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Soil Moisture Tension in Relation to Growth and Yield Of Papaya *(Carica papaya* L.*)*

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In order to maintain growth and production of papaya plants, irrigation is practiced intensively for approximately 6 months of the drier part of the year (May to October) in the Waimanalo area of Honolulu, Hawaii. During other months of the year, moisture is supplied to the plants through natural precipitation. Information relating to timing of irrigation application has heretofore been lacking to growers.

This report is based on results obtained when papaya plants were irrigated under various soil moisture tension levels during the drier months of the year. Growth and yield responses were studied under such conditions.

MATERIALS AND METHODS

Moisture release curves of soils from the Waimanalo field were made by using the pressure membrane apparatus for the 1 to 15 atmospheres determinations, and the porous plate for the ⅓ atmosphere determination. Soil samples were taken from four selected sites in the field at depths of 6 to 18 inches, and 18 to 36 inches. They were air dried, pulverized into smaller particles, and passed through a 6-millimeter sieve. After following the procedure developed by Richards (*3*) at selected applied pressures, soil moisture percentage determinations were made in duplicate.

Before converting resistance of the gypsum blocks to soil moisture tension to atmospheres, a curve relating resistances to soil moisture percentages was made. The soil moisture percentage corresponding to the resistance as read from this curve was then converted to the appropriate tension in atmospheres by using the moisture release curve determined for soil sampled at the 6- to 18-inch depth.

Calibration of resistances to soil moisture percentages was made under field conditions. Soils were sampled for soil moisture determinations at the 18-inch depth about 12 inches from the gypsum block and at approximately the same distance to the plant as that of the soil moisture indicator. For the upper limit of available water, soils were sampled 2 to 3 days after an irrigation. Sunflower was used as the indicator plant in order to deter-

mine the soil moisture percentage and the resistance of the gypsum block at the wilting point. Soil moisture percentages were then divided into six classes; each class, excepting that at the wilting point, encompassed four moisture percentages. Means of soil moisture percentages were determined from all soil moisture percentages falling within each class. A curve was made by drawing a line through each mean.

In converting resistance of blocks at the 24-inch depth to atmospheres, the calibration curve of resistances to soil moisture percentage at the 18-inch depth was used. The moisture release curve of the soil at the 6- to 18-inch depth was used in converting the soil moisture percentage to atmospheres.

The experiment was conducted in a field at the Waimanalo farm of the Hawaii Agricultural Experiment Station, Honolulu, Hawaii, using the *Solo* variety of papaya as experimental material. It was begun on July 20, 1959, when plants were about 7 months old and when most of them had initially flowered, so that identification of sex of the plants was possible.

The experiment was of the randomized block type of design consisting of four treatments in four blocks. Each plot consisted of a row of plants comprising hermaphrodites as well as females. However, experimental data were obtained from the hermaphroditic plants only. The number of hermaphroditic plants in a plot ranged from 9 to 16. In this report, whenever treatment means are compared, they are therefore expressed on a per tree basis. Plots were separated from each other by border rows.

Fertilizer applications were usually of the general garden type (10 percent N, 10 percent P_2O_5, 10 percent K_2O). In addition, during the summer of 1960, ammonium sulfate fertilizer (21 percent N) was applied on two occasions. These applications were made at quarterly intervals, more or less, at the rate of 1 pound per tree. During the irrigation treatment periods, they were broadcast on the edge of the irrigation furrows, while during the other months of the year they were broadcast around each tree.

Tensiometers were used as soil moisture indicators in treatments 1 and 2, and gypsum blocks in treatments 3 and 4. During the summer of 1959, these soil moisture indicators were installed at a depth of 18 inches in the ridge of the irrigation furrow on the side nearest the plant. Later in 1960, they were reinstalled in the furrow at a depth of 19 inches. Since the furrow was approximately 5 inches deep these soil moisture indicators were then actually at a depth of 24 inches, when compared to their former placement. They were located at the approximate center of the row. At each site, two of these indicators were located about 12 inches from each other. Distances from the plant to the soil moisture indicators were approximately 24 inches and 30 inches during the 1959 and 1960 experimental periods, respectively.

The tensiometers used were of the irrometer type, obtained from T. W. Prosser Co., Arlington, California. They were checked for accuracy with a test gauge, which had formerly been checked with a mercury manometer.

Gypsum blocks were made at the Experiment Station of the Hawaiian Sugar Planters' Association, Honolulu, Hawaii. They were selected on a basis of uniformity in readings after being soaked in water for several hours. A Coleman and Hendrix ohmmeter was used with the gypsum blocks.

Irrigation treatments for the experiment conducted during the summers of 1959 and 1960 are presented in tables 1 and 2, respectively. It was planned to have plants in treatment 1 of the 1959 experiment irrigated at about the same irrigation interval as the orchards in this area, which is about 10 days. The soil moisture tension of treatment 2 (table 1) is actually the mean derived from all tensiometer readings in this treatment.

TABLE 1. Irrigation treatments for experiment conducted during summer and fall of 1959 (July 20, 1959, to November 13, 1959). Soil moisture indicators were installed at a depth of 18 inches.

TREATMENT	SOIL MOISTURE TENSION (ATMOSPHERES) BEFORE IRRIGATIONS	MEAN INTERVAL (DAYS) BETWEEN IRRIGATIONS
1	.26 ± .04	12
2	.22 ± .06	16
3	3.1 ± 1.2	20
4	6.3 ± 1.1	43

TABLE 2. Irrigation treatments for experiment conducted during summer and fall of 1960 (May 4, 1960, to October 19, 1960). Soil moisture indicators were installed at a depth of 24 inches.

TREATMENT	SOIL MOISTURE TENSION (ATMOSPHERES) BEFORE IRRIGATIONS	MEAN INTERVAL (DAYS) BETWEEN IRRIGATIONS
1	.27 ± .01	30
2	.60 ± .02	49
3	4.3 ± .4	65
4	7.7 ± .5	77

Variation of soil moisture tension between replicated plots of the same treatment is evident (table 1). This indicates variation in soil type or some other physical property of the soil in the various plots. In order to obviate such a difference between replicated plots of any one treatment, each plot was irrigated during the experimental period of 1960 according to the soil moisture tension predetermined for that treatment (table 2).

Readings of the soil moisture indicators during the summer of 1959 were usually taken daily between 7 and 8 A.M. During the experimental period of 1960, readings were recorded every other day.

Plants were irrigated by means of furrow. Water flow was regulated at a fast rate from one end of a row until water reached the other end. It was then adjusted to a slower rate. Tensiometer readings usually began to drop after 2 hours of irrigation. Irrigation time comprised 4 hours.

Leaves from two plants of each plot were sampled at weekly intervals for leaf moisture and leaf weight determinations during the summer of 1959. The leaves sampled from each plant were the 8th leaf, a young, rapidly expanding leaf, and the 16th leaf, the most recently matured leaf. (A leaf near the meristematic apex that was an inch in length, was designated leaf number 1; and leaves sampled were the 8th and 16th, counting basipetally.) The leaves were sampled between 7 and 8:30 A.M., separated into blades and petioles, and weighed immediately for their fresh weights. Petioles were sliced into approximately ¼-inch pieces before they were dried overnight at 70° to 75° C. in order to determine their moisture contents and their dry weights.

During the early summer of 1960, leaf sample collections were continued at weekly intervals. Later, however, only the 16th leaf was sampled at bi-weekly intervals since it became apparent that the range in leaf moisture concentrations found in the tissues sampled was too small to be useful as moisture index tissues. The weight of the 16th leaf seemed to be related to the soil moisture tension regime.

Circumference measurements, of about six selected hermaphroditic trees in each plot, were made at 6-week intervals at about 6 inches from the ground. Measurements were made each time at the same points. The measurements were then squared before comparisons were made between treatment means or before applying them in statistical analyses (*2*). Since the circumference ceased to increase significantly during the summer of 1960, the measurements were discontinued thereafter.

Fruit yield data were obtained from December 1959 to May 1961. Fruits from one plot were segregated into hermaphroditic types and the numbers and weights of each type were recorded at semi-weekly intervals. Yield was expressed as pounds of fruit per tree.

Duncan's multiple range test (*5*) was used to determine significance of any difference in the treatment means of the yield data. Correlation and regression methods of statistical analyses were used to show relationships between pertinent factors. Whenever soil moisture tension was used as one of the variables, its value was taken just before an irrigation application.

RESULTS AND DISCUSSION

Moisture Release Curves

Moisture release curves of Waimanalo soil at two depths (fig. 1) indicate that their shapes are quite similar, although their soil moisture constants are distinctly different. The gradual slope of the curves indicates that

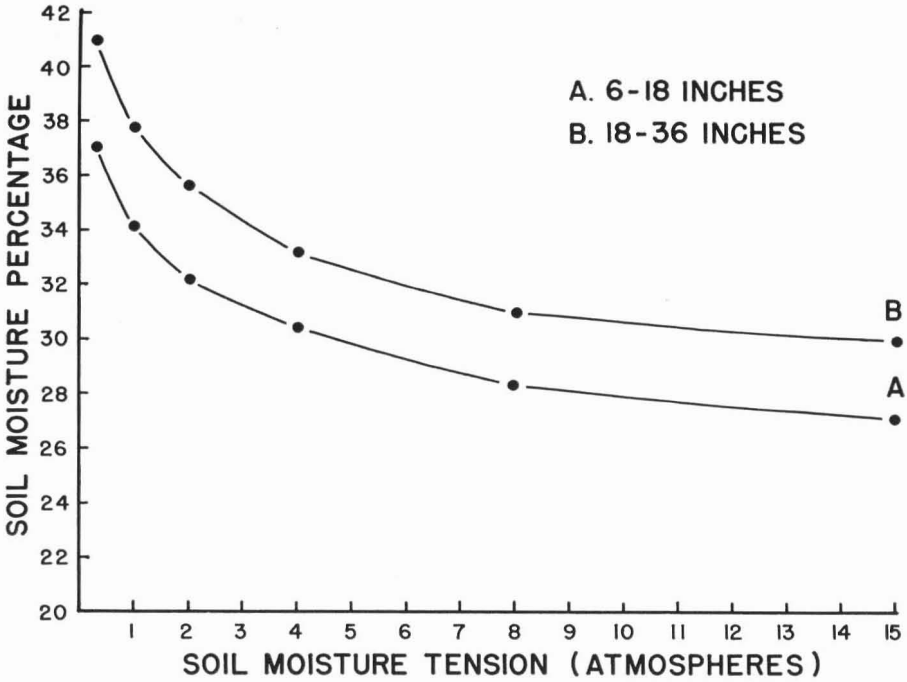


FIG. 1. Moisture release curves of Waimanalo soil at two indicated depths.

moisture is released more gradually than it is released from some soils of the Wahiawa family which contain the kaolinitic type of clay (*6*). The higher soil moisture constants for the soil sampled at the greater depth indicate that the clay content is higher than in the soil from the shallower depth.

Available moisture for the soil sampled from the 6- to 18-inch depth is 9.9 percent, while for the 18- to 36-inch depth it is 11.1 percent. If it is assumed that growth of a plant is substantially reduced after 60 percent of the available soil moisture is released, then the soil moisture tension at that critical point was 3.2 atmospheres and 3.1 atmospheres for the soils sampled from the 6- to 18-inch depth and the 18- to 30-inch depth, respectively.

GROWTH

Leaf Moisture

No significant statistical relationships between soil moisture tension and the moisture contents of either the 16th petiole or the 16th blade are indicated in table 3. However, highly significant correlation and regression coefficients for the moisture content of the 8th petiole are indicated

for the 1959 experiment. However, in 1960, the correlation coefficient was significant at only the 5 percent level.

TABLE 3. Relationships of soil moisture tension to indicated factors by use of correlation and regression methods of statistics. The regression coefficients are expressed as per atmosphere of soil moisture tension.

FACTORS	n	CORRELATION COEFFICIENT (r)	REGRESSION COEFFICIENT (b)
Leaf moisture			
8th petiole, 1959 experiment	36	—.56**	— .13 percent**
16th petiole, 1959 experiment	36	—.26 n.s.	— .003 percent**
16th blade, 1959 experiment	36	—.30 n.s.	— .09 percent n.s.
8th petiole, 1960 experiment	25	—.41*	— .10 percent n.s.
Dry weight, 16th leaf, 1959 experiment	36	—.56**	— 1.26 grams**
Dry weight, 16th leaf, 1960 experiment	48	—.59**	— 1.11 grams**
(Circumference)^2, 1959 experiment	46	—.63**	—11.6 inches**

*Significant at probability of .05.
**Significant at probability of .01.
n.s. Not significant.

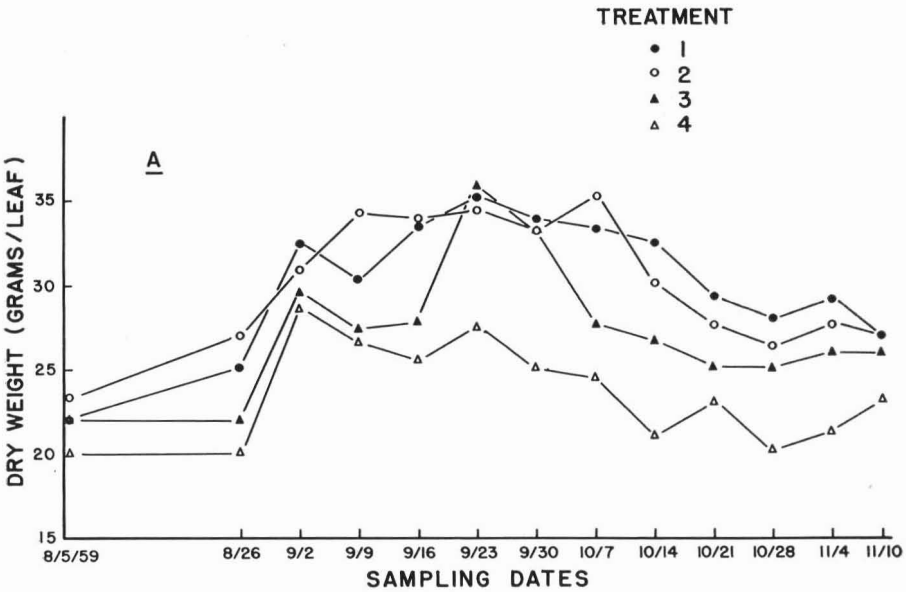
Although significant statistical relationships of soil moisture tension to moisture in the 8th petiole were indicated, use of the latter as a moisture index tissue may be limited due to the narrow range of concentration found in this tissue. Its moisture content ranged from 91.4 percent to 93.3 percent throughout the experiments.

Dry Weights of 16th Leaves

Comparisons of green weights between treatments are not presented because they are so closely related to their dry weights that results obtained were essentially the same.

Figure 2A presents the dry weights of the 16th leaves for the 1959 experiment. In general, no significant difference in dry weight is indicated between plants of treatments 1 and 2. Intermediate dry weights are indicated for plants of treatment 3. Significant difference in dry weight is indicated between plants of treatment 4 and the other treatments, beginning on September 23 and continuing until about November 10, when irrigation treatments were discontinued.

Figure 2B presents the dry weights of 16th leaves for the 1960 experiment. Weights of leaves in treatment 1 were significantly greater than those of other treatments beginning on July 6 and continuing to October. Plants in treatments 2 and 3 had intermediate dry weights while plants in treatment 4 had lower dry weights until August 17, when they had higher dry weights than previously. However, even after this date significant difference is indicated between plants of this treatment and plants of treatment 1.



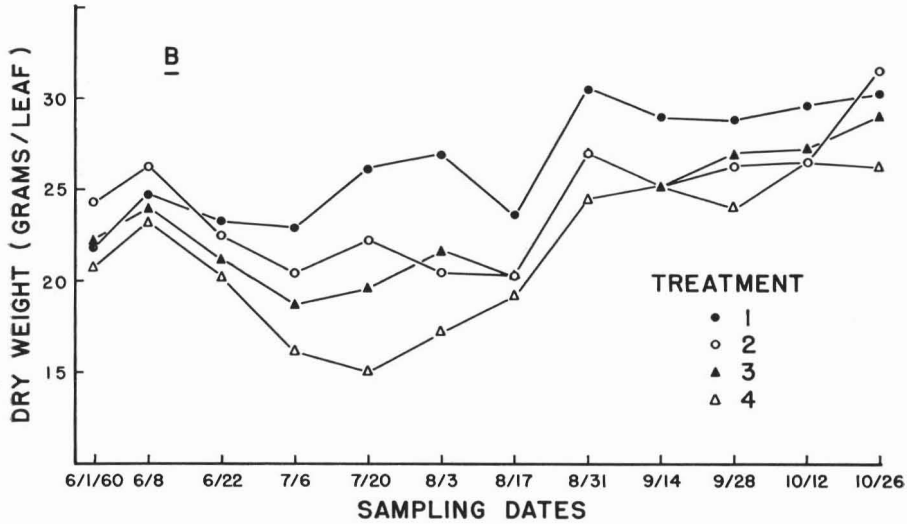


FIG. 2. Dry weights of the 16th leaf sampled from plants of the various treatments at indicated dates. A—1959 data. B—1960 data.

The 1959 data show that for treatments in which water was not limiting growth (treatments 1, 2, and 3), there was a gradual rise in leaf weights until a peak was reached at about September 23. From this period on, a gradual decline in leaf weights is indicated. Although plants at this stage had enlarging fruits, mature fruits were not harvested until December of that year. Therefore, the decline in leaf weights is associated with the onset of mature fruit production and with the approach of less favorable growth conditions.

In 1960, although differences in leaf weights are evident between plants of each treatment, no definite rise in leaf weights is indicated. This may be attributed to the continuous production of fruits during this stage of growth. The higher leaf weights from August onward into October may be associated with the lesser number of fruits produced during this period (see fig. 4).

Significant correlation coefficients and regression coefficients are shown between soil moisture tension and dry weights of the 16th leaf (table 3).

Circumference of Trunk

Difference in size of the trunk is indicated between treatments beginning on September 1, 1959, and continuing to November 23 (fig. 3). The apparent increase in trunk growth of plants in treatment 4 over the others during the winter period was undoubtedly due to the fact that these plants produced a lower fruit yield than the others and may have had more carbohydrate available for the winter growth.

Another aspect of circumference growth shown in figure 3 is that further increase in growth of plants in treatments 1, 2, and 3, after January 5, 1960, was very small. This may be associated with a continuous production of fruits from these plants from about this time.

A highly significant correlation coefficient and a highly significant regression coefficient between soil moisture tension and circumference of the trunk are shown in table 3. Other significant relationships are shown in table 4.

TABLE 4. Correlation coefficients and regression coefficients between indicated factors (Leaf moisture contents were from the 8th leaf. Data from 1959 experiment.)

FACTORS	n	CORRELATION COEFFICIENT (r)	REGRESSION COEFFICIENT (b)
Leaf moisture (X) * vs. leaf weight (Y) *	36	.45**	4.43 grams/percent**
Leaf moisture (X) vs. (circumference)^2	84	.52**	25.59 inches/percent**
Leaf weight (X) vs. (circumference)^2	84	.60**	2.21 inches/gram**
(Circumference)^2 vs. pounds fruit (Y)	55	.62**	.20 pound/inch**

*X refers to independent variable and Y to dependent variable.
**Significant at probability of .01.

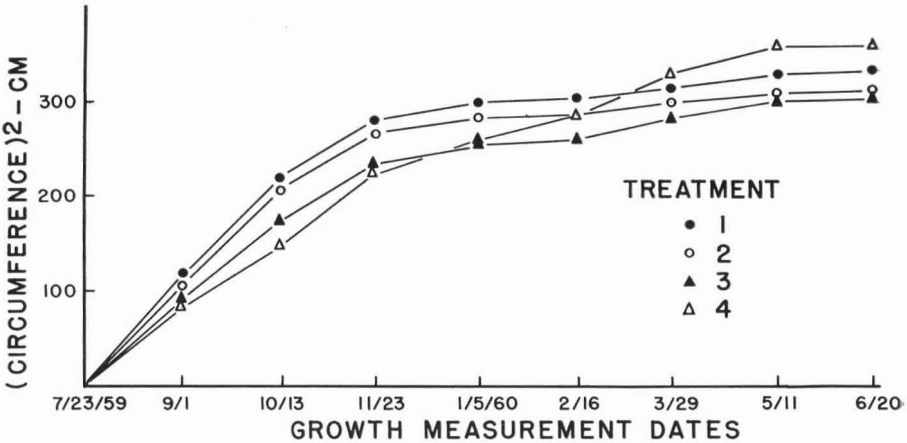


FIG. 3. Size of plants (circumference squared) from the various treatments at indicated dates.

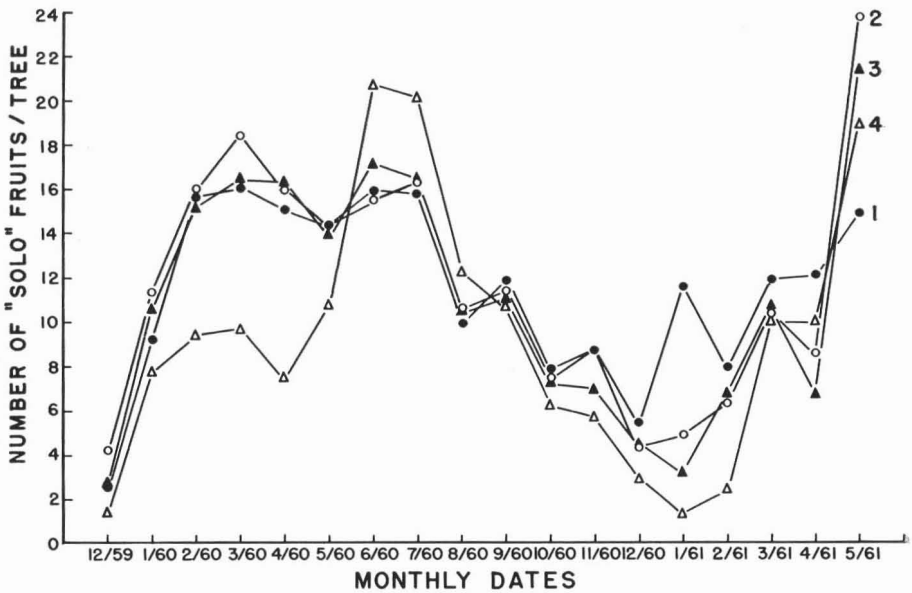


FIG. 4. The number of fruits produced per tree by plants of the various treatments by months.

YIELD

Yield for treatment 4 during the period December 2, 1959, to May 3, 1960 (table 5), was significantly less than for the other treatments. However, none of the differences among treatments 1 to 3 was significant. Apparently, any growth difference between plants in treatment 3 and the first two treatments was not sufficient to induce any difference in yield in these treatments.

Any difference in yield induced by the treatments from May 6, 1960, to May 29, 1961, was not significant statistically, although difference in yield was indicated between the treatments, excepting between treatments 3 and 4.

As indicated in table 5, the difference in yield between treatments 1 and 4 and treatments 2 and 4 was significant at the 5 percent level during the 18-month period in which yield was taken.

TABLE 5. Fruits produced by plants in various treatments during indicated dates, and expressed as pounds per tree

TREATMENT	12/2/59 TO 5/3/60*	5/6/60 TO 5/29/61**	12/2/59 TO 5/29/61***
1	71.4	167.2	238.6
2	76.2	158.0	234.1
3	71.0	152.4	223.4
4	43.2	152.6	195.8

*The difference between any 2 treatments which are not connected by a line is significant at 1 percent level of probability.
**None of the difference between treatments is significant.
***The difference between any 2 treatments which are not connected by a line is significant at the 5 percent level of probability.

The number of fruits produced by plants in each treatment on a monthly basis (fig. 4) indicates that whenever plants were not under serious moisture stress (treatments 1, 2, and 3), productivity at the early stage remained high. Later, decline in productivity did result due largely to production of carpellodic fruits during September and October and sterile flowers in November, December, and January.

Production of fruits was seriously curtailed in treatment 4 during the early productive months. However, when moisture, due to natural precipitation, became available to the plants from November 1959, a tremendous increase in growth and production of fruits resulted (figs. 3 and 4).

DISCUSSION

Growth and yield responses of papaya plants to various soil moisture tensions were shown. Although differences in growth (circumference of trunk, dry weight of 16th leaf) between each treatment were indicated during the 1959 period when the plants were under differential soil moisture tension, differences in yield resulted only between plants which were

grown in the highest moisture tension (treatment 4) and the plants which were grown under lower soil moisture tensions (treatments 1, 2, and 3). Apparently, differences in growth between plants in the lower soil moisture tension treatments (treatments 1, 2, and 3) were not sufficient to result in differences in yield.

Response of plants, which were grown under high soil moisture tension, to subsequent availability of moisture was most striking. When moisture became available to them due to rainfall, from approximately November to April, a high rate of growth resulted, which later was reflected in the significantly greater yield of fruits produced in this treatment.

Under low soil moisture tensions (treatments 1, 2, and 3), growth rate of plants as indicated by circumference of trunk became very low from November 23, 1959, onward. This may be attributed to the continuous production of fruits beginning approximately December 1959. If this low rate of growth were due to suboptimal levels of environmental factors such as sunlight intensity or temperature, then it would be expected that higher rates of growth would have occurred in these plants beginning about May and continuing throughout the summer when both light intensity and temperature are relatively high. However, these plants did not respond to such conditions. Therefore, this depression in growth rate must be due largely to the developing fruits. A similar behavior of papaya plants is indicated in a report by Shoji *et al.* (figs. 1 and 3 in (*4*)).

Difference in yield response of plants which were experimentally placed under various soil moisture tensions during the summer of 1960 was not as high as expected. This may be due to: (1) less significant difference in moisture stress induced in the plant than the year before, and (2) the moisture requirement of the plant at this stage of growth may not be as high as formerly. These two points will be briefly discussed.

Comparisons of difference in leaf moisture between plants under various soil moisture tensions during both periods cannot be made adequately since the range in concentrations indicated in the 8th petiole was too small. However, correlation and regression coefficients determined between soil moisture tension and moisture content of the 8th petiole were highly significant for the plants treated in 1959, while only the correlation coefficient at the 5 percent level was found significant for plants treated in 1960. Moreover, the regression coefficient determined for plants in the latter period, was not significant statistically.

Comparisons of differences in dry weight of the 16th leaf for both experimental periods indicate that there were more significant differences for plants treated in the 1959 period than in 1960. This difference is especially evident during the later experimental periods of both years.

Plants that were used experimentally during the summer of 1960 had probably developed more extensive root systems and were able to absorb water more efficiently than those root systems of 1959. This was antic-

ipated and provided for by installing the soil moisture indicators deeper than before. However, even with this deeper placement, the roots of the plants at this stage must have been extensive enough to absorb moisture more efficiently than in 1959.

Furthermore, the moisture requirement of plants at this stage, when fruit production is high, may not be as critical as it is earlier when vegetative growth is at a higher rate. Trunk growth was decidedly lower than it was the year before. At this stage, sugars for the developing fruits may be of more importance than moisture.

The production of sterile flowers has been associated with the soil moisture tension regimes (*1*). A significantly greater number of sterile flowers was recorded in the higher soil moisture tension treatments as compared to the lower tension plots. Since no difference in number of carpellodic fruits between treatments was recorded, the final difference in yield may be due in part to the difference in number of sterile flowers produced in the various treatments.

SUMMARY

Papaya plants of the *Solo* variety were grown in the field at Waimanalo, Honolulu, Hawaii, under three soil moisture tension conditions ranging from .22 atmosphere to 6.3 atmospheres, during the summer of 1959. During the summer of 1960, plants were grown under four soil moisture tension levels ranging from .27 atmosphere to 7.7 atmospheres. Tensiometers were used for the two "wet" treatments and gypsum blocks for the two "drier" treatments. They were installed at the 18- and 24-inch depths during the experimental periods of 1959 and 1960, respectively.

Correlation coefficients and regression coefficients determined between soil moisture tension and leaf moisture percentages of three leaf tissues, the petiole and the blade of the most recently matured leaf (16th leaf), and the petiole of a young, rapidly expanding leaf (8th leaf), indicated high significance only for the young petiole. However, it was found that the range in concentration of leaf moisture in this tissue was too small to be useful as a moisture index tissue.

It was further determined that correlation and regression coefficients between soil moisture tension and dry weights of the 16th leaf, and between soil moisture tension and circumference of the trunk were both significant at the 1 percent level of probability.

Difference in growth response as indicated by the difference in circumference measurements as well as the difference in dry weights of the 16th leaf were indicated between treatments. However, growth rate of the circumference decreased considerably at the onset of fruit production. This fact was attributed to the developing fruits.

Yield response to the various soil moisture tension treatments for plants treated during the summer of 1959 was significant at the 1 percent level

only between the plants in the highest soil moisture tension treatment and the lower moisture tension treatments. No significant difference in yield was indicated for plants differentially treated during the summer of 1960, however. Some of the factors involved in this lack of yield response are discussed.

Difference in yield between treatments for the entire duration of the experiment indicated significance at the 5 percent level of probability between the plants of the two lowest soil moisture tensions and the plants in the highest soil moisture tension.

LITERATURE CITED

(1) AWADA, MINORU.
1961. SOIL MOISTURE TENSION IN RELATION TO FRUIT TYPES OF PAPAYA PLANTS. Hawaii Farm Science 10 (2) : 7–8.

(2) COOIL, BRUCE J., S. NAKATA, and M. AWADA.
1957. PHOSPHORUS NUTRITION OF YOUNG MACADAMIA, VARIETY KEAHOU. Hawaii Agric. Expt. Sta. Progress Notes No. 113. 15 pp.

(3) RICHARDS, L. A.
1947. PRESSURE-MEMBRANE APPARATUS, CONSTRUCTION AND USE. Agr. Eng. 28: 451.

(4) SHOJI, KOBE, M. NAKAMURA, and M. MATSUMURA.
1958. GROWTH AND YIELD OF PAPAYA IN RELATION TO FERTILIZER APPLICATIONS. Hawaii Agric. Expt. Sta. Progress Notes No. 118. 12 pp.

(5) STEEL, ROBERT G. D., and J. H. TORRIE.
1960. PRINCIPLES AND PROCEDURES OF STATISTICS. McGraw-Hill Book Company Inc., New York.

(6) THORNE, M. D.
1950. MOISTURE CHARACTERISTICS OF SOME HAWAIIAN SOILS. Soil Sci. Soc. Amer. Proc. 14: 38–41.

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