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PRECISION IRRIGATION with SOLAR ENERGY

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TIMELY APPLICATION of water is important to crop growth and production. However, applications made too frequently are as harmful as subjecting crops to drought. Experience will help determine when a crop needs water.

Research on irrigation of various farm crops has resulted in the development of many methods for determining proper time and way of irrigating. Irrigation guides include direct measurement of soil moisture by inserting or placing various devices in the soil, formulas based on climatological data *(2, 14, 15, 19, 21, 22)*, change in leaf color *(1)*, water evaporation from porous surfaces *(6, 11)*, various types of irrigation gauges *(4, 18)*, and measurements of stomatal opening by infiltration of liquids *(8)*.

The term "evapotranspiration" is used to describe depletion of soil moisture. This is the summation of direct evaporation from the soil surface, plant utilization, and transpiration.

Irrigation research in greenhouses *(13, 16)* has emphasized means of uniformly distributing water. From this has developed many usable and reliable systems, such as perforated plastic pipe or tubing, special nozzles, and various systems of using individual tubes for potted plants.

Considerably less attention has been given the problem of determining when water should be applied, using some measurable standard rather than methods depending on the experience of the grower. Tensiometers are usable instruments for greenhouse conditions *(7, 10, 13, 16)*. Problems of proper placement, maintaining proper operations, and limited use with potted plants indicate the desirability of other measurements to determine irrigation needs of crops under greenhouse conditions.

SOLAR ENERGY AND SOIL MOISTURE

The amount of solar energy influences the amount of evapotranspiration. Formulas to estimate evapotranspiration include some measure of light. Direct measures of solar energy have been highly correlated with evapotranspiration *(9, 12)*. In these studies expensive instruments measuring incoming or net radiation have been used. Because of practical limitations in using such expensive instruments, indirect measurements of solar energy by use of black and white Livingston atmometers have been suggested.

Tukey, Fluck, and Marsh *(20)* developed a simple, inexpensive portable instrument that measures incoming radiation. Measurements of solar radiation with this light integrating totalizer was highly correlated with measurements made with the Epply pyrheliometer.

RELATION OF EVAPOTRANSPIRATION AND SOLAR ENERGY

In experiments at the Auburn University Agricultural Experiment Station, the amount of evapotranspiration was highly correlated to the amount of incident solar energy as determined with an illumination totalizer. Highly significant correlations were found between plants grown in pots and those in benches, Table 1.

Significant correlations were also found between evapotranspiration and evaporation of water from Livingston atmometers.

TABLE 1. CORRELATION COEFFICIENTS OF EVAPOTRANSPIRATION AND MEASURES OF SOME ENVIRONMENTAL FACTORS

Factors compared	Correlation coefficients		
	Potted plants		Plants in benches
	1st period	2nd period	
Evapotranspiration to:			
Solar energy	+ .98	+ .98	+ .93
Evaporation from white atmometer	+ .98	+ .98	----
Difference in evaporation of black and white atmometer	+ .98	+ .98	+ .93
Solar energy + evaporation from a white atmometer	+ .96	+.98	----

Evaporation of water from white atmometers is influenced by humidity. Light as well as humidity influence evaporation from a black atmometer.

Results of experiments reported indicate the possibility of using either solar energy measurements, or the difference in evaporation between a black and white atmometer as a means of determining evapotranspiration from greenhouse soils and to determine the need for irrigation. The combined use of both measures did not increase precision.

There was a problem of keeping the atmometers clean while in use. Dust and other particles tend to cling to the atmometers. In addition, algae growth occurred on its surface, much as it does on the surface of clay pots. Weekly washings were necessary to keep the surface clean.

Because of the problem of keeping the atmometers clean and the possibility of completely automating watering operation, the use of illumination totalizers is preferred as a means of determining irrigation frequency. Instrumentation is simple and inexpensive.

GROWTH AND QUALITY OF CROPS

A number of crops was grown for studying the practical use of solar energy measurements to determine irrigation needs. Crops for cut flowers included pompom and standard chrysanthemum, snapdragon, and aster. Crops for potting included chrysanthemum, rose, hydrangea, azalea, and Easter lily. Methods based on experience and tensiometers where applicable were used as comparisons.

The results of these studies, Tables 2 and 3, show that applying water on the basis of solar energy measurements was practical. The quality of the products-cut flowers or potted plants was not

TABLE 2. INFLUENCE OF LIGHT ACCUMULATION AT THREE LEVELS BETWEEN IRRIGATIONS ON GROWTH AND QUALITY OF POT PLANTS

Crop	Measure of growth and quality	Check	Light accumulation 1X	2X	4X
Easter Lily	Flowers, av. no.	4.4	4.7	4.0	4.2
(1 plant per	Plant height, in.	22.7	22.7	18.9	15.8
6-inch pot)	Length of flower, in.	6.0	6.0	5.5	4.2
Chrysanthemum	Flowers, av. no.	3.0	3.4	3.0	2.5
(1 plant per	Plant height, in.	6.6	7.0	6.6	5.5
4-inch pot)	Fresh weight of tops, g.	14.0	15.5	11.6	6.5

TABLE 3. INFLUENCE OF IRRIGATION ON BASIS OF LIGHT ON GROWTH AND QUALITY OF STANDARD CHRYSANTHEMUM FLOWERS

Item	Method of determining irrgiation need	
	Solar energy	Check
Stem length—Average, in.	36.6	32.9
Coef. of variation, pct.	9.8	8.2
Weight of shoot—Average, oz.	3.2	3.2
Coef. of variation, pct.	19.6	21.8
Salable flowers per sq. ft.	4.8	4.4
Grade distribution[1] Extra fancy, pct.	7.0	7.0
Fancy, pct.	60.0	55.0
No. 1, pct.	21.5	26.5
Design, pct.	2.0	2.0
Culls, pct.	9.5	9.5

[1] Standards developed by Gaylord and Hoxie *(7)*.

reduced and in some cases the quality was superior. Solar energy measurements provided a definite standard easily understood.

INTERVAL BETWEEN IRRIGATIONS

Experiments conducted at Auburn were also to determine the amount of light accumulation desirable between irrigations. The soil held 0.42 in. of available water at field capacity for each 6 inch layer.

At the 2X interval, Table 4, weight or stem length was not influenced. However, flower size was reduced and consequently a larger number of flowers was of lower grades. Noticeable wilting of foliage of large plants occurred when the 2X interval was used.

Plant size or stage of growth was important in utilizing solar energy as an indicator of water needs.

Soon after potting chrysanthemum plants, the frequency of irrigation for the 2X light treatment was approximately the same

TABLE 4. INFLUENCE OF LIGHT ACCUMULATION BETWEEN IRRIGATIONS ON QUALITY OF CHRYSANTHEMUMS

Variety	Light accumulation between irrigations	Distribution by grades[1]				Av. stem length	Av. wt. per stem	Av. flower diameter
		Extra fancy	Fancy	No. 1	Design			
		Pct.	*Pct.*	*Pct.*	*Pct.*	*In.*	*Oz.*	*In.*
Shasta	1X	37.5	34.5	11.7	0.6	35.9	2.4	----
	2X	33.3	45.0	9.9	0.6	35.6	2.3	----
Giant Betsy	1X	0.8	50.0	35.0	0.8	30.6	3.0	5.0
Ross	2X	0.0	24.1	69.1	0.0	30.3	2.9	4.6

[1] Standards developed by Gaylord and Hoxie *(7)*.

TABLE 5. NUMBER OF IRRIGATIONS FOR POTTED CHRYSANTHEMUMS WITH VARYING AMOUNTS OF LIGHT ACCUMULATION BETWEEN IRRIGATIONS

Date	Check	Irrigation applications Light accumulation 1X	2X
	No.	*No.*	*No.*
June 21-30	4	9	5
July 1-10	5	7	4
July 11-20	6	8	4
July 21-31	10	10	6
Aug. 1-10	7	5	3

as the control plants, Table 5. However, after 4 weeks of growth, frequency of irrigation for the 1X treatment was more nearly that of the check. This development was expected as the consumptive use of water increases with plant growth.

Type of pot and soil mixture also influenced the results. As irrigation frequency was reduced, that is more light between irrigations, the amount of plant growth decreased because of insufficient amounts of water. This decrease was less severe in a sand-peat-clay soil mixture than a sand-peat mixture. The sand-peat-clay mixture held more available water than the sand-peat mixture. Use of plastic pots also resulted in larger plants. The amount of evapotranspiration would be less, resulting in more moisture for plant growth in plastic pots that are not porous. With plastic pots, soil mixture did not influence the results when water was applied frequently. But with clay pots, there was a definite increase in plant size with the sand-peat-clay mixture.

COMPLETELY AUTOMATIC IRRIGATION

Systems designed for automatic surface irrigation have been proposed using tensiometers *(17)* or moisture blocks *(5)*. To study

TABLE 6. INFLUENCE OF POT TYPE AND SOIL MIXTURE ON GROWTH OF CHRYSANTHEMUMS IRRIGATED WITH VARYING AMOUNTS OF LIGHT BETWEEN APPLICATIONS

Type of pot	Soil mixture	Fresh weight of tops 1X[1]	2X[1]	4X[1]
		g	*g*	*g*
Clay	Sand-peat	11.5	5.7	3.0
	Sand-peat-clay	14.7	7.1	3.1
Plastic	Sand-peat	16.3	7.3	3.3
	Sand-peat-clay	16.8	9.9	5.7

[1] Light accumulation between irrigations.

complete automation, a series of tests were conducted using chrysanthemums as test plants.

Watering at periodic intervals such as daily or every third day often resulted in excellent growth of plants. However, it was noted that soil often was too wet or became too dry, depending on weather and size of plant. While this system might be usable, efficient water use correlated to actual plant needs was not obtainable.

Soil moisture tensiometers were modified to become switches *(17)* that would turn on the water. It was difficult to keep the system working properly. Variable results because of difficulty in locating tensiometers in a representative area or improper functioning were experienced.

Automatically irrigating by means of measuring accumulated solar energy proved effective. Production and quality were excellent, Table 7.

TABLE 7. CHRYSANTHEMUMS GROWN WITH COMPLETELY AUTOMATED IRRIGATION, USING LIGHT ENERGY CONTROLS

Method to determine irrigation need	Distribution by grade[1]				Stem length		Av. wt. per stem	Coef. of var.	Prod. of salable flowers per sq. ft.
	Extra fancy	Fancy	No. 1	Design	Av.	Coef. of var.			
	Pct.	*Pct.*	*Pct.*	*Pct.*	*In.*	*Pct.*	*Oz.*	*Pct.*	*No.*
Check	8.5	53.5	26.5	2.5	38.3	7.7	3.1	25.6	4.7
Solar energy automatic control	4.0	46.0	45.0	2.5	36.1	11.6	2.7	22.0	5.0

[1] Standards by Gaylord and Hoxie *(7)*.

FACTORS TO CONSIDER FOR PRACTICAL USE

These experiments have shown the possibility of determining need for irrigation by measurements of solar energy. Semi-automatic and completely automatic operation are possible. A reliable, measurable standard is used and water application is timed to actual plant use.

Moisture loss from soils to air is a result of evaporation from the soil surface or transpiration. The relative importance of each depend in part on the amount of soil surface covered by vegetation. When the surface is completely covered with vegetation, most of the loss comes from transpiration.

TABLE 8. AMOUNT OF AVAILABLE WATER IN THREE SOIL MIXTURES

Soil Mixture	Available water
1 peat, 1 perlite	0.60 gal. per cu. ft. of mixture
1 peat, 1 sand	0.23 gal. per cu. ft. of mixture
1 clay loam, 1 peat, 1 sand	0.28 gal. per cu. ft. of mixture

Total moisture loss by evaporation and transpiration is evapotranspiration. This moisture must be replenished at the proper time for economic production of crops. Applying water too often results in poor plant growth, waste of water, and higher production costs. Delayed application results in lowering of quality and economic loss.

Major moisture loss from plants by transpiration occurs through stomates. Light is the controlling factor or key in determining the opening of the stomates. If moisture deficits do not occur, the stomates will remain open as long as plants are in light.

To properly employ this criteria of water need, the grower must consider the following factors: (1) soil mixture, (2) soil volume, (3) type of container, and (4) type of plant.

Soil mixture and volume must be considered because they regulate the amount of available water. Normally sandy soils are irrigated more frequently than clay soils, and a shallow soil is irrigated more frequently than a deep soil. For typical soil mixtures, the amounts of available water for typical soil mixtures are given in Table 8.

Soil moisture is not depleted in the same amount by plants grown under the same conditions. Size of plant as well as plant species will influence the amount of water utilized (3).

SUMMARY

Results of experiments by the Auburn University Agricultural Experiment Station, Auburn, Alabama, have shown that evapotranspiration is highly correlated to solar energy. Additionally, solar energy measurements, utilizing a simple, inexpensive illumination totalizer has been shown to be a reliable guide for determining need for irrigation. Semi-automatic and completely automatic applications of irrigation has been possible.

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