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Irrigation Fundamentals

by

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Preface

During 1969 and 1970, the author was privileged to work in South America with a training program in irrigation. Part of the work included training technical specialists who would in turn be training water users in the principles of irrigation and irrigation techniques. The teaching examples and demonstrations used were a composite of ideas and techniques based on the author's experiences as an irrigator, irrigation engineer, college professor, and irrigation extension specialist. As a result, much of the material was not available in written form.

Because of the success of the training program it was suggested that a bulletin be written for use as a practical text by technicians giving irrigation training to new water users in regions or countries where irrigation developments are relatively new. This bulletin is a response to that suggestion.

No claim is made to originality for the ideas and methods of demonstration that are presented even though few references are given as to original material sources. Such references are impossible because the author cannot satisfactorily identify which ideas came from his training, his experiences, or from his associates. Generalized credit can be given however, to the wealth of information gleaned from available literature; to his colleagues Paul Christiansen, Richard Griffen, and Bruce Anderson; and to his good fortune to have been associated with recognized authorities in the irrigation field. The author also can and does accept full responsibility for the indicated interpretation of all concepts presented. Such interpretations should not be construed as representing the official positions of the sponsoring organizations.

Thanks is expressed to the Organization of American States and to USAID/csd Contract 2459, for providing part of the funds that have supported this work, and to Dr. H. B. Peterson, head of the Department of Agricultural and Irrigation Engineering at Utah State University for granting the author sufficient time to do the writing.

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Introduction

Plants are the only living organisms on earth that can use the energy of sunlight to convert the elements of the earth into food for all animal life. This unique capability has led man to cultivate various species of plants for his own use. Because the energy transfer processes of a plant require an adequate quantity of water, man also had to evolve a way to supplement natural rainfall. The resultant science of irrigation has brought vast areas of otherwise unproductive soils into production.

As the world population and its demands for food continue to gain, proper water management becomes increasingly important in optimizing agricultural production.

The Soil Reservoir

Large reservoirs for the storage of surface water are often essential to modern irrigation projects. Such reservoirs are storage basins while water is in excess and sources of supply during water shortages. Another great reservoir, however, which is a part of all irrigation projects, is the water stored in the soil. Many comparisons can be drawn between surface and soil reservoirs, but the important concept is that the water stored in the spaces between soil particles is a reservoir, and irrigation is merely a process by which that reservoir is managed.

The soil reservoir is replenished by precipitation and irrigation, and is depleted by plants or by evaporation, as illustrated in Figure 1. Water cannot enter nor be removed from the soil reservoir in any other way. Gravitational pull may cause part of the stored water to move down out of the reservoir and evaporation may dry the top few inches of soil, but the process is very, very slow. Water can be stored in a soil reservoir for long periods of time if there are no plants to remove it.

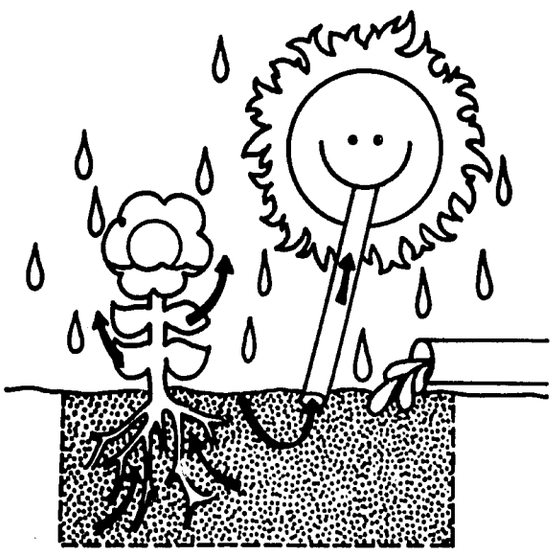


Figure 1. A simplified sketch of the hydrologic cycle as modified by irrigation.

RESERVOIR DIMENSIONS

The dimensions of a soil reservoir can be measured, and its capacity computed, just as for a surface reservoir. Unlike the surface reservoir, however, a soil reservoir beneath a given field may vary in size and capacity. What then are the factors which determine the capacity of the soil reservoir?

Surface Area

One easily observed factor affecting the soil reservoir is the surface area of the field under consideration. A 10-hectare field of a given soil type will hold more water than a 5-hectare field of the same soil type. However, from an agricultural point-of-view, the surface area of a soil reservoir is not usually considered to be variable and is of little concern because the dimensions of a particular field are fixed.

Soil Type

The volume of water stored in a unit volume of soil and generally available to plants, is that water which the soil can hold against the pull of gravity; it is a function of soil type. Fine textured soils can store larger volumes of water than coarse soils because: (a) the capillary forces in the small pores are stronger; (b) gravitational forces on the smaller bodies of water in

the pores are less, (c) there is a larger volume of pore spaces in a fine soil, and (d) a fine soil has a greater soil particle surface area. Thus a unit volume (one cubic meter) of clay soil can store more water than can the same unit volume of a sandy soil. This phenomenon can be illustrated as described in demonstration 1 in Appendix I.

The importance to irrigation of the water holding capacity of various soil types has led to considerable research aimed at quantifying such capacity. A summary of the results, showing the range of the water holding capacity of several broad soil type classifications, is given in Table 1. Table 1 can be used as a guideline when the approximate water holding capacity of a given soil type is desired. If accurate information is needed for a particular soil, specific measurements must be made.

Table 1. Water holding capacity of various soils

Soil type	Water mm/meter
a coarse sand	33 – 62
fine sand	62 – 83
loamy sand	83 – 104
fine sandy loam	104 – 146
silt loam	125 – 192
silty clay loam	146 – 208
heavy clay	103 – 208

Depth of Root Zone

A third variable affecting the size of the soil reservoir is the depth to which roots will penetrate. Since root penetration varies with the crop, the size of the soil reservoir also varies with the crop. For example, the effective root zone of corn may be as deep as 150 centimeters, whereas grass roots may be effective for only 60 centimeters. Hence, the soil reservoir of a given field is greater for corn than it is for grass. Furthermore, root development is a dynmaic process, and root depth depends on the growth stage of the crop. The roots of a newly sprouted crop will not be as deep as those of a mature crop. Hence, the soil reservoir varies with the crop and with its growth stage. When estimating the depth of the root zone for various crops, a good general rule to follow is to allow 1 to 1-1/2 centimeters of depth for every day required for crop maturity. Thus a crop maturing in 60 days would have an effective root zone depth of 60 to 90 centimeters, while one maturing in 100 days would have a root zone of 100 to 150 centimeters.

It is well to emphasize that the soil reservoir (not the crop) is the object of direct concern in irrigation. From the irrigationist's point-of-view, it is immaterial whether alfalfa or corn is growing in a field because each has an effective root zone of approximately 150 centimeters; hence the capacity of the soil reservoir would be the same for each.

Restrictive Layers

Restrictive layers exist in some soil profiles and these obstruct normal root growth. Hard pan layers, clay layers, cemented layers, or even compacted sand layers fall into this group. Not only is it difficult for roots to penetrate these layers, but the layers reduce infiltration and stop the downward flow of water thus keeping underlying soil dry. Since roots grow only in moist soils and will not penetrate dry soil "looking for water," these impermeable layers restrict most development and hence reduce the potential soil reservoir.

RESERVOIR CAPACITY

There is a maximum limit to what a soil reservoir can hold. To understand this limit it is necessary to define two basic terms, field capacity and permanent wilting point.

Field capacity is commonly defined as the amount of water remaining in the soil profile after rapid drainage ceases. This occurs about 48 hours after irrigation for most soils, but will occur earlier in sandy soils than in clay soils. For example, at the end of an adequate irrigation, the pores at the soil surface are saturated. With time, the excess water which cannot be held in the soil by surface tension and capillarity, is used by the crop or is moved through the soil profile and out of the root zone by gravity. In general, within 48 hours after irrigation, most of the excess water has moved out (rapid drainage ceases) and the soil reservoir is at field capacity. A more scientific definition states that field capacity is the amount of water retained in a soil at between one-tenth and one-third atmosphere of tension, for soils with textures ranging from coarse to fine respectively. Expressed as a percentage of the dry weight of the soil, the moisture content at field capacity will range between 15 and 35 percent, again with the higher value being associated with the finer soils. Field capacity thus can be considered the upper limit of the soil reservoir capacity.

A plant does not spend large quantities of energy to remove water from a soil at or near field capacity. As the water within the soil decreases, more energy is required to remove water and less is available for plant growth. When the plant needs more energy to remove water from a soil than is available in the plant, the plant wilts and will not recover. The moisture content at this point is called the permanent wilting point and represents the lower limit of the soil reservoir capacity. This limit depends upon soil type, water quality, and the plants involved. It is usually in the range of 10 to 15 atmospheres of tension or 5 to 20 percent moisture content by weight.

Using the preceding definitions, the total capacity of the soil reservoir can be defined as the amount of water in the soil profile between field capacity and permanent wilting point. Water holding capacities of various representative soils have already been given in Table 1.

The useable capacity of a soil reservoir however, is not the same as the total water holding capacity of a soil because by the time the permanent wilting point is reached, the crop has been destroyed, thus, only a portion of the total reservoir capacity can be used. The useable reservoir capacity is often assumed to average approximately 50 percent of the total water holding capacity, with a range of between 25 and 60 percent. The concept of useable reservoir capacity can be illustrated by means of the example shown in Figure 2.

Assume that the root zone of a particular crop is 1.8 meters deep and that the water holding capacity of a particular soil is 4 centimeters for every 30 centimeters of depth. Thus, the total water holding capacity of this particular reservoir is 24 centimeters, or in 1.8 meters of soil, 24 centimeters of water are stored at field capacity. If only 50 percent of this water is useable without retarding crop development, then the useable or operating capacity, of the soil reservoir in the example is 12 centimeters. Therefore, when 12 centimeters of water have been removed, irrigation is necessary. The remainder of the information in Figure 2 will be discussed in a later section.

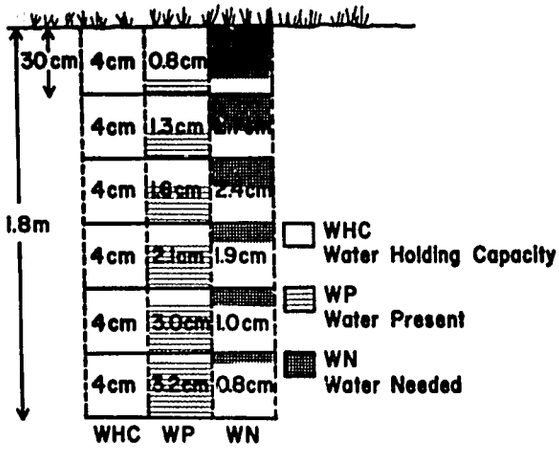


Figure 2. Useable soil reservoir capacity.

The soil reservoir concept is the fundamental basis of all irrigation practice. The soil reservoir stores water for plant use when needed. It is emptied by the plant and is refilled by irrigation and natural precipitation. It has fixed limits. The surface area of the reservoir coincides with the surface area of the field. The depth of the reservoir is regulated by the depth of the root zone of the particular crop, and the amount of water in a unit depth of soil is governed by soil type. Thus the volumetric capacity of a soil reservoir is a direct function of surface area, root depth, and soil type. These basic concepts can be illustrated by Demonstration 2 in Appendix I.

Managing the Soil Reservoir

Factors to consider in managing a soil reservoir are: water holding capacity of the soil; quantity of water that can be stored in the reservoir; quantity needed; irrigation stream size; time required to fill the reservoir; rate and method of application; and efficiency of application. A few operational guidelines can help provide efficient management of the soil reservoir.

SOIL MOISTURE MEASUREMENT

Soil moisture content can be measured by gravimetric methods, soil moisture extraction equipment, soil moisture meters, piezometers, and neutron meters. Methods involving complicated equipment are beyond the scope of this manual. Should they be

needed, professional textbooks and instruction manuals are available.

A simple and often satisfactory method of testing soil moisture content, although less precise than those previously mentioned, is the "hand-feel" test. This test is made by squeezing a handful of the soil in question and approximating the soil moisture content as explained in Table 2 (which is taken from Section 15 of the National Engineering Handbook of the Soil Conservation Service, United States Department of Agriculture). Table 2 should be used when a high degree of precision is not required. To illustrate how the preceding test can be used to determine the amount of water present in a soil reservoir, reference is made to the second column of Figure 2. If a sample of soil from the 30 centimeter depth of the soil profile would not form a ball when compacted in the hand, Table 2 would indicate a moisture content of less than 25 percent field capacity. Correlated with judgment and experience it might be estimated that the moisture content was 20 percent, or that the first 30 centimeters of the soil profile contained 0.8 centimeters of water. If the same process is continued at 30 centimeter intervals to the bottom of the profile, the results would be as shown in Table 3. Thus it was found that 12 centimeters of water, 50 percent of the soil reservoir capacity, were present, and using the criteria given earlier, irrigation is required. The quantity of irrigation water needed is merely the difference between the water holding capacity and the water present (Figure 2 column three).

A soil auger is a useful tool for a study such as described in the preceding paragraph. Two circulars from the USU Agricultural Extension Service: "How to Make a Soil Auger" and "How to Use a Soil Auger" are reproduced in Appendix II.

Table 2. Practical interpretation chart of soil moisture for various soil textures and conditions. (From the *National Engineering Handbook*, SCS, USDA, Section 15, Chapter 1)

Available moisture in soil	Feel or appearance of soil			
	Coarse-textured soils	Moderately coarse textured soils	Medium-textured soils	Fine and very fine textured soils
0 percent	Dry, loose, and single-grained; flows through fingers	Dry and loose; flows through fingers	Powdery dry; in some places places slightly crusted but breaks down easily into powder.	Hard, baked, and cracked; has loose crumbs on surface in some places
50 percent or less	Appears to be dry; does not form a ball under pressure[1]	Appears to be dry; does not form a ball under pressure[1]	Somewhat crumbly but holds together under pressure[1]	Somewhat pliable; balls under pressure[1]
50 to 75 percent	Appears to be dry; does not form a ball under pressure[1]	Balls under pressure but seldom holds together	Forms a ball under pressure; somewhat plastic; slicks slightly under pressure	Forms a ball; ribbons out between thumb and forefinger
75 percent to field capacity	Sticks together slightly; may form a very weak ball under pressure	Forms weak ball that breaks easily; does not slick	Forms ball; very pliable; slicks readily if relatively high in clay	Ribbons out between fingers easily; has a slick feeling
At field capcacity (100 percent)	On squeezing, no free water appears on soil, but wet outline of ball is left on hand	Same as for coarse-textured soils at field capacity	Same as for coarse-textured soils at field capacity	Same as for coarse-textured on soils at field capacity
Above field capacity	Free water appears when soil is bounced in hand	Free water is released with kneading	Free water can be squeezed out	Puddles; free water forms on surface

[1] Ball is formed by squeezing a handful of soil very firmly.

Table 3. Example illustrating hand-feel test for moisture content in soil profile of Figure 2.

	Soil type — Sandy loam		
Depth of sample (cm)	Observed condition of compacted ball	Estimated water content %	Estimated water content (cm)
30	no ball formed	20	0.8
60		32.5	1.3
90		40	1.6
120		52.5	2.1
150		75	3.0
180	stable ball moist film on hand	80	3.2
		Total water present	12.0

AMOUNT OF WATER TO APPLY

In the physical process of irrigation, fixed relationships exist among the flow rate of the irrigation stream, the time of application, the depth of water to be applied, and the area of the field. This relationship is expressed by:

$$QT = DA \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

where Q is the flow rate, measured in cubic meters per hour; T is the time in hours; D is the depth, in meters, of water applied and A is the area in hectares. A more useable form of equation (1) is:

$$QT = \frac{1000}{36} DA \quad \ldots\ldots\ldots\ldots\ldots \quad (2)$$

where T and A are in hours and hectares, as before, but Q is expressed in liters per second and D is in centimeters. It should be emphasized that D is the depth of water applied; it is not the depth of the root zone. Thus, if a 1-hectare field required 6 centimeters of water over every square meter of its surface area to fill the soil reservoir, it would require a total of 6 hectare-centimeters (ha-cm) or 600 cubic meters of water.

Equations (1) and (2) are very useful tools for irrigation management, for if the value of any three of the four variables are known, the fourth can be computed. Their utility can be illustrated by the following example:

Example 1.

Assume: Area of field $A = 10$ ha

Depth of water needed (To replenish the soil water to FC). $D = 12$ cm

Flow of water available $Q = 140$ *l*/sec

Required: How much time is required to apply the water needed.

Solution:

$$QT = \frac{1000}{36} DA$$

$$T = \frac{1000}{36} \frac{DA}{Q} = \frac{1000}{36} \frac{(12)(10)}{140}$$

$T = 23.8$ or 24 hours.

Other examples with different variables as unknowns can be easily developed.

In Example 1, it was assumed that all of the water applied to the field was used on the field and that absolutely no water was lost by surface run-off or deep percolation below the root zone. Such an ideal situation is extremely difficult to achieve in actual practice. In reality, the amount of water stored in the root zone is less than the amount of water applied. The ratio between the quantity of water stored in the root zone and the quantity of water applied (multiplied by 100) has been defined as the application efficiency.

In equation form, application efficiency can be written as:

$$E_a = \frac{W_s}{D} \times 100 \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

where E_a is the application efficiency, W_s is the water stored in the root zone, and D is the water applied.

This concept is illustrated in Example 2.

Example 2.

Assume:	Area of field	$A = 10$ ha
	Depth of water stored	$W_s = 12$ cm
	Flow of water available	$Q = 140$ *l*/sec
	Time of irrigation	$T = 40$ hours
Required:	Application Efficiency	

Solution: $QT = \frac{1000}{36} DA$

$$D = \frac{36}{1000} \frac{QT}{A} = \frac{36}{1000} \times \frac{140 \times 40}{10}$$

$$D = 20.2 \text{ cm}$$

$$Ea = \frac{W_s}{D} \times 100$$

$$Ea = \frac{12}{20.2} = 60\%$$

Example 3 illustrates the effect of efficiency on time required for irrigation.

Example 3.

Assume:	Area of field	$A = 10$ ha
	Depth of water needed	$D = 12$ cm
	Flow of water available	$Q = 140$ *l*/sec
	Efficiency	$E_a = 60\%$

Required: How much time is required to apply water needed?

Solution: $QT = \frac{1000}{36} \frac{DA}{E_a}$

$$T = \frac{1000}{36} \frac{DA}{E_a Q} = \frac{1000}{36} \frac{(12)}{(0.6)} \frac{(10)}{(140)} = 39.7 \text{ hrs.}$$

The efficiency concept must be considered in all irrigation designs. Application efficiencies, with equipment now available, range between 30 and 90 percent. The higher efficiencies can be obtained only with well designed, well managed systems.

INFILTRATION RATES

Infiltration rate or the rate at which water penetrates the surface of the soil is another important consideration in managing the soil reservoir. Infiltration rate varies with soil type. Generally, loose sandy loam soils have higher intake rates than tight clay soils, and hence, can absorb more water in less time. Some clay soils which shrink and crack on drying, do, however, have high intake rates.

Further analysis of Example 1 can illustrate the importance of the infiltration rate in irrigation practice. If the 140 liters/second stream were applied uniformly over the entire 10 hectares, the water would be in contact with the soil surface for the entire 24 hours of irrigation. Thus, for the soil to receive the necessary 12 centimeters in 24 hours, the infiltration rate would be 1/2 centimeter/hour, a rate much lower than for most soils. However, it is not usually possible to cover an entire field at once, hence, it is necessary to irrigate the field in "sets." If the field were irrigated in four sets of two and one-half hectares each, the water would be in contact with the soil surface of each set for 6 hours. To get 12 centimeters of water into the soil in 6 hours, would require an infiltration rate of 2 centimeters/hour, a rate that can be sustained on only very open and porous soils. A longer water soil contact time would probably be required to fill the soil reservoir. If so, runoff water loss would occur.

To illustrate the relation of intake rate to the problem of Example 1, suppose that the 140 liters/second could only be stretched across 2-1/2 hectares and tests had shown that a sustained intake rate of only 1.25 centimeters/hour could be maintained. Then:

Example 4:

Assume:	Area of field	$A = 10$ ha
	Depth of water stored	$D = 12$ cm
	Flow of water available	$Q = 140$ *l*/sec
	Infiltration rate	$I = 1.25$ cm/hr.

Field to be irrigated in sets of 2-1/2 hectares each.

Required:

Time to irrigate entire field

Solution:

Contact time for 12 cm infiltration

$$T = \frac{12 \text{ cm}}{1.25 \text{ cm/hr}} = 9.6 \text{ hours}$$

Time required to irrigate entire field

$T = 9.6$ hrs. x 4 = 38.4 hours

Depth of water applied

$$QT = \frac{1000}{36} DA$$

$$D = \frac{QT}{A} \times \frac{36}{1000} = \frac{(140)(38.4)}{10} \times \frac{36}{1000} = 19.4 \text{ cm.}$$

Efficiency

$$E_a = \frac{W_s}{D} = \frac{12\text{cm}}{19.4 \text{ cm}} \times 100 = 62\%$$

Another problem encountered in the absorption of water into the soil is that infiltration rate decreases with time. A soil that will take water at the rate of 2.5 centimeters per hour at the beginning of irrigation may only take it at the rate of 1.25 centimeters or less per hour 4 hours later. It is important, therefore, to know the total time necessary for the required amount of water to enter the soil. The variability of intake rate with time can be illustrated in the laboratory by means of Demonstration 4. Demonstrations 5, 6, and 7 are field techniques that may be used to show such variability and to determine total infiltration time for a given quantity of water.

When water is turned into a furrow or border, it is in contact with the soil longer at the head end of the field than at the bottom. This could lead to the application of excess amounts of water at the head of the furrow in order to apply sufficient water at the bottom, as illustrated in Demonstration 8. Careful consideration and control must be given to the interrelation among stream size, length of run, field slope, and infiltration rate if excessive losses by deep percolation at the head of the furrow and by runoff from the bottom are to be avoided. For example, if a small stream was put into a long furrow in open sandy soil, it may never reach the end of the furrow. By shortening the furrow and increasing the stream size, a better balance could be achieved. It has been suggested that a good first approximation in design is for the water to reach the end of the furrow in one-fourth of the time necessary to fill the root zone. Or if four hours are required to get 8 centimeters of water into a particular soil, then the stream should reach the end of the furrow in 1 hour and should be allowed to run into that furrow for a total period of 5 hours, thus making water available at the bottom of the entire furrow for the full 4-hour period. This approximation should be verified by subsequent tests with the soil auger. In open, porous soils it may be necessary to push the water through the furrow in one-half the time needed to fill the root zone, whereas in heavy soils, it may only be necessary to get it through in one-seventh of the time.

In recent years, much has been said about it and considerable research done on a so-called "cut back" system. In this system, the size of a furrow stream is "cut back" to a smaller size after the water has reached the end of the furrow. The larger initial stream is used to get the water through the furrow quickly enough to get uniform penetration and the smaller "cut back" stream is only large enough to maintain flow in the furrow for the required irrigation time. Such a system has many advantages and disadvantages. The chief advantages are a significant reduction in runoff loss.

The chief disadvantage is the increased labor and management skill required to operate such a system. Local conditions will largely dictate its feasibility.

FREQUENCY OF FILLING

How often should the soil reservoir be filled? The answer to this question requires an understanding of the consumptive use of water by crops. Consumptive use varies with temperature, relative humidity, sunlight, wind velocity, and numerous other factors, some of which are difficult to measure. A detailed discussion of this is beyond the scope of this manual, and readers who desire more information are referred to texts and technical journals devoted to its discussion. To demonstrate, however, a simplified case of how consumptive use relates to the frequency of filling the soil reservoir, let it be assumed that a mature crop of corn at a given location requires a maximum of 8 millimeters of water per day. If the useable capacity of the particular soil reservoir is 12 centimeters, then at a consumptive use rate of 8 millimeters per day, the reservoir would be depleted in 15 days. Thus, the frequency of irrigation or the frequency of refilling the soil reservoir would be once every 15 days during the maximum use period.

Summary

The purpose of irrigation is to provide water for plant needs. It is immaterial to the plant where this water comes from – whether it be from irrigation or rainfall. The reservoir from which the plant draws its water is the soil volume within the root zone of the particular crop. For a given soil this reservoir has fixed limits and a fixed capacity. Its dimensions are fixed by the surface area, the texture of the soil, and the depth of the roots. The only plant factor that influences the size of the soil reservoir is the depth to which the roots penetrate. Irrigation is a way to optimize useable capacity of the soil reservoir. Plants are pumps that remove water from the reservoir, and irrigation is the process by which the soil reservoir is filled. When proper consideration is given to the factors governing the refilling of the soil reservoir, then the purposes of irrigation are met and water will be available to the plant upon demand.

Appendix I. Demonstrations

DEMONSTRATION 1: INFLUENCE OF SOIL TEXTURE ON WATER HOLDING CAPACITY

The purpose of this demonstration is to show that fine textured soils have a greater water holding capacity than do coarse textured soils. The equipment pictured is all laboratory equipment. However, other equipment may be substituted as needed.

Equipment

Soil Material. Soils of two different textures are required. Sands of two different particles sizes, such as those shown in Figures D1-1a and 1b, are recommended. Particle size range of the sand in Figure D1-1a is from 0.3 to 0.6 millimeters. The coarse sand in Figure D1-1b ranges in size from 0.6 to 1.2 millimeters.

Glass Columns. Glass columns filled with the soils, will permit the viewer to watch the infiltration of the water into the soil and to see the rate of advance of the wetting front as the water moves down through the soil. Such columns can either be infiltrometer tubes, shown in Figure D1-2 or some other type of glass container such as pop bottles with the bottoms cut off. If glass tubes are not available, common ordinary water pipe may be used if caps are screwed on the bottom and holes drilled in the caps to permit the water to flow out. If fabrication time is available, special metal infiltrometers resembling the glass columns shown in Figure D1-2, may be constructed and used.

Wadding. Some type of porous wadding must be put in the bottoms of the columns to prevent the sand from flowing out and yet permit the water to drain from the soil Steel wool wadded and dropped into the holes in the bottom (see Figure D1-2), filter paper properly folded and worked into the bottom, or a graded gravel filter will suffice. The important thing is to be sure that the sand does not drain from the bottom of the column. Wadding material or a paper disk is also needed on top of the sand to prevent erosion when water is poured into the columns.

Stand for Columns. Some type of permanent stand is necessary to hold the columns in place. This can be a laboratory stand with the appropriate clamps, (Figure D1-2) or any arrangement that will hold the columns securely.

Water Containers. Most any type of container can be used to hold water, however, glass is preferable so that participants can see water levels and make proper eye comparisons of the water levels in each container. At least one type of glass measuring container is necessary to measure the amount of water put in and the amount of water drained out. Measuring devices which are satisfactory are graduate cyclinders (Figure D1-2) or glass measuring cups such as those used for measuring cooking materials. Beakers or ordinary water glasses are acceptable, or if these are not available, metal containers of some sort can be used.

Water. A small amount of good quality water is required. It is adviseable to color the water so that it is easier to see by those who are watching. In the photographs of Figure D1-2, a drop of ink has been added to the water in each cylinder to give it the dark color. Food coloring or dyes may also be used.

Procedures

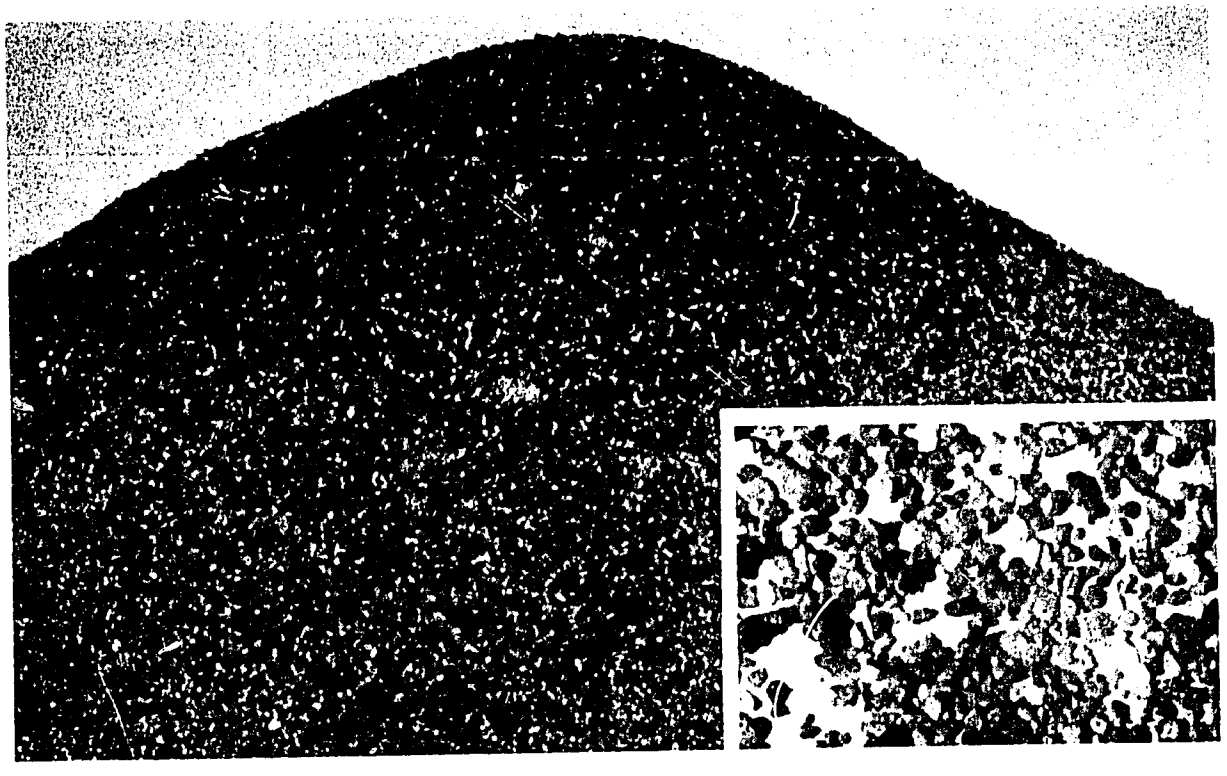
The following steps may be used in performing this demonstration.

Step 1. Set up the stand.

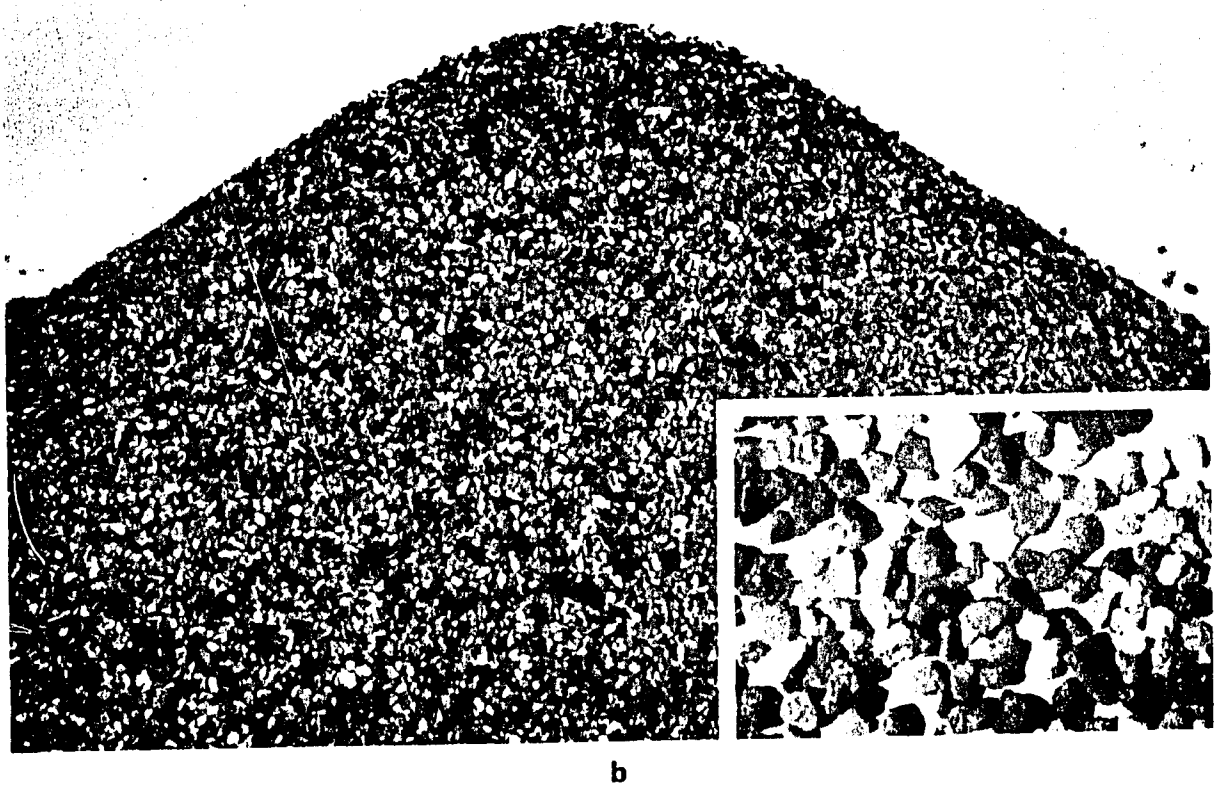
Step 2. Place the filter paper or loosely compacted wadding in the bottom of the columns, then slowly pour in the air-dry sand. While filling, move the sand stream around so that the sand does not all fall in the same location in the tube, or else separation of the soil particles, with the large particles collecting on the outside and the finer particles collecting in the middle, will occur. Occasionally, tap or jar the column to compact and settle the sand. Both columns should be filled to within 3 to 5 centimeters of the top. Then another piece of wadding or filter paper should be placed on top of the sand to prevent erosion and stirring of the soil when the water is poured in.

Step 3. Pour equal quantities of water into each of two beakers or water containers. Be sure there is enough water in each container to more than fully saturate the fine soil column. Two other water containers should be placed underneath the outlets of the columns to collect the water as it drains through. The completed setup for the demonstration is shown in Figure D1-3.

Step 4. Pour the water as rapidly as possible into both soil columns simultaneously, as illustrated in Figure D1-4. Care should be taken to not spill any water. At this point draw attention to the rate of



a



b

Figure D1-1. Sand for glass columns. (a) Fine sand. (b) Coarse sand. (Inserts are magnifications of individual particles.)

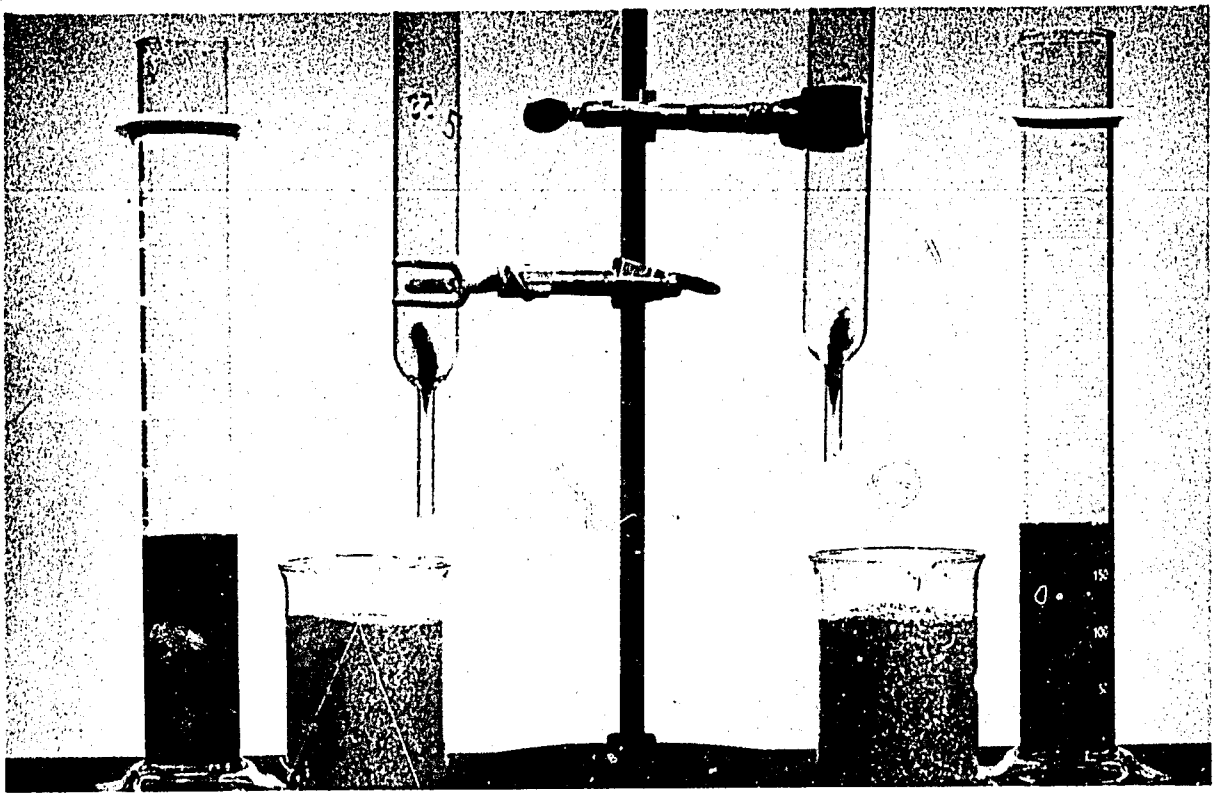


Figure D1-2. Assembled apparatus for water holding capacity demonstration.

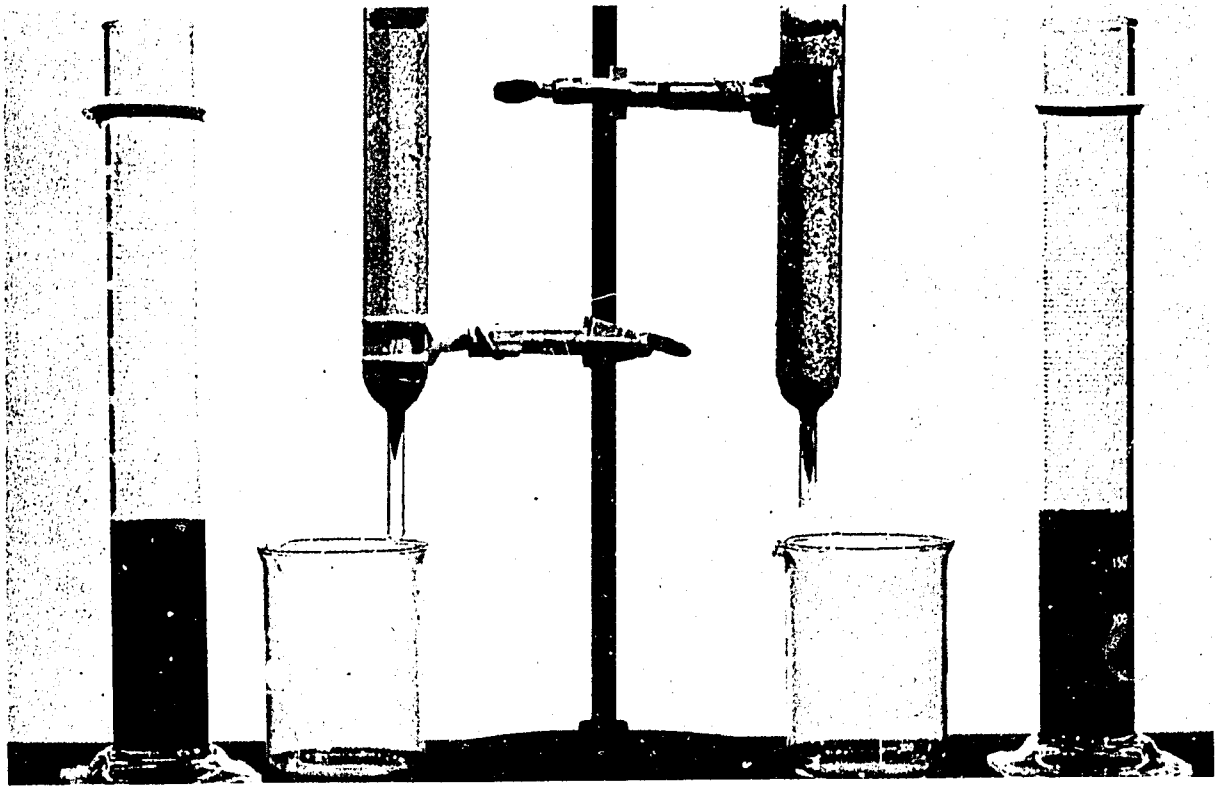


Figure D1-3. Water holding capacity demonstration apparatus ready for addition of water.

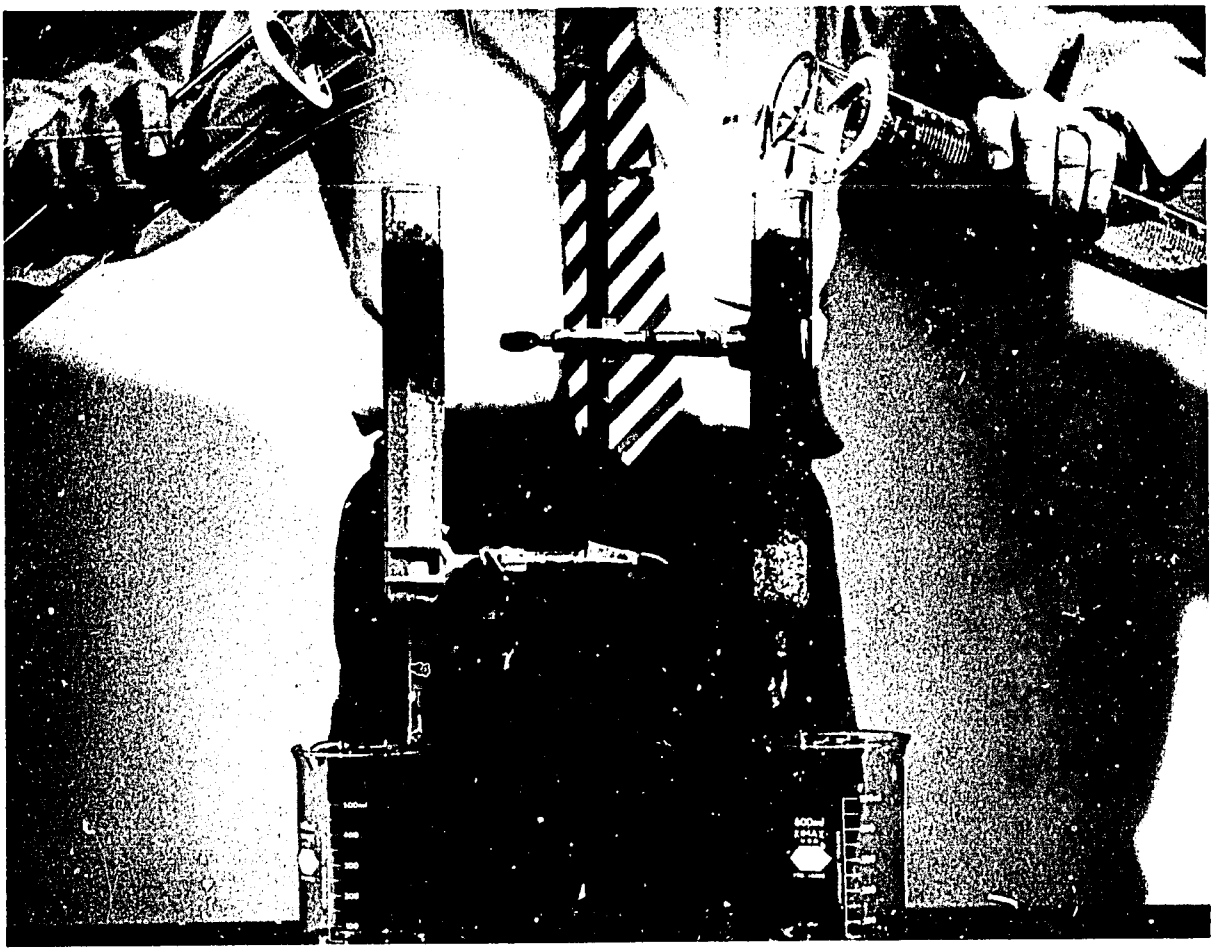


Figure D1-4. Adding water during water holding capacity demonstration.

advance of the wetting front in the two columns. As will be noted from Figure D1-4, the wetting front is nearly to the bottom in the coarse sand on the right and only about one-third of the way down in the finer sand on the left.

Step 5. Measure the drainage water. After all of the water has been poured into the columns, allow sufficient time for all free water to drain into the containers at the bottom of the columns. If the drainage containers are calibrated as shown in Figure D1-5a, drainage volumes can be compared directly. For example, the photographs show that nearly 200 millimeters of water have drained out of the coarse sand, and only about 150 millimeters of water have drained from the fine sand, indicating that the water holding capacity of the fine sand is 50 millimeters more than for the coarse sand. If, however, the containers below the soil columns are not calibrated or if more precise measurement is required, the water can be poured into a graduate cyclinder as shown in Figure D1-5b. It is easier to tell by visual inspection that more water has drained from the coarse sand than the fine sand if the measuring device is tall in comparison to its diameter, as is the case with graduate cylinders.

Summary

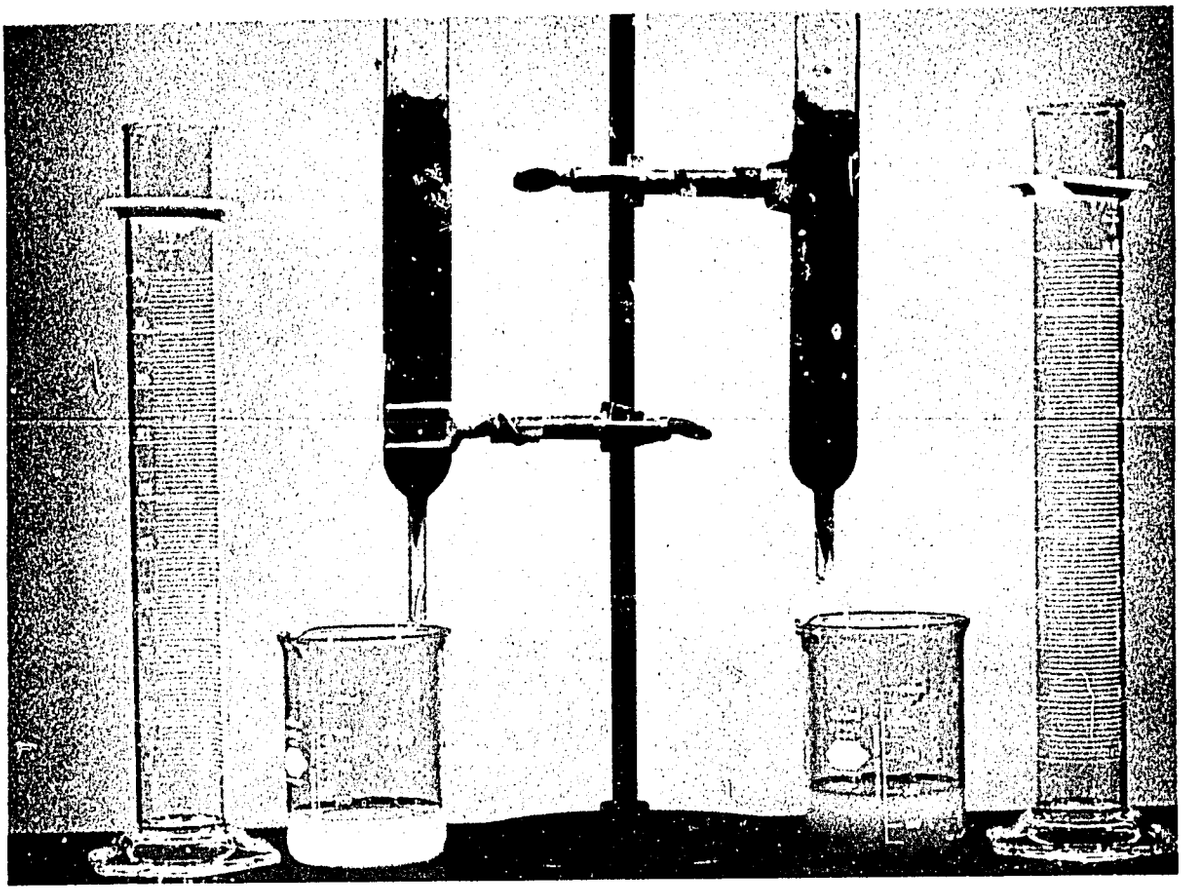
The following deductions and observations can be made from the preceding demonstration.

1. The water holding capacity of a fine soil is greater than that of a coarse soil.

2. The capacity of a soil reservoir is a function of the type of soil.

3. Water will move into the surface of a coarse soil faster than it will into the surface of a tight soil.

4. Water will move through a coarse soil faster than it will through a fine soil.



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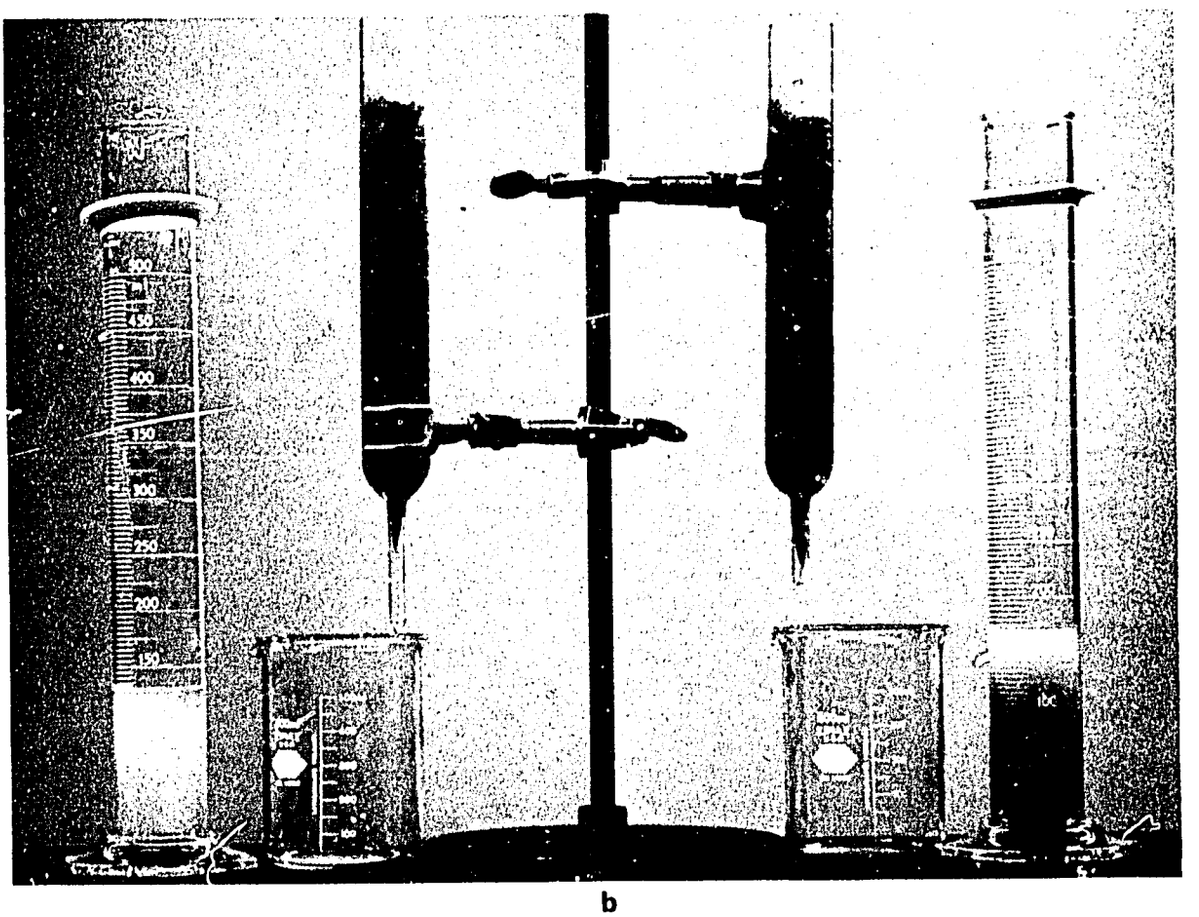


b

Figure D1-5. Comparison of water held by different sands in water holding capacity demonstration. (a) Drainage water in beakers. (b) Drainage water in graduate cylinders.

DEMONSTRATION 2: SPONGE AS A SOIL RESERVOIR

This demonstration illustrates the concept of a soil reservoir with a simple sponge.

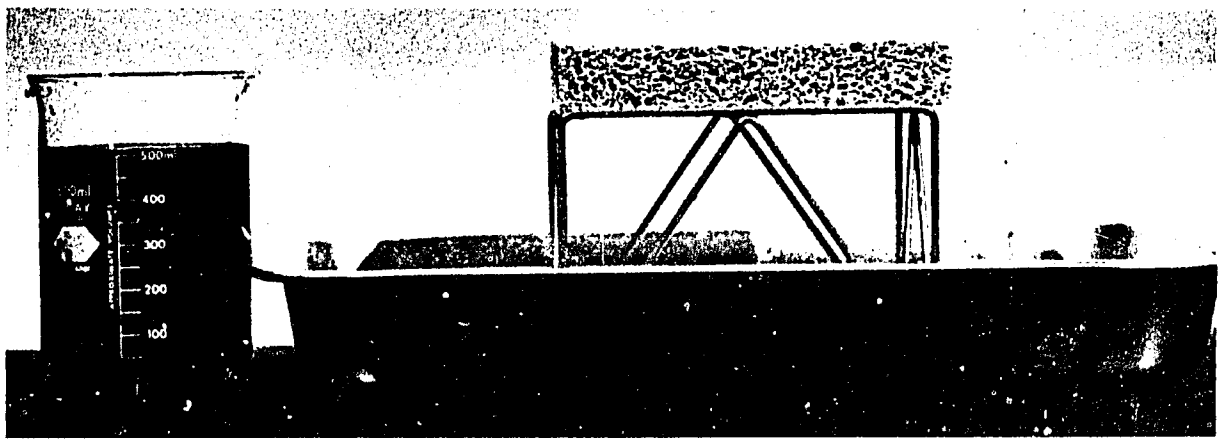
Equipment

The four pieces of equipment needed are:
a sponge
a pan for the drain water
a stand for holding the sponge and
a glass water container

Two types of stands are shown in Figure D2-1. Other stands can be made by bending a clothes hanger, bending ordinary iron wire or using hardware cloth sitting directly on top of the pan. The important feature of the stand is that it permits the water to drain freely through the sponge into the pan below. In Figure D2-1a, the water container is a calibrated glass beaker. Other acceptable types of water containers include large graduate flasks and ordinary kitchen measuring cups.

Procedures

The assembled apparatus is shown in Figure D2-1, with the stand in the drain pan and the moist sponge on top (moisten the sponge by saturating it and then squeeze out as much water as possible). Water is then poured over this moistened sponge, as is shown in Figure D2-2. Pour enough water over the surface of the sponge to more than saturate it, but do not permit any to run off the sides. In Figure D2-2a and b, the sponge is holding all of the water being poured on. In Figure D2-2c drainage is just beginning



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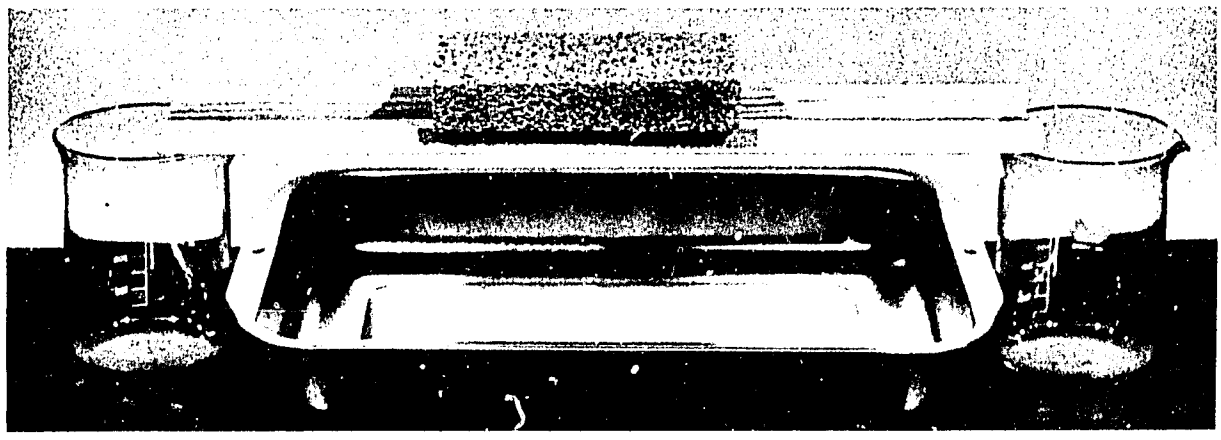

b

Figure D2-1. Assembled apparatus for the sponge-reservoir demonstration. (a) Using a metal stand. (b) Using a wooden stand.

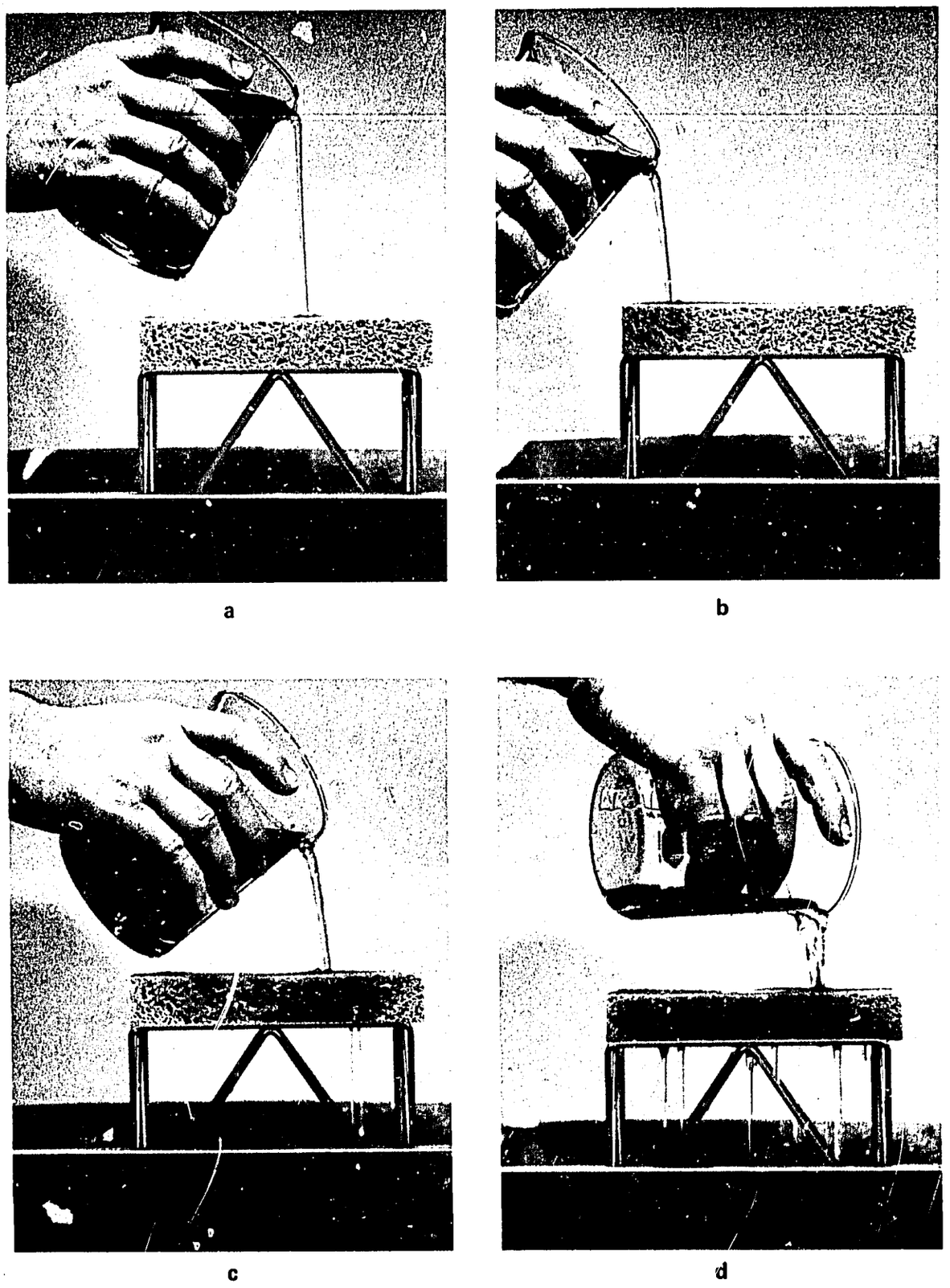

Figure D2-2. Adding water during sponge-reservoir demonstration. (a) Just beginning. (b) Sponge still holding all water. (c) Drainage beginning. (d) Massive drainage.

and in Figure D2-2d massive drainage occurs. Allow the sponge to drain for two or three minutes to remove most of the gravitational water. Next, squeeze the water out of the sponge back into the original container; be sure that all of the water is caught, as shown in Figure D2-3. The water retrieved, Figure D2-4, is the water holding capacity of the sponge.

Observations

It is quite simple to compare the sponge to a soil reservoir. The physical dimensions of the sponge correspond to the surface area of the field and the depth of the root zone. The porosity of the sponge is comparable to the porosity of the soil reservoir. Since porosity of the reservoir is a function of soil texture and since water holding capacity is a function of porosity, then water holding capacity is also a function of soil texture. The observation that an unsaturated sponge retained all water poured onto it is analagous to a soil reservoir (the depth of the root zone) absorbing all the irrigation water. When just enough water is applied to the surface of the soil to completely fill the soil reservoir, there will be no drainage and nearly all of the water in the reservoir can be recovered by the plants. It must be emphasized, however, that the reservoir is not filled until a little drainage begins to occur and unless it is filled, its holding capacity is not completely used.

A second observation, the drainage from the bottom of the sponge of excess water applied to the surface is similar to over-irrigation of a soil reservoir. It doesn't matter how much water in excess of the water holding capacity of the reservoir is applied, it is lost as far as being recoverable by the plant is concerned. It is not uncommon to find that when water users do not fully understand this concept, quantities of water far in excess of the water holding capacity of the soil reservoir are applied on the assumption that as long as water is going into the surface of the soil it will be stored by the soil for use by plants later on. This is not the case and should be emphatically pointed out. The excess water only contributes to ground water and drainage problems. It is of no benefit to the particular crop on that particular field.

Irrigation efficiency can also be illustrated by this demonstration. It will be noted that nearly 250 milliliters of water were recovered from the soil reservoir, however, 500 milliliters were poured over

Figure D2-3. Retrieving water from sponge.

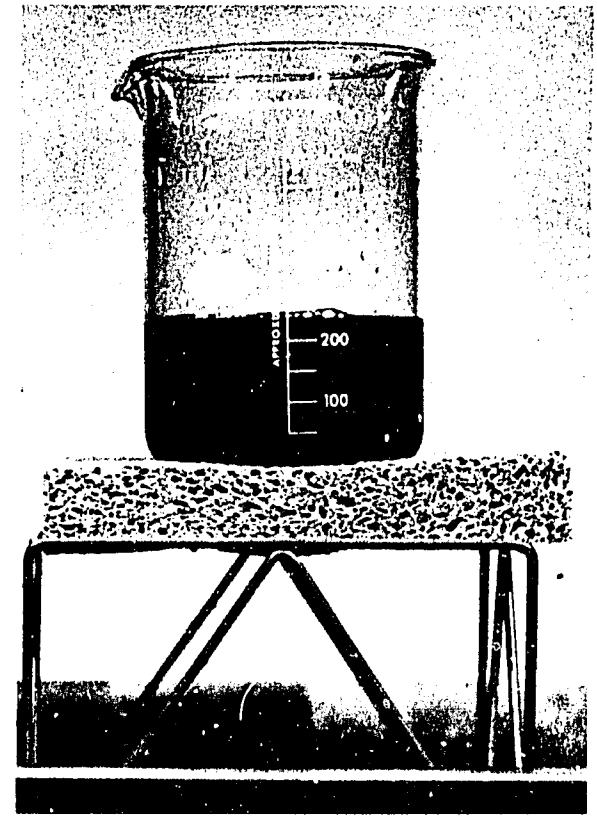

Figure D2-4. Water retrieved from sponge.

the surface of the sponge. Thus only half of the water applied was stored. This is comparable to an irrigation efficiency of approximately 50 percent.

Summary

This demonstration illustrates that:

1. Irrigation is a process of filling a soil reservoir.

2. The soil reservoir has dimensions and a fixed capacity, as governed by the size of the field, depth of the root zone, and texture of the soil.

3. When the reservoir is full, any additional water applied moves out of the root zone and is no longer available to the plants.

DEMONSTRATION 3: EXCESS APPLICATION RATES

In this demonstration, a sponge is used to show what happens when large quantities of water are run over the surface of soil in a short period of time.

Equipment

The equipment is identical to that used in Demonstration 2.

Procedures

The procedures are basically the same as those for Demonstration 2 except that the 500 milliliters of water are dumped quickly onto the sponge and allowed to spill over the sides and run into the pan, as shown in Figure D3-1.

Observations

When the water is squeezed out of the sponge into the glass beaker, less water will be recovered than with the sponge fully saturated. In the instance shown in Figure D3-2, only 200 milliliters were recoverable. Demonstration 2 showed that the water holding capacity of this particular sponge is 250 milliliters; hence, only 80 percent of the water that the sponge could hold, actually soaked into it, despite the application of much more water than its holding capacity. This is equivalent to using relatively large streams during irrigation, with much of the water running off the bottom of the field, and not leaving the water on the field long enough for it to penetrate to the complete depth of the soil reservoir. This again represents an inefficient use.

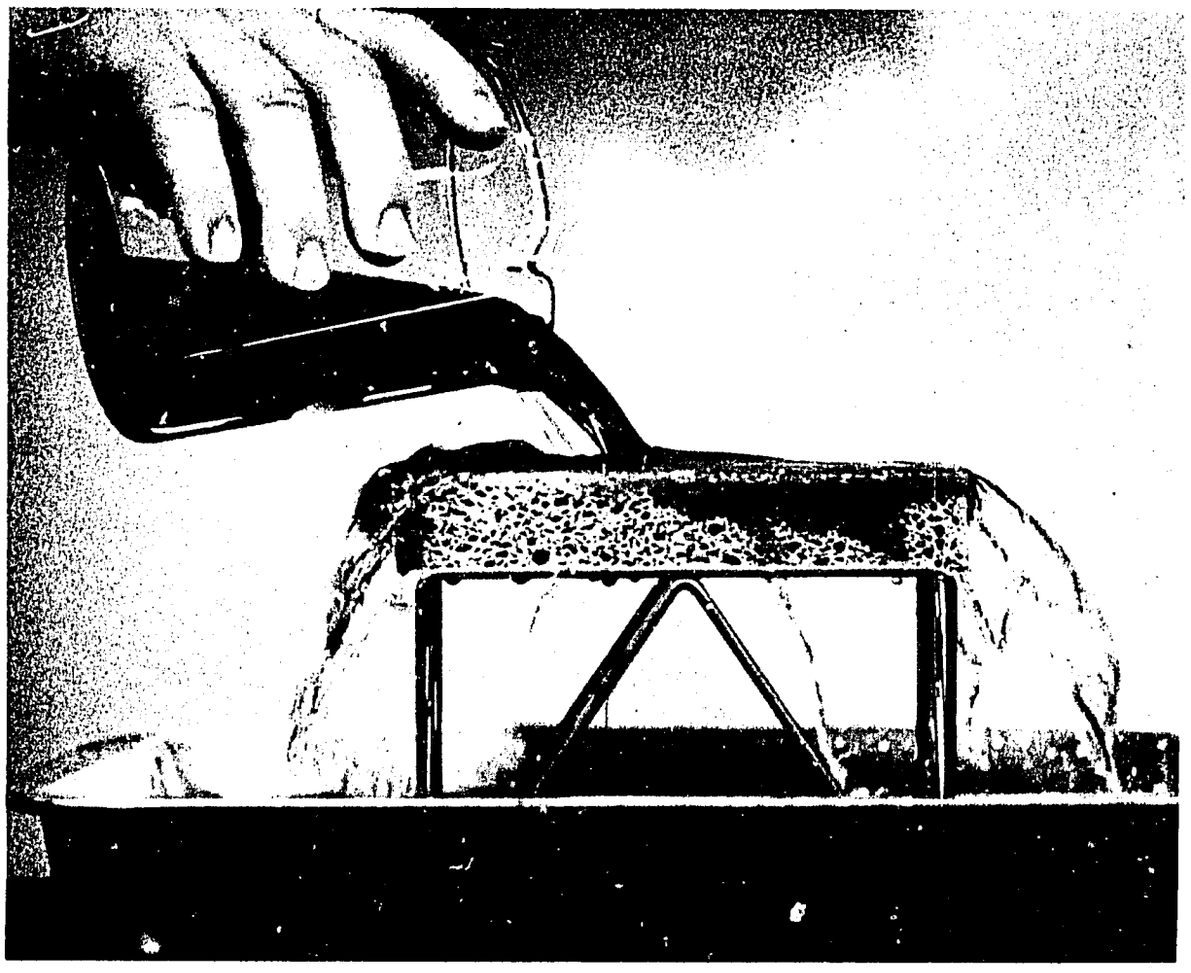

Figure D3-1. Dumping water on sponge during excess application rate demonstration.

It is well to point out that, in the field, under irrigation conditions it is necessary to know the quantity of water being applied, the water holding capacity of the soil, and the infiltration rate of the soil. These three components must be balanced if a good irrigation efficiency is to be obtained.

Summary

This demonstration illustrates that:

1. Contact time between water and soil surface is important in efficient irrigation.

2. Irrigation may not be complete when water reaches the end of the field.

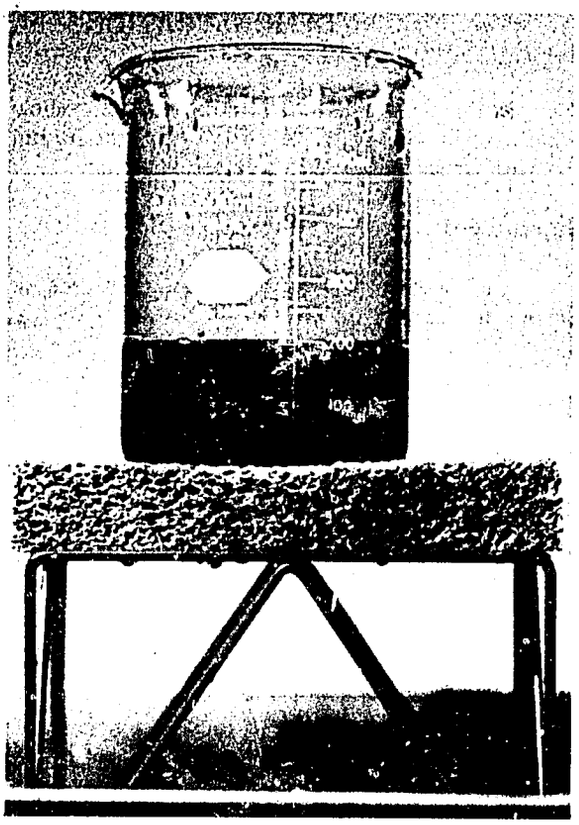

Figure D3-2. Water retrieved from sponge.

DEMONSTRATION 4: INFILTRATION AND PENETRATION RATES

This demonstration is to show water movement into the soil surface through the soil profile and the extent of these movements with time.

Equipment

A clear plastic or glass cyclinder 10 to 15 centimeters in diameter and approximately 50 centimeters high.

Ten liters of air-dry soil—this should be a loam soil, sandy soil is too porous.

Two liters of water.

A small glass or rigid clear plastic tube ¼ inch in diameter and about 55 centimeters long.

Steel wool to cover the bottom of the cylinder to a depth of 3 centimeters.

Marking pencil.

Scale.

Watch.

Procedures

Step 1. Set up the apparatus as follows: (a) cover the bottom of the cylinder with the steel wool; (b) push the small glass (plastic) tube down into the steel wool against one side of the cylinder and hold in place with a small piece of scotch tape (this tube permits the air trapped in the soil to escape as the water moves downward through the column); (c) pour the soil into the cylinder so that the surface of the soil remains approximately level during the filling process. Fill the cylinder to within 10 to 15 centimeters of the top in 2- to 3-centimeter increments and between each addition stir the soil to minimize segregation of the soil particles. Compact the soil in the cylinder by gently tapping the side with a stick or by jarring it, very carefully of course, to avoid damage. If the soil is not adequately compacted, undesirable settlement will occur during the demonstration.

When the cylinder has been filled and the soil compacted, mark the outside of the tuoe to indicate the initial soil surface. Then, place a sheet of paper, whose diameter is smaller than that of the cylinder, on top of the soil to deflect the falling water jet and prevent erosion as water is poured into the cylinder.

Step 2. Rapidly pour enough water into the cylinder to bring the water level to approximately 5 centimeters above the soil surface as shown in Figures D4-1 and D4-2.

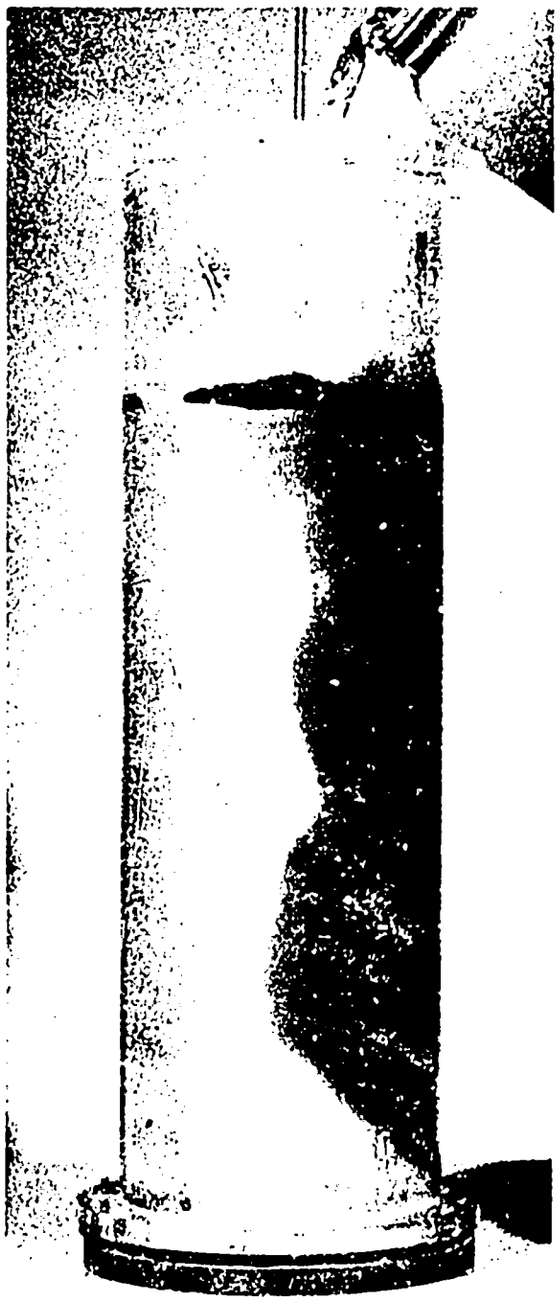

Figure D4-1. Adding water to infiltrometer for the intake rate demonstration.

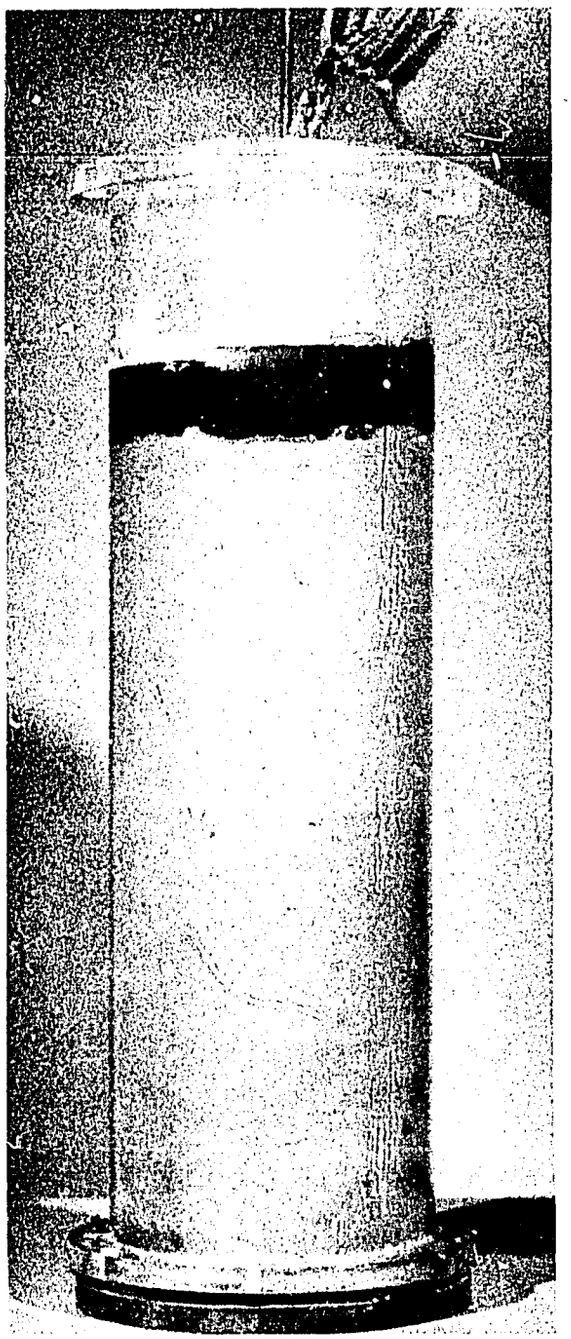

Figure D4-2. Water in infiltrometer.

Step 3. As quickly as possible mark the water surface with the marking pen. This step is shown in D4-1 and D4-2.

Step 4. Begin recording the time immediately.

Step 5. At appropriate intervals mark the water surface elevation and the depth of penetration of the water into the soil profile and record the time (see Figure D4-3).

Step 6. Record the depths and times as shown in the example data sheet of Table D4-1.

Step 7. Plot the data as shown in Figures D4-4 and D4-5. Figure D4-4 is a rectangular plot of the accumulated depth of penetration and the accumulated depth of infiltration plotted against elapsed time. Figure D4-3 is a logarithmic plot of the same information and should be used only when class participants understand the use of logarithms.

Observations

The markings on the tube constitute a graph of what happens to the infiltration rate and the penetration rate of water with time. It can be shown from these figures that for any equal periods of time the movement of the water both into the surface of the soil and through the soil is less in succeeding periods of time. For example, the depth of penetration between time periods 0:00 and 0:10 is much greater than the depth of penetration between time periods 0:20 and 0:30. The same general phenomenon can also be seen when checking the water surface markings. Figure D4-4 is merely a graphical representation of the information.

The decrease in distance of movement with time indicates a correlated decrease in the rate of water movement. The important concept here is that these decreases also occur under field irrigation conditions. Contact time between the water and the soil surface during irrigation must be adequate to allow sufficient quantities of water to penetrate into the soil profile to fill the soil reservoir.

From Figure D4-3d it can be seen that at time period 1:00, very little water is left on the surface of the soil, hence the infiltration rate is practically nil beyond that point. At time period 3:00 (Figure D4-6) the wetting front in the soil profile has moved considerably further down the column from where it was in time period 1:00. This phenomenon occurs because at time period 1:00, the upper part of the soil column was saturated, and hence, some of the pore water was subject to gravitational pull. This gravitational water moving to the lower layers constituted the wetting front. Although no more photographs were taken after 3 hours, the front continued to move for 24 hours. The wetting front is a very definitive line with the soil above the line being between saturation and field capacity while that below the line is air dry. This same phenomenon occurs under field irrigation conditions. It is impos-

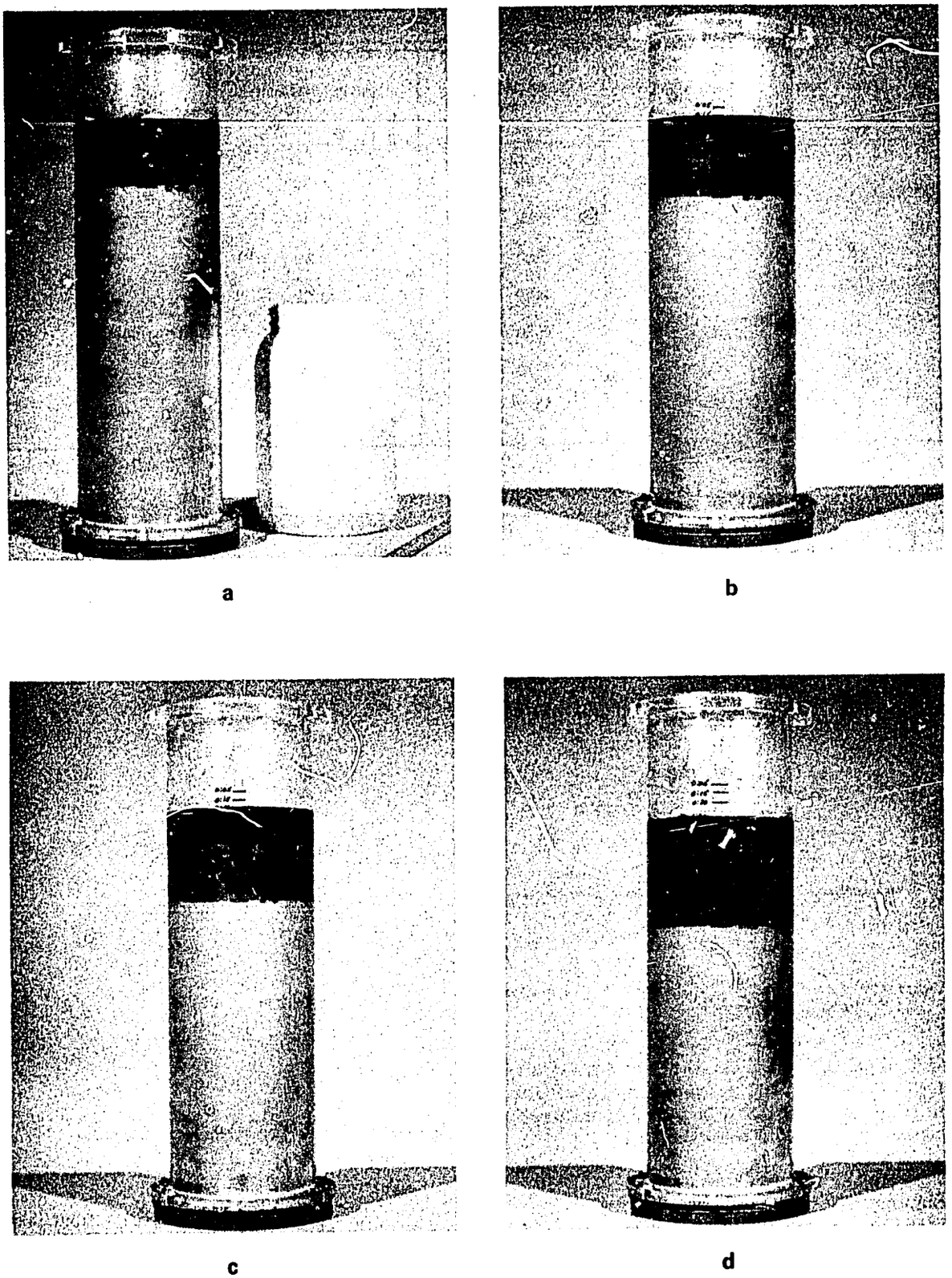

Figure D4-3. Water level drop with time. (a) After 5 minutes. (b) After 15 minutes. (c) After 30 minutes. (d) After 1 hour.

Table D4-*. Table for recording infiltration data

Elapsed time (min.)	Time of reading	Depth of water (cm)	Accumulated intake (cm)	Depth of penetration (cm)
	8:40	4.45	0.00	0.00
5	8:45	3.49	0.96	3.18
10	8:50	2.86	1.59	4.45
15	8:55	2.54	1.91	5.10
20	9:00	2.22	2.23	6.20
30	9:10	1.75	2.70	7.42
60	9:40	0.60	3.80	10.80

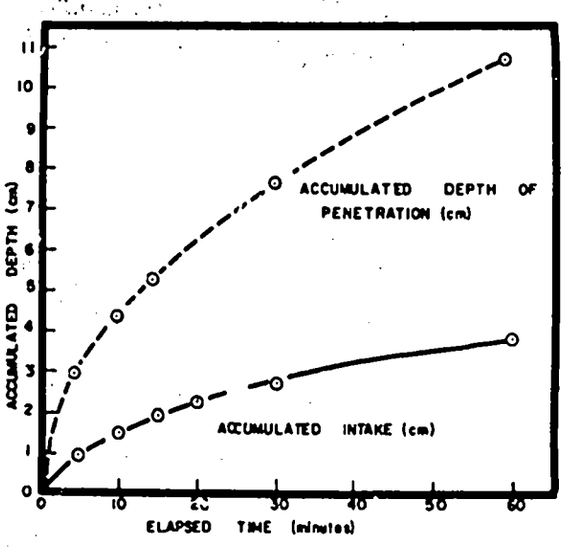

Figure D4-4. Accumulated intake and depth of penetration as a function of time.

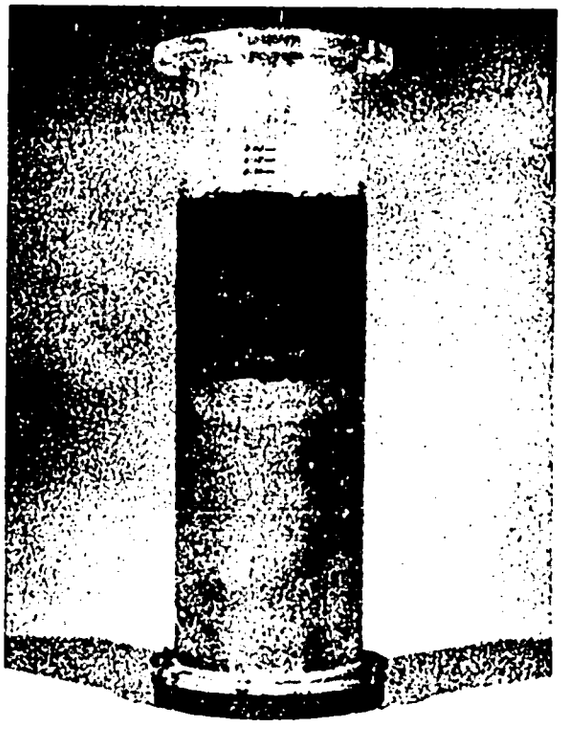

Figure D4-5. Depth of penetration after three hours.

sible to partially wet a soil. It will be filled to total field capacity or it will receive no water at all. It is, therefore, important under field conditions, to apply enough water to fill the entire root zone.

Summary

This demonstration illustrates that:

1. Infiltration rate of water into soil decreases with time.

2. Rate of advance of the wetting front in a soil decreases with time.

3. Wetting front continues to move down through the soil after the water has been shut off

until all gravitational water has been moved out of the saturated zones.

4. It is impossible to partially wet a soil during irrigation; the soil will be filled to field capacity or will receive no water at all.

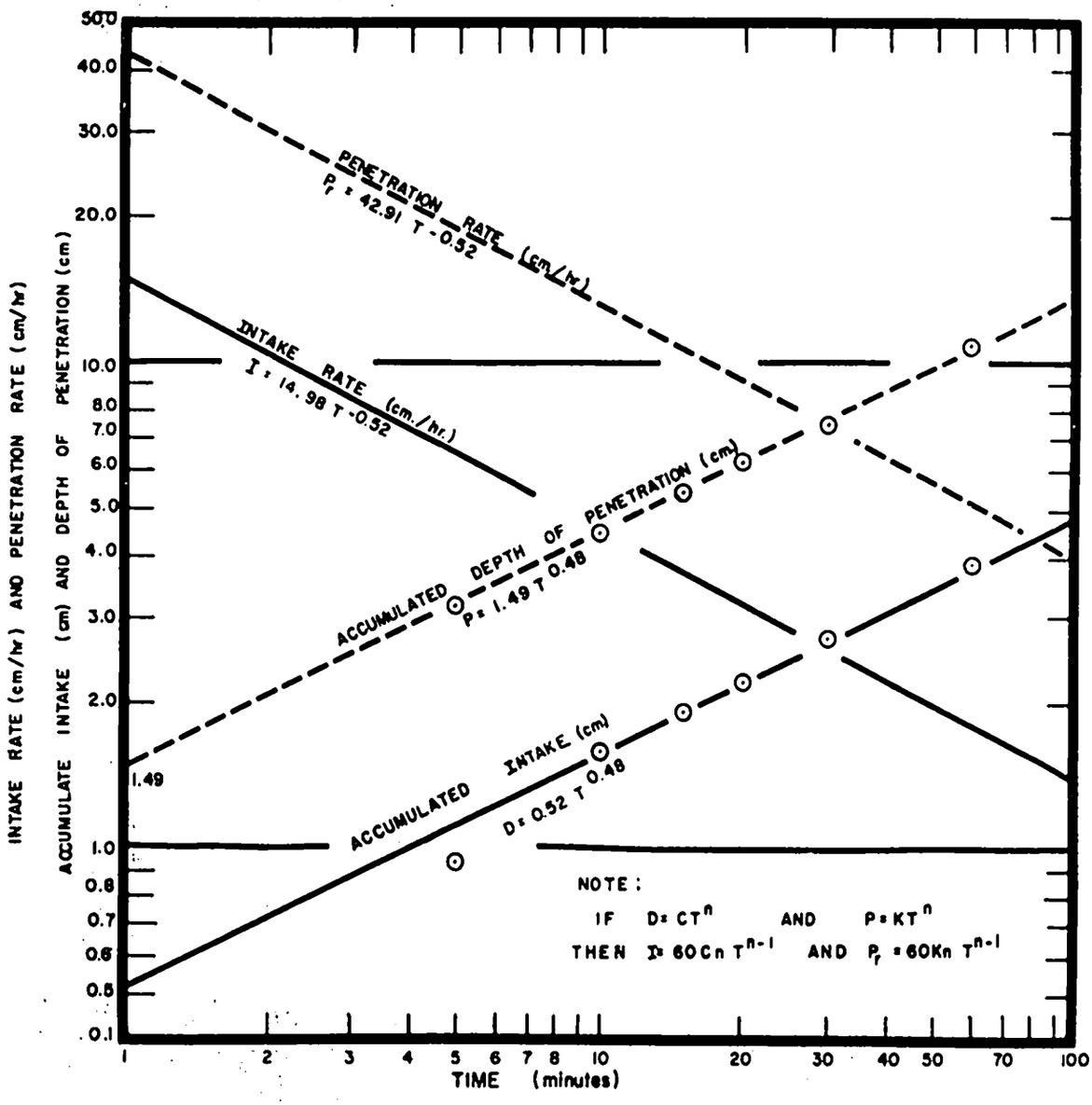

Figure D4-6. Intake and depth of penetration rates.

DEMONSTRATION 5: RING INFILTROMETERS

This demonstration uses a field technique for determining infiltration rates for various soils. A steel cylinder is driven part way into the surface of the soil. The upper part is filled with water and the rate at which the water surface drops is measured. The apparatus needed for such a test are shown in Figure D5-1. Installation and use of ring infiltrometers are depicted in Figures D5-2 to D5-4. Notes are kept as described in Table D4-1 of Demonstration 4.

Figure D5-1. Ring infiltrometer apparatus.

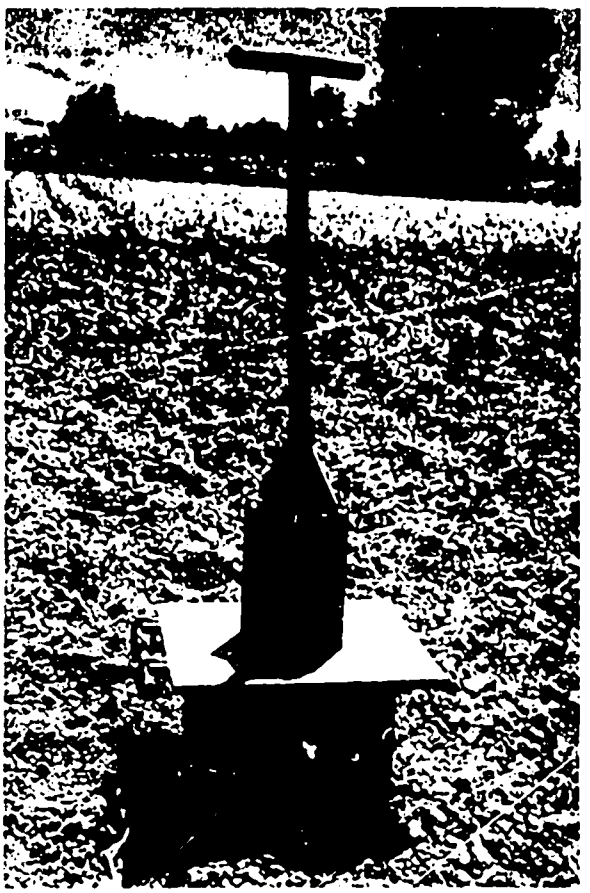

Figure D5-2. Field installation of ring infiltrometer.

Figure D5-3. Filling a ring infiltrometer.

Figure D5-4. Measuring water level in ring infiltrometer.

Techniques of installation and operation of the infiltrometers are copied from bulletin No. ARS 41-7, published in May 1956 by the Agricultural Research Service of the U.S. Department of Agriculture. Plans for making the equipment Figures D5-5 to D5-7, are also taken from that publication. Because this information is being copied, all dimensions are in the English system rather than the metric. However, there is nothing precise about the given dimensions and they may be modified to fit conventional material sizes for metric units as desired.

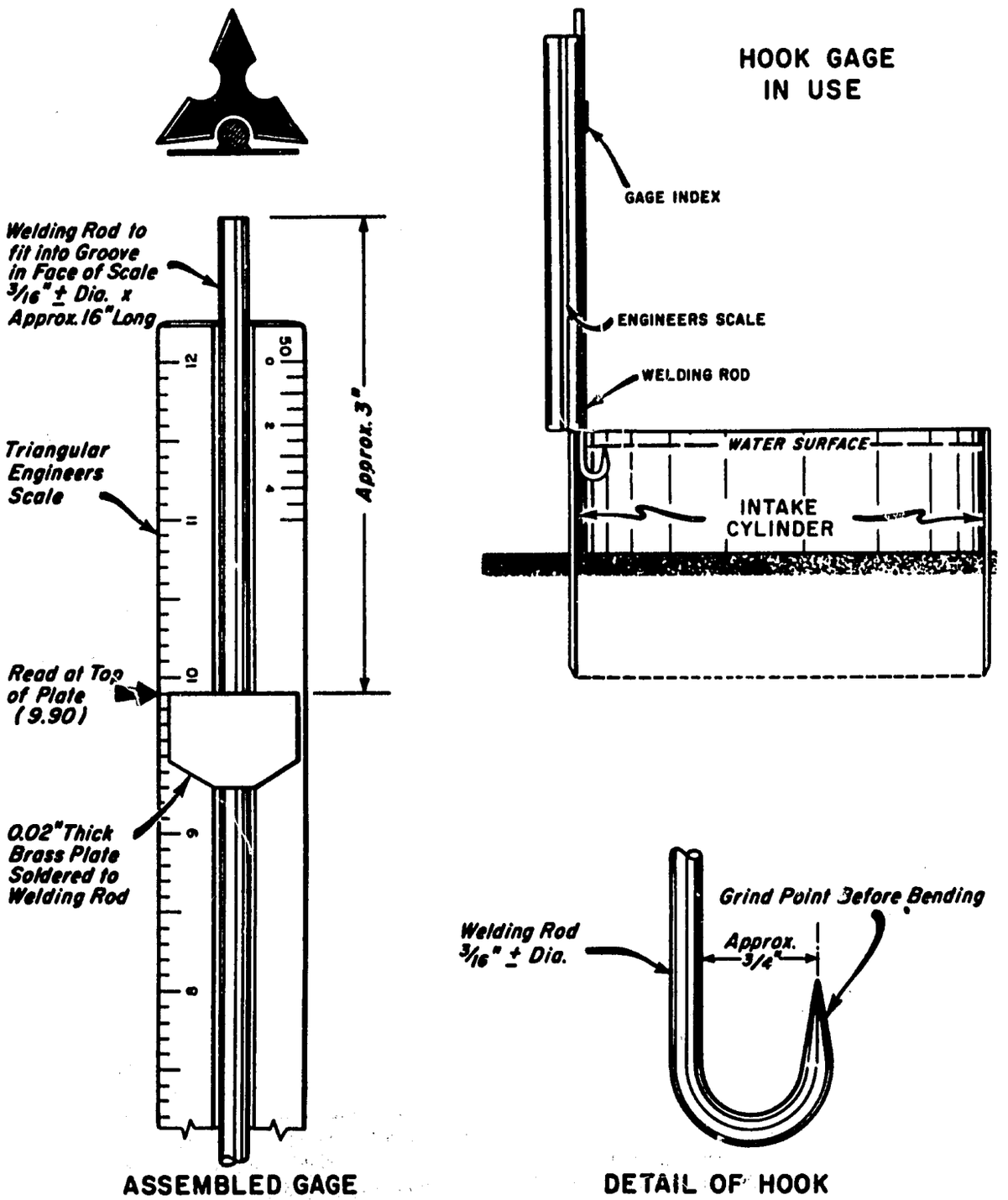

Figure D5-5. Hook gage — for use with intake cylinders.

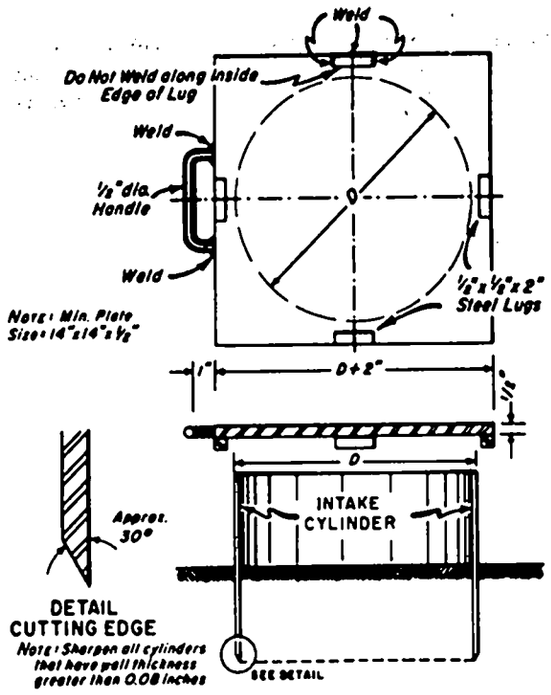

Figure D5-6. Intake cylinder and driving plate.

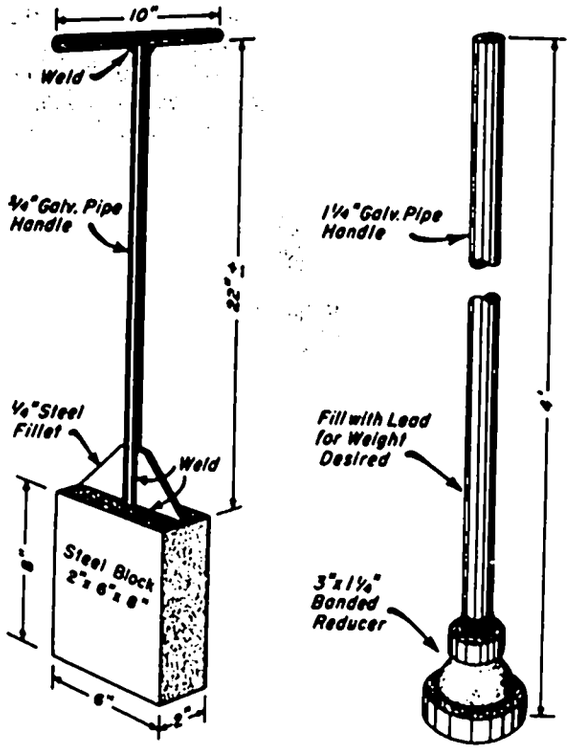

Figure D5-7. Driving hammers for intake cylinders.

Installation

1. Select a proposed exact location for each cylinder and examine carefully for signs of unusual surface distrubance, animal burrows, stones that might damage cylinder, etc. Avoid areas that may have been affected by unusual animal or machinery traffic. The individual cylinders used for a single test should be set close enough together so that they can conveniently be run simultanously. Normally they should be set within a one-half acre area.

2. Set cylinder in place and press firmly into soil.

3. Place driving plate on cylinder. Tap plate with driving hammer to get cylinder started into the soil. Check to see that cylinder is plumb (top is level). Carpenter's level can be used to check, but usually adequate leveling can be done by eye.

4. Stand on driving plate and tamp with driving hammer until the cylinder is driven to desired depth. Level of cylinder should be checked frequently. Keep it approximately plumb at all times. Do not drive the cylinder into the soil irregularly so that first one side then the other goes down. This produces a poor bond between the cylinder wall and the soil, and may disturb the soil core within the cylinder. If the cylinder gets materially out of plumb while driving, remove it and reset in a comparable nearby location. Cylinders should be driven to a depth of approximately 6 inches.

Operation

1. Place burlap or other puddling protection device on the soil within the intake cylinder.

2. Fill the intake cylinder with water to a depth of 4 to 5 inches.

3. Remove the puddling protection device.

4. Make hook gage measurement of the water surface elevation. Use cylinder edge for hook gage datum point and mark the cylinder so all subsequent measurements can be made at the same point on the cylinder. The cylinder should be filled quickly and the inital water surface observation made immediately to reduce errors due to intake during this period.

5. Record the hook gage reading and the time at which the observation was made.

6. Make additional hook gage measurements at periodic intervals and record the data. Intervals between observations usually should be short (5 to 10 mintues) at the start of the test. After 2 or 3 measurements the intervals may be increased. After about the first hour, measurements at 30 to 60 minute intervals usually will be sufficient. Observation frequencies should be adjusted to intake rates. For most soils, observations made at the end of 5, 10, 20, 30, 45, 60, 90 and 120 minutes and hourly thereafter, will provide good data. High intake rate soils may require more frequent measurements. As a general rule the intake between measurements should not be more than one inch. Measurements usually should be continued until 4 hours of time have elapsed. However, on high intake rate soils, it seldom is necessary to extend the tests beyond the time required to put about 6 inches of water into the soil. On very tight soils it may be desirable to continue the tests beyond 4 hours.

7. When the water level has dropped an inch or two in the cylinder, add sufficient water to return the water surface to its approximate initial elevation. Maintain the depth of water in the cylinder between 3 and 5 inches throughout the entire test. When water is added, be sure to record level before and after filling. Keep the interval between these two readings as short as possible to avoid errors due to intake during the refilling period. In using the data, the refilling is assumed to be instantaneous.

8. Where an abnormally high or low intake value is indicated by a cylinder, it should be dug out and the soil examined for possible causes. Record observations.

9. Remove cylinders and clean thoroughly. Mud encrusted cylinders are difficult to drive and are likely to cause excessive soil distrubance.

DEMONSTRATION 6:

INFILTRATION RATES FROM FURROWS

This demonstration uses a field technique that can determine infiltration rates from furrows when more elaborate equipment is not available.

Equipment

1. A field ready for furrow irrigation

2. One 4-liter container

3. Two pipes, 5 centimeters in diameter and 50 to 75 centimeters long

4. A shovel

5. A stop watch or a watch with a sweep second hand

Procedures

1. At a point about 3 to 5 meters from the head end of the furrow, dig a hole in the furrow large enough to submerge the 4-liter container.

2. Immediately above the hole install one of the pipes so that all water in the furrow must pass through it as shown in Figure D6-1(a). The discharge end of the pipe should be high enough to permit catching water in the 4-liter container when it is in the hole below as shown in Figure D6-1(b). Alternate methods of measuring the furrow discharge, such as the Parshall flume shown in Figure D6-2, may be used if such equipment is available.

3. If the furrow is sufficiently long, set the second pipe in the same manner as the first, but 60 meters down the furrow from the first one. If however, the furrow is not sufficiently long, set the second pipe 36 meters from the first one.

4. Introduce water into the furrow, and allow sufficient time for the flow to come to equilibrium. To insure this, permit the water to flow for 10 to 15 minutes through the second tube before any measurements are made.

5. Beginning at the lower station, measure the water flowing through the pipe in the following

Figure D6-1(a). Pipe installed in furrow for a furrow infiltrometer.

Figure D6-1(b). Measuring water flowing through pipe of a furrow infiltrometer.

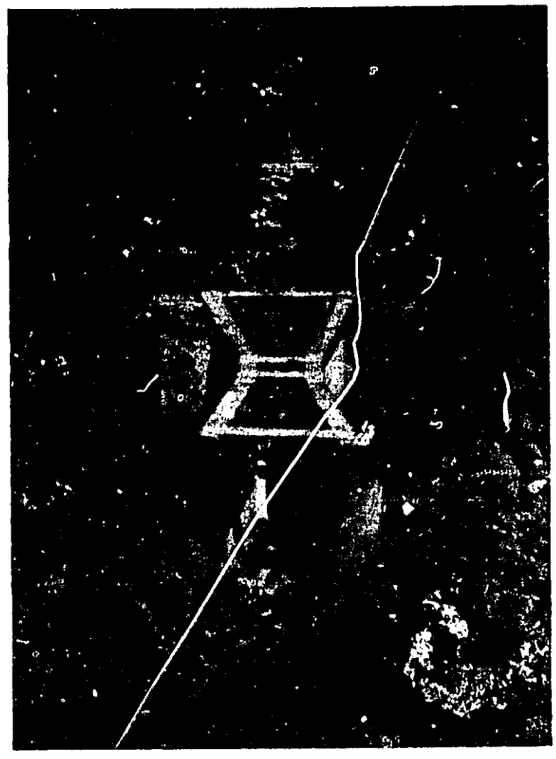

Figure D6-2(a). Two-inch parshall flume for a furrow infiltrometer.

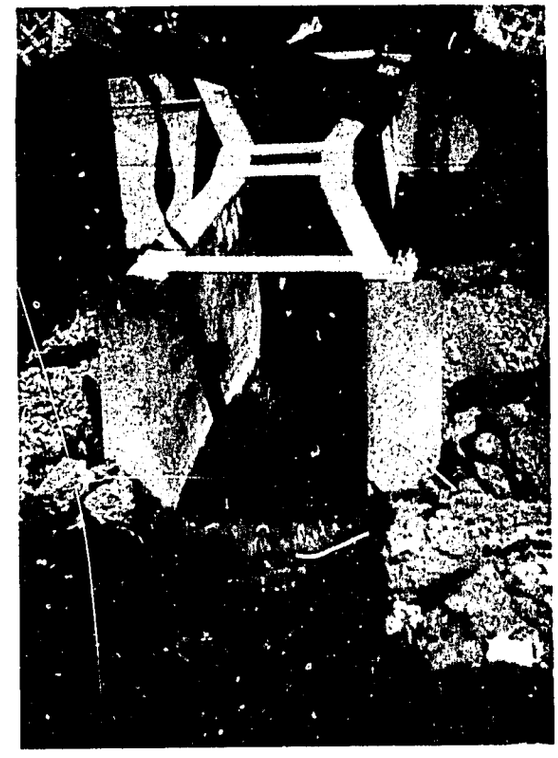

Figure D6-2(b). Water flowing through a two-inch Parshall flume.

manner: (a) insert the container into the hole and push it down until the upper lip of the container is close to where water from the pipe can flow into it; (b) quickly move the container underneath the falling nappe of water and begin timing; (c) stop timing the instant the container is filled; and (d) compute the discharge at the station (volume of water in the container divided by the filling time). Convert the discharge to the proper units; if the furrow is 60 meters long, the discharge should be in liters per minute. If it is 36 meters long, the discharge should be in liters per second.

6. Repeat step 5 at the upper station.

7. Compute the water lost by infiltration between the upper and lower stations, which is simply the difference in the two discharges.

8. Compute the infiltration rate by using the appropriate formula:

(a) when $L = 60$ meters
s = the furrow spacing in centimeters and
q = the discharge loss in liters per minute for a 60-meter furrow, then the infiltration rate is given by the following formula:

$$I = \frac{10\Delta q}{s} \text{ cm/hr}$$

(b) when $L = 36$ meters
s = the furrow spacing in centimeters and
q = the discharge loss in liters per second in a 36 meter furrow, then the infiltration rate is given by the formula:

$$I = 1000 \frac{\Delta q}{s} \text{ cm/hr}$$

9. Repeat the above process at least once about one hour after the first trial to check differences in infiltration rates at that time.

Examples

The following examples will serve to illustrate the use of the given formulas. Others can be developed as needed.

Example 1.

Assume that $L = 60$ m
$s = 50$ cm
$q = 20$ liters/minute

then $I = (10)\frac{(20)}{(50)} = 4$ cm/hr

Example 2.

Assume that $L = 36$
$s = 50$
$q = 0.2$ liters/second

then $I = \frac{(1000)(.2)}{50} = 4$ cm/hr

Note that the method described herein for determining the quantity of flow in the furrow is only one of many methods that may be used. The important point is to measure the quantity of water flowing in the furrow between two points separated by a known distance. With this information, the water lost into the surface of the soil by infiltration can be determined.

Observation

The basic assumption behind this demonstration is that one furrow fills a section of the soil reservoir whose length is equal to the length of the furrow test section and whose width is equal to the row spacing of the crop. Of course, capillary action is depended upon to move the water laterally through the soil from the furrow to the crop. Whether or not this occurs is dependent upon the row spacing.

With the information about soil intake rate gained from this demonstration, irrigation time required to fill the soil reservoir can be obtained.

Summary

This demonstration illustrates:

1. Infiltraion rates under operational field conditions.

2. Variability of infiltration rates with time.

3. How to determine total time required to apply given amounts of water.

DEMONSTRATION 7: BASIN INFILTROMETER

This demonstration uses a field technique for determining total infiltration rather than infiltration rates. The total infiltration determines how long water must be in contact with the surface of the soil to permit a given amount to soak into the profile.

Equipment

1. Four plastic strips, 50 centimeters by 100 centimeters.

2. One plastic sheet approximately 150 centimeters by 150 centimeters.

3. A shovel.

Procedures

1. Lay the plastic strips on the ground so that the longitudinal center lines on the strips form a square approximately 1 meter on each side as shown in Figure D7-1.

2. Cover the outside half of the strips with an earth embankment approximately 15 centimeters high (obtain the earth from outside the square).

3. Fold the inside portion of the plastic back over the mounds to form a basin as shown in Figure D7-2. This proceudre will form a basin with impermeable banks so that water will not soak into the banks during measurement.

4. Place the plastic sheet inside the basin.

5. Determine the amount of water needed to fill the root zone.

6. Put sufficient water in the basin to fill it to a depth approximately equal to the amount of water required in the root zone.

7. As quickly and as carefully as possible remove the plastic sheet being careful to not lose any water.

Observation

The time required for the applied depth of water to soak into the soil profile is that time water must be in contact with the soil surface to fill the root zone.

Summary

This demonstration illustrates total intake time required to apply given amounts of water.

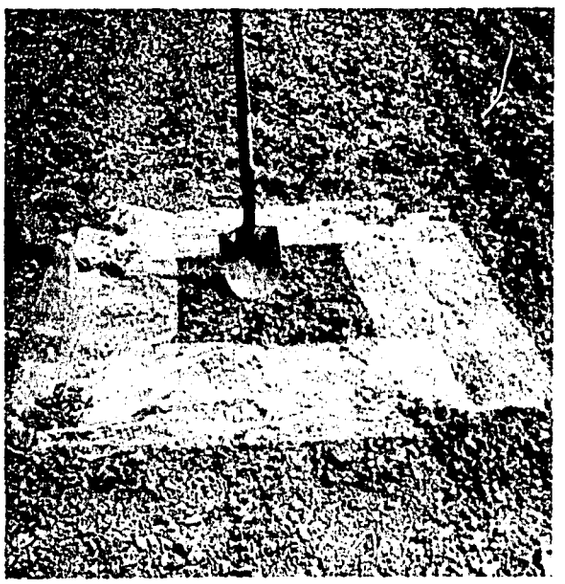

Figure D7-1. Plastic strips to seal banks of a basin infiltrometer.

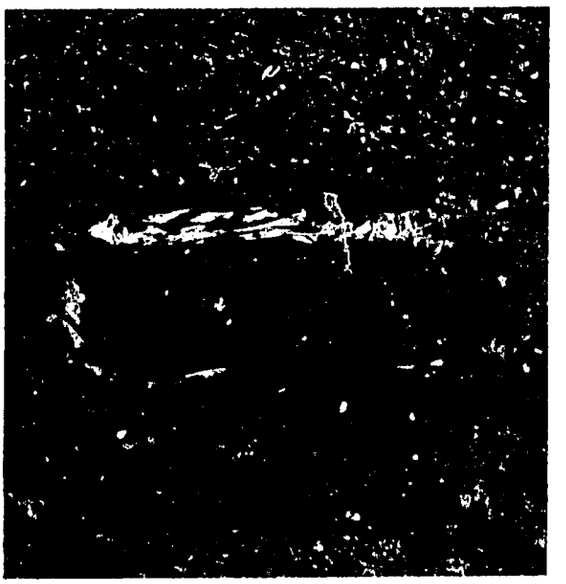

Figure D7-2. Basin infiltrometer.

DEMONSTRATION 8: GLASS PLATE INFILTROMETER

This demonstration illustrates what happens during furrow or border irrigation as well as the basic concepts of proper balance between length of run and furrow stream size or border stream size.

Equipment

1. For the infiltrometer:

   a. A stand (see Figure D8-1 for details on construction).

   b. Glass plates approximately 30 centimeters by 60 centimeters.

   c. Rubber covered clamps.

   d. Approximately 8 kilograms of air-dry loam soil. The soil should be screened to remove all coarse clods and other debris which may be present in the soil.

   e. A small stick which can be used for leveling and stirring the soil surface inside the infiltrometer.

2. For the water supply:

   a. A container of about 1 to 2 liters capacity.

   b. One meter of plastic tubing having a maximum inside diameter of 1 centimeter.

   c. Some type of a stand for the water supply.

Procedures

1. Set up the infiltrometer.

   a. Place the glass plate in the stand as shown in Figure D8-2 and then fasten in place with rubber tipped clamps. If such clamps are not available, protect the plates from metal clamps by using pieces of rubber, styrofoam, or paper. Do not permanently attach the plates to the stand because the infiltrometer needs to be disassembled for cleaning.

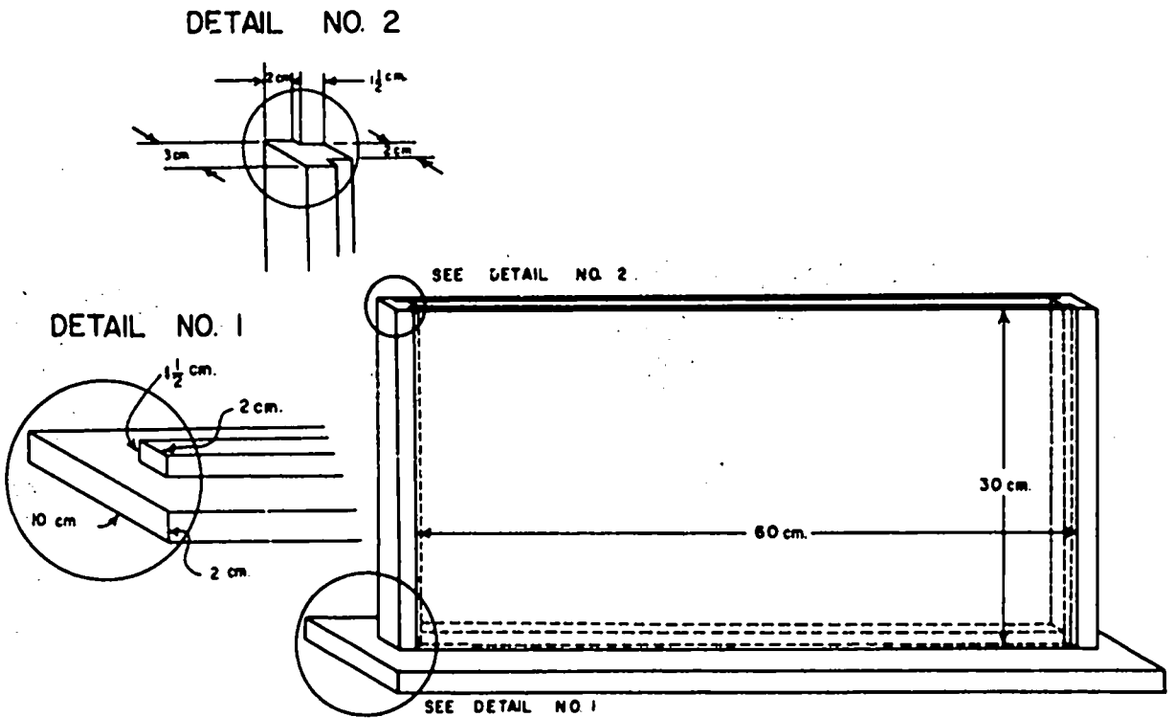

Figure D8-1. Construction details for a glass plate infiltrometer.

Figure D8-2. Assembly of a glass plate infiltrometer.

b. Next, add soil to the infiltrometer. Placing the soil in the infiltrometer is the most difficult part of this demonstration because the soil particles will tend to segregate as the soil is poured in between the glass plates. To minimize this problem, use a funnel with a spout long enough to get the soil as close as possible to the filling surface. Add the soil in layers of 1-1/2 to 2 centimeters, and stir the soil between each addition with a thin rod. The process is shown in Figure D8-3. Even here, however, a certain amount of segregation may occur (Figure D8-4). As the infiltrometer is being filled, compact the soil by occasionally lifting one end of the stand 1 to 2 centimeters above the table top and dropping it. This jars the sand and causes it to settle. Periodic

Figure D8-3. Filling a glass plate infiltrometer with sand.

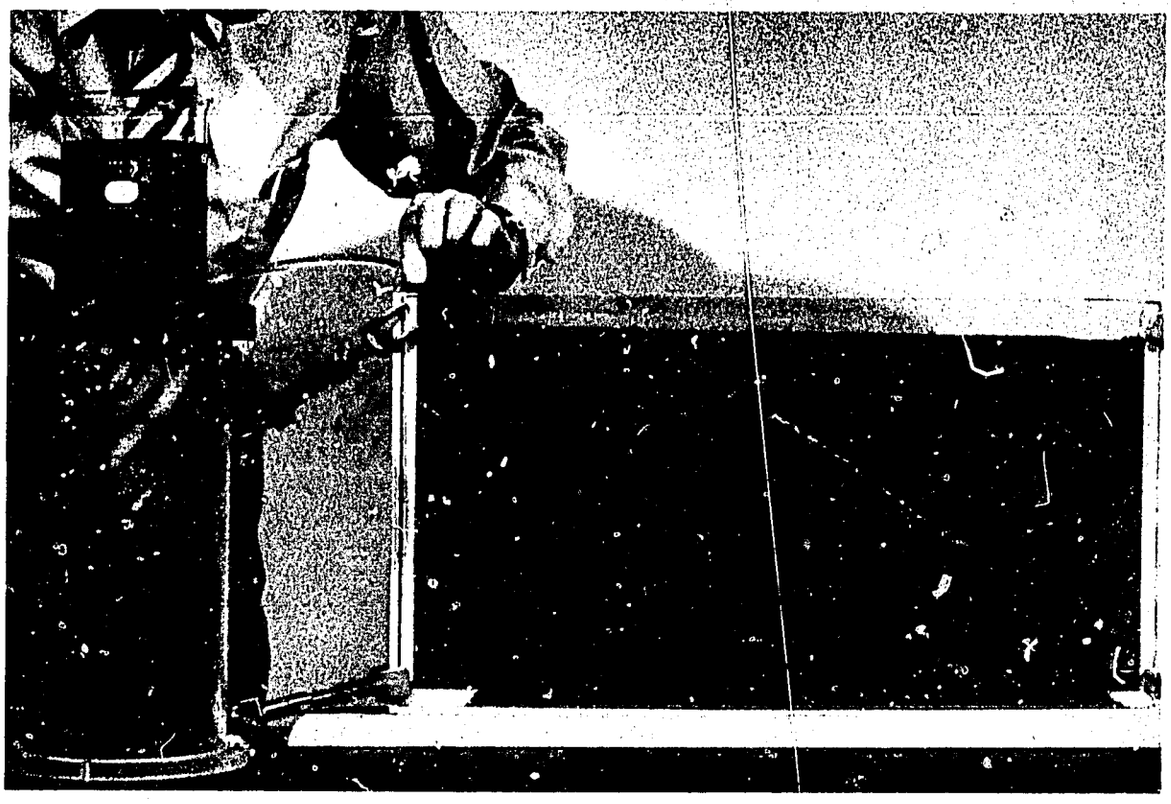

Figure D8-4. Glass plate infiltrometer ready for use.

tapping of the glass will also help. Fill the infiltrometer to the top, level off the soil with a stick and then jar it. This will leave a space at the top of the infiltrometer for water, as shown in Figure D8-4. Finally, put a piece of steel wool at one end of the infiltrometer to serve as an energy dissipator when the water is started.

2. Set up the water supply apparatus.

Place the water container on top of some kind of stand that is high enough to permit the water to be syphoned through the small plastic tube to the surface of the infiltrometer. Control the flow either by adjusting the height of the reservoir or by clamping the tube, so that the stream is small enough to not advance too rapidly across the surface of the infiltrometer and yet large enough to run the full length of the infiltrometer without seeping away. A predemonstration trial with this apparatus is essential to assure later success in front of a group.

3. Admit the water to the infiltrometer and observe the wetting patterns that follow.

Observations

1. As the water procedes along the surface of the infiltrometer, a wetting pattern will appear in the soil profile as shown in Figure D8-5. This clearly indicates the time-depth relationship that occurs in all sufrace irrigation processes. The longer the water is on the surface of the soil, the greater the depth of penetration, assuming of course, that the soil is well drained with no plow pans or other interferring layers. In the series of photographs shown herein, the original stream of water was too small and traveled only about halfway before it soaked into the soil surface as is shown in Figure D8-6. This same phenomenon can occur in a field, when the furrow stream is too small for the length of furrow that is to be irrigated. Such a situation can be corrected by either shortening the length of the furrows or by increasing the stream size. In the demonstration the stream size was increased and the water moved to the end of the infiltrometer as shown in Figure D8-7.

2. If the flow rate is too fast and water can not escape from the end of the furrow, ponding can occur there with excess water soaking into the soil to

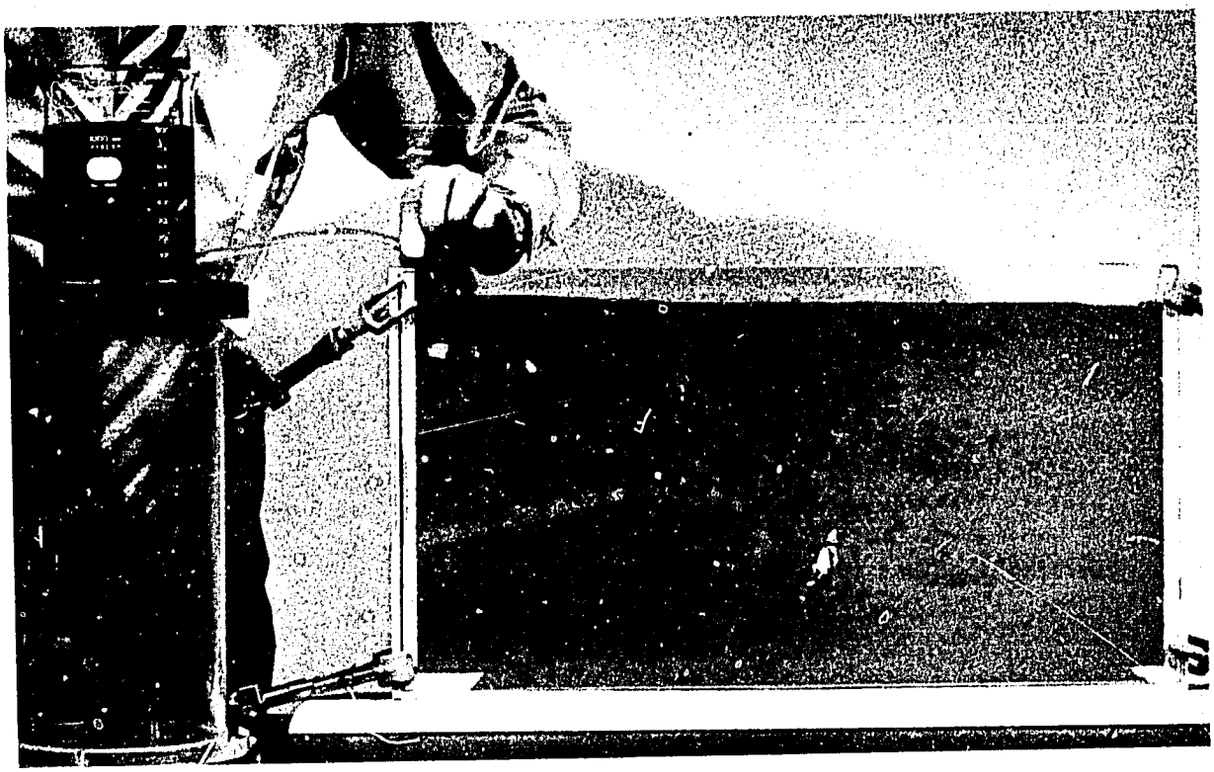

Figure D8-5. Triangular wetting front in a glass plate infiltrometer.

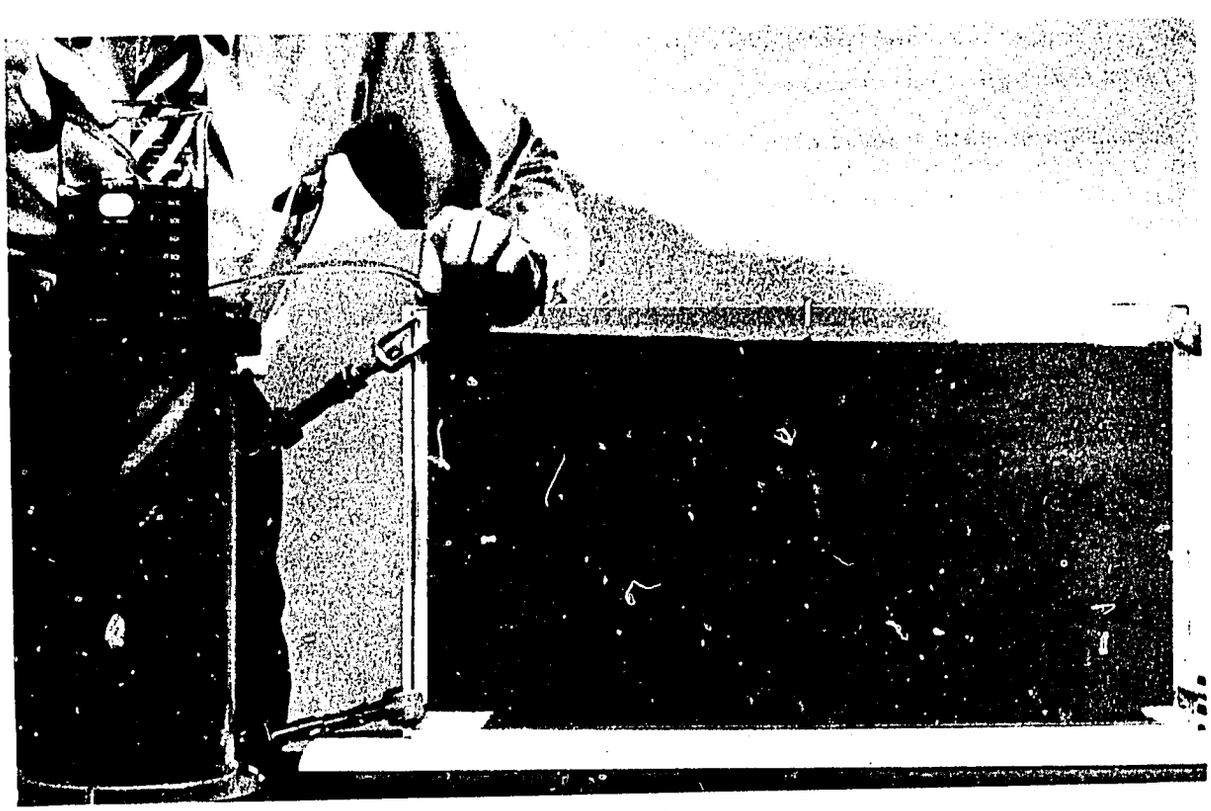

Figure D8-6. Wetting front pattern under a stalled furrow stream advance.

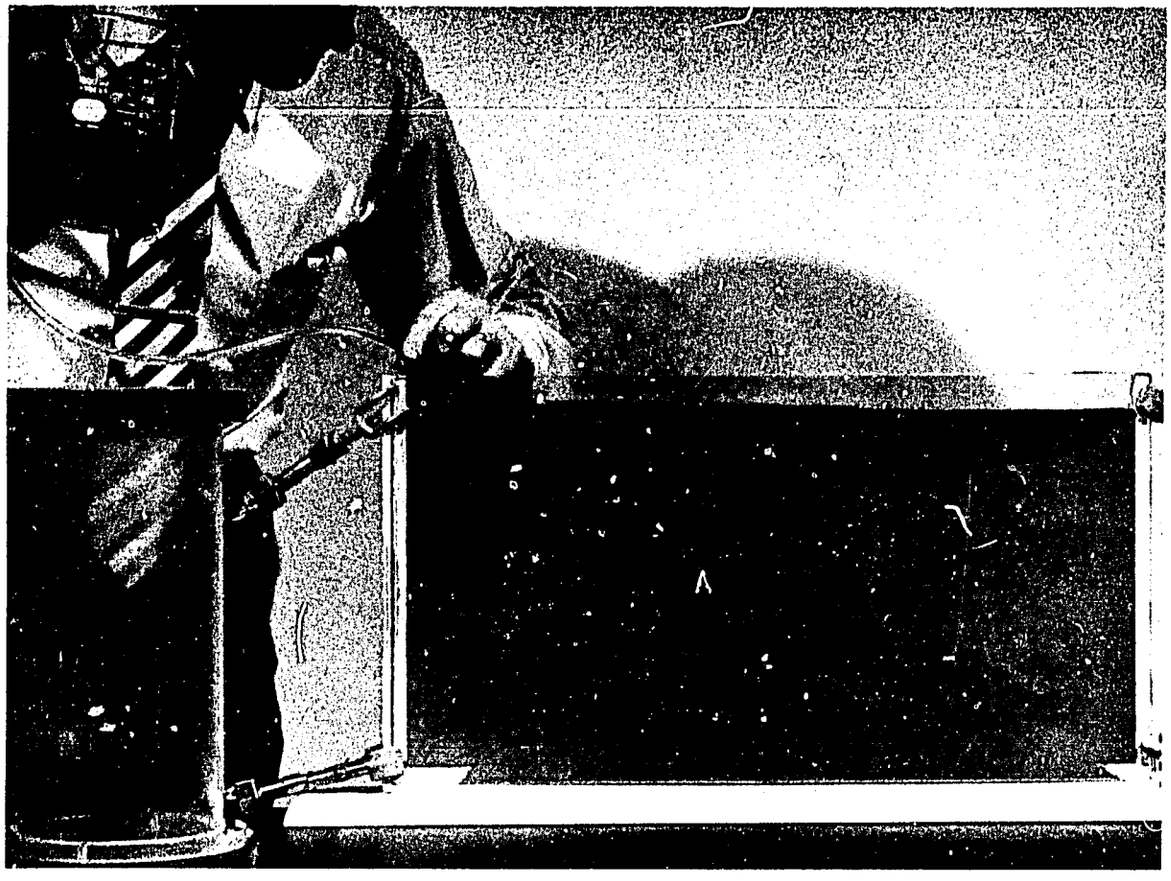

Figure D8-7. Wetting front pattern under a furrow stream of proper size.

a depth below the effective soil reservoir. If however, the water is permitted to run off at the end of the furrow, the infiltration pattern below the furrow will be similar to that shown in Figure D8-8. Runoff occurs from the end of the furrow, when the furrow stream size is too large or the furrow length is too short. Such runoff can be controlled by modifying the size of the stream which enters into the head of the furrow or by a runoff collection system at the lower end.

3. In the tube infiltrometer in Demonstration 4, after the water was off from the surface of the soil, the wetting front continued to move down through the soil profile until all of the free water had drained from the pores of the soil. A comparison of Figures D8-8 and D8-9 shows the same phenomenon. If water had been permitted to run in this infiltrometer for a longer period of time, it would have eventually soaked to the bottom of the infiltrometer. The frame would then have blocked the migration of the water and a saturated zone would have developed at the bottom of the infiltrometer. Similar conditions occur in a field when the percolating water encounters restrictive layers, or an existing ground-water table. Such excess irrigation is a major cause of water tables rising in irrigated areas, and it can reduce crop production and lead to the necessity of drainage to prevent salt buildup in the soil profile.

Summary

This demonstration is used to show:

1. At the onset of irrigation, water will penetrate more deeply into the soil profile at the head of the furrow than at the bottom.

2. Sufficient irrigation time must be allowed at the bottom of the furrow for sufficient water to fill the root zone to penetrate the surface.

3. There must be proper balance between furrow length, infiltration rate, and furrow stream size.

4. Excess water applied during irrigation may cause a high water table with all its associated problems of crop reduction and drainage.

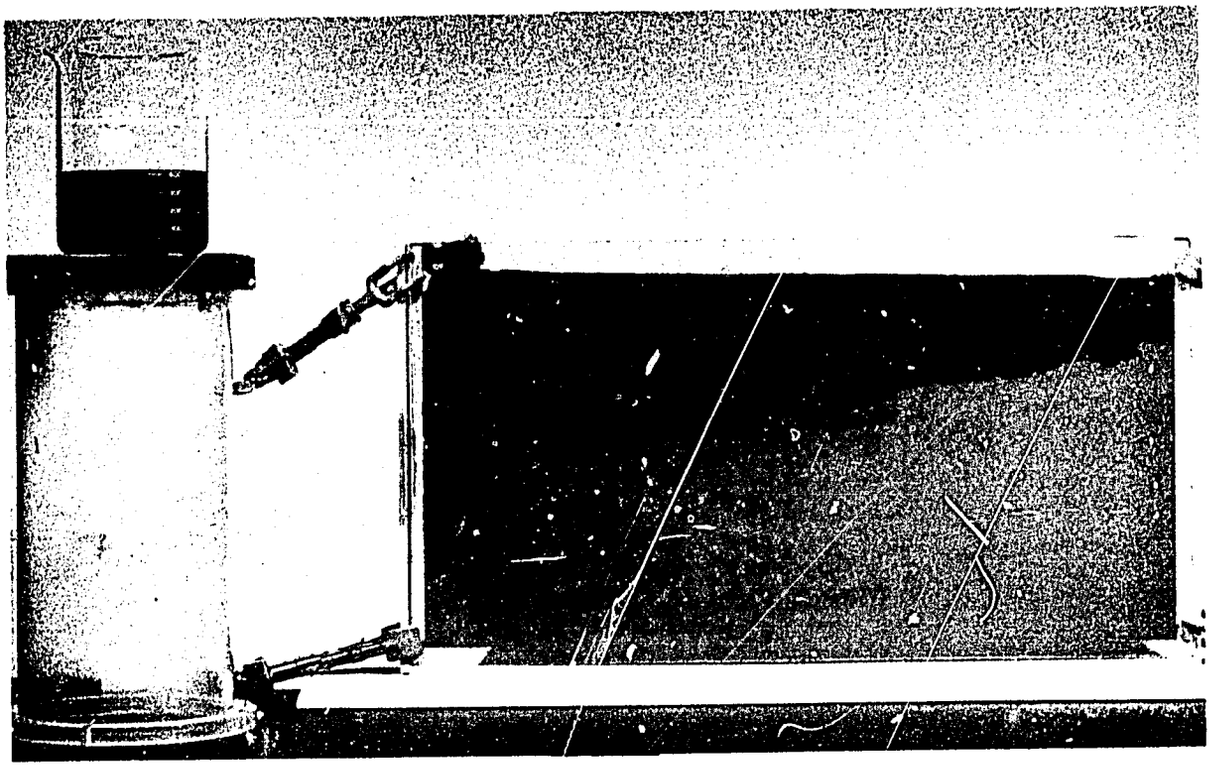

Figure D8-8. Wetting front pattern a few minutes after water shut-off.

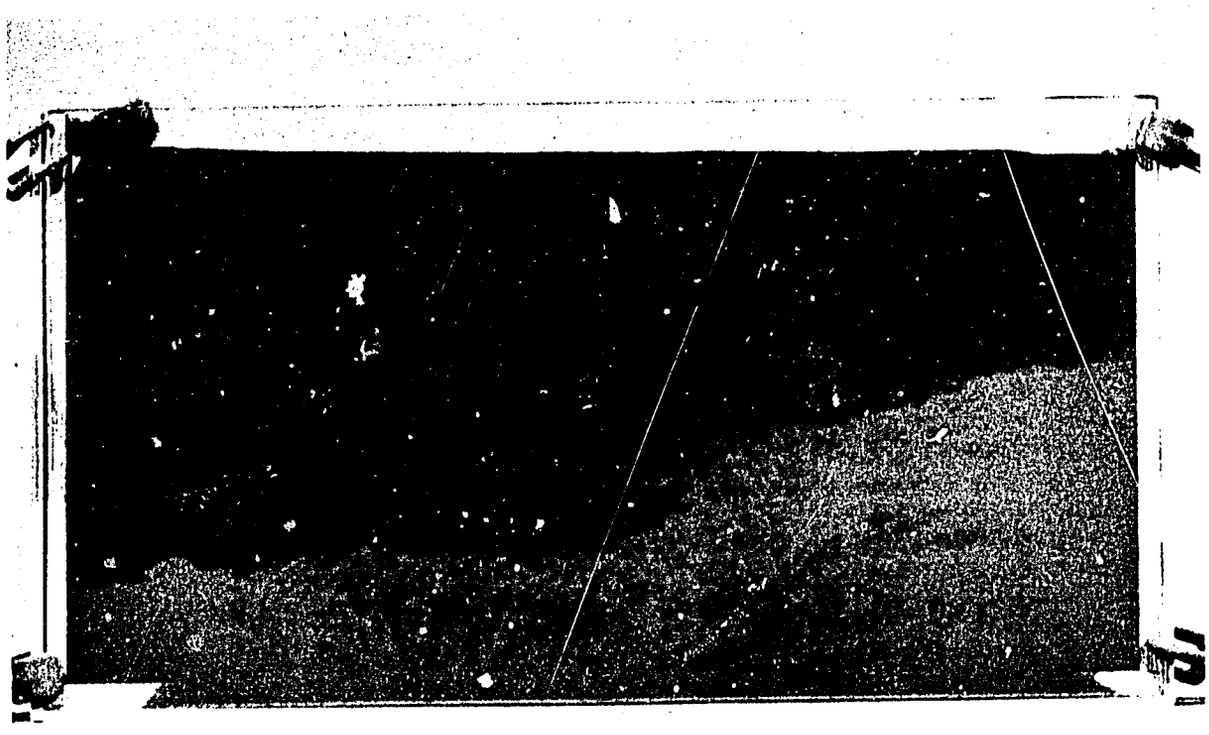

Figure D8-9. Wetting front pattern about two hours after water shut-off.

Appendix II. Soil Augers

HOW TO MAKE A SOIL AUGER[1]

A soil auger is a useful tool in helping in improve irrigation efficiency. A soil auger is not a difficult item to make, and the following pointers will help in its construction.

Materials Needed

(see Figure A1-1)

1 wood auger bit 20/16 or 1¼"

1 piece 3/8" galvanized pipe 3½ ft. long – threaded on one end

2 pieces 3/8" galvanized pipe 6 inches long – threaded on one end

1 galvanized pipe tee 3/8" size

Steps in Construction

1. Cut off the spur and the lips of the auger just back of the lips (see Figure A1-2). This will give a straight cutting edge which will cut nicely into the soil (Figure A1-3).

2. Heat the unthreaded end of the 3½ feet pipe and force the square part of the shank into the pipe. Be sure that the auger and pipe are in line.

3. Weld the auger into the pipe.

4. Screw the two 6-inch lengths of pipe into the tee.

5. Screw the pipe and auger into the tee section.

6. Starting from the end of the auger tip, mark the pipe at 1-foot intervals by making a shallow cut around it with a pipe cutter, the auger is now complete (Figure A1-4). Overall length will be just over 4 feet.

Extensions

The length of the auger can be increased merely by adding additional lengths of 3/8" pipe. It is

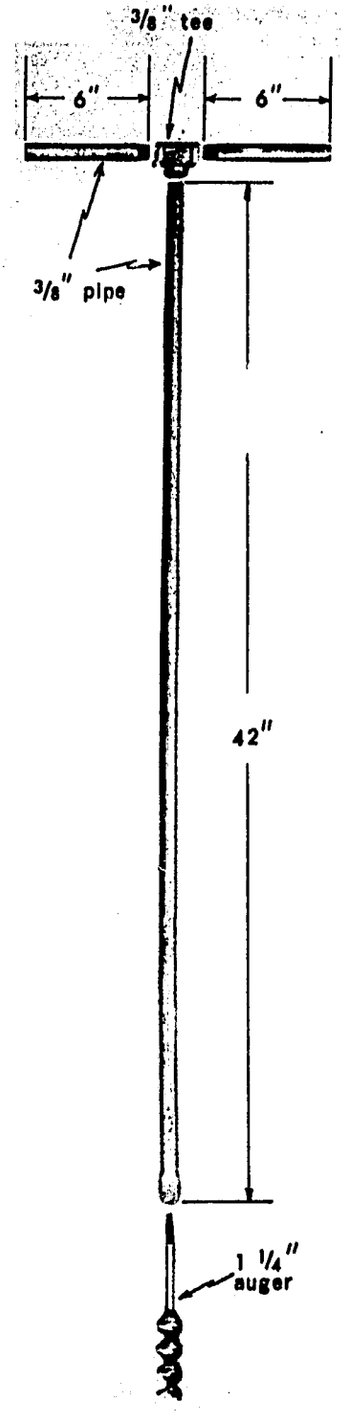

Figure A1-1. Materials needed for soil auger.

[1]Compiled in cooperation with Paul D. Christensen, Extension Soil Conservationist, Utah State University, Logan, Utah.

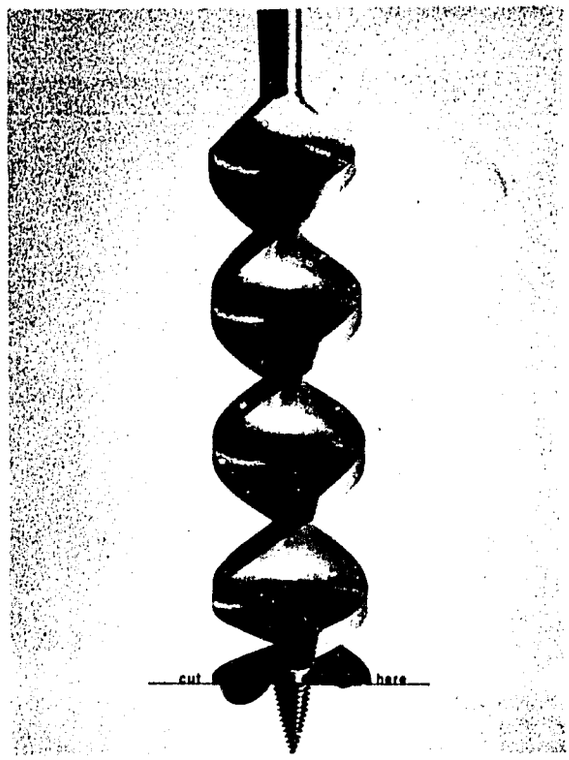

Figure A1-2. Cut location for auger bit.

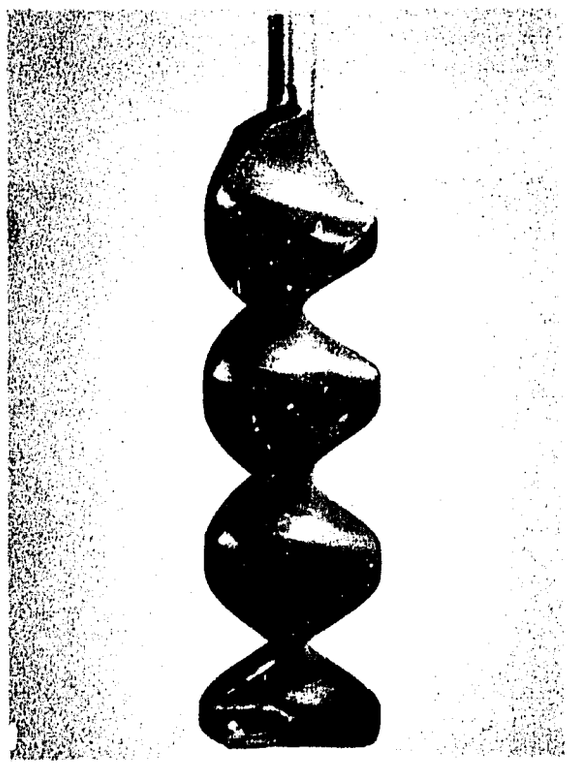

Figure A1-3. Auger bit after cuts.

suggested that these be in either 2-foot or 4-foot lengths for ease of handling.

Like all useful tools, if it is carefully made, this auger will give many years of valuable service.

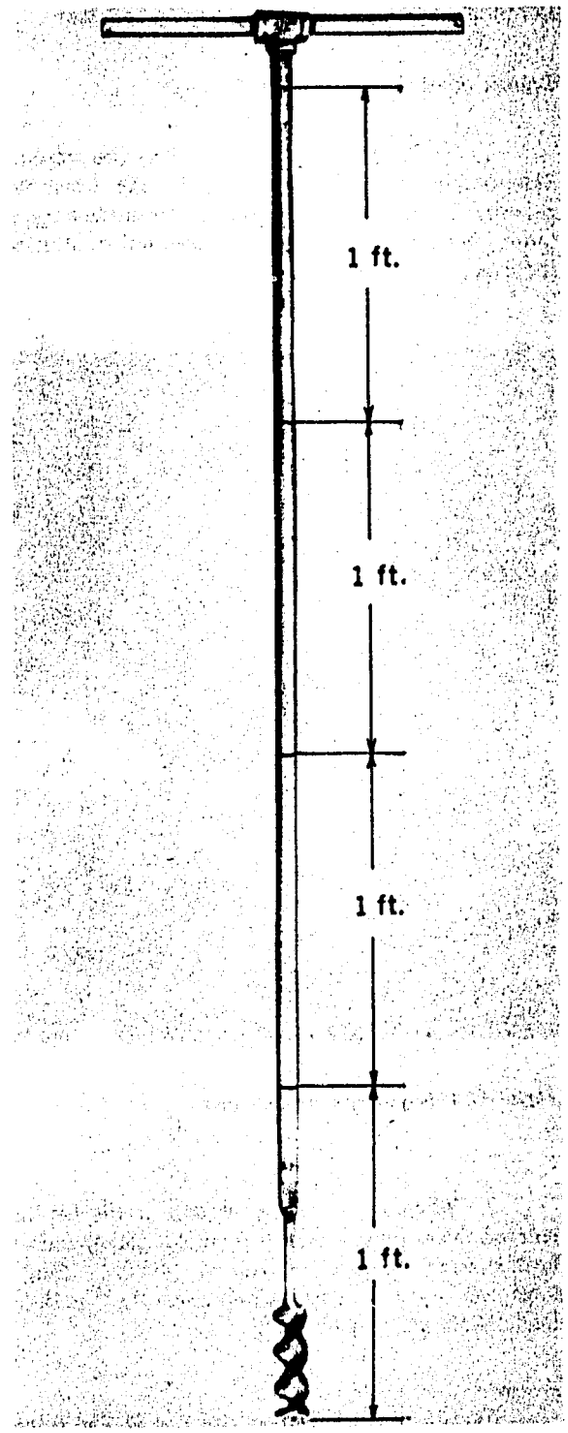

Figure A1-4. Assembled auger.

HOW TO USE THE SOIL AUGER[1]

The soil auger is a handy tool to investigate soil and soil moisture conditions. The auger is easy to operate, and it will save you time and labor. A few minutes in the field with an auger will give you vital information on your soil to depths of 4 to 6 feet.

Follow these steps to operate the auger:

1. Screw the auger into the soil as you would a brace-and-bit (Figure A2-1). Apply the necessary pressure to force it into the soil. If the surface soil is loose, pack a small area with your foot before starting the auger.

Figure A2-1. Beginning auger technique.

2. When all of the screw end of the bit has entered the soil, place your feet close together and on both sides of the auger bit. This will prevent tearing a large hole when the auger is pulled out the first time. Pull straight out (Figure A2-2).

Figure A2-2. Foot location for withdrawing auger.

3. Hold the auger in your right hand with the bit to the left. Grasp the bit with your left hand, palm up. Place your fingers between the spirals. Turn the auger to the right with your right hand. The soil will come off into the palm of your left hand (Figure A2-3).

Figure A2-3. Soil removal.

[1]Compiled in cooperation with Paul D. Christensen, Extension Soil Conservationist, Utah State University, Logan, Utah.

4. After you have examined the soil, place the auger back in the hole and repeat the process. Care should be taken to prevent loose surface soil from falling into the hole. Sometimes several "tries" are required to go below the loose surface soil. After the hole is established at the surface, it is better to keep your feet away from the hole.

5. To pull the auger out of the hole, pull straight up (Figure A2-4). Do not bend the auger by moving the handle from side to side or forward and back. If the auger sticks in the soil, twist it part way out, then pull.

Probably your greatest use of the soil auger will be to investigate soil moisture. Plants remove moisture from several feet of soil, depending upon the depth of the roots. Before each irrigation, you should determine how much moisture is required to fill the soil in the root zone. This can be done by examining the soil as you go down with the auger. Estimate the water-holding capacity of the soil in each foot of depth. Estimate the amount of water present and the amount required to bring each foot to the field capacity. Tabulate your findings similar to Table A2-1.

To estimate the water holding capacity of a soil, assume that a sandy loam soil will hold from 3/4 to 1½ inches per foot, loam soils 1¼ to 2 inches per foot, and clay soils 2 inches or more per foot.

To estimate the amount of water in the soil, squeeze the soil tightly in the hand. If a moist film is left on the hand, the soil is at 75 percent or more of field capacity. If it will form a stable ball but doesn't leave a moist film, it will be between 50 percent and 75 percent of field capacity. If it doesn't form a stable ball, it is between 25 percent and 50 percent, and if it won't ball at all, it is dry.

Figure A2-4. Auger pulling technique.

Table A2-1. Sample of a completed soil moisture check sheet.

SOIL MOISTURE CHECK SHEET					
Soil Moisture Properties	Depth	Hole Number			
		1	2	3	4
Texture Water Holding Capacity Water Present Water Needed	1	Loam 1½ ½ 1	Loam 1½ ½ 1	Loam 1½ ½ 1	Loam 1½ ½ 1
Texture Water Holding Capacity Water Present Water Needed	2	Loam 1½ ¾ ¾	Loam 1½ ¾ ¾	Loam 1½ ¾ ¾	Loam 1½ ¾ ¾
Texture Water Holding Capacity Water Present Water Needed	3	Clay loam 2 1 1	Clay loam 2 1 1	Loam 2 1 ¾	Loam 2 1 ¾
Texture Water Holding Capacity Water Present Water Needed	4	Fine Sandy loam 1 ¾ ¼	Fine Sandy loam 1 ¾ ¼	Fine Sandy loam 1 ¾ ¼	Fine Sandy loam 1 ¾ ¼
Texture Water Holding Capacity Water Present Water Needed	5	Fine Sandy loam 1 ¾ ¾	Fine Sandy loam 1 ¾ ¾	Fine Sandy loam 1 ¾ ¾	Fine Sandy loam 1 ¾ ¾
Texture Water Holding Capacity Water Present Water Needed	6	Loam 1½ 1½ –	Loam 1½ 1½ –	Loam 1½ 1½ –	Loam 1½ 1½ 1
TOTAL		3¾	3¾	3½	3½
FIELD AVERAGE NEEDED		3 5/8			