SOIL PHYSICS LABORATORY GUIDE

W. H. STEVENSON
AND
J. O. SCHAUB

SOIL PHYSICS LABORATORY — Iowa State College, Ames, Iowa

This laboratory is thirty-five by fifty feet, and is splendidly equipped for sixty-four students

Soil Physics Laboratory Guide

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PREFACE

Commendable progress has been made during the past decade in teaching Soil Physics in the Agricultural Colleges and High Schools of this country. Up to the present time, no comprehensive text book has been prepared on this subject. The instructors in the various institutions have prepared notes and outlines as they have found time and opportunity for this work.

Without doubt, there is at the present time a widespread demand for a text book which covers the various phases of the subject.

In these pages the aim has been to present to the instructor and the student a carefully outlined series of experiments in Soil Physics.

This book is the outgrowth of laboratory instruction given in the Iowa State College. A portion of the experiments outlined in this guide have been used quite generally in recent years. Many of them, we believe, are now presented for class work for the first time.

An earnest effort has been made to outline the exercises briefly and clearly in order that the student may proceed with the work without loss of time and without confusion. The exercises are also listed in a logical order with reference to their relation to each other and the skill required on the part of the student.

It is deemed advisable to assign the exercises which call for work in the field either at the beginning of the fall semester or toward the close of the spring semester.

When there are a large number of students in the soil laboratory, the work is often facilitated by dividing the class into groups and assigning a certain number of exercises to each group.

Questions are asked in connection with each experiment for the purpose of leading the student to a thoughtful study of the data which he has secured.

The illustrations are original; they are intended to show the pieces of apparatus which are new or which are not widely distributed. Descriptions of the apparatus are given for the benefit of instructors who desire to equip new soil laboratories or add to their supply of apparatus.

A larger number of exercises are incorporated in this guide than can be covered by the student in a term of average length; therefore, the work should be extended beyond the limits of one term or a portion of the exercises should be omitted.

In the preparation of this guide, the authors have drawn upon the publications of the Colleges of Agriculture and the Experiment Stations of America; upon F. H. King's "Physics of Agriculture;" A. D. Hall's "The Soil;" Robert Warington's "Physical Properties of Soil;" George P. Merrill's "Rocks, Rock-Weathering and Soils," and H. W. Wiley's "Agricultural Analysis."

Iowa State College, Ames, Iowa,
July, 1905.

W. H. Stevenson.
I. O. Schaub.

EXERCISE 1

Microscopic Study of Soil Particles

Object: To study the color, shape, size and character of soil particles in different classes of soils.

Directions:

1—Place a few grains of coarse sand upon a glass slide and after careful examination with the low power of the microscope, make drawings of several of the particles and describe them with reference to the following points:

(*a*) Color—White, grey, brown, red or black.

(*b*) Shape—Angular, rounded or irregular.

(*c*) Simple or compound.

(*d*) Size—Coarse, medium, fine or very fine.

2—Study in the same way samples of fine sand, loam, loess, clay and peat.

Questions:

(*a*) What factors determine the shape of the particles?

(*b*) How do the soils vary?

1—In regard to the size of the particles?

2—In regard to the simple or complex character of the particles?

3—In regard to the shape of the particles?

EXERCISE 2

Taking Soil Samples

Object: To acquire skill in taking samples of soil for laboratory study.

Directions:

Great care should be exercised when samples of soil are taken from the field for analysis or study in order to secure samples which accurately represent the type or types of soil to be studied.

When samples of soil are taken for laboratory purposes, the collector must use care in their selection for the following reasons:

1—"The process of analysis is long, laborious and expensive; and the labor entailed would not be justified except in case of samples taken in such a manner as to preclude the possibility of a doubt as to their typifying the peculiar soils under consideration.

2—"The samples used for analysis are very small in comparison to the total mass of material to be represented by the results of the determination, and a small variation of the sample from the true type, when multiplied and expressed in terms of the mass, would be productive of a great error in results.

3—"The soil under consideration is apt to be exceedingly variable in composition, making it a most difficult operation to secure a sample which shall represent any definite area. This is especially true of the soils of glacial origin, and the variation may not be confined to the surface but is often apparent in samples taken at the same depth in different places."

The method of taking soil samples adopted by the Soil Department of the Iowa State College is that known as the auger method and is essentially the same as that used by the Bureau of Soils of the United States Department of Agriculture.

Samples are sometimes taken with King's Soil Tube, but this piece of apparatus is not often used.

The following directions should be carefully followed in taking soil samples with an auger:

1—Select the spot where the samples are to be taken and clean the surface of the ground of grass and other vegetation.

2—Place the auger over the spot where the sample is to be taken; give the auger two or three turns to drive it into the soil, but take care not to force it into the soil so far that it cannot be readily withdrawn. The auger can be withdrawn with greater ease if it is given a slight backward turn before an effort is made to withdraw it.

3—When the auger has been withdrawn, hold it over a piece of oilcloth which is about eighteen inches square and release the soil.

4—Repeat this operation until the soil is secured to about the depth of the plow line, viz.: five to seven inches. Pour the soil from the oilcloth into a canvas bag (or air-tight glass jar, if the sample is to be used for a moisture determination) and plainly mark each receptacle with a label which gives the location where the boring was made, character of soil, depth, date and any other data which are essential for identification in the laboratory.

5—Place the auger in the hole thus made, and move it up and down the sides several times, without turning it, for the purpose of clearing the walls of the opening to such an extent that the sub-surface soil may be withdrawn without being brought in contact with the surface soil.

6—Carefully clean out the enlarged hole by sinking the auger to just the depth reached in taking the surface soil; reject the soil which is withdrawn in this operation.

7—Secure a sample of the sub-surface soil, viz.: the soil between the surface soil and the sub-soil, in the manner just described for the surface soil; in this work, care is required to detect and remove any surface soil which may adhere to the outside of the core of soil as it is removed.

8—Repeat the operation of enlarging and cleaning the hole; reject about two inches of the soil between the sub-surface and true sub-soil and then secure samples of the sub-soil to any desired depth. The sub-soil can usually be detected by a marked difference in texture and color.

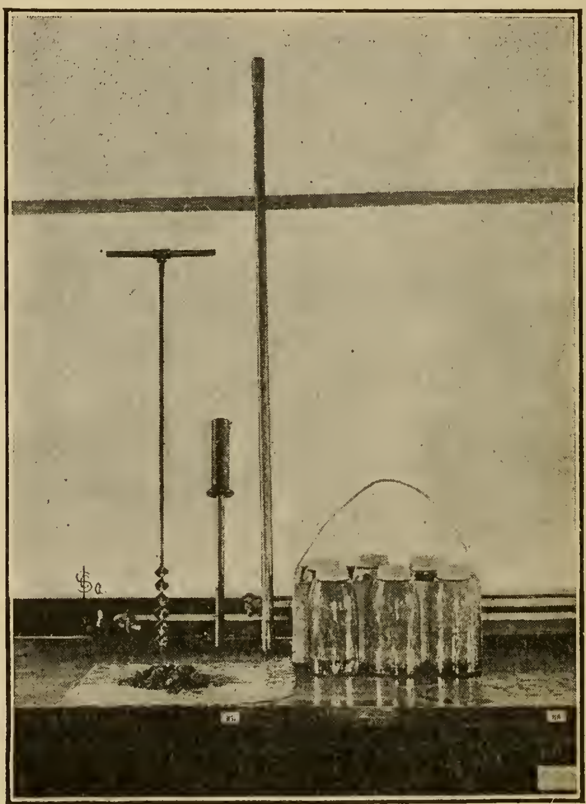

Plate 1

OUTFIT FOR TAKING SOIL SAMPLES

The auger is an ordinary wood auger one and one-half inches in diameter to which a three-eighth-inch iron gas pipe shank has been welded, giving the auger a total length of forty inches. This auger can be provided with as many additional three-foot lengths of gas pipe as are desired. The auger is fitted with a short piece of one-half-inch gas pipe for a handle. The attachment is made with a T as shown in the illustration.

A convenient auger for extended trips is one made as described above, except that a joint is placed about the middle of the shank; this device enables the operator to unscrew the auger with a wrench and pack it in a suit case.

The oilcloth is eighteen inches square; it has been found to be a very simple and convenient device for transferring the soil from the auger to the jars.

The "King" soil tube is made of brass with steel cutting edge and collar and is provided with an eight-pound hammer which is shown in the illustration. The tube is five feet long; the inside diameter of the cutting edge is fourteen-sixteenths of an inch and that of the tube one inch.

EXERCISE 3

Determination of Total Moisture in Field Samples of Soils

Object: To compare the total amount of moisture in soils under the following conditions:

1—Sod ground.
2—Tilled field.
3—Summer fallow.
4—Fall plowed.
5—Stubble.

Directions:

1—Collect quart samples of surface, sub-surface and sub-soil to a depth of forty inches; follow the directions outlined in the previous exercise. Secure samples representing the above mentioned conditions, within as small an area as possible, in order to insure uniformity in other soil conditions.

2—Determine the total moisture in duplicate for the surface, sub-surface and sub-soil, using the corresponding depth of soil from each area. As soon as the soil is removed from the auger, it should be placed in a self-sealing glass jar or screw-topped brass box and properly labeled. Before the vessels are opened to take samples for the moisture determinations, the contents should be thoroughly mixed by shaking.

3—Number and weigh a small sized drying pan or evaporating dish and place in it 100 grams of the sample to be studied.

4—Place immediately in the drying oven and keep at 100 to 110 degrees C. for four hours.

5—Allow to cool to nearly room temperature and weigh. Repeat the drying and weighing until a constant weight is obtained. The loss of weight represents the total water content of the soil.

6—Determine the percentage of moisture computed on the dry weight of the soil.

7—Tabulate the work as follows:

TOTAL MOISTURE DETERMINATION

Kind of Soil	Pan No.	Wt. Pan	Wt. Soil & Pan	Wt. 1st Drying	Wt. 2nd Drying	Wt. 3rd Drying	Dry Wt. Soil	Percent Moisture

Questions:

(*a*) Does the surface soil or sub-soil hold the larger amount of water?

(*b*) Give a list of the soils studied in the order of their water holding capacity.

(c) Discuss the reasons for this difference in the water-holding capacity of the various soils.

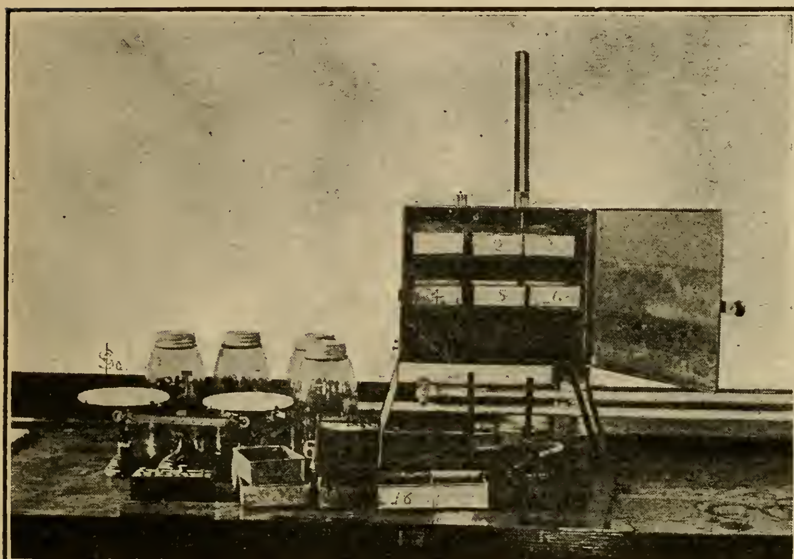

Plate 2

APPARATUS FOR THE DETERMINATION OF MOISTURE

The drying oven is of copper set on a strong iron frame. It is ten inches high, ten inches deep and twelve inches wide. The oven is provided with a centigrade thermometer and has a vent for the escape of moisture. Its cost is approximately eight dollars.

The soil pans are made of tin and are water tight. They are 4¼x3¼ inches and 1½ inches deep. This size has been found convenient when the pans are used in the oven described above. These pans can be made by any tinsmith.

The scale is known as the "Harvard Trip." It weighs accurately to a tenth of a gram and costs about eight dollars.

The jars are quart Mason jars, fitted with good rubbers to prevent evaporation.

EXERCISE 4

Determination of Capillary Moisture

Object: To compare the amount of capillary moisture in the soils used in the previous exercise.

Directions:

1—Make determinations in duplicate for the various depths of the soils to be studied.

2—Carefully weigh the required number of small pans or evaporating dishes and place in each 100 grams of soil.

3—Break up all lumps with a glass rod and spread out the soil in a thin layer over the bottoms of the vessels. Leave the soil exposed to the air at the room temperature for twenty-four hours and weigh.

4—Expose the soil as above and re-weigh until an approximately constant weight is obtained. The loss in weight represents the amount of capillary moisture in the sample.

Note—Keep all the samples used in this exercise for the determination of hygroscopic moisture.

5—Compute the percentage of capillary moisture on the basis of water-free soil and tabulate the work as follows:

CAPILLARY MOISTURE

Kind of Soil	No. Pan	Wt. Pan	Wt. Soil & Pan	Wt. 1st Day	Wt. 2nd Day	Wt. 3rd Day	Dry Wt. Soil	% Capillary Moisture

Questions:

(*a*) What is capillary moisture?

(*b*) What is the difference between a water-free soil and a soil containing capillary moisture?

EXERCISE 5

Determination of Hygroscopic Moisture

Object: To compare the amount of hygroscopic moisture in the soils used in the two previous exercises.

Directions:

1—Use ten-gram samples of the air-dried soils used in the previous exercise.

2—Heat the required number of clean porcelain crucibles with covers in the flame for a short time; cool in the desiccator and weigh accurately.

3—Place each ten-gram sample of soil in a weighed crucible and heat in an air bath at 105 degrees C. for two hours.

4—Cool in a desiccator, place cover on crucible and weigh as quickly as possible.

5—Heat again for an hour, cool and weigh; repeat this operation until the weight becomes constant.

The loss of weight from the air-dried sample equals the amount of hygroscopic moisture.

6—Determine the percentage of hygroscopic moisture on the basis of water-free soil and tabulate the work as in the previous exercises.

Questions:

(*a*) What is hygroscopic moisture?

(*b*) What is the difference between hygroscopic and capillary moisture?

(*c*) Under certain conditions, what water, in addition to the two classes referred to above, may be included in the total moisture content of a soil?

EXERCISE 6

Determination of the Variation in the Hygroscopic Moisture of Soils

Object: To compare the amount of hygroscopic moisture in sand, loam, silt, clay and peat.

Directions:

1—Determine the hygroscopic moisture in ten grams of air-dried samples of sand, loam, silt, clay and peat.

2—Use duplicate samples and follow the method given for the estimation of hygroscopic moisture in the preceding exercise.

3—Exercise care to weigh out all of the samples at the same time to avoid any change in the amount of hygroscopic moisture after a portion of the samples have been selected, otherwise the comparison will not be exact. The amount of heating given the different samples should be approximately the same.

4—Determine the percentage of hygroscopic moisture on the basis of water-free soil and tabulate the work as in the previous exercise.

Questions:

(*a*) What factors determine in a large measure the amount of hygroscopic water held by each soil?

(*b*) Does the organic matter in the soil hold the moisture in the same way that it is held by the soil particles?

EXERCISE 7

Influence of Cultivation on the Temperature of the Soil

Object: To show that loose soil is a poor conductor of heat; that when the soil is stirred deeply, the lower soil receives less heat, and under certain conditions remains at a lower temperature than when the surface receives shallow cultivation; that the cultivated surface soil is warmer than the uncultivated soil.

Directions:

1—For this experiment, prepare three plots as follows:

(*a*) Compact, uncultivated soil which is free from vegetation.
(*b*) An adjoining plot cultivated to a depth of one and one-half inches.
(*c*) Another plot cultivated to a depth of three or four inches.

2—Take the temperature of the air at four feet above the surface of the ground.

3—Take the temperature of the soil in each plot at a depth of one and one-half, three, six and twelve inches below the surface.

Note—If an unmounted glass thermometer is used, open the soil to the desired depth with a small pointed iron rod and place the bulb of the thermometer at the depth at which the temperature is to be taken. Leave the thermometer in position about two minutes before taking the reading.

4—Record the temperature for four or more different days. The temperature recorded for each depth should be the average of at least four readings taken a few inches apart.

5—Tabulate the data as follows:

Date	Hour	Condition of Weather	Temp. of Air 4 ft.	Temperature of Soil											
				Plot A				Plot B				Plot C			
				1.5 in.	3 in.	6 in.	12 in.	1.5 in.	3 in.	6 in.	12 in.	1.5 in.	3 in.	6 in.	12 in.
Mean Temperature															

Questions:

(*a*) What are the sources from which the soil receives heat?

(*b*) What effect does the loose texture of the soil have on absorption of heat? On radiation? On conduction? On evaporation? On capillarity? Give the reasons why in each case.

(*c*) What would be the final effect of all these influences on the soil temperature both of the surface and the sub-surface, while the soil is warming up in the spring? What effect in the fall? What do you find?

(*d*) What influence has the temperature of the soil upon the germination of seeds?

(*e*) What can the farmer do in the spring to warm up the soil?

EXERCISE 8

Influence of Evaporation on Soil Temperature

Object: To determine the influence of rapid evaporation upon the temperature of the soil.

Directions:

1—Prepare two plots as follows:

(*a*) A cultivated plot free from vegetation.

(*b*) An adjoining plot cultivated and free from vegetation to which sufficient water has been applied to bring the soil near the saturation point. The water should be applied several hours before the readings are taken.

2—Take the temperature of the air at four feet above the surface of the ground, and also of the soil in each plot at a depth of one and one-half, three and six inches below the surface.

3—Record the temperature for four or more different days and tabulate the data as in Exercise 7.

Questions:

(*a*) Why does evaporation lower the temperature of the soil?

(*b*) Why is an undrained soil colder than one which is well drained?

(*c*) What is the specific heat of water compared with soil?

EXERCISE 9

Effect of Rolling Upon Soil Temperature

Object: To determine the changes in the temperature of the soil due to rolling.

Directions:

1—For this experiment prepare plots as follows:

(*a*) Plot plowed five or six inches deep with the surface left loose and open.

(*b*) An adjoining plot plowed five or six inches deep with the surface rolled.

2—Take the temperature of the air at four feet above the surface of the ground and also of the soil in each plot at a depth of one and one-half, three and six inches below the surface.

3—Record the temperatures for four or more different days and tabulate the data as in the preceding exercise.

Questions:

(*a*) What is the first effect of rolling a soil which is naturally cold?

(*b*) To what is this result due?

(*c*) What influence has rolling upon the evaporation of water from the rolled surface?

(*d*) What influence has evaporation upon the temperature of the soil?

EXERCISE 10

Influence of Color on Soil Temperature

Object: To determine the difference in the temperature of dark and light colored soils.

Directions:

1—Prepare three plots as follows:

(*a*) Cultivated plot, free from vegetation.

(*b*) An adjoining cultivated plot, the surface of which has been blackened with a dressing of soot or other black material.

(*c*) A third plot, the surface of which has been whitened with a dressing of lime.

2—Take the temperature of the air at four feet above the surface of the ground and also of the soil in each plot at a depth of one and one-half, three and six inches below the surface.

3—Record the temperatures every three hours for twelve consecutive hours on a clear day and also on a cloudy day, and tabulate the data as in Exercise 7.

Questions:

(*a*) Why are dark colored soils higher in temperature than light colored soils?

(*b*) What influence has organic matter upon the temperature of the soil?

EXERCISE 11

Influence of Vegetation on Soil Temperature

Object: To determine the difference in the temperature between a soil covered with vegetation and a bare soil freely exposed to the sky.

Directions:

1—Prepare two plots as follows:

(*a*) Plot from which all vegetation has been removed.

(*b*) An adjoining plot which is covered with a heavy grass sod.

2—Take the temperature of the air at four feet above the surface of the ground and also of the soil in each plot at a depth of one and one-half, three and six inches below the surface.

3—Record the temperatures every three hours from 6 o'clock a. m. to 9 o'clock p. m., on a day when the sun is shining and tabulate the data as in Exercise 7.

Questions:

(*a*) Why is the range of temperature of a soil shaded by vegetation less than that of a bare soil?

(*b*) Why is the temperature of the shaded soil higher in the early morning than the temperature of the bare soil?

EXERCISE 12

Variation in Soil Temperature at Different Depths

Object: To study the daily, weekly and monthly variations in soil temperatures to a depth of three feet.

Directions:

1—Place four soil thermometers within a few feet of each other, at a depth of six, twelve, twenty-four and thirty-six inches respectively, in the soil which is to be studied.

2—Take the temperature of the air at four feet above the surface of the ground, and the reading of each thermometer at a given time once each day for a period of at least two or three months.

3—Tabulate the data as in Exercise 7 and at the end of the period of observation plot curves showing the daily temperature of the air and of the soil at the depths mentioned above.

Questions:

(*a*) Is there a point below the surface of the soil where the temperature is nearly constant from day to day?

(*b*) Why do the variations in temperature diminish with increased depth?

EXERCISE 13

Influence of Topography on Soil Temperature

Object: To determine the influence of the degree of inclination of the land surface and the direction of the slope upon the temperature of the soil.

Directions:

1—For this experiment, select an area where the soil of the same type is found upon an approximately level table and upon a slope.

2—Take the temperature of the soil on the level table and on the slope at a depth of six, twelve and twenty-four inches, at a given time once each day for a period of at least a week.

3—Tabulate the data as follows:

Topography of Soil	Date	Hour	Condition of Weather	Temperature of Soil at		
				6 inches	12 inches	24 inches

Questions:

(*a*) When the sun is shining, why is the temperature of the soil on a south slope higher than the temperature of a level surface?

(*b*) Why is a southeast aspect generally preferred by gardeners?

(*c*) Why is it preferable to plant corn in rows running north and south rather than in rows running east and west?

(*d*) Why does not vegetation growing upon a slope receive increased radiation from the sun as does the surface of the ground?

EXERCISE 14

The Absorption of Heat by Soils

Object: To compare the temperature of sand, loam, clay and peat at different depths, when these soils are exposed to the direct rays of the sun.

Directions:

1—Provide four zinc or tin boxes about four inches wide and eight inches deep, encased in wooden covers, except on the top. This cover serves to protect the box against all heat except the direct sunlight on the open surface of the soil.

2—Fill each of the boxes respectively with sifted air-dried sand, loam, clay and peat.

3—Take the temperature of the soil in each box at a depth of one and one-half, three and six inches and then expose the boxes to the direct rays of the sun for two hours.

4—At the end of this time, take the temperature of the air directly above the boxes and also of the soil at the depths named above.

Note—It is a good plan to provide the boxes with thermometers set at the different depths. The temperature of the soils can thus be read off directly.

5—Tabulate the data as follows:

Kind of Soil	Temp. of Air	Temperature of Soil at Beginning			Temperature of Soil After Exposure			Increase of Soil Temperature		
		1.5 in.	3 in.	6 in.	1.5 in.	3 in.	6 in.	1.5 in.	3 in.	6 in.

6—Moisten the soil in each box with a given amount of water and repeat the experiment as above in order to determine the action of moist soil under similar conditions.

Questions:

(*a*) What are the factors which influence the difference in the absorption of heat by the different soils?

(*b*) What effect has wetting on the absorptive power of the soils? Did it affect the various soils differently?

EXERCISE 15

The Effect of Lime Upon Clay Soil

Object: To determine the effect of different amounts of slacked lime upon the tenacity of clay soil.

Directions:

1—Weigh out five 100-gram samples of clay soil.

2—Add to each sample the amount by weight of calcium hydrate (slacked lime) given below:

No. 1—None.
No. 2— .5 percent.
No. 3— 1.0 percent.
No. 4— 5.0 percent.
No. 5—10.0 percent.

3—Mix each sample thoroughly on a "mixing board" and add just enough distilled water to make the soil plastic.

4—Mold each sample into the form of a stick by compressing the moist clay into a zinc mold which is one inch wide and four inches long. First line the mold with cheesecloth and compress all of the samples to the same degree and then bake in the oven at 110 degrees C. for four hours.

5—Remove the sticks of baked clay from the molds and determine the weight required to fracture each.

NOTE—This determination may be made by resting the ends of the stick of clay upon supports and suspending from the center a bucket into which shot or sand is slowly poured.

6—Tabulate the data as follows:

Sample No.	Weight Required to Fracture Stick

Questions:

(*a*) How did the lime affect the tenacity of the clay?

(*b*) What effect does a liberal application of lime have upon the physical condition of clay soil in the field?

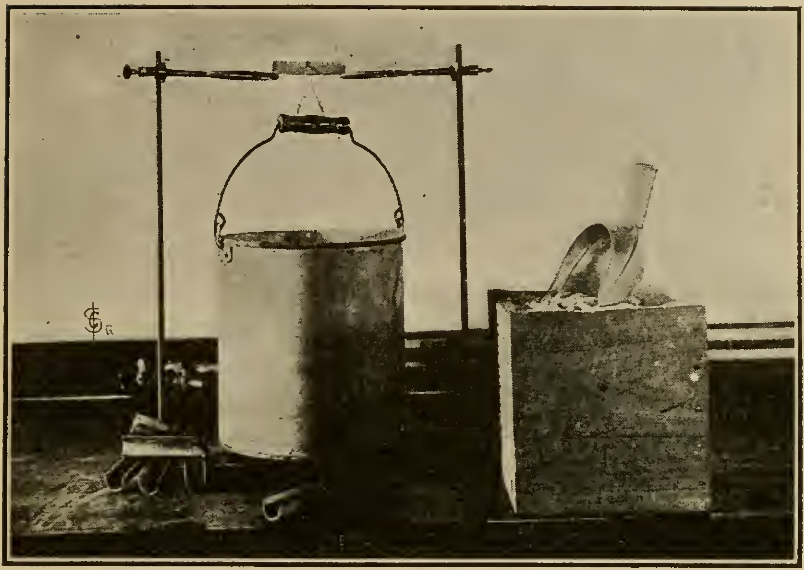

Plate 3

APPARATUS TO TEST THE EFFECT OF LIME ON CLAY SOIL

The molds in which the clay is baked are made of heavy galvanized iron. They are four and one-quarter inches long, one inch wide and three-quarters inch deep.

As shown in the illustration, retort stands provided with iron rings are used for supports and the breaking weight is a galvanized iron bucket into which shot or sand is poured.

Care must be exercised in this experiment to mount the sticks of clay in such a way that all of them are subjected to a uniform strain.

EXERCISE 16

The Flocculation of Clay

Object: To show the effect of calcium hydrate, calcium sulphate and sodium chloride in producing flocculation of clay.

Directions:

1—Weigh out accurately .2 of a gram of each salt; place each sample in a well-cleaned beaker and add 200 c. c. of distilled water.

2—Place 200 c. c. of water in another beaker for a control. Add to each of the four beakers, one gram of clay soil.

3—Stir the contents of each beaker thoroughly and then put a sample of each in a centrifuge tube and whirl in the centrifuge at lowest speed and note the time required to completely precipitate each solution, that is, to produce a clear solution.

4—Thoroughly mix the contents of each centrifuge tube and set aside; note the time required for complete sedimentation in each case.

5—Tabulate the data as follows:

Solution	Time to Precipitate with Centrifuge	Time for Sedimentation

Questions:

(*a*) Explain the action of the salts in clarifying the water.

(*b*) Why is a flocculated condition of clay soils desirable?

(*c*) What physical effect results from the liming of clay soils?

EXERCISE 17

Determination of the Apparent Specific Gravity of Soils

Object: To determine the ratio of unit weight to unit volume of different soils.

Directions:

1—Number and weigh carefully eight clean soil tubes.

2—Fill four of the tubes level full with air-dried loess, clay, loam and sand, respectively, by pouring the soils in loosely. Fill the other four tubes with the same soils, using the compacting machine and allowing the weight to fall three times from the twelve-inch mark upon each measure of soil.

3—Weigh the filled tubes carefully.

4—Measure the diameter and hight of the tubes and compute the number of cubic centimeters of soil contained in each.

5—Determine the amount of hygroscopic water in a sample of each of the soils taken when the tubes are filled.

6—Calculate the apparent specific gravity of the different soils. (Apparent Specific Gravity equals weight of 1 c. c. of soil divided by weight of 1 c. c. of water.)

7—Tabulate the data as follows and calculate the weight of an acre of the different soils to a depth of one foot.

Kind of Soil	No. of Tube	Wt. of Tube	Wt. of Tube & Soil	Vol. of Tube	Amt. Hy. Water	Net Wt. of Soil	Wt. of 1 c.c. Soil	App. Sp. Gr. of Soil	Wt. of Acre of Soil in Tons

Questions:

(*a*) Which is heavier, a coarse or fine grained soil? Why?

(*b*) What influence has the presence of stones upon the apparent specific gravity of a soil?

(*c*) What influence has plowing upon the apparent specific gravity of a soil?

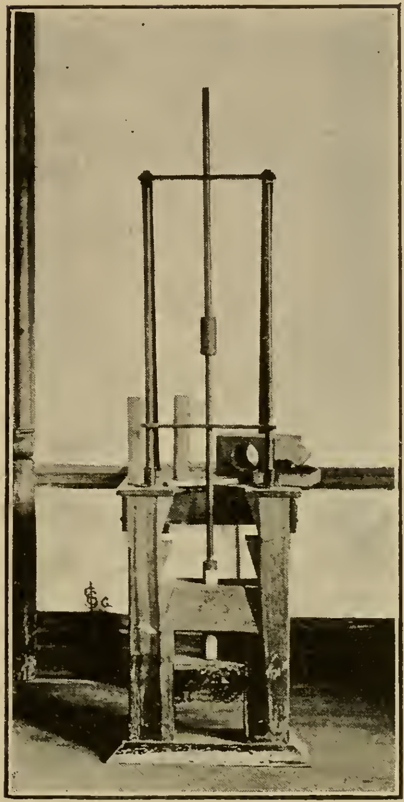

Plate 4

COMPACTING MACHINE FOR FILLING SOIL TUBES

The compacting machine shown in the illustration was designed to pack the soil into the tubes more uniformly than can be done by hand. The latter method, even when great care is exercised, gives very unsatisfactory results.

The illustration shows the construction of the compactor; the table is two feet wide, three feet long and three feet high; the wooden posts in front are six inches square. The iron shaft which carries the plunger and weight is one inch in diameter; the plunger is two inches in diameter; the weight is four inches long and two inches in diameter; the weight strikes upon a support which is attached to the shaft by a set screw.

The adjustment of the tube, plunger and weight is shown. The weight may be dropped any number of times from a given hight. The soil tubes which are shown on the compactor and which are used in Exercise 17, are made of galvanized iron with solid bottoms. These tubes are twelve inches long and two inches inside diameter.

A better grade of tubes are made of brass, but very satisfactory results are secured with the cheaper galvanized iron tubes.

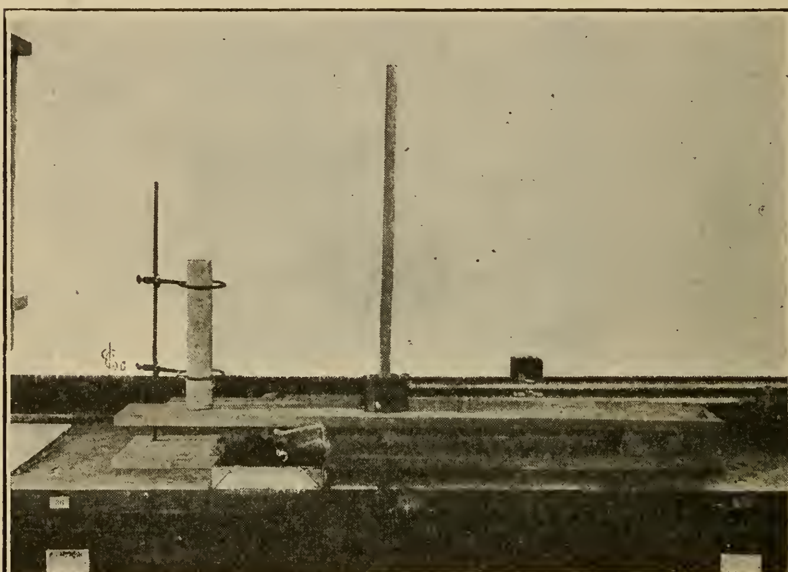

Plate 5

SPRING BOARD COMPACTOR

The spring board compactor is a cheap but a very satisfactory compacting machine. It may be used instead of the larger and more expensive compactor shown in Plate 4.

This piece of apparatus is made of one-inch pine boards, four feet long and eight inches wide. A two by four-inch block is placed between the boards, six inches from the right end. The boards are securely nailed to this block and are also fastened together by two half-inch bolts. Another block about an inch and a half in thickness is nailed to the lower board ten or twelve inches from the left end.

The wooden upright in the center is securely fastened to the lower board and passes loosely through an opening in the upper board. An iron weight of two and one-half kilos is dropped upon the board from a hight of twelve or eighteen inches. The tube which contains the soil which is to be compacted is supported by rings as shown in the illustration. The tube is filled with soil and the entire depth compacted at one operation.

EXERCISE 18

Determination of the Specific Gravity of Soils

Object: To compare the weights of different soils with the weights of equal volumes of distilled water.

Directions:

1—Fill a specific gravity flask carefully with distilled water which has been previously boiled for a few minutes and allowed to cool to the room temperature, which is recorded. Have the capillary stopper just filled with water. Wipe the flask perfectly dry and weigh.

2—Pour out about one-third of the water and place in the flask about ten grams of accurately weighed sand which has been dried to a constant weight at 110 degrees C.

3—Heat the flask for a few minutes on the water bath, until the air is expelled. Remove the flask and cool to the first temperature, and fill with previously boiled and cooled water; dry and weigh at the original temperature.

4—With the same method determine the specific gravity of loam, loess, clay and peat.

5—Calculate the specific gravity (weight of soil divided by weight of water displaced by soil), and tabulate the results as follows:

SPECIFIC GRAVITY OF SOILS

Kind of Soil	Wt. of Flask Filled with Water	Wt. of Soil	Wt. of Flask and Soil	Specific Gravity

6—From the data in Exercises 17 and 18, determine the percent of porosity, i. e., the space which in the dry soil is occupied by the air, of the different soils which were used.

Questions:

(*a*) Why is it necessary to use water-free soil?
(*b*) Why does the sand have a higher specific gravity than the clay, loam and peat?
(*c*) How does the amount of humus in the soil influence its specific gravity?
(*d*) Why is it necessary to weigh the flask each time at the same temperature?

EXERCISE 19

Determination of the Weight of Soil Per Acre

Object: To determine the weight of dry soil to a given depth per acre.

Directions:

1—Drive into the soil a brass tube (eight inches long and about three inches in diameter, sharpened at its lower edge) until the top is level with the surface.

2—Dig away the soil around the tube; empty the tube upon a piece of oilcloth and transfer the soil to a Mason jar; carefully drive the tube down again and thus obtain a sample of the succeeding eight inches. Repeat this operation until eight-inch samples of the soil have been secured to any desired depth.

3—Carefully weigh each sample.

4—Determine the total moisture in 100 grams of soil from each depth and from these data determine the dry weight.

5—Calculate in cubic inches the contents of the tube.

6—Calculate the weight of an acre of soil to the depth at which each sample was taken and tabulate the results as follows:

Kind of Soil	Depth of Sample	Cubic Inches of Soil	Weight of Soil	Percent of Moisture	Dry Weight of Soil	Wt. of Dry Soil per Acre

Question:

(*a*) Why does a soil gradually increase in weight as we go into the sub-soil?

EXERCISE 20

Determination of the Power of Loose Soils to Retain Moisture Against Gravity

Object: To compare the power of various types of loose soil to hold water against gravity.

Directions:

1—Place a disc of cheesecloth in the bottom of a perforated tube, moisten the cloth and weigh carefully.

2—Fill the tube with loose sand, exercising care not to compact the soil, and weigh the filled tube.

3—Stand the tube in a vessel containing water to a hight nearly equal to that of the surface of the soil. Leave the tube standing in this position until the surface of the soil becomes thoroughly moistened.

4—Remove the tube from the water, wipe dry, place in a small pan and weigh.

5—Cover the tube with a glass plate and set it where the water will drain away. Weigh the tube at the end of the first hour, second hour, and daily thereafter for five days.

6—Determine the hygroscopic moisture in a separate sample at the time of filling the tube.

7—Calculate on a water-free basis, the percent of water held by the sand.

8—In the same way determine the percent of water held by loam, clay, loess and peat.

9—Tabulate the data as follows:

Kind of Soil	Weight of Tube	Weight of Tube and Soil	Weight of Soil	Percent of Hygroscopic Moisture	Weight of Dry Soil

Weight of Tube and Saturated Soil	Weight of Tube and Soil at					
	1 hr.	2 hrs.	26 hrs.	50 hrs.	74 hrs.	98 hrs.

Weight of Water Retained							Percent of Water Retained						
Hours							Hours						
Saturated	1	2	26	50	74	98	Saturated	1	2	26	50	74	98

Questions:

(*a*) What is a saturated soil?

(*b*) Which type of soil loses water most rapidly at first? Which percolates for the longest time?

(*c*) Calculate the total number of pounds of water retained per cubic foot of dry soil and also the number of inches of rainfall which it represents?

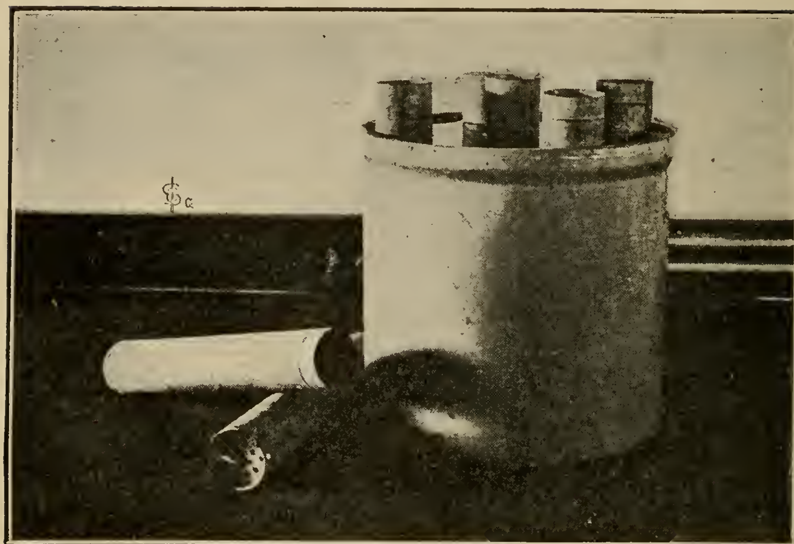

Plate 6

APPARATUS USED IN EXERCISE 20

A four-gallon jar is a convenient vessel to use in this exercise.

The soil tubes which are used to determine the power of soils to retain water are made of galvanized iron. They are twelve inches long and two inches inside diameter. The bottoms are set up one inch from the lower end and are perforated as shown in the illustration.

These tubes can be made of brass if tubes of a better quality are desired.

EXERCISE 21

Determination of the Power of Compact Soils to Retain Moisture Against Gravity

Object: To compare the power of various types of compact soils to hold water against gravity.

Directions:

1—Proceed with this experiment as in the previous exercise, except that the tubes are to be filled as follows:

Use the soil compacting machine, allowing the weight to fall three times from the twelve-inch mark upon each measure of soil.

2—Calculate on a water-free basis, the percent of water held by the compact soils and tabulate the data as in the preceding exercise.

Questions:

(*a*) What conclusions do you draw from these data, regarding the effect of rolling upon the water-holding capacity of the soil?

(*b*) What effect has cultivation upon the water-holding capacity of the soil?

(*c*) What type of soil has its water-holding capacity changed to the greatest extent by compacting.

EXERCISE 22

Effect of Humus on the Water-Holding Capacity of Soils

Object: To determine the effect of different amounts of humus upon the water-holding capacity of various types of soil.

Directions:

1—Place a disc of cheesecloth in the bottom of the required number of perforated soil tubes.

2—Prepare the following samples:

No. 1—600 grams of sand.

No. 2—570 grams of sand and 30 grams of peat.

No. 3—540 grams of sand and 60 grams of peat.
No. 4—480 grams of sand and 120 grams of peat.
No. 5—Number of grams of peat required to fill the tube to the same hight as the other tubes.

Thoroughly mix each of these samples on a "mixing board" and fill the tubes, which have been numbered to correspond with the samples, by using the soil compacting machine, allowing the weight to fall three times from the twelve-inch mark upon each measure of soil.

3—Stand the tubes in a vessel containing about four inches of water and allow them to remain in the water until the weight becomes approximately constant.

4—Remove the tubes from the water, place each in a small pan to catch the possible drainage and weigh.

5—Repeat the experiment with clay and loess.

6—Determine the percentage of water retained by each sample and tabulate the data as follows:

Sample No.	Weight of Tube and Soil	Weight of Tube, Soil and Water Held	Percent of Water Held

Questions:

(*a*) Compare the amount of water held by the mixtures with the amount held by equal weights of the sand and peat when tested separately.

(*b*) Basing your calculations on the data obtained, determine the additional amount of water which an application of eight tons of peat will enable an acre of soil to hold to a depth of five inches.

(*c*) Why does humus increase the water-holding capacity of a soil?

EXERCISE 23

The Power of Air-Dry Soils to Absorb Moisture from a Saturated Atmosphere

Object: To determine the total amount of moisture absorbed from a saturated atmosphere by different types of air-dry soil.

Directions:

1—Place 400 grams of air-dry loam in an accurately weighed soil pan; weigh also one empty soil pan to serve as a check.

2—Place the pans on a shelf in a tightly covered vessel which contains a saturated atmosphere. Record the temperature of the air in the vessel at each weighing.

3—After twenty-four hours, weigh each pan and deduct the increase in weight of the empty pan from the increase in weight of the pan containing the sample.

4—Repeat the weighings every twenty-four hours until, with the same conditions of temperature, an approximately constant weight is obtained. Weigh the pans as rapidly as possible to prevent loss of moisture by evaporation.

5—Determine the hygroscopic moisture of the loam with a special sample at the time of placing the soil in the pan.

6—Calculate the amount of water absorbed by 100 grams of the air-dry loam and the total amount of water taken from the air by 100 grams of water-free soil.

7—Determine in the same way the amount of water absorbed from the air by sand, clay and peat and tabulate the data as follows:

Kind of Soil	Wt. of Pan and Soil	Wt. of Hygroscopic Moisture	Weight of Pan and Soil			Percent of Moisture Absorbed by Air-dried Soil	Total Per-cent of Moisture in Soil
			24 hrs.	48 hrs.	72 hrs.		

Questions:

(*a*) Which class of soils absorbs the largest amount of moisture from the air? Why?

(*b*) How does the amount of water which a soil is capable of absorbing from the air compare with the moisture content of the soil when growing corn plants wilt?

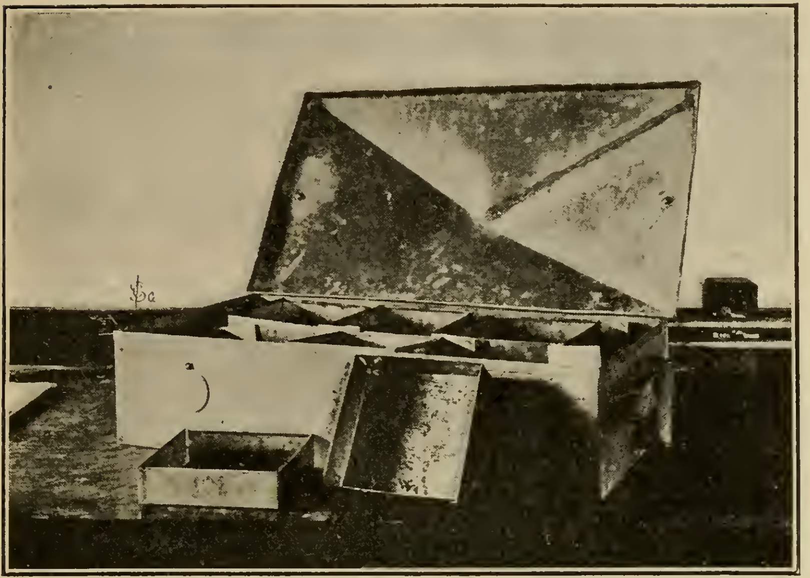

Plate 7

BOX IN WHICH SOILS ARE EXPOSED IN A SATURATED ATMOSPHERE

This box is made of zinc. It is twenty-six inches long, fourteen inches wide and six inches deep and is provided with a closely fitting cover.

There are two tiers of strips the full length of the vessel on which rest the soil pans. Openings are cut in these strips in which pieces of blotting paper are fitted. The ends of the paper extend into the water, which is kept not less than an inch deep in the bottom of the vessel.

The soil pans used in this exercise are made of tin and are six and one-half by six and one-half inches and one and five-eighths inches in depth.

EXERCISE 24

Determination of the Rate of Percolation of Water Through Soils

Object: To compare the rate of percolation of water through soils of different texture.

Directions:

1—Use in this experiment sand, clay and loam.

2—Fill, without compacting, within an inch of the overflow pipes, each of the soil tubes provided for this experiment, with one of the soils named above, and place a half-inch layer of gravel on the surface to prevent disturbance of the soil by the flowing water.

3—Connect the filled tubes with short pieces of rubber tubing, by means of the lateral inlets, and close with corks the openings at the extreme ends of the series.

4—Pour in water gently in quantities sufficient to keep the tubes almost level full and maintain the same water level in each tube.

5—Note the time until percolation begins from the drainage tubes, then place an Erlenmeyer flask beneath each. When the flow becomes constant, collect the water which percolates through the soil in thirty minutes and measure carefully.

6—Determine in the same way the amount of water which percolates in thirty minutes through compacted sand, clay and loam.

7—Tabulate the results as follows:

Kind of Soil	Loose		Compact	
	Time for Percolation	c. c. Water Percolated in 30 Min	Time for Percolation	c. c. Water Percolated in 30 Min.

Questions:

(*a*) Why does the water percolate most rapidly through the soil which has the least total pore space?

(*b*) What factors, other than texture, facilitate the percolation of water through loam and clay soils under natural field conditions?

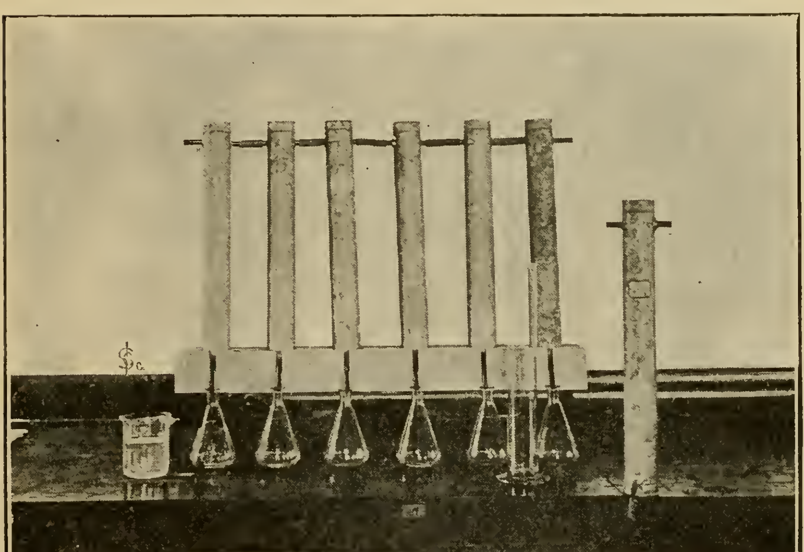

Plate 8

APPARATUS FOR THE PERCOLATION OF WATER THROUGH SOILS

The soil tubes used in this exercise are made of galvanized iron. They are eighteen inches long and two inches in diameter, with solid bottoms. The lateral inlets are three-eighth-inch tubes, one inch long; they are placed one and one-half inches below the top of the soil tubes. The drain pipe is one-quarter inch in diameter, two and one-half inches long, and is three-quarters of an inch above the bottom of the tube.

The block which is used to support the tubes is three by three inches. The holes are two and one-quarter inches in diameter, two inches deep, and are five inches from center to center.

Notches are cut in the side of the block to accommodate the drain pipes. This block can be used also in other exercises.

EXERCISE 25

Rate of Flow of Air Through Soils

Object: To compare the rate of the flow of air through soils of different texture.

Directions:

1—For this experiment use sand, loam, clay and loess.

2—Fill the required number of soil tubes provided for this experiment with the above named soils. Use the compacting machine as directed in previous exercises.

3—Connect the soil tubes successively to the cock on the aspirator with rubber tubing and note the number of degrees passed by the pointer in a given time.

4—Determine the rate of flow per hour for the different soils and tabulate the data as follows:

Kind of Soil	Degrees Passed by Pointer in Specified Time	Rate of Flow per Hour

Questions:

(*a*) What relation does the aeration of the soil sustain to the action of bacteria in the soil?

(*b*) Do the different soils sustain the same relation to each other in regard to the rate of the flow of air that is sustained in the percolation of water?

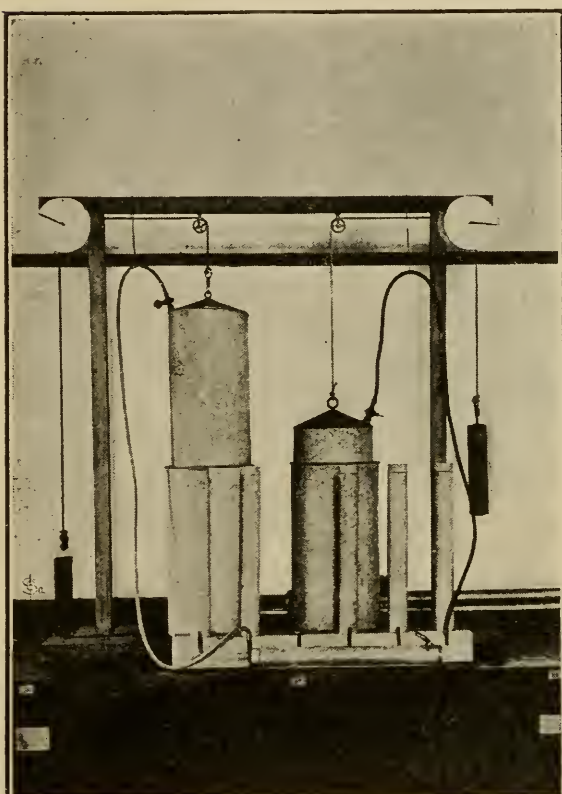

Plate 9

ASPIRATOR AND FRAME

The base of the frame is four feet long, twelve inches wide and two inches thick. The uprights and cross-bar are made of two by two-inch material. The total hight is three feet ten inches.

The outside can, which holds the water, is eighteen inches high and nine and one-quarter inches in diameter. The inside can is eighteen inches high and eight and one-half inches in diameter. It is fitted with a ring and cock as shown in the illustration.

The larger can is nearly filled with water; the smaller can is pushed down into the water with the cock open to permit the air to escape. The cock is then closed and the tube containing the soil is attached to the cock of the aspirator by means of a piece of rubber tubing which is long enough to extend to the top of the frame.

The weight is about twice as heavy as the can to which it is attached with window cord. The cord passes through a pulley near the end of the frame which is similar to the one shown in the illustration, except that the axle passes through the dial and carries a pointer. To operate the aspirator, open the cock and start the weight from the same point each time.

The soil tubes are made of galvanized iron. They are eighteen inches long and two inches in diameter. The tube near the bottom is one-fourth of an inch in diameter, two inches long and is curved upward as shown. The block in which the tubes are supported is similar to the one used in the previous exercise.

EXERCISE 26

Rate of Rise of Capillary Water in Soils

Object: To compare the rate of the rise of capillary water in soils of different texture.

Directions:

1—For this experiment use coarse sand, fine sand, loam, clay, loess and peat.

2—Select twelve glass tubes, one inch in diameter, of uniform bore, and close one end of each by means of a piece of cheesecloth, firmly tied on.

3—Fill six of the tubes with the finely pulverized air-dried soils, pouring the soil in loosely, care being taken not to compact it. Fill the remaining six tubes by compacting the soil by gently tapping the tubes during the time of filling.

4—Place the tubes in a wooden frame in such a manner that the lower ends are immersed in about an inch of water.

5—Make readings at the following intervals: 1 hour, 2 hours, 3 hours, 6 hours, 9 hours, 12 hours, 18 hours, 24 hours, 36 hours, 48 hours, and daily thereafter until no further rise is noted. Note the total hight to which the water has risen and the rise in the water column since the previous reading.

6—Tabulate the data as follows:

	Hight of Water in Inches											
Kind of Soil	1	2	3	3	9	12	18	24	36	48	72	Hours
Loose												
Compact												

Questions:

(*a*) What factors influence the capillary rise of water in soils?

(*b*) Does the water rise to the greatest hight in the soil in which the rise is most rapid at first?

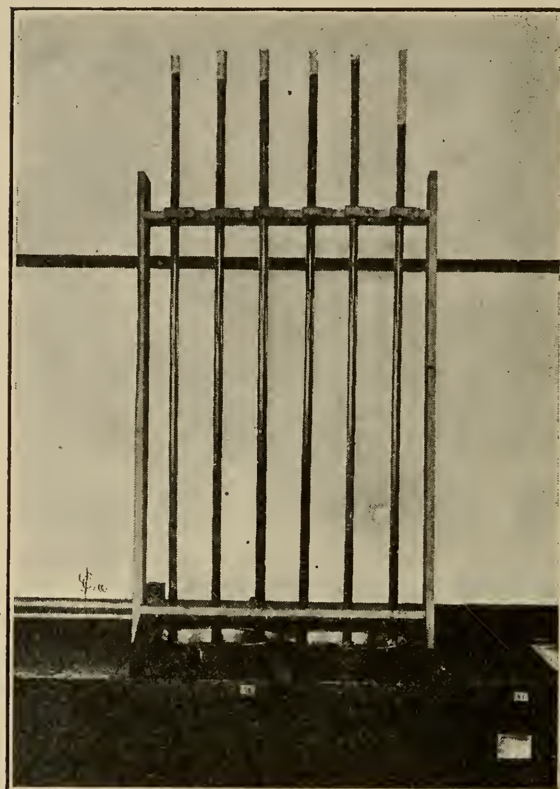

Plate 10

APPARATUS FOR THE STUDY OF THE CAPILLARY RISE OF WATER

The frame in which the glass tubes are supported is two and one-half feet wide and four feet high. It is made of material one inch thick and four inches wide. The frame rests upon two blocks, sixteen inches long. The holes in the upper cross-bar, which receive the glass tubes, are flush with the edge and the tubes are held in position by wooden buttons as shown.

EXERCISE 27

The Amount of Capillary Moisture at Different Hights from the Water Table

Object: To determine the amount of capillary moisture held at different hights from the water table by soils of different texture.

Directions:

1—Use the same soils which were used in the preceding exercise.

2—Fill six sectional brass soil tubes, five feet in length, over the lower ends of which pieces of cheesecloth have been firmly tied, with the finely pulverized air-dried soils, pouring the soil in loosely, care being taken not to compact it. Fill six other tubes by compacting the soil by tapping the tubes gently.

3—Place the tubes in a frame with the lower ends standing in about one inch of water.

4—At the end of thirty days, separate the one-foot sections from each other and determine the percent of moisture held in each successive foot above the water table. For the moisture determination use about a 100-gram sample of the soil taken from the top of each section.

5—Tabulate the data as follows:

Kind of Soil	Percent of Moisture									
	Loose					Compact				
	—	2 ft.	3 ft.	4 ft.	5 ft.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.

Question:

(*a*) Why is there a difference in the percent of water held at the different hights from the water table?

EXERCISE 28

The Effect of a Layer of Green or Well-Rotted Vegetable Matter Upon the Capillary Rise of Water

Object: To determine the extent to which a layer of vegetable matter breaks the capillary rise of water in soils.

Directions:

1—Select three glass tubes about two feet long and two inches in diameter, of uniform bore, and close one end of each by means of a piece of cheesecloth firmly tied on.

2—Fill one tube with finely pulverized air-dried loam, pouring the soil in loosely. Fill a second tube with the same soil to a depth of one foot; then place in the tube a two-inch layer of coarsely cut green material and complete the filling of the tube with the loam. Fill the third tube in the same way except that well-rotted manure is to be substituted for the green material.

3—Place the tubes in a frame with the lower ends standing in about one inch of water.

4—Observe the rise of the capillary water in each tube and report in narrative form your observations, which should extend over one week.

Question:

(*a*) What is the practical lesson taught by this experiment?

EXERCISE 29

The Effect of Mulches on Evaporation of Water from Soils

Object: To determine the amount of evaporation which takes place from soils when they are cultivated at different depths and when they are mulched with various materials.

Directions:

1—Fill the required number of soil cylinders provided for this experiment with fine air-dried loam, compacting the soil uniformly and filling the cylinders to the same level.

2—Treat the soils in the different cylinders as follows:

No. 1—No treatment.
No. 2—Cultivated one inch deep.
No. 3—Cultivated three inches deep.
No. 4—Cultivated five inches deep.
No. 5—Mulched with two inches of leaves.
No. 6—Mulched with two inches of cut straw.

3—Cultivate the soil each day by thoroughly stirring the surface to the required depth.

4—Fill the water supply tubes on the cylinders with water to the same level every day, and after evaporation begins, keep a careful record for one week of the amount of water given off every twenty-four hours. Cover the supply tubes with corks or glass plates in order to prevent evaporation from the water surface.

5—Determine the surface area of the cylinders and compute the number of tons of water evaporated per acre during a period of one week.

6—Repeat this experiment with a sandy soil.

7—Tabulate the data as follows:

Number of Cylinder	Number of c. c. Water Evaporated								
	1st day	2d day	3d day	4th day	5th day	6th day	7th day	Total No. c. c. Water	Tons per Acre

Questions:

(*a*) What is the effect of a mulch?

(*b*) Which method of cultivation conserves the greatest amount of moisture?

(*c*) Is the amount of water evaporated from day to day the same? If not, why?

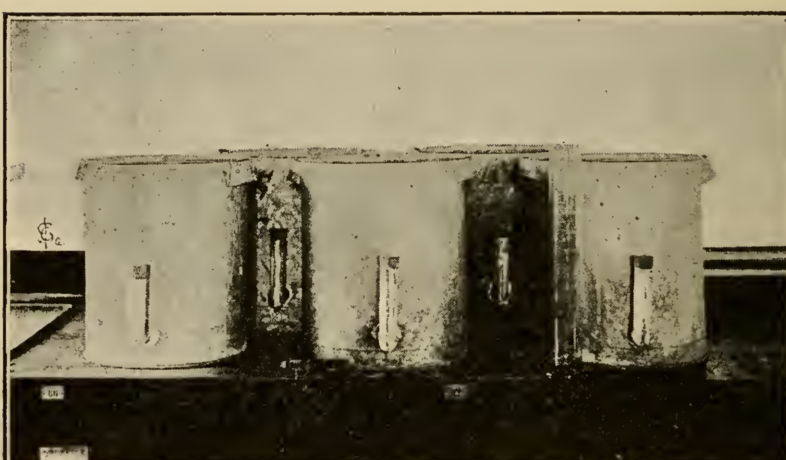

Plate 11

APPARATUS FOR THE STUDY OF THE EFFECT OF MULCHES

The cylinders are made of galvanized iron. They are eleven inches in diameter and thirteen inches high.

The water supply tubes are one inch in diameter. Cylinders of this style permit evaporation to take place from quite a large area.

EXERCISE 30

Effect of Wetting the Surface of the Soil on the Moisture Content of the Sub-Soil

Object: To study the translocation of water occasioned by wetting the surface of the soil.

Directions:

1—Select a plot of fallow ground eight feet square and make moisture determinations with samples taken in six-inch sections down to a depth of three feet. Each sample should be made up of soil from several borings.

2—Add to the plot slowly with a sprinkler, 128 pounds of water.

3—Twenty-four hours after applying the water, take composite samples near the points at which the first samples were taken and determine the amount of water in each. Also take samples a few feet from the wet area and determine the moisture content.

4—Make moisture determinations in the same way forty-eight hours after applying the water.

5—Tabulate the data as follows:

Depth of Samples	Wet Area			Area Not Wet	
	Percent of Water			Percent of Water	
	Before Wetting	24 hrs. After Wetting	48 hrs. After Wetting	24 hrs.	48 hrs.

Questions:

(*a*) What effect may a light rain in summer have upon the water content in some of the lower strata?

(*b*) In dry weather is it advisable to simply wet the surface around a recently planted tree? If not, why?

(*c*) Why is it advisable to practice shallow cultivation as soon after a considerable rainfall as the implements will work satisfactorily?

EXERCISE 31

Determination of Loss on Ignition

Object: To determine the loss on ignition due to the removal of water in combination with certain materials, all organic acids and ammoniacal compounds, all organic matter and the carbon dioxide in carbonates.

Directions:

(Method of the Official Agricultural Chemists.)

1—Place five grams of the water-free soil in a weighed crucible and heat to low redness.

2—Stir the soil occasionally and continue the heating until all organic material is burned away, but below the temperature at which alkaline chlorides volatilize.

3—Moisten the cold mass with a few drops of a saturated solution of ammonium carbonate, dry and heat to 150 degrees C. to expel excess of ammonia. The loss in weight of the sample represents organic matter, water of combination, salts of ammonia, etc.

4—Determine by this method the loss on ignition, of the following soils: sand, loam, clay, loess and peat.

Tabulate the data as follows:

Kind of Soil	No. of Crucible	Wt. Crucible and Soil Before Heating	Wt. Crucible and Soil After Heating	Loss on Ignition	Percent of Loss

Questions:

(*a*) Does the soil change color on ignition? Why?

(*b*) Why is there a greater loss on ignition with loam than with sand?

EXERCISE 32

The Effect of Organic Matter on Baking of Clay Soils

Object: To show the degree to which organic matter prevents the baking of clay soils.

Directions:

1—Secure four one-gallon jars provided with drainage outlets and fill them to within one inch of the top as follows:

No. 1—Clay.

No. 2—Clay thoroughly mixed with five percent of peat by weight.

No. 3—Clay thoroughly mixed with ten percent of peat by weight.

No. 4—Clay thoroughly mixed with twenty per-cent of peat by weight.

2—Apply enough water to saturate the soil, using the same amount of water in each case, and expose the jars to the direct rays of the sun until the soil is baked.

3—Examine the soils and determine the ease with which the baked surface can be pulverized with the fingers.

4—Record your observations in narrative form in your note book.

Questions:

(*a*) What causes a clay soil to bake?

(*b*) In what way does the crust formed by the baking injure the growing plant?

(*c*) How does organic matter tend to prevent the "running together" or baking of soils?

(*d*) What can the farmer do to prevent the baking of the soil?

EXERCISE 33

The Granular Structure of Soils

Object: To compare the granular structure of surface, sub-surface and sub-soils.

Directions:

1—Secure samples of the surface, sub-surface and sub-soil of loam without destroying the granular structure.

2—Examine a small portion of each sample with the microscope; make drawing showing the granular structure and note the shape and size of the granules.

3—Place about ten grams of each sample in a shaker bottle with 75 c. c. of distilled water and shake for fifteen hours.

4—Again examine each sample with the microscope and note the difference in the size and structure of the particles.

Questions:

(*a*) What factors cause a difference in the granular structure of a soil at different depths?

(*b*) Why is granulation a desirable property of soils?

EXERCISE 34

The Effect of Alternate Wetting and Drying Upon Granulation

Object: To study the effect of alternate wetting and drying upon the granulation of a loam soil rich in organic matter and a clay soil deficient in organic matter.

Directions:

1—Mix 400 grams of each of the soils with water and completely puddle by working on the "mixing board."

2—Mold each sample into a large ball; place the balls on a board or cloth and thoroughly dry by exposing to the rays of the sun or heating in the oven at about forty degrees C.

3—Again moisten the mass and dry as before. Repeat the operation two additional times.

4—Examine the soils after each period of drying and describe in narrative form what has taken place.

EXERCISE 35

The Effect of Alternate Freezing and Thawing Upon Granulation

Object: To study the effect of alternate freezing and thawing upon the granulation of a loam soil rich in organic matter and a clay soil deficient in organic matter.

Directions:

1—Mix 400 grams of each of the soils with water and completely puddle by working on the "mixing board."

2—Mold each sample into a large ball; place the balls on a board or cloth and expose in a freezing temperature until the soil is frozen solid.

Note—In freezing weather the balls may be exposed out of doors; at other times, if a cold storage room is not at hand the balls may be placed in a covered can and packed in ice and salt after the manner of an ice cream freezer.

3—Next thaw out the soils by exposing the balls at the temperature of the laboratory.

4—Repeat this alternate freezing and thawing three additional times.

5—Examine the soils after each period of thawing and describe in narrative form what has taken place.

EXERCISE 36

The Effect of Organic Matter on Granulation

Object: To study the effect of organic matter upon the granulation of a soil rich in that material.

Directions:

1—Secure a loam soil which is rich in organic matter.

2—Wet about 300 grams of the soil and thoroughly puddle by working on the "mixing board." Then mold the soil into a large ball.

3—Place another 300-gram sample in a percolator and leach out the soluble salts with a one percent solution of hydrochloric acid. Wash the soil free of acid, puddle and mold into a ball.

4—Extract the soluble salts from another 300-gram sample of soil; wash free from acid and transfer the soil to a four-liter bottle. Nearly fill the bottle with a four percent solution of ammonia and shake occasionally for twenty-four hours in order to extract a portion of the humus. Decant the ammonia solution into a vessel and set aside. Wash the soil free from ammonia and mold into a ball.

5—Freeze and thaw the three balls four times in the manner described in the preceding exercise.

6—Note the appearance of the balls after each period of thawing.

7—Evaporate the ammonia solution which was used in extracting the humus from ball No. 3 nearly to dryness on the water bath.

8—Mix the residue left after the evaporation, with the soil from which it was removed. Mold the mass into a ball and freeze and thaw four times.

9—Compare the condition of this ball after each thawing with the condition of the other balls.

Questions:

(*a*) Why is the soil in better condition for cultivation after a cold winter?

(*b*) What influence has organic matter on granulation?

EXERCISE 37

The Chromic-Acid Method of Determining Organic Matter

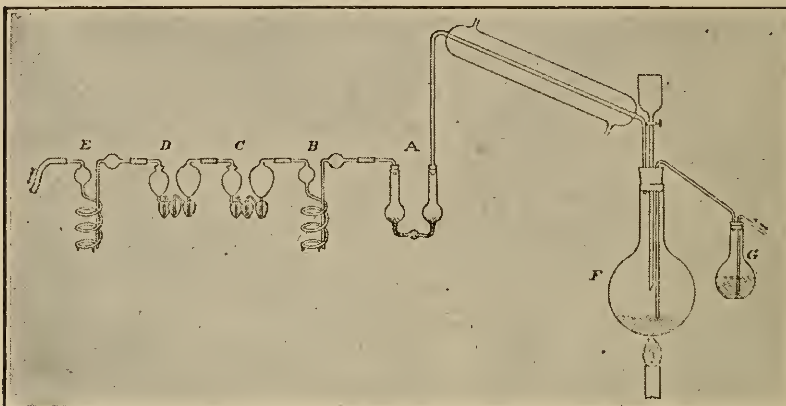

Fig. 1

THE DESCRIPTION OF THIS METHOD IS TAKEN FROM BULLETIN NO. 24, BUREAU OF SOILS

The combustion is effected in a round-bottomed flask F, Fig. 1, of about 400 c. c. capacity, fitted with a three-hole rubber stopper. The stopper is fitted with a dropping funnel, a tube for the introduction of air previously freed from carbon dioxide by bubbling through a solution of potassium hydrate in the flask G, and a tube leading through a condenser to a train of absorption bulbs. This train contains first, a Peligot tube A, containing a saturated and slightly acidified solution of silver sulphate to absorb both hydrochloric acid and sulphur trioxide or dioxide should they be generated; then a guard tube B, containing concentrated sulphuric acid, followed by a potash bulb C, and an acid bulb D, to be weighed with the potash bulb. An acid guard bulb E, completes the train. The whole apparatus is attached to an aspirator so that air free from carbon dioxide can be drawn through the combustion flask and train. The procedure is as follows:

"A sample of the soil, usually about ten grams, is carefully weighed and brought into the combustion flask. If the sample be rich in organic matter, it has been found advisable to introduce also some sand, previously ignited before the blast, and in an amount dependent roughly upon the apparent quantity of organic matter in the soil. From five to ten grams of pulverized potassium bichromate are then added and the whole mixed thoroughly by shaking, care being taken to prevent any of the mixture adhering to the sides of the flask above the level of the mixture. The flask is closed securely by the stopper, and a gentle stream of air drawn through the whole apparatus by means of the aspirator. When this stream of air has been passing for about ten minutes, concentrated sulphuric acid (sp. gr. about 1.83) is slowly and cautiously run in by means of the dropping funnel until the tip of the glass tube for the introduction of air is covered. When this point has been reached, and if no very vigorous action is taking place, the combustion flask is slowly heated until the sulphuric acid commences to give off fumes. It is held at this temperature for from five to ten minutes, and then allowed to cool slowly, unless there is reason to believe combustion has not been complete, in which case the temperature is again raised. Care must be exercised to see that a steady current of air be kept passing through the apparatus, and that the mixture in the flask be not forced back toward the wash bottles. If necessary, quite a rapid stream can be drawn through the absorption bulbs without much risk of losing the determination. It is advisable to have the bulb of the dropping funnel empty before commencing the heating, so that the tube can be quickly opened. In over 400 experiments with this method, the flask broke but once, and then the dropping funnel could not be opened because it contained a quantity of sulphuric acid. A sudden large increase of pressure was generated in the flask, owing to faulty manipulation. The dangerous character of such an accident is sufficiently obvious, but with ordinary care, liability of its occurrence is extremely small."

MODIFICATIONS FOR SOILS CONTAINING CHLORIDES AND CARBONATES

In many soils from arid, semi-arid or marshy areas there is a considerable content of chlorides. By following the procedure just described with these soils, chlorine gas may be generated, which would be collected in the potash bulbs, forming a mixture of the chloride and hypochlorite in proportions difficult to estimate accurately, and vitiating any attempt to determine the amounts of carbon dioxide absorbed. We have made a number of attempts to get around this difficulty and have found that it can be met quite simply. If the bichromate of potash be not mixed with the sample before running in the concentrated sulphuric acid, but be dissolved in the acid itself and the solution be slowly and cautiously run in upon the soil, with no attempt to heat the mixture until the reaction in the flask has proceeded for some time, no hydrochloric acid, chlorine nor chromyl chloride gas is generated, or in but very small amounts. The procedure thus modified has been used a large number of times with artificial mixtures and natural soils, and has proven satisfactory, although no explanation is obvious why hydrochloric acid should not be formed and oxidized under these conditions. We can only say that, although we discovered the fact empirically, we have thoroughly tested it with the most gratifying results for the method.

When the amount of chlorides is relatively large, it has sometimes been found desirable to treat the sample with a small volume of dilute sulphuric acid, adding more acid in small quantities from time to time, if necessary, to digest on the steam bath until the major part of the hydrochloric acid has been removed, and to evaporate as much of the water remaining as can be done without permitting a noticeable action of the solution upon the organic matter. The combustion is then carried out as above described.

With soils which contain carbonates of the alkalies or alkaline earths, it would probably be found satisfactory first to treat with sulphurous acid to decompose the carbonates and drive out the carbon dioxide without oxidizing the organic matter, and then try to get rid of the water and sulphurous acid by evaporating to dryness before proceeding with combustion.

This method presents, however, a number of difficult manipulations and requires a great deal of time. It has been found, in the experience of this laboratory, much more convenient to make a separate determination of the carbon dioxide liberated from the carbonates, by treating a separate sample of the soil with dilute sulphuric acid (1:6 by volume), and subtracting the amount thus found from the total obtained in the combustion. While this method is not entirely free from objections for very accurate work, it does unquestionably lead to values with all the accuracy necessary for most purposes to which the determination of the organic matter in a soil is applicable.

In determining the percentage of organic matter in the soil from the percentage of carbon dioxide found, it is of course necessary to use a conversion factor which, multiplied by the weight of CO^2, gives the weight of organic matter. The factor generally used for this purpose is 0.471, based upon Wollny's investigation of the percentage of carbon in the humus of the soil.

NOTE—Another method for the determination of organic carbon in soils is now used by the Illinois Experiment Station. This method, which has been found to be quite satisfactory, is described in detail in the Journal of the American Chemical Society, Vol. 26, page 294, and Vol. 26, page 1640.

EXERCISE 38

STANDARDIZATION OF THE EYE-PIECE MICROMETER*

Object: To determine the number of spaces on an eye-piece micrometer which the soil particles must cover to belong to a given grade.

Directions: In order to separate the particles of a given sample of soil into different grades according to size, it becomes necessary to measure them with sufficient accuracy to determine the grade within which limits they fall. As the greater mass of the soil particles are microscopic objects or bodies of such small dimensions that we cannot measure them accurately without first enlarging them sufficiently to permit of exact measurements, the compound microscope is used for this purpose.

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*From laboratory notes used at the Illinois College of Agriculture.

To be able to measure accurately bodies of such small proportions, it is essential that we possess a standard or measure whose value is known with each different degree of magnification resulting from different optical combinations. The stage micrometer is well adapted to this purpose and affords a fixed standard of comparison where it can be used. There are certain conditions, however, which make its use unadvisable for general miscroscopic work. One of these is its cost and its liability to be broken when it is used for the purpose of direct comparison with the object to be measured. Another is the mechanical difficulty connected with the ruling of a stage micrometer which shall be accurate and sufficiently close to permit satisfactory measurements when used under a high power. To avoid these objections as well as to facilitate rapid measurements with the microscope and to obviate the annoyance of using a stage micrometer in connection with the object to be measured, we employ for our purpose the eye-piece micrometer, which possesses the advantage of being more accurately ruled where high powers are desired.

When using the eye-piece micrometer it is placed within the ocular of the microscope and above the lenses so that it is not enlarged as is the object to which it is to be compared. The value of the rulings upon the eye-piece micrometer is .1 mm., but as the value of the object changes with each combination of the microscope, it becomes necessary for us to know the magnifying power of each combination of lenses in order to determine the size of our object, or to first standardize the eye-piece micrometer for each combination which we are to use by comparing it with a standard of known value which is magnified to the desired degree. This is done by comparing the eye-piece with the stage micrometer and computing the value of one space of the eye-piece micrometer for each combination of the microscope. When this is known the number of the spaces which the soil particles must cover to belong to a given grade is determined by dividing the value of one space into the size of the particle. This operation is performed for each of the grades and the results are arranged in a tabular form together with the actual size of the particles and the combinations of the microscope used in measuring them for convenience in saving computation during analysis.

Each student will make the standardizations and compute the value of the eye-piece micrometer with the different combinations of the microscope needed to measure the particles and tabulate the results as follows:

Div.	Name	Size of Particles	Spaces of Micrometer	Objective and Ocular
1	Fine gravel	2 to 1 mm.		
2	Coarse sand	1 to .5 mm.		
3	Medium sand	.5 to .25 mm.		
4	Fine sand	.25 to .1 mm.		
5	Very fine sand	.1 to .05 mm.		
6	Silt	.05 to .005 mm.		
7	Clay	.005 to .0001 mm.		

EXERCISE 39

Mechanical Analysis of Soils

Object: To determine the percentage of gravel, fine gravel, coarse, medium, fine and very fine sand, silt and clay in a sample of "fine earth."

Directions:

1—Thoroughly mix, upon a heavy paper or oilcloth, the sample of air-dried soil to be analyzed; take from the well-mixed mass about 100 grams of soil and weigh accurately; roll the sample with a wooden rolling pin and sift it with a 2 mm. sieve. Weigh all small stones and pebbles which do not pass the sieve and determine the percentage of this material.

2—Place about ten grams of the sifted soil which is designated as "fine earth" in a crucible and dry to a constant weight in an oven maintained at 110 degrees C.

3—Place five grams of the water-free soil in a shaker bottle and add about 75 c. c. of distilled water and ten drops of ammonia. Exercise care in weighing the sample of soil and in transferring it to the bottle.

4—Place the bottle in the shaking apparatus and agitate it until a microscopic examination of the contents shows that the soil particles are completely separated and no compound particles exist. "When this condition is reached the individual particles will appear clear and semi-transparent in the field of the misroscope, while any remaining compound particles will be darker and variously colored from reflected light. This may require from twelve to twenty-four hours, or even longer, depending very much upon the nature of the soil. As the determination is quantitative but a small amount of the liquid is taken from the bottle with a capillary pipette, and mounted on a slide for examination. When the examination is complete, the slide and cover glass are carefully rinsed with distilled water back into the shaker bottle to recover the small portion of soil taken. Great care is necessary throughout the analysis to prevent the loss of any part of the sample and for the purpose of comparison and greater accuracy in results, duplicate samples are used of each soil analyzed."

5—When no compound particles are found in the samples, transfer the contents of the shaker bottles into centrifuge tubes.

6—Place the tubes in the centrifuge, care being taken to have the weight evenly distributed so that the apparatus will run steadily. Rotate the tubes in the centrifuge for two or three minutes at a speed sufficiently high to throw down all particles except those which belong to the grade listed as clay. To determine the speed and time required for this operation, examine the suspended material with the microscope, taking the sample and mounting it as described above.

7—When it is found that no particles larger than .005 mm. are left in suspension, carefully decant the liquid in each tube into a weighed 400 c. c. beaker, which is numbered to correspond with the number of the tube.

8—Nearly fill the tubes with distilled water which is delivered with sufficient pressure to thoroughly stir up the contents of the tubes.

9—Continue to rotate the centrifuge and decant until the contents of each tube are free from particles which belong to the grade designated as clay. Care must be taken to determine quite accurately just the time required for the particles larger than .005 mm. to settle, for if the centrifuge is rotated too long, a portion of the clay also goes down and the time required to complete the separation is thus greatly lengthened.

10—Evaporate the contents of the beakers to dryness on the water bath; then dry the residual matter in the beakers to a constant weight in the oven at 110 degrees C. and determine the percent of clay in the sample of soil.

11—After the clay particles have been separated as described above, place the tubes in a rack and thoroughly stir the contents by filling the tubes with distilled water which is delivered under pressure.

12—Examine the suspended material with the microscope and in this way determine the length of time required for all the particles to settle which are larger than .05 mm. Decant into large beakers which are numbered to correspond to the number of the tubes. Repeat the operation of stirring the contents of the tubes and decanting until all of the silt particles are removed.

13—Set aside the beakers containing the silt for twelve hours or more, or until all of the silt has settled. Then decant nearly all of the water from each beaker; carefully transfer the silt to a weighed and numbered porcelain or nickel dish and evaporate to dryness on the water bath. Dry the silt in the oven at 110 degrees C. to a constant weight and determine the percent of silt in the sample of soil.

14—Wash the sand which is left in the tubes after the clay and silt are removed, into weighed and numbered crucibles; evaporate to dryness on the water bath and dry to a constant weight in the oven at 110 degrees C. Weigh and record as total sand.

15—Separate the sand into the various grades by the use of a series of sieves fitted with bolting cloth and determine the percent of each grade in the sample of soil.

16—Make a mechanical analysis of the soils furnished by the instructor and tabulate the data as follows:

MECHANICAL ANALYSIS

Sample No.________ Date__________

Gravel > 2 mm. ______Percent

Analysis of 5 grams of soil < 2 mm.

	No. Dish Sands 1-5____	No. Dish Silt 6____	No. Dish Clay 7____
Wt. Dish & Soil	__________	__________	__________
Weight of Dish	__________	__________	__________
Weight of Soil	__________	__________	__________

	Diameter mm.	Weight grams	Percent
1	2 - 1		
2	1 - .5		
3	.5 - .25		
4	.25 - .1		
5	.1 - .05		
6	.05 - .005		
7	< .005		
Total			

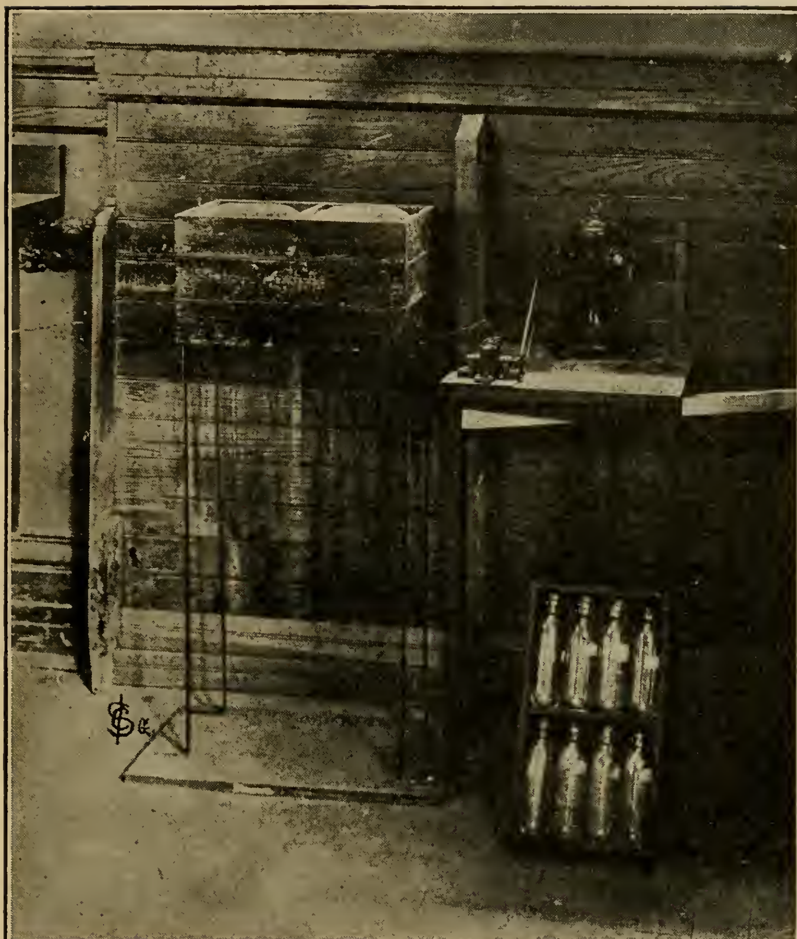

Plate 12

MECHANICAL SHAKER USED IN PREPARING SOILS FOR MECHANICAL ANALYSIS

The shaker consists of a platform which carries the trays resting upon four three-quarter-inch iron supports which are thirty inches high.

The trays are divided into individual compartments, each tray holding eight bottles which correspond to the number of samples usually analyzed at a time. The trays are made of half-inch material. They are sixteen inches long, nine and one-quarter inches wide and three inches deep outside measurement.

Each tray has a pin placed at either end, which fits into holes in the tray above it, so that four or more trays may be placed upon the shaker at one time.

The shaker is driven by a 110-volt, one-sixteenth-horse power motor which is belted to a fiber worm reducing gear provided with a crank to which the shaker is connected as shown in the illustration. The motor is provided with a regulating rheostat to adjust the speed when the shaker is not fully loaded.

The 110-volt motor with shaker attachment costs about twenty-five dollars.

The bottles for use in the shaker may be purchased from Whitall Tatum Company, Philadelphia. They are known as eight-ounce sterilizing bottles, flint glass, graduated. They require E & A rubber stoppers No. 1. They cost about four dollars per gross.

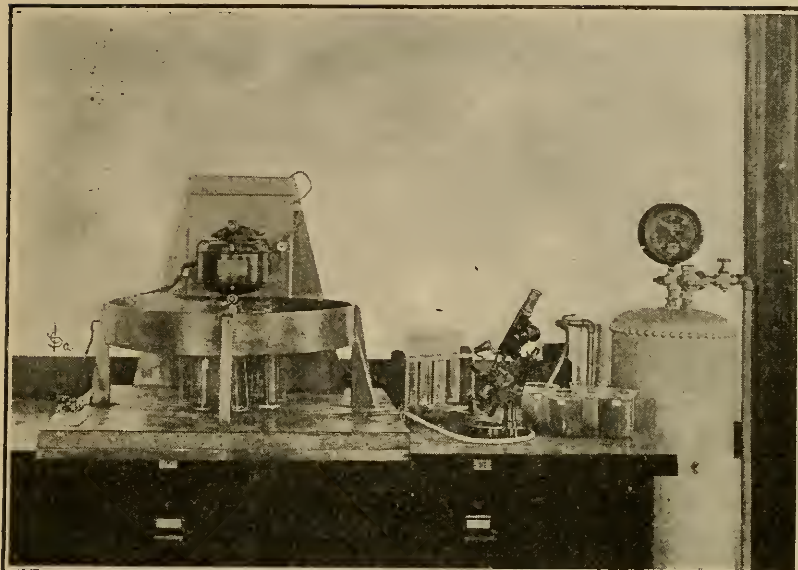

Plate 13

CENTRIFUGAL MACHINE USED IN MECHANICAL ANALYSIS OF SOILS AND TANK FOR THE SUPPLY OF DISTILLED WATER UNDER PRESSURE

The following description of the centrifugal apparatus which is shown in the illustration is taken from Bulletin No. 24, Bureau of Soils:

"The centrifugal apparatus consists of a 110-volt, sixteen-inch fan motor mounted with its shaft in a vertical position, to which is attached a spider carrying eight trunnioned frames. The distance from the center of the motor shaft to the center of the trunnion screws is 10 cm., and the depth of the trunnioned racks is 15 cm. The centrifugal tubes consist of large, heavy glass test tubes, 18x3 cm., which are supported in the trunnioned racks. The aperture in the upper ring of the support is made large enough to admit the test tube readily, while the opening in the lower ring is smaller than the tube and is faced with a felt cushion on which the tube rests. It is important that the tubes should be thoroughly annealed; otherwise breakage is apt to occur under the strain to which they are subjected during rotation. To protect the operator from such accidents a guard surrounds the movable portion of the machine.

"The motor is provided with a rheostat in its base, giving four different speeds, which enables one to start the motor slowly and bring it gradually up to full speed. The machine, when loaded and running at full speed, requires about one minute to stop after the circuit is opened. To avoid this delay, the motor is provided with a reversing switch, by means of which the direction of the current through the armature may be reversed and the motor brought quickly to rest. Before stopping the machine in this way, the rheostat should be set at the first speed, then slowly moved to the second or third in order that the motor may not be subjected to too great mechanical and electrical strain in the reversing process."

A jet of distilled water under considerable pressure is needed to wash the samples from the shaker bottles and in bringing the soil into suspension after it has been packed into the bottom of the tubes by centrifugal action. For this purpose, a thirty-gallon tank is located near the centrifugal machine. The tank is filled about half full of distilled water and air is admitted from the pressure cock. The water is drawn from the tank through a pipe and rubber tubing as shown. If the laboratory is not provided with compressed air a large bicycle pump may be used. The tank and fixtures are not expensive and have been found very satisfactory.

Plate 14

NEST OF SIEVES USED TO SEPARATE SAND INTO THE VARIOUS GRADES

The large brass sieve shown in the illustration is six inches in diameter with 2 mm. meshes.

The nest of sieves is made of brass and is four inches in diameter. The two upper sieves have circular perforations 1 mm. and .5 mm. respectively. The two lower sieves are made of silk bolting cloth stretched over brass frames and held in position by slip rings.

The sieves shown in the illustration are fitted with silk bolting cloth.

The bolting cloth may be purchased from B. F. Starr & Co., Baltimore, Md.

EXERCISE 40

Mechanical Analysis of Soils by the Beaker Method

Directions:

1—Thoroughly mix upon a heavy paper or oil-cloth, the sample of air-dried soil to be analyzed; take from the well-mixed mass about 100 grams of soil and weigh accurately.

Roll the 100-gram sample with a wooden rolling-pin and sift it with a 2 mm. sieve. Weigh all small stones and pebbles which do not pass through the sieve and determine the percentage of this material.

2—Place about thirty grams of the sifted soil which is designated as "fine earth" in a porcelain dish and dry to a constant weight at 110 degrees C.

3—Place twenty grams of the water-free soil in a shaker bottle and add about 75 c. c. of distilled water and fifteen drops of ammonia. Exercise care in weighing the sample of soil and in transferring it to the bottle.

4—Place the bottle in the shaking apparatus and agitate it until a microscopic examination of the contents shows that the soil particles are completely separated. (See the preceding exercise for the method of making this examination.)

5—When no compound particles are found in the samples, transfer the contents of the shaker bottle into a 400 c. c. beaker; add about 200 c. c. of distilled water and stir thoroughly with a glass rod.

6—Allow the contents of the beaker to settle until all particles larger than .05 mm. have subsided. This is determined by examining a drop of the turbid liquid which is drawn from near the bottom of the beaker with a capillary pipette, under a microscope fitted with an eye-piece micrometer.

7—When all of the particles larger than .05 mm. have subsided, decant the turbid liquid containing the silt and clay into a larger beaker. Repeat this operation until all particles smaller than .05 mm. have been removed.

8—Transfer the sediment to a weighed evaporating dish, dry to a constant weight in the oven at 110 degrees C. and weigh as total sand.

9—Further separate the sand into the various grades by passing it through a series of brass sieves four inches in diameter which fit into each other. The first sieve has circular openings 1 mm. in diameter and the second .5 mm. The particles passing through the lower sieves are sifted through screens of No. 5 and No. 13 bolting cloth.

10—Allow the turbid liquid in the beaker containing the silt and clay to settle until the microscope shows that all particles larger than .005 mm. have settled.

11—Decant the liquid containing the clay into a third beaker of about 2000 c. c. capacity. Stir the sediment in the bottom of the beaker with more water, allow to settle and decant. Repeat this operation until all particles smaller than .005 mm. are removed.

12—Wash the silt into a small weighed porcelain dish. Evaporate to dryness on the water bath. Dry to a constant weight in the oven at 110 degrees C. and weigh.

13—Accurately measure the clay water in the third beaker and, after thoroughly stirring, take an aliquot portion, evaporate to dryness on the water bath, dry to a constant weight in the oven and weigh.

14—Make a mechanical analysis of the soils furnished by the instructor and tabulate the data as in the preceding exercise.

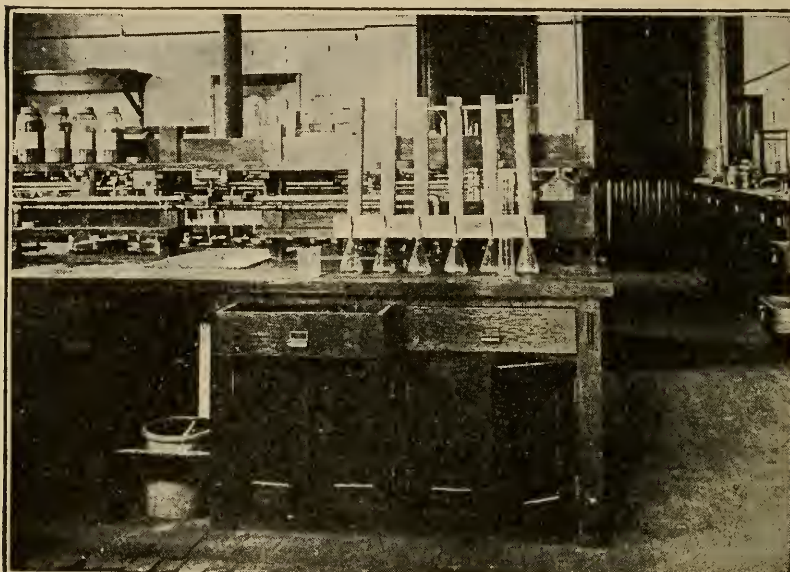

Plate 15

STUDENTS' LABORATORY DESK

The illustration shows one end of a desk used in the Soil Physics Laboratory at the Iowa State College. The desks are thirty-three inches high, sixty inches long from the end to the center of the sink, and have a total width of fifty-six inches. Students work on both sides of these desks.

The space from the end of the desk to the center of the sink is provided with two sets of drawers and lockers. This arrangement enables the class to work in two sections; the student in each section has a drawer and locker in which to store and lock up his apparatus and has five feet of desk room during his laboratory period.

The desks are supplied with sinks, gas cocks and water cocks as shown. All of the plumbing is exposed and thus is easily kept in repair. The lower shelf is five inches wide and is five inches above the desk. The upper shelf is six inches wide and is fifteen and one-half inches above the desk.

APPENDIX

Laboratory Notes

Each student should keep a careful record of his laboratory work in a well-bound notebook. This book should always be at hand during the progress of an experiment and all data should be recorded promptly. It is never safe to record weights or data of any kind on loose sheets of paper. They are too often lost.

The outlines for the tabulation of data which are printed in the guide are for the direction of the student. No figures should be entered in the guide but the data should be recorded in the notebook as indicated in the outlines.

The student should study each exercise carefully, before beginning work, in order to obtain a clear understanding of the nature of the exercise, the directions to be followed and the data to be secured. All of the experiments should be done in duplicate.

The laboratory directions should not be copied into the notebook but all of the data should be recorded in tabular form and a brief, concise statement should be made covering the following points:

1—The object of the experiment.
2—The materials used.
3—The apparatus employed.
4—The manner of conducting the experiment.
5—The facts noted during the progress of the experiment.
6—The conclusions which are drawn, and finally suggestions regarding any changes in the experiment.

With nearly every experiment, questions are asked; the answers to these questions should be given in full in the notebook. The student should refer to authorities on Soil Physics as an aid in answering some of the questions and his statements should embody a complete, comprehensive answer.

Each experiment should be written up at the time it is performed. Confusion and loss of time inevitably follow an effort to write up several experiments which have been worked out but only the weights or measurements recorded.

The notebook should be kept in a neat and orderly way and should always be ready for examination by the instructor. The student should never fail to correct the errors which are marked by the instructor, and it is far better to perform a limited number of experiments correctly than to pass over a large number in a slip-shod manner.

Precautions to Be Used in Weighing

The following directions for weighing are taken from the laboratory notes used in Johns Hopkins University:

1—Sit directly in front of the center of the balance so as to avoid parallax while observing the movements of the pointer.

2—See that the balance is level.

3—Release and arrest the beam with a slow and steady movement of the hand. Jerky movements are sure to injure the knife edges. The beam should be arrested only when it is in a horizontal position.

4—Avoid giving to the pans any rotary motion in a horizontal direction and all other movements which would cause a knife edge to scrape on its bearing.

5—Release the pans before releasing the beam.

6—Arrest the beam and pans before placing anything upon or removing anything from the latter.

7—Place the object to be weighed and the larger weights in the middle of the pans.

8—See that the rider is not so near the beam as to be hit by it while swinging.

9—All weighings should be made with the balance case closed.

10—If the beam does not begin to swing as soon as it is released, set it in motion by wafting the air over one of the pans with the hand or by raising and releasing it again.

11—Hot objects cannot be correctly weighed, owing to the upward draughts which they create about the pans on which they rest. They may also, through their heating effects upon the beam, produce a change in the relative lengths of the arms.

12—Hygroscopic and volatile substances, also those which absorb carbon dioxide from the air, must be weighed in closed vessels. If the vessels have been tightly closed while hot, there may be diminished pressure within, in which case they must be opened for a moment before weighing.

13—All substances which are exposed to the air condense moisture on their surface to an extent which sensibly affects their weight. The amount of moisture thus condensed varies with the humidity of the atmosphere; hence a substance which is transferred from a desiccator to the balance pan will gain weight for a time, while one which is brought from a damper atmosphere than that within the balance case will lose weight. By keeping drying reagents in the case, it is endeavored to maintain a fairly uniform condition of humidity, and thus to reduce the errors from this source to a minimum. Powdered substances which have been dried in a hot bath, or in a desiccator, should be weighed in closed vessels; since, owing to the great surface which they present to the air, they condense large amounts of moisture. In all cases, it is necessary to be sure that the object which is being weighed has ceased to gain or lose weight before taking the final reading.

14—An object which, like glass, is likely to become electrified by friction, should not be wiped or brushed immediately before weighing. Glass and quartz weights often become strongly electrified when lifted out of their places in the box in which they are kept.

15—Long tubes and other objects not easily centered on the pans should be suspended from the hooks above the pans.

Weights and Measures, with Equivalents

Metric

Meter (Unit of Length)	Millimeter (mm.)	= 0.001 meter
	Centimeter (cm.)	= 0.01 meter
	Kilometer	= 1000 meters
	Micron	= 0.001 millimeter
Gram (Unit of Weight)	Milligram (mg.)	= 0.001 gram
	Kilogram (kilo)	= 1000 grams
Liter (Unit of Capacity)	Cubic Centimeter	= 0.001 liter

1 millimeter	=	0.03937 (or 1-25 approx.) inch 1000 microns
1 centimeter	=	0.3937 (or 2-5 approx.) inch 0.0328 foot
1 meter	=	39.37 inches 3.28 feet
1 micron	=	1-25000 inch 0.001 millimeter

1 gram	=	0.035 ounce 0.0022 pound	Avoir.
1 kilogram	=	35.27 ounces 2.2 pounds	Avoir.
1 liter	=	1.056 (or 1 approx.) quart 61.02 cu. inches 1000 cu. centimeters	

1 sq. millimeter	=	0.00155	sq. inches
1 sq. centimeter	=	0.1550	sq. inches
1 sq. meter	=	1550	sq. inches
1 sq. meter	=	10.76 sq. ft.	
1 cu. millimeter	=	0.00006	cu. inch
1 cu. centimeter	=	0.0610	cu. inch
1 cu. centimeter	=	0.001 liter	
1 cu. meter	=	35.32 cu. feet 61025.4 cu. inches	
1 inch	=	25.399 millimeters	
1 sq. inch	=	6.451 sq. centimeters	
1 cu. inch	=	16.387 cu. centimeters	
1 foot	=	30.48 centimeters	
1 sq. foot	=	0.093 sq. meter	
1 cu. foot	=	0.028 cu. meter	

AVOIRDUPOIS WEIGHT

1 pound	=	16 ounces	
1 ounce	=	28.35 (or approx. 30)	grams
1 pound	=	453.59 (approx. 500)	grams

FORMULAE, ETC.

A cubic foot of water weighs 62.42 pounds

TEMPERATURE: Centigrade degree = 0.555 (Fahr.–32°);
$95°$ F. = 0.555 (95°–32) = 34.97° C.
Fahrenheit degree = 1.8 x Cent. + 32°
80° C. = 1.8 x 80 + 32 = 176° F.

Area of circle = πr^2, where r = radius. $\pi = 3.1416$

Circumference of circle = $2\pi r$

$$\text{Radius} = \frac{\text{Circumference}}{2\pi}$$

Area of cylinder = $2\pi r\, h$; where r = radius of cross section, and h = hight or length

Volume of cylinder = $\pi r^2 h$

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