by the authors functions in 3 modes: 1) manual control, in which the user can turn devices on and off from the keyboard of the computer, 2) timer control, in which the user specifies an irrigation schedule and the computer takes over all irrigation and chemical injection tasks, and 3) an automatic mode in which the computer senses the soil-water status and irrigates when it reaches a critical level.

This system was installed and tested in greenhouses (11) and will be tested for the operation of citrus trickle irrigation systems. The results of this study will be presented in a future paper.

Summary

Computer software has been developed to be used as an aid in trickle irrigation system management. This software (available through: IFAS Software Communication and Distribution, Florida Cooperative Extension Service, GO22 McCarty Hall, University of Florida, Gainesville, FL 32611) has been designed to run on any MS-DOS or CP/M based computer and is available to the public on a variety of disk formats.

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EFFECTS OF TRICKLE IRRIGATION METHODS AND AMOUNTS OF WATER APPLIED ON CITRUS YIELDS[1,2]

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Additional index words. drip irrigation, spray irrigation.

Abstract. **A 5-yr study of the production of 'Valencia' orange [Citrus sinensis (L.) Osb.] in response to amount of water applied and method of trickle irrigation was conducted. Irrigation scheduling was based on 100%, 50% and 25% of potential evapotranspiration calculated from pan evaporation, with irrigation delays following rainfall. Citrus yield was not influenced by the amount of irrigation applied, indicating that all treatments provided sufficient water to avoid yield-limiting stress. Yields were strongly related to irrigation method, with the spray irrigation systems which covered 28%-51% of the area under the tree canopy increasing yields by 65% as compared to the non-irrigated control. Drip irrigation systems which irrigated 5%-10% of the canopy area increased yields 41%-44%. Rainfall distributions also strongly influenced yields of both the irrigated and non-irrigated treatments. Yields of all treatments were greatest when rainfall distributions in the months of April-October were above average.**

Trickle irrigation has become an increasingly popular method of irrigation of citrus in Florida (3). This has occurred because trickle irrigation systems are relatively low in cost (4), and their use results in sufficient yield increases that they are cost-effective (4, 5). There is also the ability to obtain a measure of freeze protection when under-tree spray emitters are operated during some freezing conditions (1, 2, 7, 8).

This work was initiated to study the effects of trickle irrigation on citrus yields for the sandy soils and humid climatic conditions of Florida. Trickle systems used for citrus irrigation in Florida are commonly of two general types: 1) point-source drip types, and 2) low flow rate spray types. Drip systems generally operate at lower flow rates per tree irrigated than spray systems, thus resulting in lower system costs. However, as compared to drip emitters, spray emitters are capable of irrigating a much larger fraction of a tree root zone per emitter because of the very limited lateral movement of water from trickle emitters in typical Florida deep sandy soils.

Our objectives were specifically to quantify yield increases resulting from trickle irrigation of citrus under climatic, soil, and grove management conditions typical of the central ridge citrus production area of Florida, and to quantify yield differences which might occur due to the amount of irrigation water applied or to the type of trickle irrigation system used. Fruit quality responses and responses to fertigation are presented in a companion paper (6).

Materials and Methods

Trickle irrigation systems were installed in a mature 'Valencia' orange grove on rough lemon rootstock (*Citrus*

[1]Florida Agricultural Experiment Stations Journal Series No. 9566.
[2]The excellent work of the late J. Mostella Myers in the design, installation and data collection for the early years of this research is greatfully acknowledged.

jambhiri Lush) at the Citrus Research and Education Center at Lake Alfred, Florida. Both drip and spray types of trickle emitters were installed. Treatments consisted of irrigations using 2 drip emitters (2-Drip), 4 drip emitters (4-Drip), 1 spray emitter (1-Spray) and 2 spray emitters (2-Spray) per tree. Nominal 1-gal/hr drip emitters and 10-gal/hr spray emitters at a 10 psi operating pressure were used.

Drip emitters were located on a tree loop beneath the tree canopy and about 4 ft from the trunk. Emitters were installed directly on the loop tubing and just above the soil surface.

Two types of spray emitters were used. For the 1-Spray treatments, emitters with 280-degree spray patterns were used. Their diameters of coverage were about 11 ft. They were located 4 ft from the tree trunks and oriented so that they did not spray directly on the trunks. For the 2-Spray treatments, emitters with 180 degree spray patterns were used. They were located on opposite sides of the tree trunks, 1 ft from the trunks, and they sprayed in opposite directions beneath the canopy. These emitters had 6 ft radii of coverage.

Trees were located in rows 30 ft apart and spaced 15 ft within the rows. Tree canopies overlapped within the rows. They were approximately 18 ft wide perpendicular to the rows.

The soil type was an Astatula fine sand, a hyperthermic, uncoated typic Quartzipsamments. This is a deep sand soil typical of the central ridge citrus production area of Florida. It has a water-holding capacity of less than 8% by volume at field capacity.

Irrigations were scheduled based upon long-term pan evaporation records at Lake Alfred. Fig. 1 shows the distribution of pan evaporation data used. The upper curve shows the monthly distribution of measured pan evaporation. The second curve shows the estimated potential evapotranspiration (ETp). It was calculated as 0.7 times pan evaporation. The ETp was the amount of irrigation scheduled for the spray emitter high application treatments. The annual total was about 48 inches. The third curve from the top in Fig. 1 was calculated as 0.5 times ETp. It totaled about 24 inches annually. This was the irrigation amount and distribution scheduled for the spray emitter low application treatments and the drip emitter high application treatments. The bottom curve was calculated as 0.25 times ETp. It totaled about 12 inches annually. This was the amount and distribution scheduled for the drip emitter low irrigation application treatments.

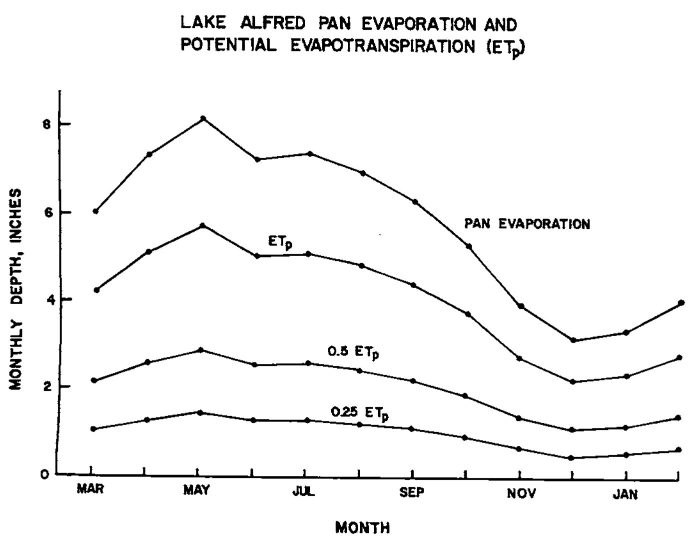

Fig. 1. Monthly distributions of pan evaporation and irrigation applications used in this research. ETp = potential evapotranspiration.

Irrigations were timer-controlled with an override in the event of rainfall. The override was provided by a programmable controller that we built. It was programmed to delay the scheduled irrigation for 1 day following rainfall of 0.25-0.50 inches. It delayed irrigations for 2 days for rainfall depths greater than 0.50 inches. No delay was provided for less than 0.25 inches of rain.

Drip irrigations were scheduled daily when rainfall did not occur. Amounts were programmed on irrigation timer-controllers for 2-week periods. Spray irrigations were scheduled on a variable frequency and amount basis. Frequencies varied from every third day during summer months to every sixth day during winter months. All of the same irrigation application treatments were designed to apply the same amount of water on a monthly basis, within the limits of interruptions due to rainfall.

Irrigation and fertigation treatments were statistically arranged as a 4 emitter types X 2 irrigation levels X 3 fertigation levels factorial design and replicated 4 times in single tree plots. Treatment trees were separated by non-treatment buffer trees. Irrigation treatments were analyzed by combining the 3 fertigation treatments to produce 12 tree groups because irrigation treatments were independent of fertigation treatments. The control for this research was 4 non-irrigated trees, 1 per block.

Data were collected for 5 crop years of March-February, beginning in March, 1978, and ending in 1983. A sixth year's data were lost due to a severe freeze in late December, 1983. Yield data were obtained by hand-picking the individual treatment trees.

Results and Discussion

Table 1 shows the areas of the citrus root zones irrigated by the 4 trickle irrigation treatments. Data are shown as percentages of the total land area and as percentages of the area under the average tree canopy. Areas irrigated ranged from 5.2% of the under-tree canopy area for 2 drip emitters per tree to 50.7% for 2 spray emitters per tree. Corresponding areas were 3.1% and 30.4% of the total land area including alleys between tree rows, respectively.

Table 1. Irrigation treatments and irrigated areas.

Treatments	Irrigated area: Under canopy (%)	Irrigated area: Total land (%)
2-Drip emitters per tree	5.2	3.1
4-Drip emitters per tree	10.4	6.2
1-Spray emitter per tree	28.4	17.0
2-Spray emitters per tree	50.7	30.4
Non-irrigated control	0	0

Areas and corresponding volumes were determined by field measurements. The horizontal extent of the wetted areas were measured after locating the wetted zone by digging approximately 1 ft below the soil surface after an irrigation cycle. Because of the very sandy soil at the research site, the wetted area was determined to be cylindrical in shape rather than bulb-shaped as is typical of heavier-textured soils. For that reason, the extent of the wetted zone was readily determined after the unevenly wet loose surface soil was removed. Also, because of the approximately cylindrical shape of the soil wetted, the volume of the tree root zone irrigated could be determined by multiplying the wetted area by the depth of water penetration.

Irrigated depths applied. Table 2 shows the depths of irrigation applied in this research. Data are given annually for each of the 5 yr of this study, and a 5-yr average was calculated for each of the treatments. The annual and 5-yr average rainfalls measured at the field site, and the long term (69-yr) average rainfall measured at the nearby Lake Alfred Citrus Research and Education Center are also shown. Finally, the bottom line shows the design maximum irrigation applications for the various treatments.

In every case the actual water applications were less than the design maximum applications. This occurred because the programmable controller that we built would override the timer-controlled irrigation applications when rainfall occurred. The water savings that resulted from the use of the rainfall override is the difference between the actual water application and the design maximum application for each treatment. Water savings ranged from a low of 2.09 inches for the 2-Spray low depth of application treatment to a high of about 10.7 inches per year for both of the high depth of application spray emitter treatments.

Annual rainfalls ranged from 39.81 to 64.17 inches per year at the research site. The 5-yr average of 50.58 inches was almost exactly the long-term average of 50.74 inches. Although some trends in irrigation reductions can be seen for wet years as opposed to dry years because of the rainfall override of the irrigation timers, that trend was not consistent for all years of record or all treatments. This occurred at least partially because of the differences in rainfall distributions from year-to-year. However, because of the small range in water applications from wet to dry rainfall years, this also suggests that a more sophisticated means of scheduling irrigations is required so that only the supplemental water requirements of the tree are applied. Such a method would be irrigation scheduling based upon direct measurements of soil water contents in the tree root zone, or based on daily measurements of climatic parameters or pan evaporation rather than long term average values with 1- and 2-day delays following rainfall.

Irrigation depth effects on yields. Little difference in yields occurred as a result of the amount of irrigation applied. The 5-yr averages were not significantly different for the low versus high irrigation depths for all methods of application. This demonstrated that even the smallest depth of application studied was adequate to maximize yields for the method of irrigation used and that water applications in excess of those were wasted. This also demonstrated that yield reductions did not occur as a result of over-irrigations using the high depth of application treatments.

Irrigation method effects on yields. Because yield differences were not significantly different as a function of the depth of irrigation applied, all yield data were combined as a function of irrigation method in Table 3. Yields are given in boxes of fruit per tree and as a ratio to the yield of the non-irrigated control. Additional yield data are given in a companion paper (6).

In Table 3, a general trend of increasing yields is shown from the non-irrigated control to the drip *emitter treatments* and to the spray irrigation treatments. This trend is better shown graphically in Fig. 2. In that figure, the solid bars show the 5-yr average yields, and the dashed bars show the range in yields encountered during this study.

Table 3. Citrus yield as a function of irrigation method.

Year	Non-irrigated control	Drip emitters		Spray emitters	
		2/tree	4/tree	1/tree	2/tree
1978-79	3.56[z]	3.89	4.14	4.60	4.95
	1.00	1.09	1.16	1.29	1.39
1979-80	3.31	5.22	4.82	5.44	5.34
	1.00	1.58	1.46	1.64	1.61
1980-81	1.78	2.70	3.25	3.53	3.53
	1.00	1.52	1.83	1.98	1.98
1981-82	3.07	4.84	4.34	5.34	5.60
	1.00	1.58	1.41	1.74	1.82
1982-83	3.81	4.91	5.10	5.64	6.11
	1.00	1.29	1.34	1.48	1.60
5-yr avg.	3.11	4.31	4.33	4.91	5.11
	1.00	1.41	1.44	1.63	1.68

[z]Top line for each year represents yield in boxes/tree; second line yield relative to non-irrigated control (=1.00).

In Fig. 2, yields increased with increasing areas of coverage of the tree root zone. Yields ranged from a 5-yr average of 3.11 boxes per tree for the non-irrigated control to 5.11 boxes per tree for the 2-Spray treatment. Yields for the 4-Drip treatment (4.33 boxes per tree) were only slightly greater than those of the 2-Drip treatment (4.31 boxes per tree), but the range in yields was less for the 4-Drip treatment, and the minimum yield obtained was 3.25 boxes per tree as compared to 2.70 boxes per tree for the 2-Drip treatment. These results demonstrate that yields are increased as the area of coverage of the tree root zone is increased.

In Table 3, relative yield increases with respect to the non-irrigated control were also presented. Interpreting yields in this manner allows other factors which may have influenced yields in a given year, such as freeze damage, to be eliminated if it can be assumed that the effects of those factors uniformly affected production in all treatments. Relative yield increases were greater for the spray as compared to the drip irrigation treatments. Fig. 3 presents

Table 2. Citrus irrigation and rainfall—Lake Alfred.

Year	Drip emitters				Spray Emitters				Rainfall (inches/yr)
	2-Low	2-High	4-Low	4-High	1-Low	1-High	2-Low	2-High	
	Irrigation depth inches/yr								
1978-79	8.40	16.50	11.33	16.80	20.72	40.31	22.21	41.44	48.23
1979-80	8.16	14.92	10.49	16.31	19.09	37.20	21.56	38.18	59.71
1980-81	8.25	15.75	11.02	16.50	18.09	35.33	21.59	36.19	39.81
1981-82	8.20	15.98	9.42	16.40	18.20	38.70	22.79	36.41	41.00
1982-83	7.81	13.91	9.43	15.61	18.21	36.43	22.20	36.42	64.17
Avg.	8.16	15.41	10.34	16.32	18.86	37.59	22.07	37.53	50.58
Design Max. irr.	12.08	24.16	12.08	24.16	24.16	48.33	24.16	48.33	50.74[z]

[z]Indicates 69-yr average rainfall.

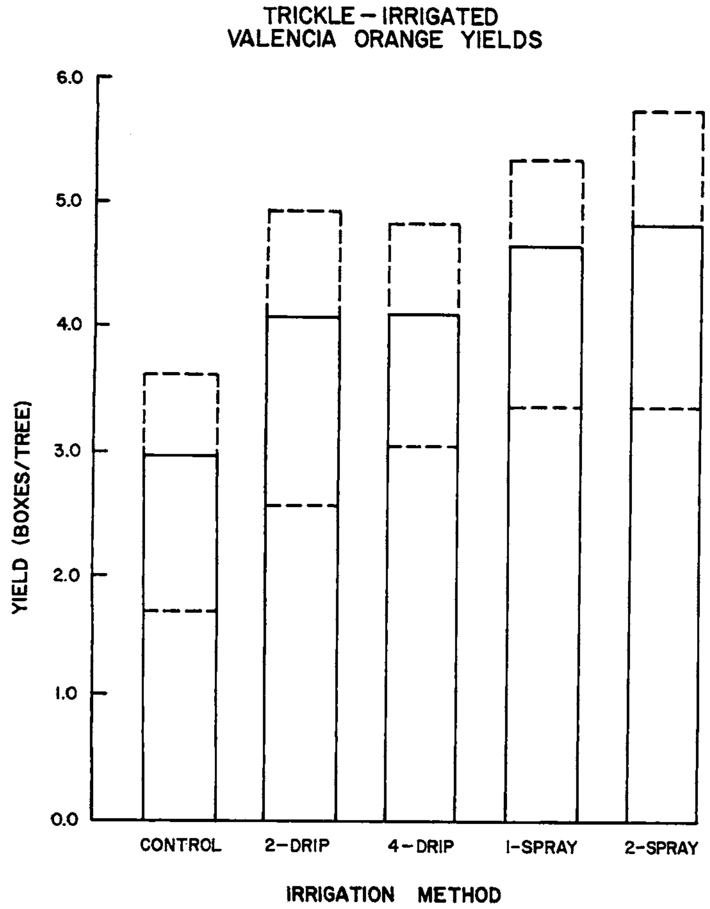

Fig. 2. Five-yr average yields of 'Valencia' orange using trickle irrigation. Dashed bars show maximum and minimum yields for the period of study.

relative yields graphically, and illustrates the importance of the area of the root zone irrigated. Relative yield increases ranged from 41% for the 2-Drip treatment to 68% for the 2-Spray treatment when averaged for the 5 yr of this study. Also, when presented as relative yields, the 5-yr minimum and maximum values observed for each treatment increased consistently with area of coverage.

Rainfall effects on yields. Rainfall affected non-irrigated citrus yields considerably in this study. Yields ranged from 1.78 boxes per tree in 1980-81 when annual rainfall was 39.81 inches to 3.81 boxes per tree in 1982-83 with 64.17 inches of rain.

Because the trickle irrigation systems we studied irrigated only up to 50.7% of the area beneath the tree canopies, and therefore did not provide all of the tree's water requirements, rainfall also affected irrigated citrus yields. Yields tended to be greatest for the years with greatest rainfall. However, this trend was not consistent for all years or all treatments.

Rainfall distributions during the year were found to be better correlated with citrus yields than annual rainfall amounts. From Table 3, yields in 1981-82 ranged from 1.09 to 2.07 boxes per tree greater than those in 1980-81, despite the fact that annual rainfall increased only slightly (from 39.81 to 41.00 inches). Irrigation applications were also approximately equal both years. Rainfall distributions, however, were considerably different during those 2 yr. Monthly rainfall distributions are shown graphically in Fig. 4-8. In each figure, the rainfall distribution is shown as a solid line. The 69-yr average rainfall at Lake Alfred is shown as a dashed line for comparison. In 1981-82 (Fig. 7) considerably more of the annual rainfall was concentrated

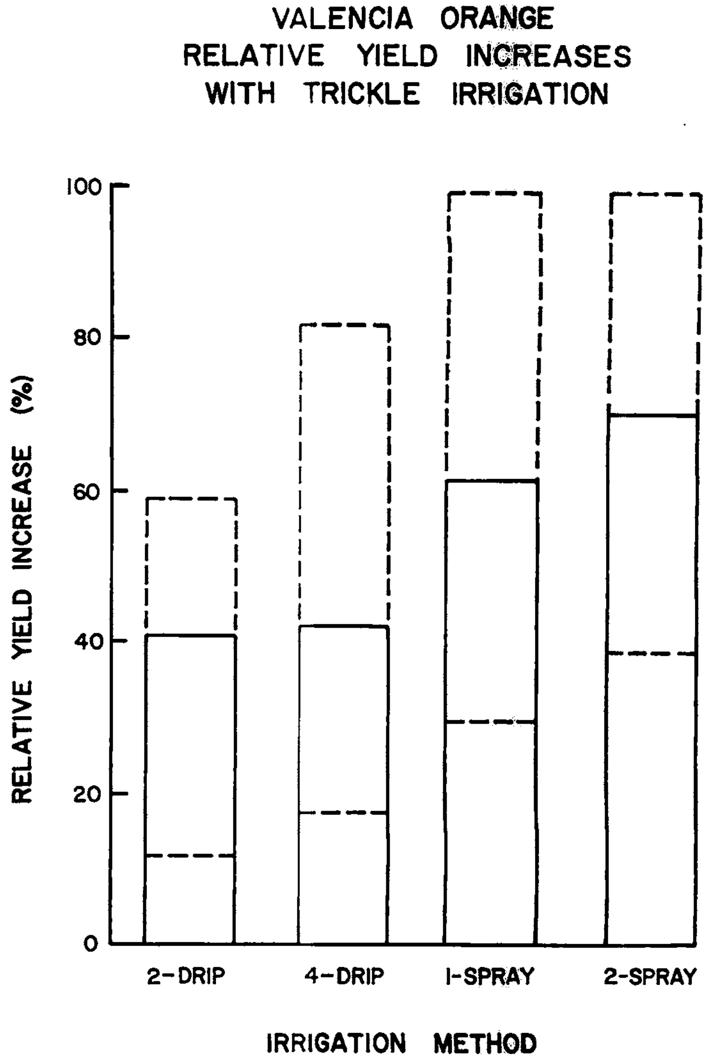

Fig. 3. Relative yield increases of 'Valencia' orange for 4 methods of trickle irrigation as compared to the nonirrigated control. Dashed bars show maximum and minimum relative yields for the period of study.

in the critical months of April-October as compared to the 1980-81 year (Fig. 6).

The greatest irrigated and non-irrigated yields occurred in 1982-83. This occurred because rainfall exceeded the average in all months from April-October (Fig. 8). Ir-

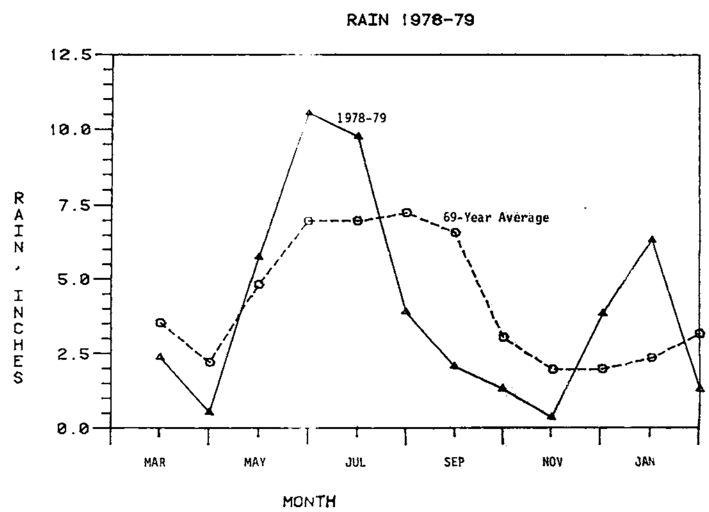

Fig. 4. Long-term average and 1978-79 rainfall distributions at the research site.

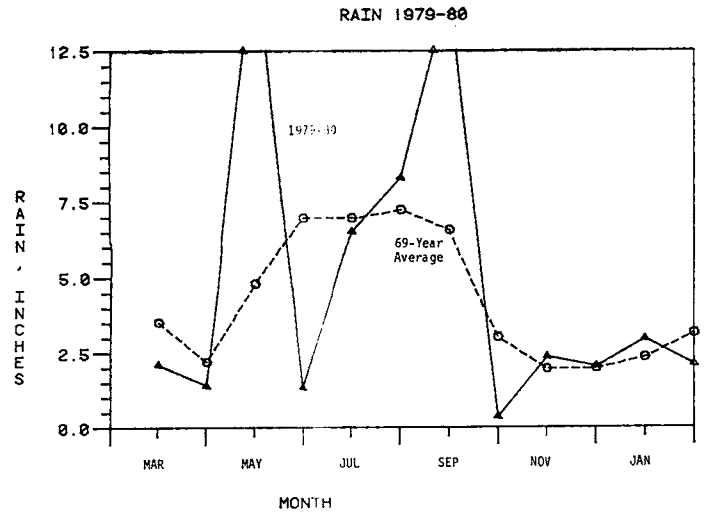

Fig. 5. Long-term average and 1979-80 rainfall distributions at the research site.

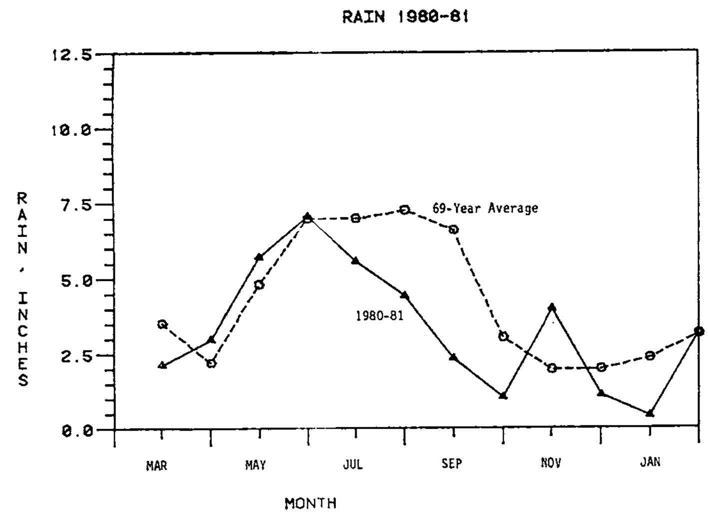

Fig. 6. Long-term average and 1980-81 rainfall distributions at the research site.

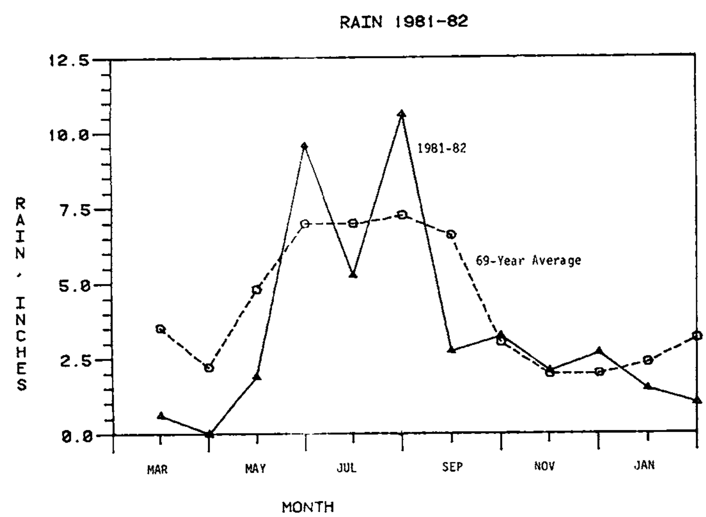

Fig. 7. Long-term average and 1981-82 rainfall distributions at the research site.

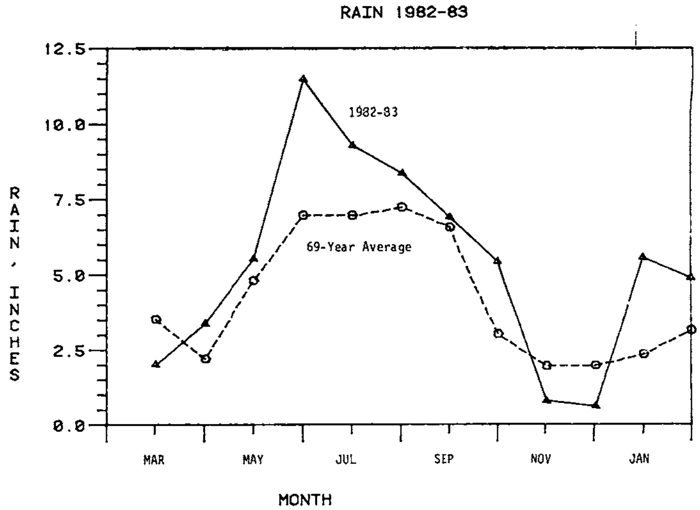

Fig. 8. Long-term average and 1982-83 rainfall distributions at the research site.

rigated and non-irrigated yields were also large in 1979-80 when annual rainfall was 59.71 inches (Fig. 5). Yields were not as large as in 1982-83, however, because of the non-uniform distribution of rain. In that year, less than average amounts occurred in June, July and October. Also, much of the very large amounts that occurred in May and September were lost to deep percolation because of the limited soil water-holding capacity.

For this study, rainfall amounts and distributions were found to be correlated with both irrigated and non-irrigated yields. Rainfall distributions above average in the months of April-October resulted in the greatest yields.

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