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INTERRELATIONSHIP BETWEEN WATER-SOIL AND PLANTS IN THE DRIP IRRIGATION SYSTEM

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ABSTRACT. Drip irrigation has been widely accepted as a replacement for other methods of irrigation and is also being widely used as a method to supplement water during shortages of rainfall in humid regions. The drip system is flexible as to the time and amount of water applied to the root zone. Several factors can be carefully controlled with the system. This becomes more important as irrigation water becomes scarcer and more costly.

The growing need to increase crop production on more and more marginal lands requires a more precise control of both water and nutrients to improve their availability to the plant and reduce nutrient losses by leaching from the root zone. In many areas of the world the use of poorer quality irrigation waters are being used for crop production. In most cases the use of drip systems will be the best method of irrigation for these marginal waters.

INTRODUCTION

Drip irrigation is a system of watering according to the plants needs, as opposed to flooding or sprinkling and allowing the soil to dry for long intervals of time. Basically, the improvement in crop production from a drip system is the result of frequent irrigations in the right place with the right amount of water. With good quality water and a well designed sprinkler irrigation system, crop yields, in many cases, would be similar to drip irrigation. However, in the case of many row crops, drip irrigation adds water only in the area where the root system is present. This is a saving in water when the plant root-system is small. With sprinkler or furrow systems, one must irrigate a much larger volume of soil in order to apply enough water to the least favored area to last until the next irrigation. On annual crops, the greatest savings in water occurs early in the season. As the plants grow and the root systems expand they use more water from a larger area.

Irrigation management practices in the semi-arid winter rainfall regions of the west, requires a continuous supply of irrigation water because of little or no rainfall during the growing season. For summer rainfall, semi-humid regions, rainfall is frequently erratic in timing and amounts. In these regions, soil water storage is exceeded, causing soluble nutrients to be leached out of the root zone, followed by limited soil aeration which could cause crop damage /Phene, 1974/. Excess rainfall problems

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in these regions can be improved with frequent irrigations and minimum leaching of nutrients by using a drip irrigation system.

Phene /1974/ indicates that one can minimize the use of the soil as a storage resorvoir for both water and nutrients, by frequent application of soluble nutrients and water in small quantities to the soil at any given time. This reduces leaching by heavy rains and, also,. frequent application of water in small quantities provides adequate water for crop growth and leaves air-filled soil pore volumes available for rainfall storage. The water and nutrients are supplied to the soil where the roots are most active. Studies in sandy soils of the southeastern Coastal Plains of the U.S.A. showed that daily low-rate application of nitrogen and potassium with a drip irrigation system improved nutrient uptake of the crop and reduced leaching loss of nutrients /Phene, 1974/. In this study it was shown that the range of soil matrix potential for optimal plant growth could be controlled with a drip system and proper management practices /Figure 1/. In the sandy loam soil, the optimal range was before the soil matric potential decreased below -0.4, which causes plant water strees and below -0,08, which causes oxygen stress.

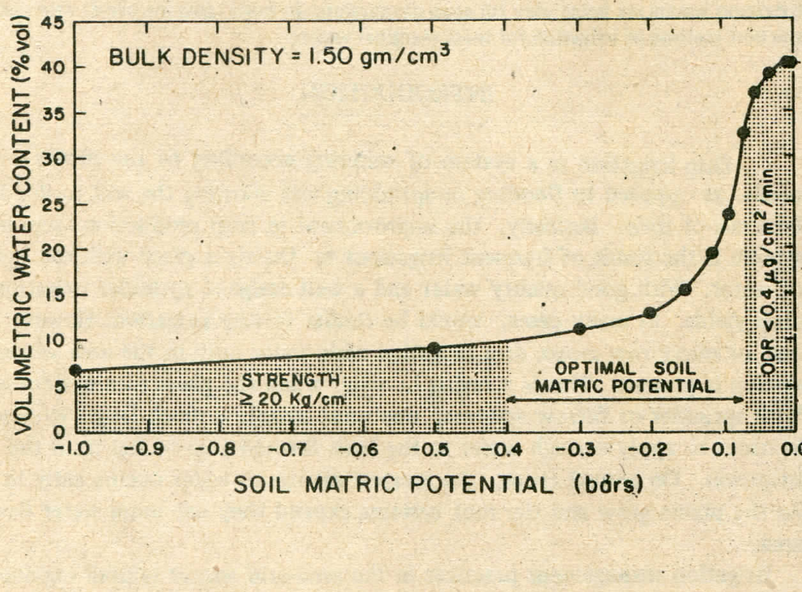

Figure 1. Water desorption, ODR, and strength limiting soil matric potentials of a sandy loam soil /adapted from Phene, 1974/

In the arid western United States, irrigated agriculture is a major consumer of fresh water. Irrigation methods are very important in better irrigation efficiency. A recent report by Jury, Sinai and Stolzy /1979/ compared the distribution and relative efficiency of various irrigation methods used in California /Table 1/. The efficiency is estimated as the ratio between water delivered to the plant root zone, to water present at the head of the irrigation system. This does not take into account drainage, but accounts for deli very losses due to seepage above the field, surface runoff beyond the field, and evaporation during application. The overall efficiency of 0.64 for the different systems, was calculated by summing the individual efficiencies and then multiplying by the fraction of the total area irrigated by each method. About 36 % of all water present at the head of the irrigation system never enters the plant zone.

One can sepculate about water savings resulting from changes in irrigation method. If, for example, 10 % of all border irrigation systems were changed to drip systems then the overall efficiency of California irrigation systems would rise from 0.64 to 0.655. About 3 x $10^{10} m^3$ of water is consumed by irrigated cropland each year in California. Assuming that this is 50 % of the water present at the head of each irrigation system, then the change in irrigation efficiency would produce a fresh water savings of 9.0 x $10^8 m^3$/yr or about 730,000 acre ft/yr. Also a change to the more efficient drip irrigation system would minimize drainage water volumes, which could help alleviate excess drainage problems.

REVIEW OF RELATED RESEARCH

Field experience has shown that drip irrigation is most advantageous under conditions which are marginal for other methods. According to Rawitz and Hillel /1974/, both fundamental and engineering solutions are needed to determine and control the proper balance between evapotranspiration /ET/, leaching requirement and water application. Excess leaching can easily take place under drip irrigation and salt accumulations at the periphery of the wetted soil volume can be a serious problem for seasonal crops. Rawitz and Hillel indicated in their research paper of 1974 that system designs for proper combination of emitter spacing, discharge, and irrigation frequency for various climatic, crop and soil conditions were needed. They also indicated that theoretical model development was a long way from being applicable to system design because of the complexity of the whole system.

Jury and Earl /1977/ observed that water movement through bare soil irrigated from a single emitter showed substantial deviations from predictions based on isotropic soil water transport properties. Irrigations at one-week intervals resulted in a larger amount of water being transferred laterally from the emitter than for daily irrigation of the same application rate and weekly volume of water. It was found that more water ponded at the surface under the emitter for the weekly than for the daily irrigation. They indicated one should avoid using models which do not include the effect of surface ponding for soils having different ponding rates with time. Earl and Jury /1977/ in a related study with summer squash /*Curcurbita pepo* var. Zucchini/ showed matric potential and soil water content oscillated

Table 1. Distribution and Relative Efficiency of Various Irrigation Methods used in California. /Jury, Sinai and Stolzy, 1979/

Method of Irrigation	Hectares* x 10^6 Irrigated	% of Total	Efficiency +
Border, basin or flood	1.72	46.8	0.7 †
Furrow	1.27	34.6	0.5
Movable sprinkler	0.51	13.8	0.75 – 0.8
Solid set sprinkler	0.13	3.5	0.85
Drip	0.01	0.3	0.9 – 0.95
Subirrigation	0.04	1.0	?
Total	3.68	100.0	0.64 x

*1 Hectare = 10^4 m^2 = 2.47 acres

† Assuming lined canals

+ Efficiency is defined as water entering root zone / water supplied at the head of the irrigation system.

x Overall efficiency is the weighted average of the separate efficiencies.

markedly between irrigations in the weekly irrigated plots when compared to the more steady behavior of daily irrigated plots. However, the weekly plots had greater lateral movement due to surface ponding beneath emitters. Bacause of this ponding there was an interaction of plant roots with the water regime. Squash roots, in weekly irrigated plots were more evenly distributed through the soil volume as compared to daily irrigated plots where roots were concentrated near to and below the emitter. In their study, they suggested, evaporation losses from weekly irrigated plots were 40 % lower than in daily irrigated plots.

Conclusions drawn from both of the above studies has important implications as to the frequency and timing of water application, emitter spacing, and water application in relation to variable climatic and crop demands. Roots near the emitter that were watered daily extracted most of the water applied, while roots near the emiter and treated weekly took only a portion of the water applied, allowing the rest of the water to move further through the soil. For these reasons crops watered by widely spaced emitters on soils with low hydraulic conductivity would yield better under weekly irrigations than under a more frequent regime.

Vineyard studies on sandy clay soil with drip irrigation, showed that the main active soil layer supplying water to the roots was restricted to a strip 2 m wide and 120 cm deep beneath the rows /Goldberg, Rinot and Karu, 1971/. Shorter irrigation intervals and smaller amounts of water applied per irrigation decreased the variations of water in the root zone with a continuously higher moisture regime.

The percentage of wetted area compared to the whole area depends on the discharge, spacing of emitters and soil type. Absolute values for percentage of wetter area should be experimentally established. Keller and Karmeli /1974/ indicate that in arid areas one should wet a minimum of one-third of the potential root volume for widely spaced tree crops but in heavy rainfall areas, 20 % of the area is reasonable.

Drip irrigation studies with mature citrus trees on deep sandy soil of South Australia showed root densities followed a pattern similar to the wetting profile /Cole and Till, 1974/. The maximum growth of roots were around the emitters. They found a three-fold increase in soil salinity from the leached zone beneath the drippers to the edge of the wetting front. However, yields increased only after improved fertilizer management and reduced amounts of water were applied. Willoughby and Cockroft /1974/ in Victoria, Australia studied changes in root patterns of peach trees on a sandy loam topsoil overlying medium to light clay. With newly planted trees, roots proliferated an area out from the emitters where there were ideal moisture conditions but the root died in the saturated zone nearer the emitters. With mature trees a whole new root system was established after a drip irrigation system was installed.

Comparison of drip, furrow and sprinkler irrigations were made by Bernstein and Francois /1973/. They showed, with good quality water, that the drip-irrigation plots out-yield the furrow and sprinkler-irrigated plots by 50 %. With poor quality water drip irrigation was reduced by 14 % when compared to drip with good quality water but there was a 54 and 94 % reduction in yield for furrow- and sprinkler-irrigated plots, respectively. However, by increasing the irrigation frequency for furrow and sprinkler treatments, yield differences were significantly decreased. Drip irrigation required about one-third less water than furrow irrigation for maximum yield of bell peppers.

Cabbage production in drip irrigation treatment was the same as furrow irrigation treatments when water was applied at 1.3 and 1.05 times ET, but yields were decreased 10 and 43 % respectively when 0.8 and 0.5 times ET were applied by the two methods /Bucks et al., 1974/.

Five experiments were conducted at the Imperial Valley Conservation Research Center in southern California on Holtville silty clay loam with cantaloupe production /Willardson, Bohn and Huber, 1974/. Irrigation methods had important effects on earliness and yield of spring cantaloupes. Those planted on raised beds with both furrow and drip irrigations matured one week earlier and produced more and larger melons than those planted on flat beds. The furrow irrigation system, generally, did produce significantly higher yields of cantaloupes than the drip system but water efficiency was better with drip irrigation. About 50 % more water was applied with furrow irrigation than was required with drip irrigation to produce the same weight of cantaloupes on both raised and flat bed plantings. However, the drip irrigated cantaloupes had a slightly wilted appearance in the afternoons during fruit production. This would suggest the plants were unable to meet peak ET demands. Root systems of drip-irrigated cantaloupes were limited to the ball of earth, while those of furrow-irrigated melons ranged throughout the plant bed. Meek /unpublished data/ during 1979 studied watermelon production on this same station with drip irrigation. He was concerned about soil aeration in this non-compacted fine textured soil. He measured water potential and soil oxygen at three depths under the plant and two distances and depths from the plant. Tensiometers were used to measure water potential. Soil oxygen was measured using double membrane polarographic probes. These probes were temperature compensated with a low rate of oxygen consumption and a fast response time. The data in Figure 2 shows soil oxygen and water potential for two drip irrigation treatments at a 15 cm depth below the plant. The top part of the figure is a weekly drip irrigation and the bottom part is a daily drip irrigation. The

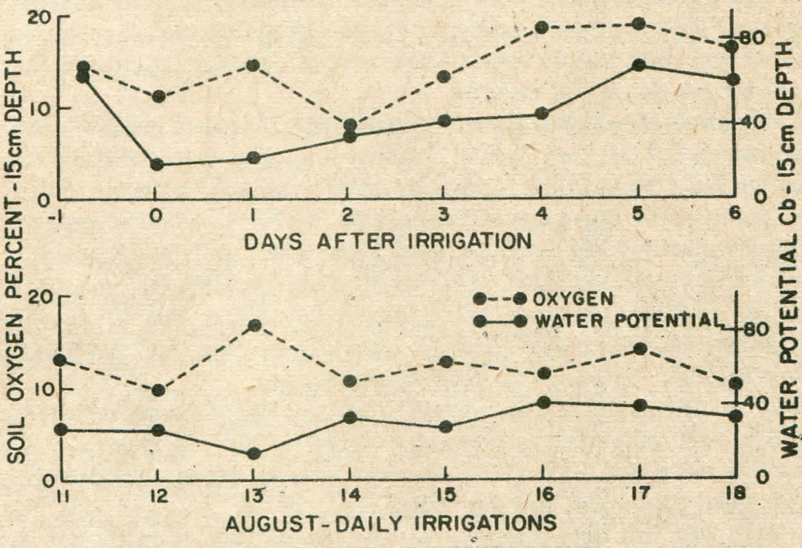

Figure 2. Soil water potential and soil oxygen comparisons for weekly and daily drip irrigation treatments on silty clay loam with watermelon production /Meek, unpublished data/.

water was added for 5.8 hours for the weekly irrigation and 50 minutes per day for the daily irrigation. The same total weekly quantity of water was added to each treatment which amounted to 120 % of ET for the area wetted. These data show that water movement was controlled at the soil surface so that it moved through the soil profile in the unsaturated phase. Water potentials were never higher than -10 cbs; this allowed oxygen to diffuse from the atmosphere into the soil profile. The lowest soil oxygen value was between 7 and 8 % two days following the weekly irrigation. Yields were not significantly different for the two treatments.

ORCHARD CONVERSIONS TO DRIP IRRIGATION SYSTEMS

Gustafson et al. /1974/ talked about the tremendous interest in drip irrigation by fruit growers in the early part of 1970. This interest caused many growers to convert their orchards to drip irrigation systems. Changing the method of irrigation posed many questions to growers, manufacturers, suppliers and installers of irrigation equipment. As indicated by Rawitz and Hillel /1974/, due to lack of research behind installations of drip systems, it was difficult to extrapolate information from successful installations to the design of new ones under different conditions. One of the areas of California that produces lemons, oranges and avocados is along the coast north and west of Los Angeles, California. The topography of the area is level to mountainous with winter rainfall and a mild climate due to the ocean. There are several different cultural practices used in the production of fruit. In this area we studied six orchards being converted to drip irrigation systems /Kirkpatrick and Stolzy, unpublished data/. The six orchards were three lemons, one orange and two avocado for a total of 102 ha. The drip system replaced sprinkler systems /pullhose; permanent set, low-head; portable aluminum pipe/ and furrow systems /contoured furrow, furrow and furrow on terraces/. The data in Table 2 is from three of the six orchards, and gives a comparison of water and labor used before and after conversion to drip irrigation with one drip emitter per tree.

Since the use of drip emitters resulted in the shortening of the interval between irrigations, yearly per orchard reductions in water use was over 58 % with more than 64 % saving in labor use. The total water volume saved from all orchards over a three-year period averaged $1.04 \times 10^6 m^3/yr$.

The soil moisture profile distribution was dependent upon the total volume of water applied at a given irrigation. For a given soil, the planar /cross-sectional/ area at any given soil depth that was wetted to 75 % available soil moisture content was, in a wide range of soil types, and could be correlated with the total volume of irrigation water delivered at the emitter. Each soil had its own relationship, but once established it was highly predictable and useful in determining the number of emitters required to adequately irrigate the tree. One emitter per tree proved effective for young trees but another emitter was needed on the opposite side for 6 to 8 year old trees. This provided a suitable environment for root development which increased the supply of water to the older and larger tree.

Table 2. Orchard descriptions, irrigation methods and regimes, and per hectare per irrigation water and labor uses: Comparisons between previous irrigation methods and regimes and present regimes using one drip emitter per tree. (Unpublished data, Kirkpatrick and Stolzy).

Orchard description and water and labor use	California plantclimate zone and orchard					
	Coastal-Interior Valley				Coastal area	
	Citrus[z]		Orange[y]		Avocado[w]	
Hectares	49.01		17.01		8.10	
Age, yr	8		5 & 21		5 & 8	
Density, no. trees/ha	326		279		267	
Planting distance, m (T X R)	4.6 X 6.7		4.9 X 7.3		6.1 X 6.1	
Topography	level		3% slope		± 40% slope	
Soils	gcs-fsl		gcsl		sil/c	
Previous irrigation system[u]	ph-s		cf		sslh-s	
Conversion comparisons						
irrigation	before[t]	drip[s]	before	drip	before	drip[q]
no. cycles/yr	18	26	8	15	10	18
days to irrigate orchard	10	3	30	4	4	1.5
days water run during cycle	10	3	30	4	4	1.5
hours water run/unit/cycle	24	24	24	48	24	36
unit delivery rate, l/min	1.89	0.30	1.892	0.36	1.89	0.11
water per irrigation						
m^3/ha	444.45	130.37	4,810.0	253.65	727.28	65.45
m^3/tree	1.363	0.436	17.225	0.908	2.725	0.245
labor per irrigation						
man-hr to irrigate orchard	110	18	120	6	20	4
man-hr/ha	2.246	0.368	7.060	0.353	2.471	0.494

[z] There are 40.10 ha of Eureka and Lisbon lemon selections (*Citrus limon*[L.] Burm. f) and 8.91 of Valencia sweet orange trees (*C. sinensis* [L.] Osbeck 'Olinda').

[y] Selections of Valencia Sweet orange trees (*C. sinensis*).

[w] *Persea americana* Mill. 'Haas'.

[v] Soil texture: g, gravelly; c, coarse, f, fine; s, sand; l, loam; si, silt; c, clay.

[u] Irrigation method, ph-s, pullhose sprinkler; cf, contoured furrows; sslh-s, solid set, lowhead sprinkler.

[t] Alternate row middles irrigated 12 hr every five days.

[s] There are 21.38 ha at 0.11 l/min and 27.62 ha at 0.44 l/min per tree

[q] Orchard receives nine irrigation cycles of 24 hr (spring and fall) and nine of 48 hr (summer) at a rate of 0.076 l/min per tree, applied every 14 days.

[p] Equivalent to one sprinkler head per tree for 24 hr.

The soil moisture content profile distribution about the emitter remained nearly constant as the interval between irrigations was shortened. Thus, under daily or high frequency irrigation one can have situations where changes in soil water potential remained almost constant. Monitoring soil water potential was desirable to determine if the volume of water applied resulted in a perched water table or if it was sufficient to offset ET losses and provide for a leaching factor.

Growers ware urged to examine the soil profile before any decision was made to convert to drip irrigation. They were encouraged to consider the design of the drip system as to emitter rate, number, and placement of emitters and the frequency of irrigation.

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