended to decrease their ψ_L values as time progressed. On the other hand, treatment HPD was highly efficient through most of the season, showing high soil moisture content (Fig. 14) that caused a high and more stable plant water status (Fig. 16).

The effect of mulching on the water status of cantaloupe plants was also studied. The data obtained are presented in Fig. 17 and Tables 17, 18, 19, 20, and 21.

The greatest differences in ψ_L among treatments were found at 89 days after planting. The trends observed indicated that treatments HPD and OPD had the highest ψ_L values, -5.7 and -9.9 bars, respectively. On the other hand, treatments OP, CT and VE had lower plant water potentials: -13.1, -13.2 and -13.8 bars, respectively. However, the fact that plants in treatments HPD and OPD were more vigorous allowed them to extract and transpire more water; therefore, their ψ_L values at 96 DATP decreased. It is interesting to note that HPD was the only treatment that had moisture content within the range of available water (Fig. 14) at 89 DATP. Plants in the other treatments had lower soil water content but did not attain levels of severe water stress, maintaining their ψ_L values below -14 bars. This suggests some adaptations of cantaloupe plants under restricted water availability.

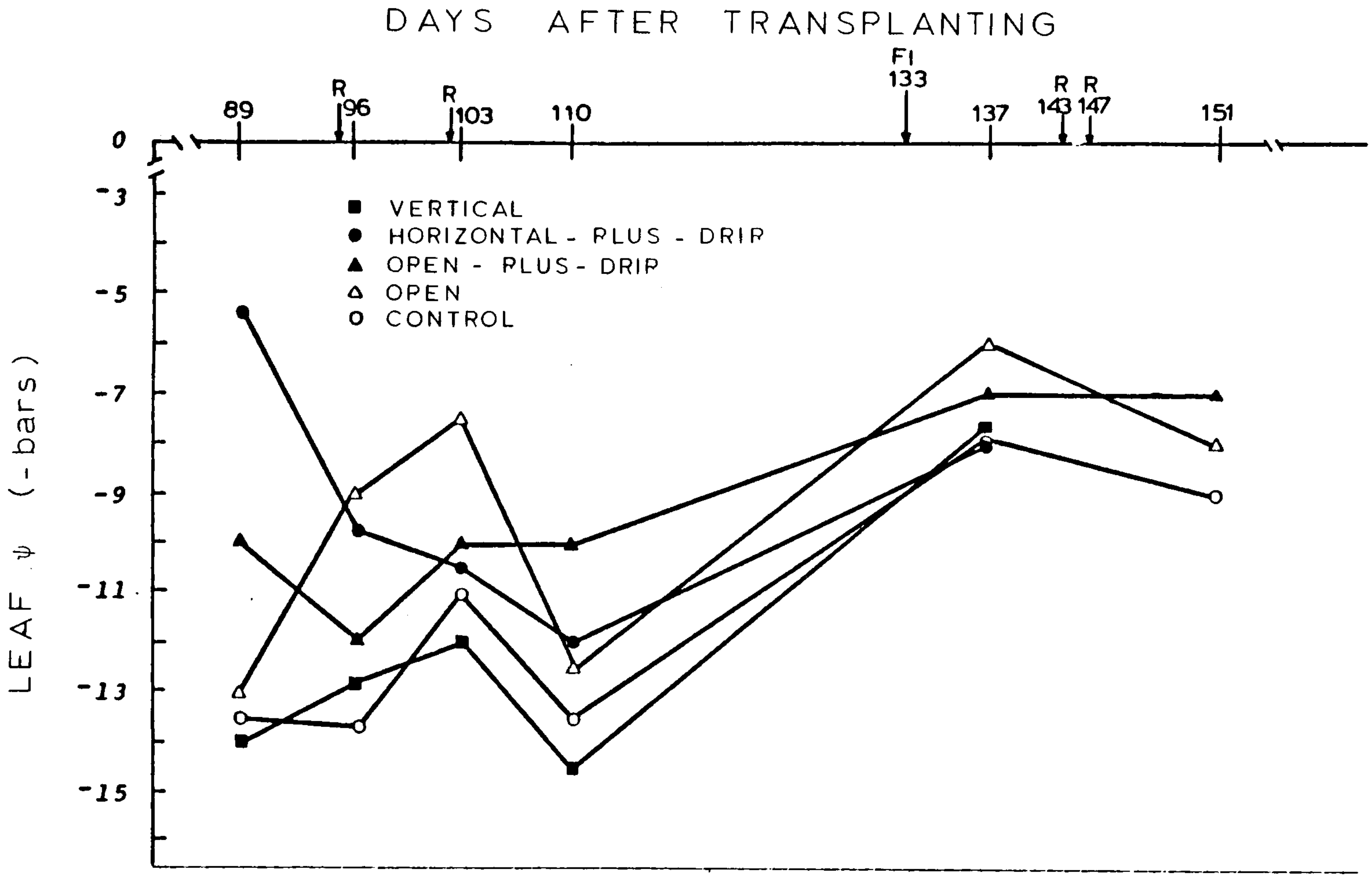


Fig. 17. Leaf water potential for cantaloupe under different mulch treatments. -- Tucson, Summer 1983. *Plants in these treatments were no longer functional due to a severe attack of downy mildew (Pseudoperonospora cubensis).

Table 17. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of cantaloupe plants under different mulch treatments at 89 DAP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	13.8	13.8	0
Horizontal-plus-drip	5.7	5.6	0.1
Open-plus-drip	9.9	10.0	0.1
Open	13.1	13.2	0.1
Control	13.2	12.6	-0.8

Table 18. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of cantaloupe plants under difrerent mulch treatments at 96 DAP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	12.8	12.2	-0.6
Horizontal-plus-drip	9.8	9.9	0.1
Open-plus-drip	12.3	12.5	0.3
Open	8.9	9.9	1.0
Covered*	-	-	-
Control	12.8	12.7	0.1

* No plants.

Table 19. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of cantaloupe plants under different mulch treatments at 103 DAP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	11.8	10.8	-1.0
Horizontal-plus-drip	10.6	11.2	0.6
Open-plus-drip	10.1	10.5	0.4
Open	7.5	7.4	-0.1
Covered*	7.5	7.4	-0.1
Control	8.1	7.7	-0.4

* No plants.

Table 20. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of cantaloupe plants under different mulch treatments at 110 DAP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_ρ	ψ_P
Vertical	14.4	14.1	-0.3
Horizontal-plus-drip	12.2	12.3	0.1
Open-plus-drip	10.4	12.2	1.8
Open	12.6	12.7	0.1
Covered*	-	-	-
Control	13.4	14.4	1.0

* No plants.

Table 21. Leaf water potential (ψ_L), osmotic potential (π), and turgor pressures (ψ_P) of cantaloupe plants under different mulch treatments at 137 DAP.

Mulch Treatments	Values (bars)		
	ψ_L	ψ_π	ψ_P
Vertical	7.3	10.3	3.0
Horizontal-plus-drip	8.5	10.1	1.6
Open-plus-drip	7.6	10.1	2.5
Open	6.3	9.4	3.1
Control	7.6	10.4	2.8

The occurrence of rainfall before 96 and 103 DATP was described in the preceding section for tomato and pepper. This attenuated the plant water stress on these dates. With the exception of treatment HPD, which decreased its ψ_L, the overall tendency in all treatments was to increase ψ_L and ψ_π values on the cantaloupe plants. As explained earlier, the negative values of ψ_P shown in Tables 17, 18, 19 and 20, are an artifact originating from errors and possible contamination in the psychrometers.

The high evaporative demand, coupled with the extremely low soil water content at 110 DATP caused an overall decrease in ψ_L in all treatments but the OPD, which had a ψ_L 2 to 4 bars higher than the other treatments (Table 20 and Fig. 14).

The general tendency of the ψ_L values for treatments VE and CT was to remain lower than those observed for the other mulch treatments from time of plant establishment through 110 DATP. On the other hand, the tendency of the water status of plants in the other treatments for the same period of time fluctuated within a range of 4 to 5 bars. This was influenced by differences in plant water use, as well as differences in environmental conditions pertinent to each day of measurement. For instance, differences in efficiency of storage and usage of rainfall under the different mulching conditions resulted in a differential response to water stress among treatments.

The increase in plant water potential at 137 DATP was caused by the flood irrigation supplied at 133 DATP. As shown in Fig. 14 and Table 21, plants in all treatments increased their ψ_L and ψ_π. It is also important to note that values of ψ_P at this time were the highest throughout the season. Treatments OP and OPD still maintained lower negative values of ψ_L as compared to the other treatments.

As described for the tomato and pepper plants, a rain storm occurred between 143 and 147 DATP. This caused high ambient and soil moisture content, which had a detrimental effect on cantaloupe plants, since these environmental conditions favored a severe attack of Downy mildew fungus (Pseudospora cupeusis). This disease caused severe damage in most of the cantaloupe plants, especially in treatments HPO and VE. For this reason, data from these treatments are not shown at 145 DAP (Fig. 14). Therefore, only treatments OPD, OP, and CT are presented. The results obtained indicated that ψ_L values at 144 DAP followed the same general trend observed throughout the season. Even though small differences in ψ_L existed among treatments, these values are directly associated with the soil moisture content (Fig. 14). For instance, the least negative value of ψ_L is related to the highest soil moisture content (treatment OPD); the same relationship is maintained for treatments OP and CT.

The observed trends in ψ_L, ψ_π and ψ_P indicated distinctive fluctuations that were attributable to the single or combined effects of the following factors: (a) efficiency of the mulch in reducing soil water evaporation, (b) plant soil extraction and use differences among treatments, and (c) differences in soil temperature.

In a similar manner, differences in all the physiological parameters in the different vegetables studied may be associated with the following factors: (a) differential stomatal density and sensitivity to water stress, (b) differential resistance to water uptake and flow within the plant's vascular system, and (c) differences in root size, depth and root-shoot ratio.

Soil Temperature

Soil temperature values at the 12-cm soil depth, from 26 to 149 DATP, are presented in Table 22. Soil temperature differences under the various mulch treatments is important, since the scarcity of water and the high evaporative demand typical of arid and semiarid regions may result in excessive soil temperatures which are detrimental to seed germination and plant growth. Feddes (15), in studying different vegetables, reported that 27 C (80 F) and 25 C (72 F) were the optimum temperatures for melon and tomato plants. Therefore, this temperature range was used as a reference in the current study for comparing soil temperatures among the treatments.

Table 22. Soil temperatures (C) at various dates after planting using different mulching treatments.*

Mulch Treatment	Days after Transplanting (DATP)											
	26	28	52	66	72	79	89	121	126	133	141	149
Vertical	35	38	40	40	38	35	35	33	37	32	27	23
Horizontal plus-drip	20	23	25	26	27	34	25	27	27	31	24	21
Open	33	35	40	41	38	35	36	32	38	32	32	23
Covered	35	34	40	41	37	35	35	32	37	32	34	22
Control	35	37	40	40	37	35	37	32	38	32	32	21

* Soil temperatures measured at a depth of 12 cm.

The observed soil temperatures were highly affected by the presence of mulch in the HPD treatment. No other mulch treatment used in this study had such a dramatic effect in reducing soil temperature. This might be expected since the mulch material in treatment HPD entirely covered the soil surface. The mulch reduced the quantity of direct solar radiation reaching the soil surface. In the other treatments, the mulch covered less than half of the soil surface (treatments OPD and OP), exposing the other half to direct solar radiation. This heated the soil to levels similar to those in the bare soil of the control treatment (Table 22).

The trend observed indicated that at 26, 48, and 52 DATP the soil temperature in treatment HPD was 14.5, 13.7 and 15 C lower than the average temperature for the other treatments, VE, OP, CO and CT (Table 22). A similar trend was found at 66 and 72 DATP. The soil temperature 66 DATP reached the highest value (40-41 C) throughout the entire experimental period in all treatments except for the HPD treatment, which reached only 26 C. It is interesting to note that even during periods of high ambient temperature, for example 72 DATP (Table 23), plants in treatment HPD were under optimum soil temperature (Table 22) as compared to plants in all other treatments, which had temperatures 14 to 15 C higher. Similar results have been obtained by other researchers (36, 40). The magnitude of the differences between treatment HPD and the other treatments was reduced

Table 23. Ambient temperatures (C) associated with the soil temperature data presented in Table 22.

	Days after Transplanting (DATP)											
Temperature	26	48	52	66	72	79	89	121	126	133	141	149
Maximum	32	39	40	40	42	40	38	38	38	37	37	24
Minimum	11	15	16	24	27	22	23	21	21	20	18	15
Average	21.5	27	28	32	34.5	31	30.5	29.5	29.5	28.5	27.5	9.5

to 1 C at 79 DATP. This reduction is attributed to both the increase in temperature in treatment HPD, and the slight reduction in temperature in the other treatments. The factors that triggered this response are associated with a light rain which occurred 79 DATP and to the initiation of a steady reduction in ambient temperature through the remainder of the season (Table 23).

Soil temperature in the HPD mulch treatments averaged 10, 5, and 10 C lower as compared to the other treatments at 89, 121, and 126 DATP. Even though variations in magnitude existed on different dates, still a definite reduction in soil temperature resulted in the HPD treatment as compared to the other treatments. The lack of soil temperature differences among mulch treatments at 133 DATP is attributed to the flood irrigation which increased the soil moisture content (Fig. 14) in all treatments. Therefore, it is concluded that the water applied reduced (except in treatment HPD) and stabilized the fluctuations in soil temperature regardless of the mulch treatment. This occurred because the addition of moisture to an initially dry soil increases its thermal conductivity (physical property of the soil describing its ability to conduct heat by molecular motion). This happens for two reasons: first, coating the soil particles increases the thermal contact between grains. Second, since the soil pore-space is finite the addition of pore water must expel a similar amount of pore air (41). As time progressed, soil water differences became evident due to evapotranspiration. In this way, by 141 DATP, the treatments with the highest soil-water content had the lowest soil temperature. For instance, treatment HPD had approximately 27% moisture and a soil temperature of 24 C. On the other hand, treatments OP, CO, and CT, which had lower soil moisture contents (Fig. 14), had soil temperatures ranging from 32 to 34 C.

As described in the preceding section for plant water status, the occurrence of rainfall 147 DATP had the same effect on soil temperature as the flood irrigation. Soil temperatures were reduced and stabilized within the same range in all treatments. Under saturated soil water conditions, the soil temperature in the horizontal-plus-drip treatment was identical to that of the control (21 C) (see Table 22). Another factor that contributed to the overall reduction in soil temperature was the lower values of ambient temperature at the end of the growing season; for example, maximum and minimum air temperatures were 24 and 15 C, respectively, as compared to 42 and 27 C at 72 DATP in the middle of the growing season (Table 23).

Based upon the results obtained, it was concluded that the presence of mulch on the entire soil surface (treatment HPD) reduced the quantity of direct solar radiation reaching the soil surface. Therefore, not only did it reduce the evaporation losses but it also provided an optimum soil temperature range for plant growth throughout the season. The other mulch treatments had soil temperature values essentially similar to that of the control.

Plant Yield

Total yield of fruit for tomato, pepper and cantaloupe plants is shown in Table 24. Yields are expressed in kg fresh weight/40 m^2 (area of each experimental unit).

The trend observed indicated a clear tendency for higher yields in all vegetables studied in the horizontal-plus-drip treatment (Table 24). For example, the tomato plants in treatment HPD produced 99.6 kg. If this is considered as 100%, then plants in treatments OP, OPD, CO, VE and CT produced 54.5, 52.8, 28.5, 25.7, and 12.1%, respectively, of that in the HPD treatment. Regardless of the water applied through the drip system, no differences in yield were found between the OP and OPD treatments. This evidenced the effectiveness and the potential increase in productivity of the mulch in the OP treatment, even without supplemental water. On the other hand, both treatments VE and CO resulted in relatively low yields. Even though treatment VE had a high soil water infiltration rate, it did not result in higher yields, mainly because the soil lost water readily in the bare soil between the trenches containing the mulch.

Table 24. Total plant yield (kg fresh weight/ 40 m^2) for tomato, pepper and cantaloupe plants under different mulch treatments.

Mulch Treatment	Plant Yield (kg fresh weight/40 m^2)		
	Tomato	Pepper	Cantaloupe
Vertical	25.6	8.7	31.0
Horizontal plus-drip	99.6	45.7	53.8
Open-plus drip	52.6	31.9	29.2
Open	54.3	26.4	--
Covered	28.4	6.8	--
Control	12.1	--	--

It is interesting to note that even under water stress, tomato plants could still produce some fruit. The quantity of the fruit was low compared to the other treatments that had more available water; however, this suggests that tomato plants somehow can adapt to high levels of water stress.

The yield data recorded on pepper plants, shown in Table 25, also indicated that plants in the HPD treatment had the highest yield (45.7 kg). Yield in treatments OPD, OP, VE and CO accounted for 69.8, 57.5, 19.0 and 14.8%, respectively, of that obtained in treatment HPD. No data were collected from the control treatment since none of the pepper plants survived the high water stress.

In a similar manner, cantaloupe plants also had the highest yields (53.8 kg) under the HPD treatment. Melon plants in the VE and OPD treatments produced only 57.6 and 54.2%, respectively, of that obtained in the HPD treatment. The reason plant yield in treatments OP, CO, and CT is not reported here is because plants in those treatments were severely damaged by downy mildew. However, prior to the damage, cantaloupe plants had grown in a similar manner as those cantaloupe plants that were not affected by the fungus.

Although only individual effects of mulch treatments were studied in this test, the results strongly suggested a combination of mulch treatments that provided high water infiltration (VE) and one that effectively reduced water loss (HPD) would greatly improve the mulch's efficiency in retaining enough water for plant growth and productivity under conditions of limited water supply in an arid to semiarid environment.

Practical Applications

The practical applications of the information obtained from conducting this research appear unlimited. The results of this study evidenced the possibility of producing different vegetable crops under limited water supply through a low-cost soil water conservation technique: mulching. This is particularly relevant considering the climatological characteristics prevalent during the course of the study: erratic, and low rainfall (323 mm), coupled with high ambient temperatures; 42 C maximum and 27 C minimum (mean 34.5 C). Collectively, they created conditions of high water and temperature stress for plant growth. Therefore, the alternatives for the use of mulch for food crop production in a desert environment are many. For instance, urban home owners could develop a small-scale food production system by using an organic mulch as a means of reducing soil water evaporation. This would greatly reduce the frequency of irrigation needed to maintain healthy and vigorous plants. This may not only be beneficial in vegetable and fruit tree production, but also for ornamental plants. This is of particular importance in cities, where the lack of adequate amounts of water has become a major problem which needs to be resolved through better water conservation practices.

Depending on the region, the plant to be grown, and whether mulching is practiced by the home owner or on a larger scale in cultivated land, mulches will have a beneficial effect on soil and plant environment through water conservation and soil temperature moderation.

Another application would be for the small-scale farmer who has a limited amount of water or depends entirely on rainfall. The use of mulches also opens the possibility for substantial improvement in the nutritional patterns of the farmer and his family by producing better food crops which normally require large amounts of water. This is particularly important in countries where a high percentage of the population is poor and malnourished.

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