SELECTED MOISTURE RELATIONSHIPS AND IRRIGATION OF CONTAINER-GROWN NURSERY STOCK

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Jack Stanley Wikle

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By

Jack Stanley Wikle

AN ABSTRACT

Submitted to the College of Agriculture
Michigan State University of Agriculture and
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ABSTRACT

Water retaining characteristics of five growing media were determined by pressure plate and pressure membrane apparatus. The five media were: sand, clay loam, sand-peat mixture and sand-peat-clay loam mixture.

Phaseolus vulgaris plants were grown in the five media under five moisture regimes as follows: regime 1, irrigation at a moisture stress midway between waterholding capacity and 0.1 atm. stress; regime 2, irrigation at 0.1 atm. moisture stress; regime 3, irrigation at 1 atm. moisture stress; regime 4, irrigation at 5 atm. moisture stress; and regime 5, irrigation at 15 atm. moisture stress. Other *P. vulgaris* plants were grown in the sand-peat-clay loam mixture and subjected to sub v.s. surface irrigation treatments and polyethylene contrasted with no polyethylene around the growing media.

Forsythia intermedia plants were grown under similar treatments with the exception that sand, peat and clay loam were not used.

Evaluations of oven dry weights of roots and shoots gave the following results:

Under equivalent moisture regimes, growth of *P. vulgaris* roots and shoots was significantly less in sand medium than in sand-peat or in sand-peat-clay loam mixtures. Root and shoot growth of *P. vulgaris* and *F. intermedia* plants

grown in sand-peat and sand-peat-clay loam mixtures was not significantly different.

Maximum root and shoot growth of the P. vulgaris and F. intermedia plants resulted under moisture regime 2.

Growth of P. vulgaris roots and shoots under moisture regime 1 was equal to that under moisture regime 2, however growth of F. intermedia roots and shoots was significantly reduced under moisture regime 1.

Moisture regime 3 resulted in P. vulgaris root and shoot growth and F. intermedia shoot growth equal to that under regime 2, however, F. intermedia root growth was significantly reduced.

Under moisture regime 4, P. vulgaris shoot growth and F. intermedia root growth were significantly less than under regime 3. P. vulgaris root growth and F. intermedia shoot growth were not limited significantly although values approached significance.

Moisture regime 5 resulted in growth of P. vulgaris roots equal to that under regime 4, and significantly reduced growth of P. vulgaris shoots and F. intermedia roots and shoots.

F. intermedia plants subjected to sub and surface irrigation treatments and to polyethylene and no-polyethylene treatments exhibited their maximum growth under moisture regimes 3 and 4. Growth was reduced by regimes 1, 2 and 5.

Sub irrigation reduced root growth of *F. intermedia* in contrast to surface irrigation, however, shoot growth was not affected.

The polyethylene treatment in contrast to the no-polyethylene treatment significantly reduced both root and shoot growth of *F. intermedia*.

The text is augmented by 12 tables and 2 figures. Data on frequency of irrigation necessary under various moisture regimes and treatments is included.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Page

INTRODUCTION

Growing of nursery stock in containers is an established practice in California (Baker 1957) and is rapidly increasing in importance in many other areas of the United States (Reisch 1959).

Container production has several advantages over field culture. Since growing conditions for container plants are more uniform and more readily controlled by the grower, it is possible to increase standardization and mechanization of cultural procedures. Another advantage is that container production makes possible extending the marketing period from the spring planting season through the summer . Furthermore some plants can be sold when they are in bloom and most appealing, and the container can be a more attractive package than the usual burlap wrap used for field stock.

Maintenance of adequate moisture levels for optimum growth of container plants has been a major problem. Since soil in containers dries more rapidly than soil under field conditions, plants must be irrigated frequently. This irrigation often requires much expensive hand labor. Little literature directly concerned with moisture relationships and problems in irrigation of container plants is available (Baker 1957 and Reisch 1959).

The following study was initiated to obtain information for establishing irrigation practices for container grown nursery stock.

REVIEW OF LITERATURE

Pioneers in biological research and more recent workers, have compiled an impressive mass of literature in the field of soil water and plant growth relationships. It has long been recognized that the water holding capacity of fine textured soils is generally greater than that of coarse textured soils. The common method of evaluating amounts of water held by soils has been oven drying of the soils to determine the percentage of moisture held on an oven dry weight basis.

The Available Moisture Range. - - - Research by Briggs and McLane (1907) and Briggs and Shantz (1912a) has become classic and is frequently cited in current literature. Briggs and McLane (1907) established that the moisture equivalent, which is the percentage of moisture held by a saturated soil after being subjected to a force of 1000 times that of gravity in a centrifuge, is a characteristic moisture retaining value for a given soil. The moisture equivalent was found to closely approximate field capacity for many soils particularly those of fine texture (Veihmeyer and Hendrickson 1931).

Briggs and Shantz (1912a) studied many plants to determine variations in ability of plants to reduce the moisture content of a soil before the plants exhibited permanent wilting (wilted lower leaves do not regain

turgor when exposed to humid atmosphere), and concluded that variations in abilities of different plants to extract the moisture content of a soil before permanent wilting takes place were insignificant. They designated the percentage of water held at permanent wilting as the wilting coefficient below which plant growth would not take place. They noted also that plants native to dry regions demonstrated no greater ability to reduce soil moisture content prior to permanent wilting than other plants.

Thus the moisture equivalent as a value for the moisture content of a soil at field capacity and the wilting coefficient as a value for the moisture content of a soil at cessation of plant growth, were established as constants which have been increasingly utilized as limits of the range of moisture available to plants in a soil.

Briggs and Shantz (1912b) also determined that the percentage of moisture held by a soil at the wilting coefficient could be calculated from the moisture equivalent by dividing it by 1.84. However, Veihmeyer and Hendrickson (1928) demonstrated that the moisture content at permanent wilting could not be calculated reliably from the moisture equivalent. Veihmeyer and Hendrickson also noted at that time that plants are able to reduce the percent moisture content of different soils to dif-

ferent stages of dryness before permanent wilting results.

Veihmeyer and Hendrickson (1931) have preferred to use field capacity instead of moisture equivalent in their work as being most representative of the upper limit of moisture generally utilized by plants. They feel that field capacity is an acceptably definite soil moisture content at which drainage is reduced to a constant level if there are no discontinuities in structure or texture and no water table. Veihmeyer and Hendrickson (1934) concluded that the simplest and most accurate method of determining the permanent wilting percentage (term in current usage for the wilting coefficient of Briggs and Shantz) was growing and wilting plants in the soil. They also noted that the importance of surface forces in soils in causing wilting of plants is indicated by experiments showing that the permanent wilting point for a given soil does not vary with kind of plant or climatic conditions. Methods of measuring field capacity, the permanent wilting percentage of soils and the importance of these measurements have been reviewed by Veihmeyer and Hendrickson(1949).

Breazele and McGeorge (1949) have proposed another method of determining the wilting percentage of soils. This method involves the jacketing of small amounts of

soil on tomato plant stems. They found that the adventitious roots which developed in the soil would bring the moisture content of the soil to a constant level by either reducing the moisture content of moist soils or increasing the moisture content of dry soils. The authors feel that this moisture level can be taken as the wilting percentage on the basis of comparisons with the wilting percentage computed by dividing the moisture equivalent by 1.84.

Fallacy of Maintaining Moisture Levels below Field Capacity.- - - Shantz (1924) pointed out that practically all experiments on plant growth at differing moisture levels, which had been conducted previously, had been designed without adequate knowledge of soil moisture conditions and the difficulties of controlling soil moisture. Two common errors were comparing unlike soils at the same percentages of saturation and trying to bring dry soil to a certain percentage of moisture below field capacity by adding water to the surface.

Veihmeyer and Hendrickson (1927) and Hendrickson and Veihmeyer (1933) reiterated the point made by Shantz, that achieving any uniform moisture level between field capacity and the permanent wilting percentage by application of water to soils on which plants are growing is impossible. Veihmeyer and Hendrickson (1927) also in-

dicated that contrary to the then popular belief, that water moves with considerable speed by capillarity from moist to dryer soils, their results showed that movement is slow in rate and slight in both amount and extent.

Moisture Regime Experiments and Availability of Water within the Available Range. - - - Recognition of the impossibility of maintaining moisture levels between field capacity and the permanent wilting percentage resulted in what are commonly called moisture regime experiments in which soils are allowed to dry to various moisture levels and then irrigated sufficiently to bring the total volume of soil to field capacity.

On the basis of their moisture regime experiments with fruit trees and container plants, Veihmeyer and Hendrickson (1927) and Hendrickson and Veihmeyer (1933) stated that results indicated soil moisture is equally available to plants at all soil moisture contents from field capacity to about the permanent wilting point, and that there is no relationship between moisture content and either use of water or growth in length of plants within this range.

Since that time, conflicting evidence has been presented for and against water being equally available to plants throughout the available moisture range (field capacity to permanent wilting percentage).

In more current work, Hendrickson and Veihmeyer (1950) subjected walnut trees to two moisture regimes, a wet treatment and a dry treatment. With both treatments, moisture levels dropped to the wilting percentage on occasions, but the moisture percentages for the dry treatment were reduced lower and for longer durations. Moisture determinations were made by the soil sampling technique and growth was recorded by measuring increase in the trunk diameter. In this instance, less growth of wet treatment trees than dry treatment trees was attributed to a difference in nitrogen levels between treatments. However, the authors took issue with evidence by Allemendinger et. al. (1943), Kenworthy (1949) and others who found that moisture was not equally available in the available range. Citing the results of the above walnut tree experiment, Hendrickson and Veihmeyer state that their belief in water being equally available is further justified and that greatest growth does not result from maintaining soil moisture high in the available range.

The most plausible reason of those advanced by other workers, for Hendrickson's and Veihmeyer 's findings is that most of their work was done with sandy soils which hold nearly the entire amount of water in the available range at very low tensions.

In the research mentioned above, Allemendinger et.al.

(1943) and Kenworthy (1949) conducted similar experiments in which apple trees were grown in containers and times for irrigation were determined by tensiometer readings for the wetter levels and by wilting of leaves at the lower levels. Treatments were irrigation when 20,40 60,80 and 100 percent of the available water was removed. In both cases allowing 80 percent of the available moisture to be removed before irrigation, resulted in significant reductions in tree growth indicating that water was not equally available throughout the available range.

Working with beans, Ayers et. al. (1943) studied the relationships of salt concentration and moisture tensions with bean growth and yield. The beans were irrigated when water was reduced to the point that it was held by the following tensions: 250 cm. of water, 750 cm. of water, and approaching 15 atm. (plants appreciably wilted by mid morning). They found that bean growth and yield were reduced as the soil moisture tension at the time of irrigation was increased, even though beans in the first two treatments were always above the wilting points.

Blair et. al. (1950) grew sunflowers in containers of soil for which weights had been calculated at various moisture levels. The containers were weighed daily. The time rate of elongation of sunflower stems was mea-

sured in relation to soil moisture depletion following the final irrigation. They found that the time rate of stem elongation of the sunflowers was markedly reduced before half of the available water was depleted, and that the rate of stem elongation dropped to zero during the extraction of the last quarter of the available soil water and before the permanent wilting percentage was attained.

Wenger (1952) used the weighing technique to maintain three moisture levels on sweet gum and pine seedlings grown in containers in the greenhouse. The seedlings were grown on three soils: clay, silty clay loam and sand. Treatments were moisture level maintained at the moisture equivalent, irrigation when moisture level dropped to 60% of the available moisture and irrigation when moisture level dropped to 20% of the available moisture. Significant differences in growth in length and increase in fresh weight were found between maintaining the moisture level at the moisture equivalent and irrigating when 20% of the available moisture remained.

Stanhill (1957) reviewed and analyzed the previous water regime experiments (soil allowed to dry to definite point and water is applied to bring it back to field capacity). More than eighty percent of the papers reviewed indicated that growth was affected by differences in

available water before the soil was rewetted. No papers were included in which soil moisture was reduced to the wilting percentage for more than a short period of time. In all papers reporting significant results except one (carrot seed crop), greatest yields were recorded at highest moisture levels. The ratio of positive to negative results was significantly greater in experiments with annual plants than in experiments with perennial plants. The ratio was significantly smaller in field experiments than in experiments with plants in containers, and significantly greater when vegetative growth was measured than when reproductive characteristics were evaluated. There was no significance in the ratios when an available water scale was used contrasted to a soil moisture tension scale, or when positive and negative results ratios were compared in respect to date of publication.

Gingrich and Russell (1957) compared growth responses of corn roots to seven soil moisture tensions and corresponding osmotic stresses. They found that growth of the corn roots showed a linear response to osmotic stress throughout the 1/3 to 12 atm. range used. On the other hand, growth responses to changes in moisture tension were linear except in the 1 to 3 atm. range. The authors believed that the effect of water transmission characteristics of the soil must be most pronounced

in the 1 to 3 atm. range.

Jones and Johnson (1958) used tensiometers and gypsum moisture blocks to measure available moisture in field plots of onions and potatoes. Both crops responded to irrigation at .3 atm. tension (80% of the available water remaining), while delaying irrigation until 1.2 atm. tension (40% of the available water remaining) had a very detrimental effect on both crops.

Woodhams and Kozlowski (1954) have studied the effects of soil moisture stress on carbohydrate development in bean and tomato plants. The plants were grown under three moisture regimes and analyzed for starch and sugars. Results indicated that appreciable moisture stress is imposed on roots before moisture is depleted to the permanent wilting percentage and that each developed stress effects changes in the metabolic status of the plants as indicated by differences in carbohydrate reserves.

<u>Percent of Available Moisture Range v.s. Soil Moisture Stress</u>.- - - It should be noted that in the preceeding review of moisture regime experiments, some workers have measured moisture as percent of the available range, while others have recorded moisture available in terms of the soil moisture stress developed, usually in atmospheres or centimeters of water.

Livingston and Koketsu (1920) advocated a dynamic approach to measuring the water supplying power of soils by use of porous porcelain absorbing cones. Using these cones they found that the water supplying power of several soil combinations was the same at permanent wilting. Later work has developed the feeling among research workers in soil water and plant relations (Kramer 1949, Richards and Wadleigh 1952) that the tension with which water is held by the soil (soil moisture stress) is more significant for use in comparing plant responses to differing moisture levels and different soils than is percent moisture within the available range.

Moisture retention curves obtained by plotting moisture stress against percentage of water held by a soil indicate not only percent moisture available but the tensions which must be applied by plants to take up the water. Note that coarse soils hold most of their available water at low tensions while fine textured soils with wider ranges of available moisture hold much water at the higher tensions.

Richards and Weaver who have done extensive research on moisture stress and methods of measuring it, have developed the pressure plate and the pressure membrane. These devices have been accepted as the most convenient means for measuring the soil moisture stress and the per-

cent moisture content as they interact within the available moisture range (Richards and Wadleigh 1952).

Richards and Weaver (1943) have compared permanent wilting percentages and moisture equivalent values determined with sunflower seedlings and centrifuge, with 1/3 atm. and 15 atm. percentages determined with the suction plate and the pressure membrane. They found that the 1/3 atm. percentage corresponds closely to the moisture equivalent for coarse textured soils, and that for 102 of the 119 soils tested the permanent wilting percentage is in the range between the 15 atm. percentage and 1.5% of the moisture above that figure.

Richards and Weaver (1944) reported that for 64 of 71 soils, the 15 atm. percentage was found to be between the first permanent wilting percentage (permanent wilting of lower leaves) and the ultimate wilting percentage (permanent wilting of all leaves). Also on the average for the soils studied, the 1/3 atm. percentage corresponded closely to the moisture equivalent. They concluded that tensiometers, suction plate, pressure plate, pressure membrane or centrifuge may be used for determining equivalent negative pressure or soil moisture tension but cannot be used for determining free energy without disregarding osmotic effects.

Soil Amendments and Effect on Available Moisture Capacity. - - - Another aspect of concern in considering

the available moisture capacities of soils is the effect of soil amendments that are sometimes added to change water holding characteristics or structure.

McCool (1932) reported that adding peat and fertilizer salts to sand soils resulted in satisfactory growing media. He noted that optimum ratios of sand to peat were low while optimum ratios of finer textured soils to peat were higher.

Feustel and Byers (1936) found that no moisture economy resulted from adding peat up to equal parts by volume to clay loam soil. Mixtures of peat with a clay loam were capable of absorbing 40 to 50 percent more moisture (on volume basis) than clay loam alone, but an increased evaporation rate and higher moisture content at the wilting point were said to counteract the initially higher moisture holding capacity. However, they did find that improved moisture conditions may be obtained by incorporating peat with sand or sandy soils.

Tukey and Brase (1938) grew apple trees in boxes of soil and in boxes with soil and peat mixtures. Water was added as necessary to maintain the boxes at several predetermined weights (not a moisture regime experiment as not enough water was added to bring boxes to field capacity or moisture equivalent). They found that addition of peat to soil (50% by volume) increased

growth of roots in all cases and of shoots in most cases. The effect of the peat was attributed to better contact of soil with roots, improved aeration, easier penetration of rainfall and less runoff, and easier penetration of roots because of decreased density.

Havis (1943) reported that differences in organic matter content of Chenango loam resulting from additions of manure over a twenty-seven year period did not result in a statistically significant increase in available moisture, while with a Chenango fine sandy loam, there was a significant increase in percentage of available water in the manured plots.

Jamison (1953) reached the following conclusions by use of moisture tension determinations: for most fine textured soils with unrestricted drainage, increases in total porosity through tillage, granulation or addition of organic matter results in increased air capacity and unavailable water capacity along with a decrease in available water capacity; apparent increases in available water capacity stated on a percent basis are the result of diluting the medium with a lighter material; addition of peat to a sandy soil is in effect adding a fair water holder to a very poor water holder; only with coarse textured soils will increases in organic matter result in available water capacity increases

and good structure improves field water relationships because of increased water infiltration.

Moisture Loss Reduction by Plastic. - - - In relevant work, Letey and Peters (1957) used plastic material to cover corn plots. The purpose of the plastic was to prevent the wetting of low moisture treatment plots by rainfall. The authors found that efficiency of water use was much greater in covered than in uncovered plots.

Later, Shaw (1959) grew corn on plots covered with plastic material which intercepted rainfall and reduced evaporation. Soil moisture loss from plastic covered plots averaged 46 percent of the total water loss from an uncovered plot. Corn yield from the uncovered plot was 129 bushels per acre, while yield from the plastic covered plot was 121 bushels where the profile was not "recharged" with water in the spring and 104 bushels where the profile was "recharged". The reduction in yield where the profile was "recharged" was believed to be due to the condensation of moisture under the plastic, resulting in excess water in the surface soil early in the season and to very favorable weather giving high yields under the natural conditions.

PROCEDURE

During the spring and summer of 1959, determinations on moisture relationships and irrigation of container grown nursery stock were carried out on the campus of Michigan State University at East Lansing, Michigan.

The purpose of this research was to determine the effects on growth of container grown nursery stock of the following variables: five moisture regimes, five growing media, sub irrigation contrasted with surface irrigation and a polyethylene covering around the soil mass contrasted with no polyethylene covering.

Five growing media which are representative of media used for container plant production and readily available at Michigan State University were selected for use. One medium was Canadian peat which was used as it came from the bale with the exception that a few large fiber masses were discarded. The second medium was a coarse sand of the type used in greenhouse potting mixtures at M.S.U. The third medium was a clay loam which was sifted through a ½ inch mesh screen to remove larger clods and debris. The fourth medium was a mixture of 50% of the sand and 50% of the peat, and the fifth medium was composed of 1/3 sand, 1/3 peat and 1/3 clay-loam (mixture on volume basis).

The two mixtures (sand-peat and sand-peat-clay loam) were mixed to the point of presenting a fairly homogeneous appearance. The media were steam sterilized (180°C. for 30 minutes), samples to be used in laboratory determinations were taken and the media stored in the containers to be used in the experiments ("plantainers," number 10 cans crimped to somewhat less than the usual volume and punched with drainage holes).

The samples of the sterilized media were placed in soil sampling cores (metal cylinders, 3 inches in dia. and 3 inches in depth, inside dimensions). The media were retained in these cores by filter paper and cheese cloth which were fixed in position at the lower end by a rubber band. Five cores of the sand-peat-clay loam mixture and four cores of each of the other media were used. The cores were saturated by immersion and weighed (all weighing was done on a balance tared to read weight of the media and water). The amounts of water the media retained against various tensions were then determined by use of pressure plate apparatus as described by Richards (1949). The cores of media were subjected in turn to pressures of 0.1 atm., 1/3 atm., 0.5 atm. 2/3 atm. 1 atm., and 2 atm. for 48 hour periods. Weights were taken prior to each pressure change, after which

the samples were oven dried for 48 hours and the percent moisture (on oven dry basis) retained at each tension was computed by the following formula:

$$\% \text{ Moisture Retained} = \frac{(\text{Equilibrium Wt.}) - (\text{O.D. Wt})}{\text{O.D. Wt.}} \times 100$$

Five samples of the sand-peat-clay loam mixture and four samples each of the other media were then placed on the pressure membrane described by Richards (1949), and allowed to come to equilibrium with a pressure of 10 atm. Another set of samples was allowed to come to an equilibrium with a pressure of 15 atm. on the pressure membrane. After coming to equilibrium on the pressure membrane the samples were weighed, oven dried, and re-weighed, and the percentages of moisture held at 10 and 15 atmospheres were computed.

The mean percentages of water held by the five media at the various tensions are given in table 1. Moisture retention curves (Figs. 1 and 2) were plotted to illustrate graphically the relationships between soil moisture tension and moisture retention for the five media. Upon evaluation of these curves and related literature, it was decided that the moisture levels at which the containers would be irrigated should be as follows:

1. A moisture percentage midway between water hold-

TABLE 1

PERCENT MOISTURE RETENTION BY 5 MEDIA AT SATURATION, WATERHOLDING CAPACITY AND AT EQUILIBRIUM WITH VARIOUS PRESSURES ON THE PRESSURE PLATE AND THE PRESSURE MEMBRANE

Medium	Saturation	Water-holding Capacity	Pressures							
			0.1 atm.	1/3 atm.	0.5 atm.	2/3 atm.	1 atm.	2 atm.	10 atm.	15 atm.
Sand	20.00* (26.34)*	16.78 (22.1)	2.76 (3.63)	2.18 (2.87)	2.07 (2.73)	1.75 (2.30)	1.44 (1.90)	1.12 (1.48)	.67 (.88)	.67 (.88)
Peat	1064.52 (66.00)	626.01 (38.8)	351.48 (21.79)	329.00 (20.40)	276.69 (17.15)	226.71 (14.06)	219.36 (13.60)	207.24 (12.85)	98.93 (6.13)	108.33 (6.71)
Sand-Peat	84.54 (58.08)	53.42 (36.7)	25.75 (17.69)	23.85 (16.38)	21.14 (14.52)	20.38 (14.00)	19.58 (13.45)	18.51 (12.72)	9.43 (6.48)	8.21 (5.64)
Clay Loam	41.39 (39.52)	37.13 (35.5)	26.93 (25.72)	25.06 (23.93)	23.98 (22.90)	22.64 (21.62)	21.87 (20.89)	20.93 (19.99)	7.88 (7.53)	7.55 (7.21)
Sand-Peat-Clay Loam	55.79 (51.33)	37.11 (34.1)	29.97 (27.57)	22.12 (20.35)	21.76 (20.02)	20.06 (18.46)	19.20 (17.66)	18.54 (17.06)	7.74 (17.12)	6.74 (6.20)

*Note: Percentages not enclosed in parenthesis are calculated on the basis of the oven dry weight of soil. Percentages enclosed in parenthesis are calculated on a volume of soil basis.

[illegible]

[illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]	[illegible]	[illegible] (0.02)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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* [illegible]

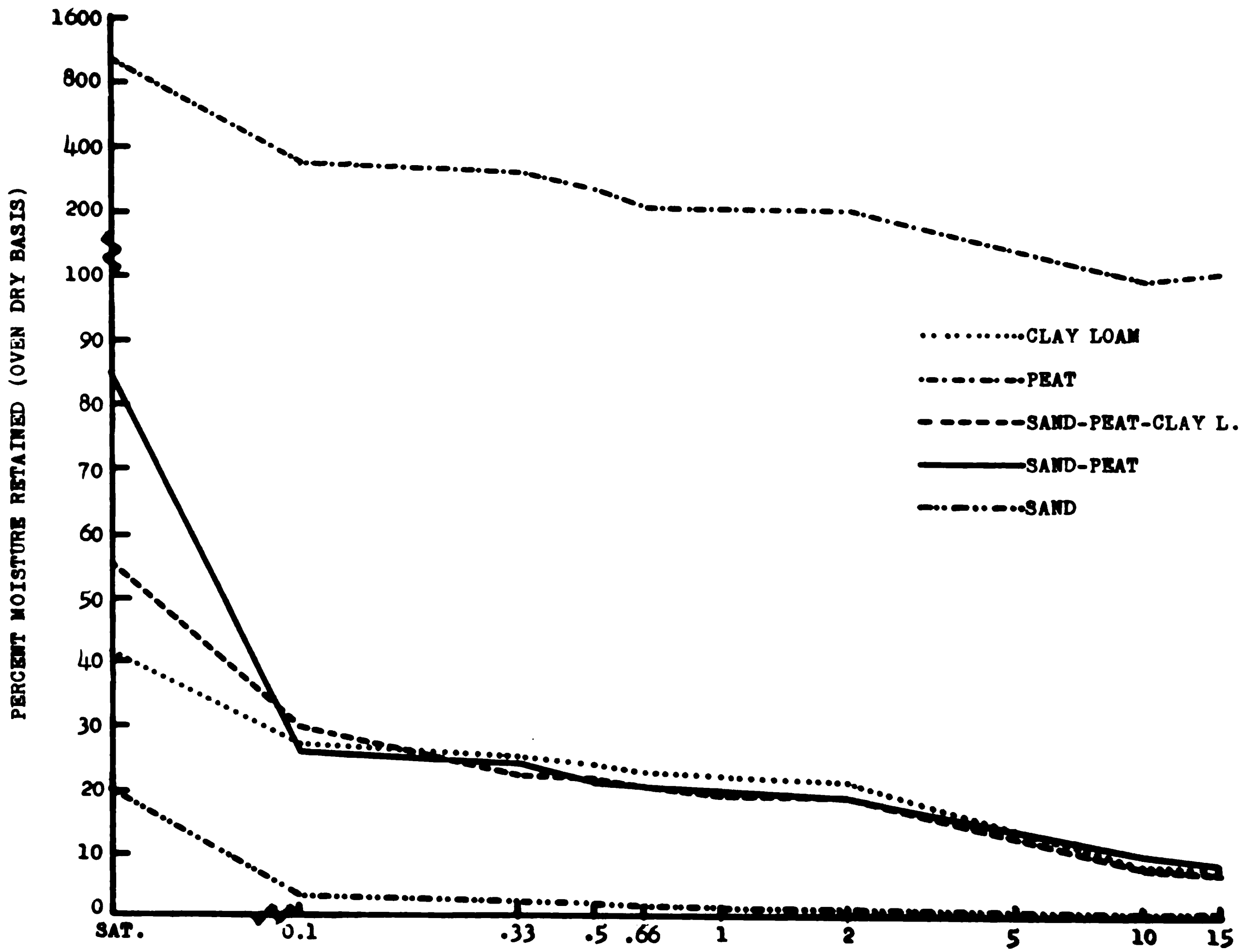

Figure 1. Curve of Moisture Retention for 5 Media (Oven Dry Basis)

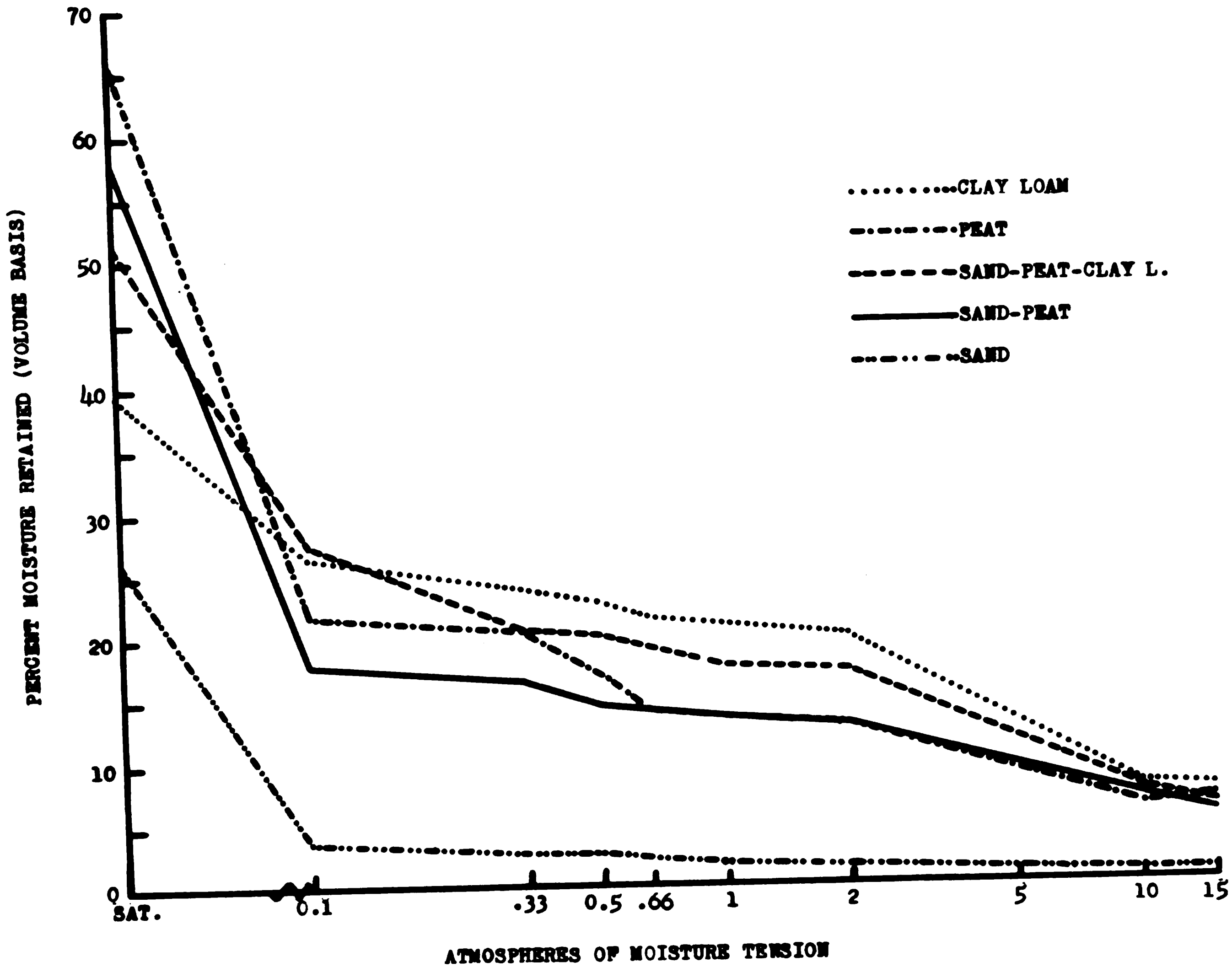

Figure 2. Curve of Moisture Retention for 5 Media (Volume Basis)

ing capacity and 0.1 atm. tension.

2. A moisture percentage corresponding to 0.1 atm. tension.

3. A moisture percentage corresponding to 1 atm. tension.

4. A moisture percentage corresponding to 5 atm. tension.

5. A moisture percentage corresponding to 15 atm. tension.

The waterholding capacity was determined by saturating containers of media and noting decreasing weights until drainage decreased to a low constant rate. The term, waterholding capacity is used to designate the amount of water held under these conditions since field capacity refers to field conditions of unrestricted drainage. The point midway between waterholding capacity and 0.1 atm. was selected as a moisture level possible to maintain and one that should indicate growth responses under moist conditions. The five atm. moisture level was selected as a point in the region where many plants are suspected to begin suffering from water deficiency (Erickson, 1959). The 15 atm. level was selected as a point recognized to be too dry for plant growth. The 0.1 and 1 atm. levels were selected as in-

termediate points in the available range.

After the laboratory determinations, the media were repotted. At potting time, the containers of each medium were emptied together, the medium was remixed and random samples were taken and oven dried to determine the percent moisture at time of potting. Each container was numbered and weighed individually. Containers in which polyethylene bags and/or glass wool (used to cover drainage holes in some containers) were to be used, had the weight of the glass wool and/or the polyethylene included with the container weight. These weights were recorded separately for each container of medium. The containers were then refilled with medium, reweighed and the weights recorded. Subtracting the weight of container, polyethylene and glass wool from the total planted weight gave the weight of medium in each pot; and subtracting the weight of water present at potting time from the weight of medium at potting time gave the weight of oven dry medium in each container.

The weight for each container at the moisture level at which it was to be irrigated was determined by adding the appropriate weight of water to the weight of oven dry medium, container, glass wool, polyethylene, and seeds or rooted cutting. Table 2 shows the percentages of water

TABLE 2

PERCENT MOISTURE ON OVEN DRY BASIS RETAINED AND THE MOISTURE STRESS DEVELOPED UNDER FIVE MOISTURE REGIMES

Medium	Moisture Regime				
	No. 1 Midway Between Waterholding Capacity and 0.1 atm. Stress	No. 2 0.1 atm. Stress	No. 3 1 atm. Stress	No. 4 5 atm. Stress	No. 5 15 atm. Stress
Peat	488.75	351.48	219.36	145.0	108.33
Sand	9.77	2.76	1.44	1.0	.67
Sand-Peat	39.59	25.75	19.58	13.25	8.21
Clay Loam	32.03	26.93	21.87	13.5	7.55
Sand-Peat-Clay Loam	33.54	29.97	19.20	12.5	6.74

used in calculating the container weights at irrigation for each of the five media.

All plants were grown in a greenhouse to prevent rains from affecting results of the experiments.

The initial experiments were conducted with bean plants (Phaseolus vulgaris) to obtain data and evaluate the experimental procedure in a relatively short period of time. Five beans were planted per container on June 17th, 1959.

Experiment 1. was conducted to determine the effects of the five growing media, the five moisture regimes, and interactions between the media and moisture regimes on the growth of Phaseolus vulgaris. 100 containers of bean plants were grown for this experiment. A split plot design was used in which the major split was for media and the minor split was for moisture regime. Moisture regimes were randomized within media and media were randomized in each of four replicates.

Experiment 2. was conducted to determine the effects of a polyethylene covering over the soil mass contrasted with no polyethylene, sub irrigation contrasted with surface irrigation, and the five moisture regimes on bean plants growing in the sand-peat-clay loam medium. Sixty containers of bean plants were started for this experi-

ment. Thirty containers had the soil mass enclosed in a polyethylene bag which fitted the container and was folded down over the top of the soil mass, while thirty containers were without polyethylene. Drainage holes were punched near the bottoms of the polyethylene bags. In this experiment a split plot design was also used. The plots were split for the poly - no poly treatment and for irrigation. The five moisture regimes were randomized within each treatment and the treatments were randomized within three replicates.

From the June 17th planting date through June 23rd all of the containers were irrigated daily to maintain moisture levels sufficient for germination.

From June 24th through July 15th, the 160 containers were weighed daily and irrigated when the weights dropped to the computed weight for irrigation. The irrigations were recorded so that irrigation frequency could be compared for various treatments. Thus, each container was maintained under a moisture regime which varied from water holding capacity to a predetermined moisture level, some being allowed to dry considerably more than others.

Containers that were surface irrigated were watered with a sprinkling can by adding approximately ½ inch of water. Water drained from the containers indicating

that the water level was raised to water holding capacity. In the case of containers with the polyethylene covering around the soil mass, water tended to leak down the sides between the polyethylene and the container wall instead of through the soil. However, enough water moved through the openings in the polyethylene where it was folded over the top of the soil, that the weight was increased. Irrigation frequency for polyethylene containers was much less than that for non-polyethylene containers.

Containers that were sub irrigated, were set in three inches of water for 30 to 45 minutes.

When a few plants began to show symptoms of nitrogen deficiency, all plants were given equal amounts of a complete, soluble fertilizer in the irrigation water at the following irrigation. The bean plants received one fertilization.

The bean plants were measured on July 1st, 8th, and on the harvest date, July 15th. On July 1st, the tops of some plants were removed from pots with five bean plants so that there were no more than four per container. Also a number of the shoots removed, were measured and weighed to obtain the fresh weight per mm. of plant stem. This weight was used to calculate the increase in weight of the plants in each container and this increase was added to the weight of the container at irrigation.

On July 8th, measurements were again taken and shoots were removed so that there were but two plants growing per container. Samples were again weighed and the calculated increase in plant weights added to the weight of each container at irrigation.

At harvest, plants were bagged with the shoots and roots separate for oven drying. Difficulty was experienced in freeing roots from the media that contained peat. Although an effort was made to remove the peat from the roots a thorough job was impossible. Therefore, the oven dry weights of the roots include some peat. It was observed that the weight of peat included in each root weight is apparently directly proportional to the oven dry weight of the roots.

At the harvest of the beans, the growing media were saved for use with rooted forsythia cuttings in the following experiments.

On July 23rd, a rooted forsythia (Forsythia intermedia) cutting was potted in each container. The media used previously for the beans were used for the forsythia after they were remixed and samples were taken for determination of percent moisture content at potting time. The forsythia cuttings used were selected for uniformity in size and leaf area. Using calculations similar to those for the bean experiments, the weights of the containers at various moisture levels for irrigation were determined.

Experiment 1. for the forsythia was similar to experiment 1. for the beans; however, the growing media used were limited to 20 containers of sand-peat and 20 containers of sand-peat-clay loam. It had been decided not to include the other three media in this experiment so that the containers could be weighed twice daily to maintain maximum control over the moisture regimes. Also, it was felt that the sand-peat and sand-peat-clay loam were most significant for container growing.

Experiment 2. for the forsythia cuttings was similar to experiment 2. for the beans except for the substitution of rooted forsythia cuttings for the bean plants.

The forsythia were fertilized once when they first began to show signs of nitrogen deficiency, by adding equal amounts of soluble, complete fertilizer to the irrigation water.

The greenhouse was given a thick coat of whitewash about the first of August to reduce high temperatures associated with greenhouses during summer operations.

By pinching new growth it was possible to limit all forsythia growth to one long main shoot. The elongation of this shoot in centimeters was measured on July

27th, Aug. 3rd, 11th, 18th, 30th, and Sep. 13th and 30th when the plants were harvested. As with the bean plants, container weights for irrigation were adjusted after measurements, by adding weight of new growth; which was calculated in this case by sampling forsythia plants in the same stage of growth and growing in the same area but not included as a part of the experiment.

The harvest of the forsythia was conducted in the same manner as the harvest of the beans; again some peat moss could not be removed from the roots and the amount of peat remaining seemed to be directly proportional to the extent of the root system. The forsythia roots and shoots were oven dried and weights were taken for use in the statistical analysis.

RESULTS AND DISCUSSION

Moisture Retention Curves. - - - Moisture retention curves with moisture stress plotted against percent moisture remaining in the soil have been frequently used in soil water research to illustrate moisture retaining characteristics of soils. These curves commonly have the moisture stress plotted on a log scale to not only reduce the scale to a workable size, but to exaggerate the part of the scale showing the water held at low tensions since this water being greatest in volume and most available to plants is usually considered more important to plant growth than water held at higher tensions.

Although many workers have recorded moisture levels as percentages of the available range and have plotted moisture retention curves using percent moisture retained on an oven dry weight of soil basis, the results of these methods are at best extremely difficult to evaluate unless bulk densities are given. Figure 1 is similar to the oven dry weight basis moisture retention curves common in the literature. It is obvious that this type of graph cannot be used to compare soils of different bulk densities, i.e., sand loam with clay loam, with any degree of accuracy.

By use of the following formula, the percentages

of moisture retained on a volume basis were calculated:

(Bulk Density) (% H_2O O.D. Basis) = % H_2O Vol. Basis

Moisture retention curves showing moisture retained on a volume basis in the media used in the experiments are plotted in Figure 2.

Figure 2 shows that, while sand has a comparitively low moisture holding capacity, the other media have moisture holding capacities that do not differ greatly. It is difficult to make a good general statement concerning the moisture holding capacities of the media in the range from saturation to 2 atm. tension since it is not known whether to attach more importance to comparitively large amounts of water held at low tensions (such as saturation and 0.1 atm.) or the smaller amounts of water held at higher tensions (0.3 to 5 atm.). In general, at tensions above 0.3 atm., the clay loam holds the most water while sand-peat-clay loam retains about 90 percent and sand-peat retains about 65 percent of the volume held by clay. It should be noted that the sand-peat-clay loam medium holds more moisture than the sand-peat medium throughout most of the available range.

Germination. - - - Poor germination reduced the amount of data obtained in the experiments with bean (*Phaseolus vulgaris*) plants. In experiment 1 there

were 6 containers of peat media, 16 containers of clay loam media and one container each of sand-peat and sand-peat-clay loam media in which germination failed to take place. In experiment 2, there was no germination in 6 of the containers with the polyethylene covering around the growing media. Initially the low rate of germination in the peat and the clay loam media and in the polyethylene treatment containers was thought to be due to excess moisture which limited aeration during the period of time that all containers were irrigated equally to maintain sufficient moisture for germination to take place. However, the moisture retention curve (Figure 2) does not justify the theory that excessive moisture was the only factor causing the low rate of germination observed. The clay loam held a comparitively low volume of water on saturation while the peat held a comparitively high volume at this point. Conversely, at 0.1 atm. stress, the clay loam retained a relatively high volume and the peat a relatively low volume of water. The sand-peat-clay loam which held more water than clay at saturation and more than peat at 0.1 atm. stress supported good germination. It is now felt that insufficient aeration of the peat resulting from high water content at very low tensions was the limiting factor in the germination in the peat. The much lower rate of germination in

the clay loam very likely occurred when high moisture content and crusting of the surface combined to limit aeration. Difficulty of penetration of the clay crust by the germinating seedlings was also a factor.

The low rate of germination in the polyethylene covered media was undoubtedly due to deficient aeration resulting from limited drainage.

Deterioration of Bean Seedlings. - - - About 10 days after planting, a number of the bean seedlings in the polyethylene treatment containers wilted and began breaking off at the soil line where the tissues were brownish and mushy in appearance. In all cases of wilting, the soil was moist under the polyethylene and water was condensing on the underside of the polyethylene where it covered the top of the soil mass.

Tests for pathogens were made by innoculating cucumber seedlings with tissues from the weakened plants. These tests were negative. However, this is not considered as conclusive evidence that damping off organisms were not present as moisture conditions in the petri dishes containing the cucumber seedlings may not have been suitable for infection of the seedlings. (Benoke 1960).

Excessive Temperatures. - - - Temperature readings were taken to determine if excessive temperatures under the polyethylene were high enough to be the cause of the observed deterioration of bean plants in the polyethylene treatment containers. On June 29th (a bright, clear day) at 2:30 P.M. the mean temperature for five polyethylene containers (moisture regimes I through 5) was 50.45°C. while the mean temperature for corresponding non-polyethylene containers was 44.2°C. Both of these mean temperatures are too high for growth according to Hagan (1952) and may even approach the thermal death point. It is not known whether the differences in temperature for the lengths of time that they were maintained, were crucial in the degeneration of the seedlings under the polyethylene treatment. Temperatures taken on July 8th (a bright, clear day) again showed about a 6°C. difference in polyethylene and non-polyethylene temperatures. The polyethylene mean was 44.1°C. and the non-polyethylene mean was 37.4°C.

<u>Inconsistancies in Irrigation</u>. - - - When containers with the polyethylene covering around the growing media were surface irrigated, water tended to filter down the sides of the container between the polyethylene and the container wall instead of through the media. However, enough water moved through the openings in the polyethylene where it was folded over the top of the media that the water content was increased and irrigation was infrequent as compared with non-polyethylene treatment containers. It is unlikely that the

moisture levels of more than a few of the surface irrigated poly treatment containers were raised completely to water holding capacity by surface irrigation.

Some containers of clay loam media were also difficult to irrigate as water tended to drain between the container wall and the media instead of through the media. This was due to the combined effect of shrinkage of the soil and a thin surface crust.

Missing Data. - - - Statistical analysis of the results of some portions of the experiments with bean plants was not possible due to excessive amounts of missing data as a result of low germination rate in the peat media, clay loam media and polyethylene treatment containers.

Bean data for growth in sand, sand-peat, and sand-peat-clay loam media was analyzed.

Growing Media Results. - - - Growing media affected plant growth even though the plants in different media were maintained under the same moisture regimes (Tables 3 and 4). Though there were no significant differences in root and shoot growth between sand-peat and sand-peat-clay loam grown plants, both sand-peat and sand-peat-clay loam grown plants showed significantly better root and shoot growth than plants grown in sand medium. This indicated that some factor other than moisture stress was effective in limiting growth in the sand me-

TABLE 3

Influence of 3 Media on the Growth of *Phaseolus vulgaris* while under 5 Moisture Regimes

Growing Medium		Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
Sand		0.97	0.67
Sand-Peat		1.64	2.00
Sand-Peat-Clay Loam		1.86	1.54
LSD	.05	0.48	0.80
	.01	0.72	1.20

TABLE 4

Influence of 2 Media upon the Growth of *Forsythia intermedia* while under 5 Moisture Regimes

Growing Medium	Mean Shoot Growth	Mean Root Growth
	(Grams of Oven Dry Weight)	
Sand-Peat	3.82	5.21
Sand-Peat-Clay Loam	4.34	5.04

LSD not significant at .05 level.

dium or increasing plant growth in other media.

As pointed out by Richards and Wadleigh (1952) availability of water to plants is related not only to moisture stress but to the unsaturated permeability of the soil. Richards and Wadleigh (1952) as well as other authors have also indicated that unsaturated permeability drops to a low level when as little as 0.1 atm. tension is developed and becomes almost zero at tensions approaching 1 atm. Apparently the plants which do not have root systems that permeate the entire volume of media in a container are able to reduce the moisture content of the soil a few centimeters at most from the roots. Due to unsaturated permeability which is zero for practical purposes, soil not permeated with roots will be effectively reduced in moisture level only by evaporation. Therefore the bean seedlings and unestablished forsythia cuttings were subjected to moisture stresses for a period of time prior to irrigation that were greater than the stresses calculated. The magnitude and duration of these excessive stresses was apparently related to the moisture holding capacity of the media from which the roots extracted moisture. Plants growing in sand -peat-clay loam media may not have been subjected to as severe a moisture stress as those growing in sand due to the extra volume of water

available.

Rate of evaporation from the media would also have had an effect on the intensity and duration of the moisture stress developed. Predicting of probable evaporation rates from soils is a complex problem due to the many factors involved (Baver 1956, Richards and Wadleigh 1952). The author feels that the pattern of evaporation of moisture from the media used must have been such that the cumulative effects of differences in volume of moisture held and differences in evaporation rate from the media, resulted in moisture stresses near the roots in sand that were larger and/or of longer dufation than those near roots in the sand-peat and sand-peat-clay loam media. It is suggested that establishing of drying curves for media not containing plants would be of value in evaluating this hypothesis.

Moisture Regime Results. - - - The results of the experiment with beans grown on three media while under five moisture regines (Table 5), indicate that shoot growth was maximum under moisture regimes 1, 2 and 3, that shoot growth was reduced under regime 4 and minimum under regime 5. Root growth of beans in the same experiment was best under moisture regimes 1, 2 and 3 and was reduced under regimes 4 and 5.

Similar experiments conducted with forsythia plants

TABLE 5

Influence of 5 Moisture Regimes on the Growth of *Phaseolus vulgaris* Grown in 3 Media

Moisture Regime		Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
1. (Irr. below 0.1 atm. stress)		1.93	1.55
2. (Irr. at 0.1 atm. stress)		1.90	1.86
3. (Irr. at 1.atm. stress)		1.70	1.56
4. (Irr. at 5 atm. stress)		1.18	1.09
5. (Irr. at 15 atm. stress)		0.73	0.96
LSD	.05	0.31	0.48
	.01	0.41	0.65

grown in two media while under 5 moisture regimes (Table 6) showed that maximum shoot growth was produced under moisture regimes 2, 3 and 4. Shoot growth under regime 1 was significantly less than under regimes 2 and 3 while minimum shoot growth was produced under regime 5. Root growth of the forsythia plants was maximum under regime 2 while plants under regime 3 produced significantly less roots than those under regime 2 and plants under regimes 1 and 4 produced significantly less roots than those under regime 3. The minimum root growth was produced under moisture regime 5.

The effects of moisture regime on growth of roots and shoots of forsythia plants while under poly.-no poly. and sub-surface irrigation treatments (Table 7) were notably different from the results above. Maximum shoot growth was produced under moisture regimes 3 and 4. Less shoot growth was produced under moisture regimes 1 and 2, and minimum shoot growth was produced under moisture regime 5. Root growth was maximum under moisture regimes 3 and 4 and minimum under moisture regimes 1, 2 and 5.

In reviewing the total results on the moisture regime experiments it can be seen that moisture regime 5 (irrigation at 15 atm. tension) resulted in poor growth as would be expected since 15 atm. tension has been ac-

TABLE 6

Influence of 5 Moisture Regimes on Growth of *Forsythia intermedia* Grown in 2 Media

Moisture Regime		Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
1. (Irr. below 0.1 atm. stress)		3.69	5.06
2. (Irr. at 0.1 atm. stress)		5.28	6.65
3. (Irr. at 1 atm. stress)		5.26	5.81
4. (Irr. at 5 atm. stress)		3.99	4.81
5. (Irr. at 15 atm. stress)		2.19	3.26
LSD	.05	1.37	0.31
	.01	1.86	0.42

TABLE 7

Influence of 5 Moisture Regimes on Growth of *Forsythia intermedia* while subject to Polyethylene and No Polyethylene and Sub and Surface Irrigation Treatments

Moisture Regime		Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
1. (Irr. below 0.1 atm. stress)		2.59	2.91
2. (Irr. at 0.1 atm. stress)		2.62	2.77
3. (Irr. at 1 atm. stress)		3.13	3.73
4. (Irr. at 5 atm. stress)		3.21	3.87
5. (Irr. at 15 atm. stress)		1.62	2.53
LSD	.05	0.51	0.43
	.01	0.69	0.58

cepted as a value for the wilting point and as a point where no growth takes place.

Moisture regime 4 (irrigation at 5 atm. tension) is apparently a critical regime. It has generally resulted in reduced growth of both shoots and roots except in the experiment in which plants were subject to the poly.-no poly. and the sub-surface irrigation treatments. In this experiment regime 4 was one of those found to be optimum and regime 2 which was an optimum regime in other experiments was found to reduce both shoot and root growth. These results, which contradicted results of the other experiments, were very likely caused by insufficient aeration due to poor drainage resulting from the polyethylene covering of the media in some containers. Apparently insufficient aeration in these containers was more limiting than the moisture stresses applied with exception of the 15 atm. stress.

Moisture regime 3 (irrigation at 1 atm. tension) was generally conducive to maximum root and shoot growth except that it limited the growth of forsythia roots.

Moisture regime 2 (irrigation at 0.1 atm. tension) was also conducive to maximum growth except in the case of poly.-no poly., sub-surface irrigation treatment containers as stated above.

Moisture regime 1 (irrigation at a tension midway

between waterholding capacity and 0.1 atm.) was satisfactory for good growth of bean plants but was limiting to the growth of forsythia roots and shoots. Evidently forsythia plants were more sensitive to poor aeration of the media than bean plants.

Poly.-No Poly. Treatment Results. - - - Root and shoot growth of forsythia were both reduced by a polyethylene covering around the growing media as contrasted with no polyethylene (Table 8). Again the explanation is insufficient aeration of the growing media due to insufficient drainage and the polyethylene covering.

Surface Irrigation Contrasted with Sub Irrigation Results. - - - Shoot growth of forsythia plants was not affected by the irrigation treatments (Table 9). However, root growth of the forsythia plants was significantly increased by surface irrigation as compared with sub irrigation. It is felt that this may have been the result of no poly. treatment plants receiving more water when surface irrigated than when sub irrigated and poly. treatment plants receiving less water when surface irrigated than when sub irrigated.

Frequency of Irrigation Results. - - - As would be predicted, the frequency of irrigation of the non-poly treated containers was much greater than that for the containers with a polyethylene covering around the grow-

TABLE 8

Influence of Polyethylene and No Polyethylene Treatments on Growth of Forsythia intermedia while under 5 Moisture Regimes and subject to Sub and Surface Irrigation Treatments

Treatment	Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
Polyethylene	2.23	2.46
No Polyethylene	3.04	3.86

LSD significant at the .05 level.

TABLE 9

Influence of 2 Irrigation Treatments on Growth of *Forsythia intermedia* while under 5 Moisture Regimes and subject to Polyethylene and No Polyethylene Treatments.

Irrigation Treatment	Mean Shoot Growth (Grams of Oven Dry Weight)	Mean Root Growth (Grams of Oven Dry Weight)
Sub Irrigation	2.36	2.56
Surface Irrigation	2.90	3.76
LSD .05	N.S.	1.13

ing media (Table 10), since the polyethylene covering reduced the rate of evaporation from the media.

There was little difference in frequency of irrigation for sub irrigated plants as contrasted with surface irrigated plants (Table 10).

Plants under moisture regimes where irrigation was to be applied at low tension were irrigated much more frequently than those that were irrigated at high tensions (Tables 11 and 12). On the other hand, contrary to what might be expected, plants growing in media with low water holding capacities were not irrigated as often as plants growing in media with high water holding capacities. This result can be explained by the fact that plants grew better in media of high water holding capacity (probably due to suffering less moisture deficit prior to irrigation than plants in low moisture holding media prior to the time that roots permeated the entire amount of media). Larger plants with larger root systems will transpire more water and be more efficient in reducing the water level of the media than will smaller plants. Thus even though they are growing in media of high waterholding capacity, they will be irrigated more often than small plants growing in media of low water holding capacity.

TABLE 10

Influence of Poly-No Poly Treatments, Sub-Surface Irrigation Treatments and 5 Moisture Regimes on Intervals between Irrigation of *Forsythia intermedia*

Treatment	Number of Plants Included in Mean	Mean Number of Days between Irrigations
Poly.-No Poly.		
Polyethylene	30	10.6
No Polyethylene	30	4.3
Irrigation		
Sub Irrigation	30	6.4
Surface Irrigation	30	5.8
Moisture Regime		
1	12	3.2
2	12	4.6
3	12	7.0
4	12	9.6
5	12	21.3

TABLE 11

Influence of 3 Media and 5 Moisture Regimes on Intervals between Irrigation of *Phaseolus vulgaris*

Treatment	Number of Plants Included in Mean	Mean Number of Days between Irrigations
Sand Medium		
Moisture Regimes		
1	4	11.3
2	4	5.0
3	4	3.8
4	4	3.5
5	4	3.5
Sand-Peat Medium		
Moisture Regimes		
1	4	12.5
2	4	7.3
3	4	5.5
4	4	4.0
5	4	3.0
Sand-Peat-Clay Loam Medium		
Moisture Regimes		
1	4	15.3
2	4	14.3
3	4	7.0
4	4	4.5
5	4	2.3

TABLE 12

Influence of 2 Media and 5 Moisture Regimes on Intervals between Irrigation of _Forsythia intermedia_

Treatment	Number of Plants Included in Mean	Mean Number of Days between Irrigations
Sand-Peat Medium		
Moisture Regimes		
1	4	3.4
2	4	6.0
3	4	7.3
4	4	9.3
5	4	13.4
Sand-Peat-Clay Loam Medium		
Moisture Regimes		
1	4	2.1
2	4	2.7
3	4	5.0
4	4	7.3
5	4	11.3

Conclusions:

1. Moisture retention curves with percent moisture on a volume basis are of more value in evaluating water supplying characteristics of a growing medium than moisture retention curves with percent moisture on an oven dry basis.

2. Plants do not necessarily grow equally well under equal moisture regimes if the media are varied.

3. Sand alone is a medium that retains little water for plant growth.

4. Sand-peat and sand-peat-clay loam are approximately equal in their water supplying "power" as indicated by plant growth.

5. (a) Moisture regime 2 (irrigation at 0.1 atm. tension) resulted in maximum growth of bean and forsythia plants.

(b) Moisture regime 1 (irrigation at a tension midway between waterholding capacity and 0.1 atm.) resulted in bean plant growth equal to that under regime 2 and limited the growth of forsythia plants.

(c) Moisture regime 3 (irrigation at 1 atm. tension) resulted in growth of bean plants and of forsythia shoots equal to that under regime 2 and inhibited growth of forsythia roots.

(d) Moisture regime 4 (irrigation at 5 atm. tension) limited growth of both bean and forsythia plants.

(e) Moisture regime 5 (irrigation at 15 atm. tension) resulted in minimum growth of both bean and forsythia plants.

6. A polyethylene covering of the growing medium reduced the growth of forsythia and caused limited growth under moisture regimes that called for irrigation at low tensions.

7. Shoot growth of forsythia plants was little effected by surface as contrasted with sub irrigation. However, on plants subjected to poly.-no poly. treatment, surface irrigation increased root growth.

8. A polyethylene covering of the growing media resulted in a large decrease in the frequency of irrigations needed under a given moisture regime as compared with media not covered with polyethylene.

SIGNIFICANCE OF RESULTS AND CONCLUSIONS FOR CONTAINER GROWING OF NURSERY STOCK

Growing Medium (Soil Mix). - - - Sand proved to be a poor medium for holding water for plant growth. The other media studied did not exhibit differences in water holding capacity that were great enough to cause any one medium to be recommended over another. Therefore, choice of a media (other than sand) for container production, should be made on the basis of considerations other than water holding capacity. It was noted that clay loam was the only medium used that had a tendency to crust or harden and shrink away from the walls of the container.

Amount and Frequency of Irrigation. - - - The necessity of applying enough water to raise the moisture level of the entire volume of media to waterholding capacity (field capacity) if the media in the bottom of the container is to be wetted, was pointed out by the literature reviewed. Drainage of water from a container of media with uniform composition is usually a good indication that enough water has been applied to wet the medium to capacity. Only with special situations such as soluble salt concentrations that require leaching would applying appreciably more or less than enough water to wet the entire amount of medium be recommended.

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Evidence indicates that media may be allowed to dry until about 1 atm. of moisture stress is developed and should definitely be irrigated before stress increases to 5 atm. Although some commercial devices for measuring moisture stress (tensiometers, resistance blocks) are available, their value in container-growing media has not been established. Observations of the author indicate that in growing established plants media may be allowed to dry until the surface material is unquestionably dry and should then be irrigated within 12 to 24 hours depending on the intensity of evaporating conditions.

Drainage. - - - Good drainage has been shown to be very important as excessive moisture retention prevents adequate aeration of the media which in turn inhibits root activity. Possibilities of over irrigation are greatly reduced by good drainage.

Polyethylene Covering of Growing Medium (Soil Mass). - - - The polyethylene covering of the growing media which greatly reduced water loss by evaporation, also limited growth because of poor aeration due to limited drainage. The author suggests that instead of covering the entire amount of media with polyethylene, the polyethylene might be cut to cover the exposed upper surface. This polyethylene could be perforated as ne-

cessary to provide adequate aeration.

Sub Irrigation. - - - Flooding a tray or basin-like structure in which the containers remain permanently should prove to be an economical method of irrigating large numbers of container plants.

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