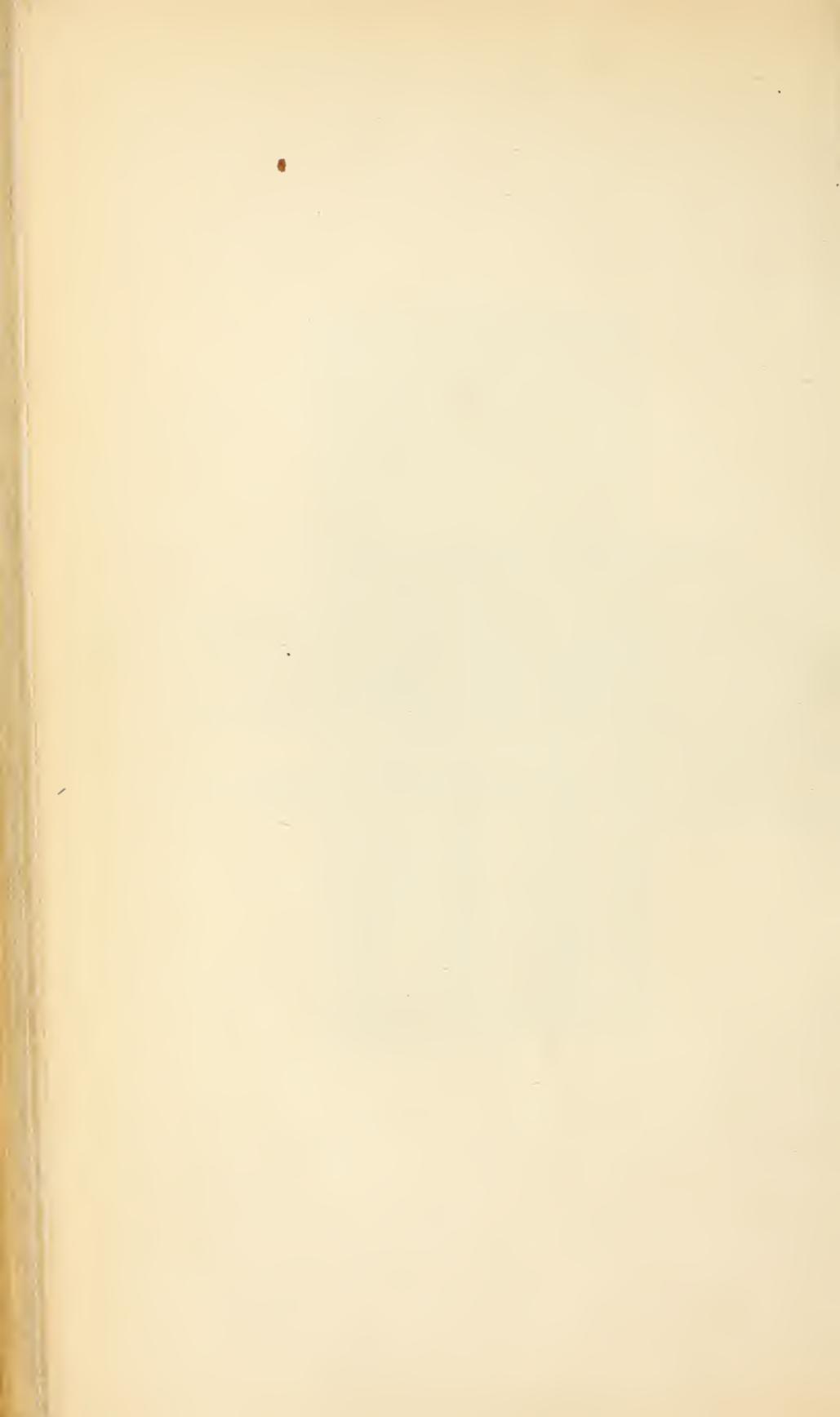




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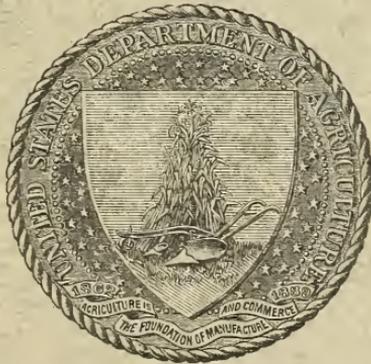
AN ELECTRICAL METHOD

OF

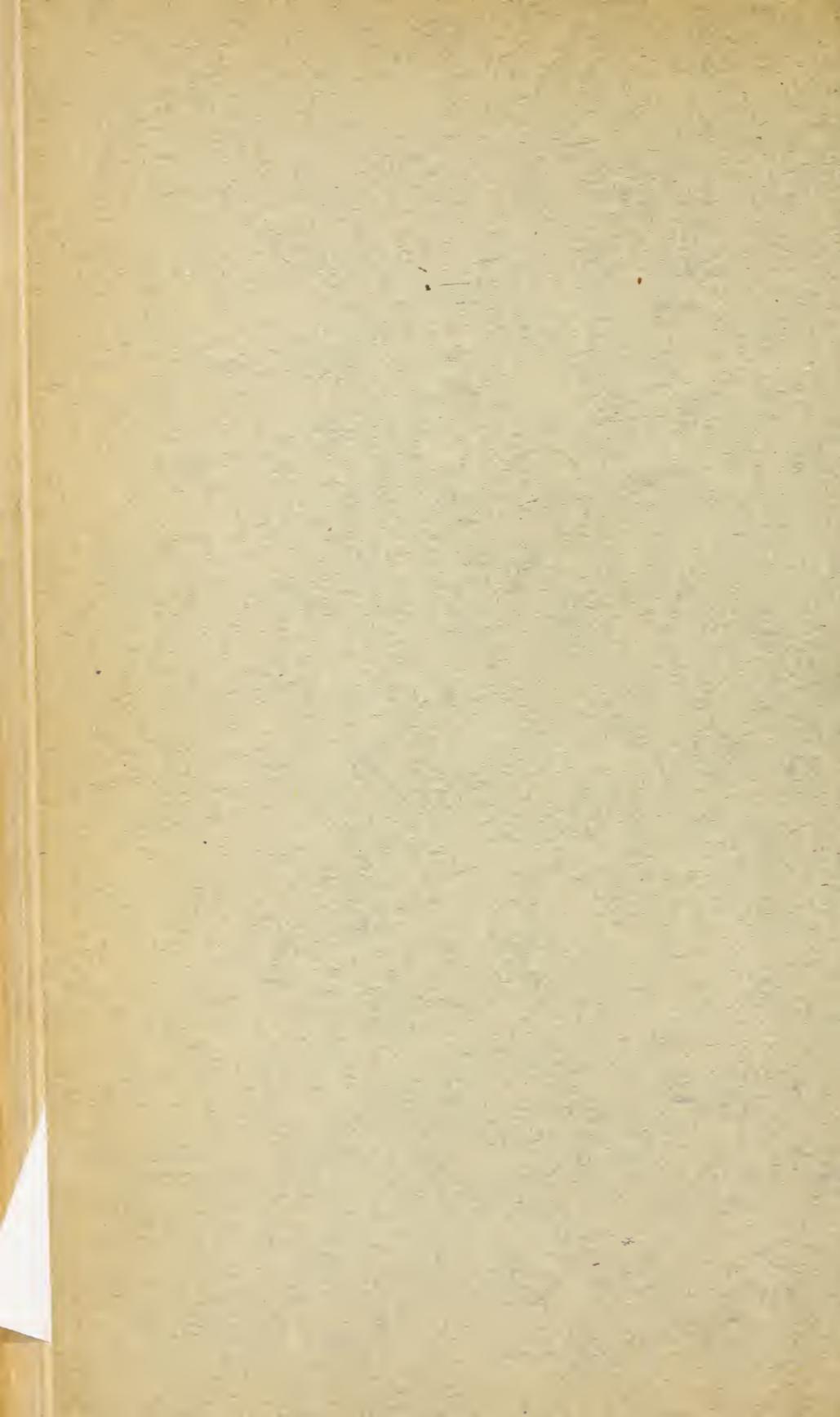
DETERMINING THE MOISTURE CONTENT
OF ARABLE SOILS.

BY

MILTON WHITNEY, FRANK D. GARDNER, AND LYMAN J. BRIGGS.



WASHINGTON:
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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,

Washington, D. C., March 11, 1897.

SIR: I have the honor to transmit herewith a description of an electrical method of determining the moisture content of arable soils. This is the first of a series of three bulletins descriptive of methods of soil investigation. They are necessarily technical, and are intended mainly for those interested in the development of soil investigation.

I recommend that this be published as Bulletin No. 6 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

TABLE OF CONTENTS.

	Page
Introduction.....	5
Solubility of soils.....	7
The nature and electrical properties of solutions.....	9
Table of the specific resistance and molecular conductivity of salt solutions of different strength.....	10
The bridge box for measuring soil resistances.....	11
Temperature-compensating cells.....	14
Soil electrodes.....	14
Mode of burying electrodes in the soil.....	16
Connections and use of bridge box in field work.....	17
Standardization of field electrodes.....	20
Table of the electrical resistance of a limestone soil from Lexington, Ky..	22
Table of reciprocals for calculating the conductivity of soils.....	25

ILLUSTRATIONS.

	Page.
FIG. 1. Bridge box employed in measuring the resistance of soils	12
2. Interior of bridge box	13
3. Soil electrodes	15
4. Surface electrodes	16
5. Switch box arranged for six sets of electrodes	20
6. Field records of limestone soil near Lexington, Ky	26

AN ELECTRICAL METHOD OF DETERMINING THE MOISTURE CONTENT OF ARABLE SOILS.

INTRODUCTION.

For a long time the importance of having a reliable and convenient method for determining the amount of moisture in soils has been recognized. It has been pointed out a number of times that the rain does the plant little positive good until it enters the soil, where it can be absorbed by their roots. The rainfall record furthermore does not necessarily indicate the character of the season, for an abundant rainfall poorly distributed may give a very poor growing season, while a small rainfall properly distributed may give an exceedingly favorable season. A record of the actual amount of water in the soil from day to day would, on the other hand, give the absolute value of the moisture conditions under which plants are growing, and even without reference to the rainfall data it would show, if the character of the soil was understood, whether the conditions were favorable or otherwise for the crop.

All crops do not need the same amount of water, but, on the contrary, different classes of crops and different agricultural interests require very different conditions as regards moisture.

The geographic and geologic features of a country, especially the location of large bodies of water, the elevation and direction of mountains, and the prevailing winds determine to a great extent the climate and particularly the rainfall of a country. As a result of this there are large areas which, by reason of their position, have a high rainfall or which are deficient in this respect.

While these physiographic conditions control the general climatic conditions of a locality they are not the only conditions which control the moisture supply of plants, for if the soil of these large areas were perfectly uniform there would be a monotonous uniformity in the character of the crops which could be economically produced. Fortunately there is a great variety of soil conditions. Soils differ very markedly in their texture and physical properties, so that even with the same amount of rain falling on adjacent fields the texture of the soil of one field may be so open and porous as to let most of the rainfall descend rapidly, while the soil of the other field may be so close and retentive as to hold a very much larger volume of water at the disposal of crops. There are thus in these different kinds of soils conditions suited to different classes of plants, and by taking advantage of them and adapting our crops and methods to these natural conditions we have that

opportunity for a great diversity of crops and agricultural interests which gives strength and independence to an agricultural community.

It is necessary therefore for the most perfect development of the agricultural possibilities of any soil that we should be able to determine the moisture content of the soil in order that we may select the crops best suited to the existing natural conditions, or that we may be able to control these conditions to a certain extent through methods of cultivation, fertilization, and irrigation.

In greenhouse culture the florist maintains very different conditions of both moisture and temperature for lettuce, tomatoes, violets, carnations, and even for the different varieties of roses; so different, indeed, are the conditions adapted to these several crops that he must have separate houses in order that the conditions may be properly controlled. It is an exceedingly valuable thing to realize that in nature we have just as different conditions in soils of different texture and that it is only through an appreciation of this that the highest development of any community may be assured.

The only method of determining the moisture content of soils in general use is the very simple one of taking a sample of the soil from the field at any desired depth and drying it at the ordinary temperature of the air or at the temperature of 100° to 110° C. This method, as used by this Division, has been described in Bulletin No. 4. The method is neither convenient nor accurate. From long experience we have found that, owing principally to the inequalities in the field and to the difficulty of taking representative samples, the method is not reliable for a single determination to within 2 per cent above or below the actual amount determined by twenty or thirty duplicate observations; that is, for any single determination there is a plus or minus error of 2 per cent apparently irrespective of the amount of water present. This is from 7 to 30 per cent of the actual amount of water usually present in soils, so that the results of single determinations are not accurate to within 16 per cent on the average of the actual amount of water in the soil.

Various other methods have been proposed for the determination of the amount of moisture in soils, but with very slight success. It is desirable, of course, on account of the inequalities of the soil, to have a method which will determine the variation in the amount of moisture at a particular place and depth in the field. Several methods were tried at the New York Experiment Station and described at length in the annual report for 1886. Bricks were buried about 8 inches deep in the soil and taken up from day to day and weighed. This method, besides being very inconvenient, was found to be entirely unreliable. The bricks were not able to absorb more than half as much water as the soil would contain. Porous terra cotta was then tried, but while it was found that this would absorb quite as much water as the soil it would not give it up readily after being saturated by rains. Finally a

method was devised which, with some modifications, has been used at other places. A graduated tube is let down into the soil for a few inches, and water is allowed to flow out through a small opening either directly into the soil or into a piece of porous tile. It is assumed that more water will leave the graduated tube in a dry soil than in a wet one, and the quantity which flows out in a certain time will bear some proportion to the amount of water contained in the soil. This method has never yet proven entirely satisfactory or reliable.

The possibility of using the electrical resistance of soils for the determination of moisture, which forms the subject of the present bulletin, was suggested some years ago by the necessity of thoroughly grounding lightning rods, telephones, and telegraph lines. If these are not carried to a considerable depth so that the terminals are constantly in a moist soil, the lines do not work in dry seasons, since the current can not readily pass off when the soil around the terminals becomes dry. Such a method seemed particularly desirable, for if it could be perfected electrodes could be permanently buried in the soil, to remain undisturbed during the entire season, and by measuring the resistance to the passage of a current through the soil the amount of moisture in the soil could be determined. This suggestion was taken up about ten or twelve years ago, and has been worked on as opportunity permitted until the present time. The investigations were thus started before the modern conceptions of the nature and principles of salt solutions and of electrical conductivity had been developed. Much of the data obtained, therefore, was entirely inexplicable at that time, and it is only in the light of modern investigations in the field of physical chemistry that it has been possible to carry the work to a successful termination.

At present we look upon the soil as a difficultly soluble compound, and upon the soil moisture as a salt solution derived therefrom. By treating the moisture from the standpoint of a solution and following the modern ideas of physical chemistry on the nature of salt solutions an entirely new conception is thrown upon the nature of soils and several new lines of investigation are pointed out.

SOLUBILITY OF SOILS.

Soils are composed of fragments of various minerals and salts, each more or less soluble in water. Even the quartz grains are slightly soluble, especially in water containing carbonic acid, as the soil waters usually do. The solution of solids is quite analogous to the evaporation of liquids. In the presence of water the different minerals and salts constituting the soil throw off molecules of their substance into the liquid. Many of these molecules in moving through the liquid fall again upon the surface of similar undissolved matters and are thus withdrawn from solution. When the number of molecules thrown out

from the solid is exactly equal to the number which fall on the solid from the solution a neutral condition is maintained which is called saturation.

In the case of a mixture of different minerals and salts, as in the soil, the solubility of each is nearly independent of the presence of the others. The actual amount of each one of these mineral substances which can be dissolved before a condition of saturation is reached depends upon the solution pressure on the surface separating the mineral from the solvent, just as the evaporation of the solution depends upon the vapor pressure at the surface of the liquid. A saturated solution of some minerals and salts therefore may contain a large weight of the substance, while with other difficultly soluble compounds the saturated solution contains only a minute quantity of the solid. It is easy to see, therefore, that a saturated solution of silica or of other difficultly soluble minerals in the soil may be formed when water is added to the soil, while the actual amount of mineral in solution is extremely small.

The solubility of minerals and salts and the saturation coefficient, like the evaporation of liquids, is dependent upon the temperature, the rate and extent of diffusion, and upon some other conditions of which we know comparatively little. It follows, therefore, that the concentration of the soil moisture can not be a very constant quantity nor a very simple thing. When a certain amount of pure water is mixed with a soil all the constituents of the soil are dissolved to a greater or lesser extent. Of the readily soluble minerals and salts, possibly all which come in contact with the liquid are dissolved, and so far as they are concerned the solution is still far from saturation. With the more difficultly soluble compounds, however, the slight amount of substance actually dissolved really forms a saturated solution. Slight changes in temperature will disturb the balance and cause more of the compounds to go either into or out of solution.

It is apparent that when more water is introduced into the soil the salt solution will be diluted, the solution pressure will be diminished, and more of the solid substances will be dissolved until the concentration again increases and the solution pressure is again equal to the pressure on the surface of the solid. On the contrary, when water is withdrawn from the soil through evaporation or transpiration through plants, the concentration of the solution is increased and a portion of the difficultly soluble salts will be thrown out of solution on the solid again until an equilibrium in pressure is attained. We should thus expect that the concentration of the soil moisture as well as the actual amount of salt in the soil will vary constantly with every change in the conditions affecting the solubility of such difficultly soluble compounds.

THE NATURE AND ELECTRICAL PROPERTIES OF SOLUTIONS.

For the purpose of the present investigation the soil is considered as a difficultly soluble compound, and it will be studied through the salt

solutions in accordance with the nature and electrical properties of solutions as developed in the recent work in physical chemistry.

The present theory of the nature and electrical properties of solutions as they bear upon the soil investigations may be briefly stated. When common salt is dissolved in water the salt undergoes a partial dissociation—that is, a portion of the molecules in solution are broken down into part molecules, or ions, so that the solution will contain sodium ions, and chlorine ions, besides a number of sodium chloride molecules. These ions carry enormous charges of electricity, and it is upon these ions that the electric conductivity of solutions depends. The more dilute the solution the greater the proportion of dissociation of the molecules until the solution contains one gram equivalent of salt (i. e., a weight of the substance in grams numerically equal to its molecular weight) in a thousand liters of water or a thousandth normal ($n/1,000$) salt solution, when the dissociation is practically complete. Solutions of most of our common salts of the same molecular concentration, for example, a tenth normal ($n/10$) sodium chloride solution and a tenth normal ($n/10$) potassium nitrate solution containing an equal number of chemical equivalents per cubic centimeter have nearly the same specific electrical resistance and conductivity.

The specific resistance of a solution is a resistance of one cubic centimeter of the liquid between parallel electrodes each having an area of one square centimeter placed one centimeter apart. The specific conductivity as used in this bulletin is the reciprocal of the specific resistance. For example, the specific resistance of a $n/10$ sodium chloride solution is about one hundred ohms at 24° C. The specific conductivity, therefore, would be 0.01 of a unit of conductivity at this temperature. The unit of conductivity is the reciprocal of the ohm. It has no specific name. The conductivity of a solution depends directly upon the dissociated molecules or ions present; the undissociated molecules are inert and play no part whatever in the electrical conductivity.

Since solutions of like molecular concentration have the same number of chemical equivalents, and since these chemical equivalents carry equal electrical charges, all simple salt solutions of the same molecular concentration and temperature would have the same conductivity, except that the degree of dissociation is not exactly the same and that the ions themselves have somewhat different velocities. A solution of one-half the concentration of another contains one-half as many molecules, but rather more than half as many ions because of the greater dissociation in the dilute solution. The specific conductivity of such a solution would therefore be a little more than half of the first solution.

The following table¹ shows the variation in the specific electrical resistance, the molecular conductivity, and the extent of dissociation of a number of the salts commonly found in the soil or applied to it as fertilizers in solutions of equal molecular concentration at a uniform temperature of 18° C.

¹ Compiled from the work of F. Kohlrausch.

The specific resistance and molecular conductivity of salt solutions of different strength.

Molecu- lar volu- me.	Specific resist- ance.	Molecu- lar con- duc- tivity.	Salt dissoci- ated.	Salt not dissoci- ated.	Molecu- lar volu- me.	Specific resist- ance.	Molecu- lar con- duc- tivity.	Salt dissoci- ated.	Salt not dissoci- ated.
NaCl					KCl				
1,000	9,338	107.1	100.0	0.0	1,000	7,889	126.8	100.0	0.0
100	978	102.3	95.5	4.5	100	821	121.9	96.1	3.9
10	109	91.9	85.8	14.2	10	88	111.3	87.7	12.3
1	13.5	73.9	69.0	31.0	1	10.2	97.7	77.0	23.0
NaNO ₃					KNO ₃				
1,000	9,876	101.3	100.0	0.0	1,000	7,970	125.5	100.0	0.0
100	1,037	96.4	95.2	4.8	100	838	119.3	95.1	4.9
10	115	86.8	85.7	14.3	10	96	104.5	83.3	16.7
1	15	65.6	64.8	35.2	1	12.5	79.9	63.7	36.3
$\frac{1}{2}$ Na ₂ CO ₃					$\frac{1}{2}$ K ₂ CO ₃				
1,000	9,984	110.2	100.0	0.0	1,000	7,680	129.8	100.0	0.0
100	1,047	95.5	86.7	13.3	100	869	115.1	88.7	11.3
10	138	72.5	65.8	34.2	10	107	93.4	71.9	28.1
1	22	45.4	41.2	58.8	1	15.2	66.0	50.8	49.2
$\frac{1}{3}$ H ₃ PO ₄					$\frac{1}{3}$ K ₂ SO ₄				
1,000	9,701	102.9	100.0	0.0	1,000	7,795	128.3	100.0	0.0
100	1,190	84.0	81.7	18.3	100	857	116.7	91.0	9.0
10	219	45.7	44.4	55.6	10	105	95.0	74.4	25.6
1	47.1	21.3	20.7	79.3	1	14	71.0	55.7	44.3

The molecular volume of the first column expresses the concentration of the solution. A molecular volume of ten indicates that the solution contains an amount of salt expressed in grams numerically equivalent to the molecular weight, dissolved and diluted to ten liters, thus making a tenth normal ($n/10$) solution. The molecular conductivity is the conductivity of a quantity of the solution containing one gram molecule, placed between parallel electrodes one centimeter apart. The molecular conductivities, as given in the table, are multiplied by one thousand. In order, therefore, to obtain the real values, the decimal point will have to be moved three places to the left. The last two columns of the table show the percentage of dissociated and undissociated salts in the solutions, assuming that in a solution of $n/1,000$ the dissociation is complete.

It will be noticed that the sodium and potassium carbonates and potassium sulphates have twice the conductivity of the other salts, while phosphoric acid has three times the conductivity. This is because one of the ions formed by the dissociation of these salts carries two or three times as great an electric load as the others.

Temperature plays an important part in the conductivity of a solution, for between certain limits of temperature the resistance decreases or the conductivity increases as the temperature rises. This is due to the influence of temperature on the dissociation and on the frictional

resistance which the fluid offers to the passage of an ion through it. As the dilution increases and the dissociation becomes more nearly complete the effect of the temperature on the dissociation becomes less and less, and finally vanishes when the dissociation is complete.

There are, therefore, three principal factors which influence the electrical conductivity of soils, and which as a rule are constantly changing, namely, the temperature, the water, and the soluble salt; in other words, the amount and concentration of the salt solution and the temperature. Therefore, to determine the temperature of the soil, the water content, or the amount of salt dissolved in the water, it is necessary to know two of these three values at the time of observation in order to establish the other.

Advantage was taken of the influence of temperature on the resistance of solutions to construct a temperature cell, which is essentially a salt solution inclosed in a hermetically sealed glass tube, in which neither the salt nor the water can change. The solution used has the same temperature coefficient as the soil, so that the variation in the electrical resistance of this cell when buried in the soil will give the temperature of the soil; or, if it is used as one arm of the Wheatstone bridge in place of one of the standard comparison coils, it will eliminate the temperature effect altogether in measuring the electrical resistance of the soil. The same cell, therefore, will thus answer a double purpose.

THE BRIDGE BOX FOR MEASURING SOIL RESISTANCES.

For the measurement of the electrical resistance of the soil the Wheatstone bridge method is used with the alternating current and a telephone to indicate when a balance has been obtained. For the measurement of resistances in the field it is necessary to have an instrument sufficiently accurate, and yet with a very wide range. It must at the same time be portable, substantial, compact, and light. The instrument illustrated in figs. 1 and 2 is the outcome of long experience in both the field and laboratory.

The box is of half-inch maple, 13 inches long, 11 inches wide, and $4\frac{1}{2}$ inches in height. When closed, as represented in the figure, the working parts are protected from dust and injury. The only part exposed is the current interrupter or "make-and-break" apparatus of the induction coil, which must be exposed for convenience in adjustment. This is seen in a recess on the right-hand side of the box. To the right of the recess are placed the two binding posts for battery connections, with the battery switch beneath. The connections for the telephone are on the opposite side.

The bridge consists essentially of a rheostat, comparison coils, induction coil, and a watch receiver telephone, with suitable electrical connections. One arm of the bridge contains a 1,000-ohm comparison coil, a second arm contains a 900-ohm coil and a 100-ohm coil connected in series, while the third arm contains the rheostat.

The rheostat contains 102 10-ohm coils, each coil separately adjusted and soldered to suitable contact studs arranged in two concentric circles, with an arm to make contact with successive points. These contacts are mounted for insulation in a hard rubber plate, and must be accurately spaced and so adjusted that contact is made or broken within $\frac{1}{10}$ of a division on the scale on either side of a middle point between the scale divisions. The sliding contact, consisting of two shoes formed of spring brass, must work freely and without noise, making perfect contact with every point. Contact is made with one point before it is broken with another, so that the circuit is not interrupted. The two extra 10-ohm coils are added for convenience in measuring resistances near the 1,000-ohm, or zero, point on the scale.

By means of the switch represented in the left-hand corner of the closed box, four 1,000-ohm coils can be successively connected in series with the rheostat, so that the total resistance can be varied from 0 to 5,020 ohms. This switch when standing at the upper 0 or to the right

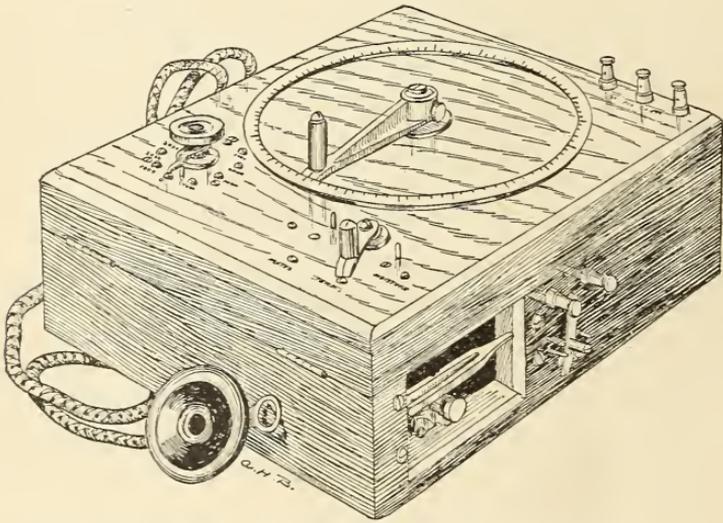


FIG. 1.—Bridge box employed in measuring the resistance of soils.

of it short circuits the 900-ohm coil in the second arm of the bridge, which changes the ratio of the bridge arms to 1 to 10, and thus increases the range of the box tenfold.

The resistance to be measured is attached by means of lead wires to the binding posts marked "Plates." The temperature cell between the electrodes is attached to the posts marked "Cell," one binding post being used in common. When the switch in the right-hand corner of the box stands at "Temperature" the temperature cell is thrown in as the unknown resistance for the purpose of taking the temperature of the soil. When it stands at "Plates" the soil electrodes are thrown in so that the resistance of the soil itself forms the fourth arm or unknown resistance of the bridge. When the switch stands at "Moisture" the

soil remains as the unknown resistance, while the 1,000-ohm comparison coil is thrown out and the temperature cell is substituted for it as one arm of the bridge in order that temperature effects shall be eliminated.

The two switches described are formed of brass segments, insulated on hard rubber, with movable arms suitably connecting these segments. All switch connections and contacts are made inside the box, which is dust proof. All the comparison coils are wound accurately to within one-tenth of 1 per cent. The 10-ohm resistance coils are wound in a single layer to diminish capacity and self-induction and must not be out more than 1 ohm between 0 and 1,000.

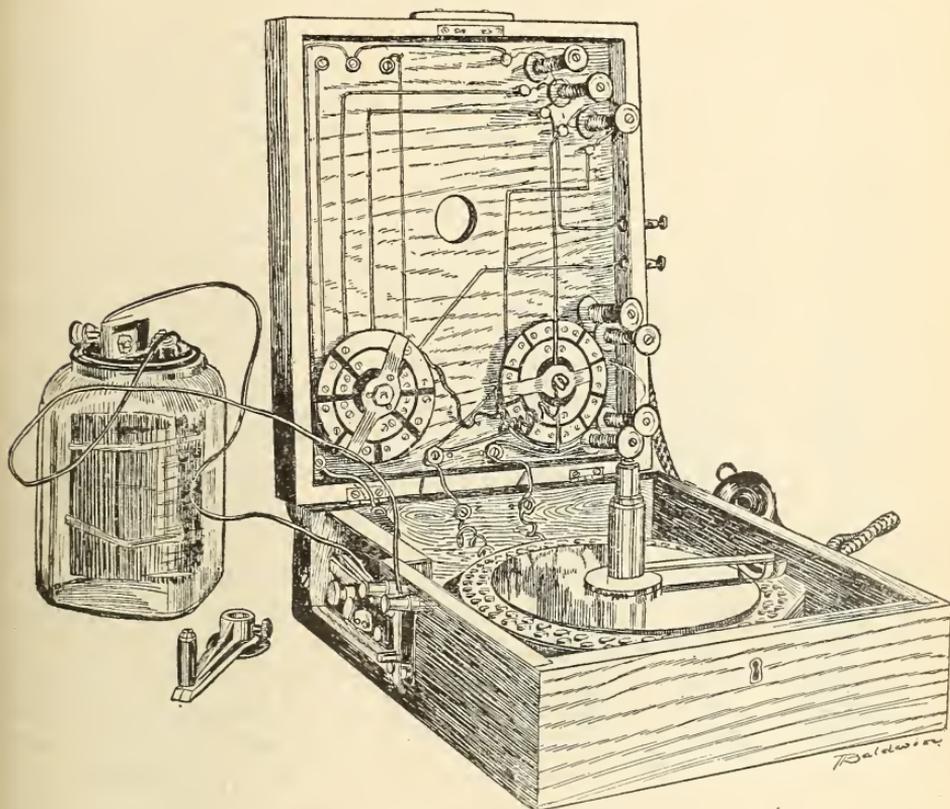


FIG. 2.—Interior of bridge box.

The induction coil is small, since little current is desired and that of rather low potential. The vibrator or contact breaker consists of a small tuning fork or single reed, driven by means of the induction coil, giving not less than 400 vibrations per second. One prong of the fork passes in front of the induction coil core, about one-sixteenth of an inch distant, and carries a very flexible spring of phosphor bronze tipped at its free end with platinum. A set screw rigidly attached to the base of the induction coil makes contact with the spring. The induction coil must be capable of giving a clear, musical note in the telephone, of high pitch and free from rasping or grating sounds.

The contact arm in the rheostat is connected to a handle and pointer on the top of the box. This pointer works over a scale graduated to 10 ohms. By removing the pointer the cover of the box can be lifted for the purpose of cleaning the contacts.

A good watch receiver telephone, inclosed in a hard rubber case with as little metal exposed as possible, is provided with each instrument, with a flexible cord for electrical connection with the binding posts. The box is shown open in fig. 2 to give an idea of the arrangement of the interior.

TEMPERATURE-COMPENSATING CELLS.

As the electrical resistance of a salt solution is influenced by the temperature, it is necessary to know the exact temperature of the layer of soil in which the resistance is to be taken and to correct the resistances accordingly, or that a method be devised by which this temperature influence may be eliminated in taking the resistance. Numerous objections have been urged against thermometers for determining the temperature of the soil at different depths, and, besides, the use of thermometers would have necessitated the correction of all resistances so as to reduce them to a uniform temperature. A much more convenient method has been devised for eliminating the temperature effect, based upon the influence of temperature on the electrical resistance of an electrolyte. This method as used to determine the temperature of soils will be more fully described in Bulletin No. 7 of this Division. For use in the method of moisture determination it is unnecessary to standardize the cells, although it is advisable of course to determine the temperature as well as the moisture of soils.

The compensating cell as it is used in this method for eliminating the temperature effects on the electrical resistance of the soil consists of a small glass tube, about 3.5 millimeters in internal diameter, with platinum electrodes fused into each end, the cell being nearly filled with a salt solution. The electrodes are made of No. 25 platinum wire twisted at one end into flat spirals which are parallel to each other in the cell and are 3 inches apart. The spiral should be plated with a good coat of platinum black to make the minimum in the telephone sharper. The salt solution consists of 90 per cent of four-fifths normal sodium chloride solution and 10 per cent commercial alcohol. This has approximately the same temperature coefficient as the soil. Lead wires are soldered to the ends of the platinum electrodes.

The method of determining the temperature coefficient of soils and the standardization and calibration of these cells for use in determining the temperature of soils will be given in Bulletin No. 7.

SOIL ELECTRODES.

The electrodes finally adopted for field work consist of carbon plates, each 3 inches long, three-eighths of an inch wide, and three-sixteenths of

an inch thick. Each electrode is copper plated on one end, and an insulated No. 20 copper wire soldered to the plating of a length sufficient to reach above the surface of the ground to the measuring instrument. The carbon strips after being electroplated and having the wires attached are soaked for some time in distilled water to remove any salts or acids which may have accumulated during the plating and soldering. Two of these electrodes with wires attached are then mounted on the face of a wedge-shaped wooden block, which is made in two pieces and fitted together by means of a tongue and groove. These blocks when put together are 6 inches long, $1\frac{1}{4}$ inches wide, and seven-eighths of an inch thick. The back is slightly curved, while the front is flat with a groove in the center for the temperature cell. Before use the blocks should be painted with a heavy coat of asphalt varnish. The electrodes are cemented to the block on either side of the temperature cell by means of marine glue.

One of the carbon electrodes must have been previously electroplated at the bottom end also, and to this the bottom platinum wire of the temperature cell is soldered. The upper electrode of the cell is soldered to a copper wire similar in insulation and as long as those fastened to the carbons. The wires should be fastened to the block by small staples, so that in handling they will be less

liable to be broken from their soldered connections. The soldered parts and exposed wire of the temperature cell, together with all of the copper plating, must be insulated by covering with sealing wax, so that there will be no current through the soil except by way of the carbon electrodes. When mounted the edges of the carbons are filed down even with the block and their faces slightly rounded so as to nearly fit the curvature of a $1\frac{1}{2}$ -inch hole. The wire leading from the temperature cell should have the number of the cell permanently attached, preferably on a piece of metal. The depth to which each set is to go will determine the length of the lead wires. Fig. 3 shows a set of these electrodes mounted and one of the blocks taken apart. The insulation is left off the electrodes to show more clearly the connections.

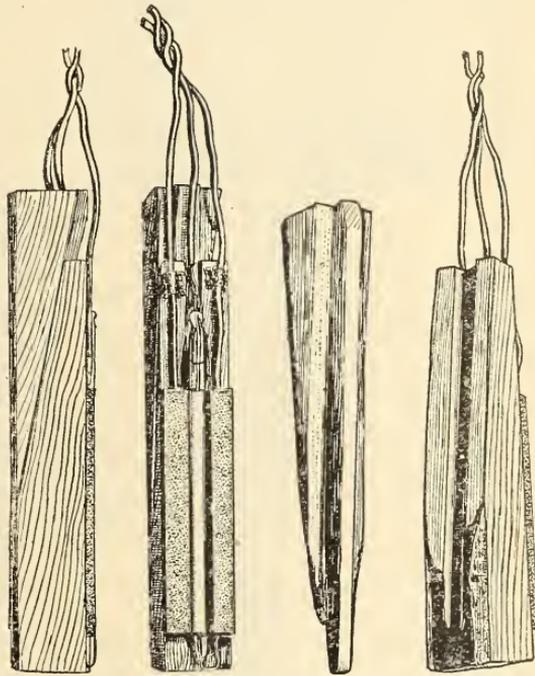


FIG. 3.—Soil electrodes.

The surface of the ground, being exposed directly to climatic changes, is subject to such great and such sudden variations in electrical resistance, as well as to cultural methods, that the surface electrodes have to be considerably modified to suit the conditions for depths less than 3 inches. The top inch of soil is subject to considerable change in level, due to the action of winds, rains, and cultivation, and for most cultivated plants it serves more as a mulch and protection for the lower depths than as a feeding place for the roots of plants. For this reason

it has seemed best to adopt from 1 to 3 inches as the shallowest depth at which to determine the moisture.

The electrodes used for the surface have three or more carbon electrodes instead of two. They are mounted diagonally on a thin piece of board, 3 by 5 inches in dimensions, so that when the ends of the electrodes are cut diagonally across the perpendicular height will be 2 inches. The outside carbons are connected at their lower end by a wire soldered to an electro-plated surface, while the bottom platinum wire of the temperature cell is soldered to the bottom of the middle electrode. Wires are then attached to one of the outside carbons and to the inside carbon, as well as to the upper electrode of the temperature cell. A stake is provided which can be driven into the ground until the top of the board is level with the surface, when the top of the electrodes and the top electrode of the tem-

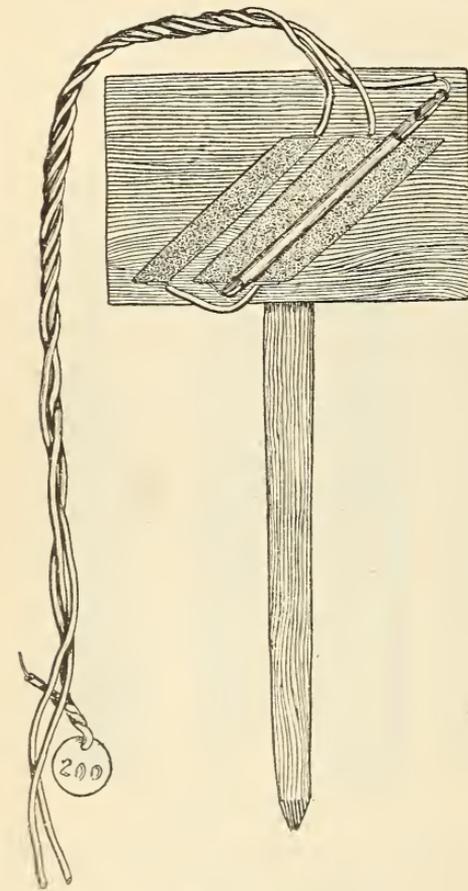


FIG. 4.—Surface electrodes.

perature cell will be 1 inch below the surface. All the wood must be well protected by asphalt varnish. This form of electrode is shown in fig. 4, without the insulation.

MODE OF BURYING ELECTRODES IN THE SOIL.

To bury electrodes for field use an ordinary 1½-inch wood auger is extended to a length of three or more feet and a hole is bored vertically in the soil to a depth to which the lowest set of electrodes is to be placed. A piece of wood or metal 3 feet long and not over an inch in

diameter, with a screw fitted in one end, is used to insert the electrodes into the auger hole. The two parts of the block upon which the electrodes are mounted are held together by a rubber band. The pole is screwed into the top end of the back piece of the block. The depth to which they are to go is then marked off on the wires and the electrodes are carefully lowered into the hole. The wires are then held firmly in one hand while the pole is pressed down with the other. This causes the wedge-shaped back of the block to slide upon the other, and forces the electrodes and the cell close against the side of the hole. By tapping the pole gently with a hammer the electrode may be firmly embedded in the soil, when the pole may be unscrewed from the block and the electrodes left in position with the three lead wires coming to the surface. The wires from each set of electrodes must be permanently marked with the number of the cell and the depth at which they are placed.

Several sets of electrodes may in this way be put at different depths in the same hole, or if they are to be placed close together two holes can be used. When they are all in position the hole is filled with melted pitch to prevent water from accumulating, and at the same time to thoroughly insulate the wooden blocks and wires.

To bury the surface electrodes in the field an excavation is made to a depth of 3 inches, leaving one perpendicular side. The stake is then driven into the ground, so that the carbon plates and temperature cell are close to the perpendicular wall. The loose dirt is then packed firmly around the back of the electrodes. Care must be taken not to disturb these surface electrodes even by stepping on the soil in the immediate vicinity, for this not only changes the structure of the soil and its relation to water, but also brings a greater amount of soil within the area through which the current passes.

CONNECTIONS AND USE OF BRIDGE BOX IN FIELD WORK.

The selection of a site for taking the moisture observations in a soil, together with the treatment which the land should receive, has been fully discussed in Bulletin No. 4 of this Division. Plats should, as a rule, be laid off to insure a sufficient space around the instruments to protect them from injury and in order that the proper conditions may be uniformly maintained over a certain area.

The electrodes should be buried in the center of the plat. The depth at which to place various sets of electrodes depends upon the nature of the investigation. If it is desired to study from a large number of plats the comparative effects of different fertilizers or methods of cultivation on the conservation of soil moisture, the expense, labor, and time necessary for making the observations must be considered. In this case a single depth and a single set of electrodes for each plat will probably be sufficient. When one set of electrodes only is used it

should be placed at a depth corresponding to 3 to 6 inches below the surface. Where only a few plats are to be studied more electrodes should be put in, at 1 to 3 inches, 9 to 12 inches, and 21 to 24 inches. These four depths are those adopted for study by this Division where it is feasible to have so many observations taken.

If the observations are taken on or near the plats, the wires from the electrodes should be brought together to a switchboard for convenience in connecting them with the measuring apparatus. The Western Union form of pin switch is the simplest and cheapest for this purpose. It should consist essentially of three parallel brass bars and three rows of brass disks, mounted on a hard-wood base seven-eighths of an inch thick, and reenforced so that it shall not warp. The wires from the soil electrodes and temperature cells are connected to the disks by means of the nuts at the back of the board. The free electrode should be attached to a disk on the top row. The electrode soldered to the temperature cell should be attached to the middle row, while the wire from the temperature cell should be attached to the bottom row of disks. The number of disks and the length of the bars will depend, of course, upon the number of sets of electrodes to be joined up. The parallel bars are connected by insulated wires to the proper binding posts of the bridge box.

When the plugs are all out of the switchboard there is no connection between the bars and the disks, and no connections, of course, between the buried electrodes and the bridge box. Connections can, however, be made either with the temperature cell to take the temperature of the the soil, or with the electrodes alone, or with the electrodes and the temperature cell thrown in as one arm of the bridge, to eliminate temperature effects.

The apparatus is inclosed in a substantial wooden box with a suitable lock and handle, so that it can be carried or shipped to the field. The switchboard is placed on the inside of the cover and attached by flexible insulated wires to the bridge box and to the wires from the soil electrodes. The telephone is to be connected to the binding posts on the left-hand side of the box, and the battery, consisting of one or two good, dry cells, or preferably of one or two Gonda cells, connected to the binding posts on the right-hand side of the box.

Insert the plugs for the proper connections with the ground and close the battery switch, which should start the vibrator. Place the telephone to the ear, and if the buzzing sound is not heard slightly adjust the set screw in front of the vibrator, and if necessary spring the vibrator a little with the finger in order to set it going. By slightly adjusting the set screw a clear, shrill note can be obtained. Care must be taken not to run the set screw too violently against the spring contact, as it is liable to injure the spring.

The switch at the right-hand corner of the bridge box is placed on the point marked "moisture" or "temperature," as the case may be;

then the left-hand switch is turned, so as to reduce the sound in the telephone as much as possible. Then the arm of the rheostat is moved about the graduated circle until a point is found at which the sound in the telephone is very indistinct. By moving the arm on either side of this point the sound is found to increase, and by quickly moving the arm back and fourth over this point it may be located very exactly. This minimum in the telephone shows when the balance has been attained. The number of thousands of ohms, indicated by the switch on the left-hand side of the box, added to the hundreds of ohms, which the pointer indicates on the circle of the rheostat, gives the resistance in the soil which is desired. When the switch on the left-hand side of the bridge box is on the upper 0 or to the right of it, the ratio of the bridge coils is changed, and the reading of the rheostat must be multiplied by 10.

When the reading for one depth is completed the plugs in the switch board are moved so as to connect the instrument with any other depth desired.

If the note in the telephone is so loud as to interfere with the location of the minimum sound, it can generally be lessened by adjusting the set screw. It is due to too much current, and can be remedied also by introducing resistance into the battery circuit or by reducing the number of cells. When the vibrator refuses to give a clear note in the telephone, the contacts between the set screw and the spring have become fouled and should be carefully cleaned with a piece of fine emery paper. If through long use the platinum tip in the spring of the vibrator which comes in contact with the set screw is worn out, the vibrator should be taken out and a fresh piece of platinum soldered on the tip. At times the handle of the rheostat should be taken off and the top of the box thrown back and the contact studs cleaned with very fine emery. A little attention to these details will greatly facilitate the satisfactory operation of the instrument.

If the bridge box has to be located a considerable distance from the plots, or if plots from widely different localities are to be joined by lead wires to a single place of observation, the wiring will assume large proportions and will be quite an item of expense. In order to reduce the amount of wiring a different form of switch may be used in which the connections with the ground electrodes are made by mercury contacts between platinum tips projecting into hermetically sealed glass tubes. Three of these tubes, corresponding to the three lead wires from each depth, are mounted on a block, which can be tipped up by a suitable arrangement by pulling a wire from the point of observation. Any number of these contacts can thus be made, and this form of switch necessitates only three wires from the switch to the measuring box with one wire or string for making the proper connections. A very simple tumbling switch box, arranged for six sets of electrodes, on these

principles has been constructed in the division, which is illustrated in fig. 5.

STANDARDIZATION OF FIELD ELECTRODES.

It has already been pointed out that the electrical resistance of soils is influenced by the temperature and the soluble salt content as well as by the amount of moisture. The temperature effect can be eliminated by substituting the temperature cell for one of the comparison coils in the bridge. As the salt content of the soil is liable to change during the season, and as there is at present no convenient method for recording

this change in the field, it is necessary to standardize the field electrodes occasionally throughout the season by taking samples of the soil and determining carefully either the amount of moisture or the amount of soluble salt in the sample.

In artificial soils, and where the salt content does not vary, the conductivity of the soil with different percentages of water gives very nearly a straight line—that is, every percentage of water has the same value in increasing or decreasing the conductivity whether the soil is wet or dry. The data for this statement, together with a method of determining the soluble salt content of soil, will be published in another bulletin.

When the electrodes are buried, samples of the soil from at least four or five localities in the immediate vicinity should be taken at the depth corresponding to each

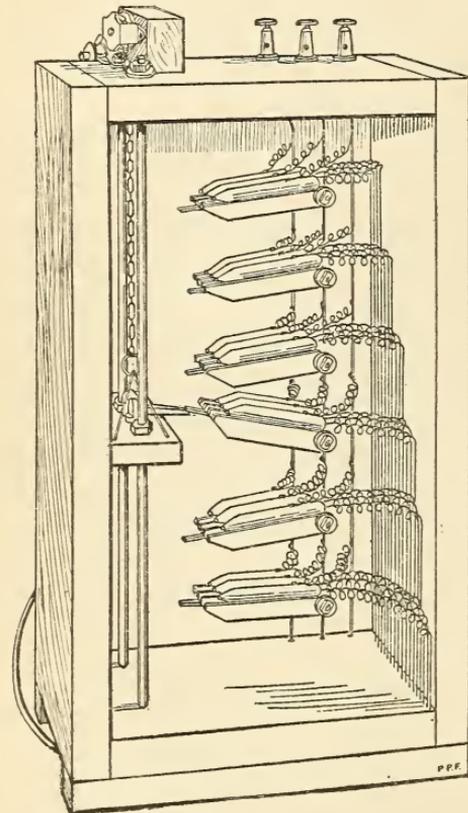


FIG. 5.—Switch box arranged for six sets of electrodes.

of the electrodes. These samples should be taken in brass tubes or by augers, according to circumstances, and put into well-stoppered bottles, well mixed, and then actual moisture determinations made by drying at 110° C. Four or five days later, or when the resistance has changed sufficiently to indicate that there has been an appreciable change of the water content of the soil, another set of samples should be taken in the same way from at least four or five localities quite near the electrodes and at the same depth at which the electrodes are buried. If the soil contained, for example, 11 per cent of water at the

first determination and 7 per cent at the second, the difference in conductivity, divided by the difference in the per cent of water, will give the value in units of conductivity corresponding to 1 per cent of water. This gives a constant which, if divided into the difference between any other conductivity and the conductivity when there was 11 per cent of water present, will show by how many per cent the water has changed, and if this is subtracted from 11 per cent it will give the actual water content at the time of observation. This is expressed in the following simple formula:

$$\frac{C - C_1}{p - p_1} = k$$

$$W = p - \frac{C - C_x}{k}$$

where C = the highest observed conductivity, C_1 = lowest conductivity, C_x = any other conductivity, p = per cent of water corresponding to C , p_1 = per cent of water corresponding to C_1 .

This gives the value of 1 per cent of water in units of conductivity which will be used as a constant, indicated by k in the above formula, until the electrodes are restandardized.

When no abrupt or excessive changes are noticed in the resistance, as in seasons when the weather conditions are uniform or at depths not affected by slight variation in the climatic conditions, the electrodes should be restandardized at least once a month in order that the constant (k) found from the previous standardization may be changed if necessary to meet the changed conditions in the soil.

In the case of the shallow electrodes or of any electrodes which show a marked change in resistance after a rainfall, they should be immediately restandardized, and again four or five days later when the resistance indicates an appreciable change in the soil moisture, so as to get a new value for the constant k . In case only two standardizations are made during the change from one abrupt change to another, the constant thus obtained is used to integrate the readings for the whole of that period.

During the past season seven instruments have been put into the hands of practical farmers in the truck, tobacco, wheat, and grass lands of Connecticut, Pennsylvania, North Carolina, Kentucky, and Tennessee, and four very satisfactory records have been kept, covering periods of from one to three months. The work during the past season was done mainly to test the efficiency and durability of the instruments, and to see if they could be properly worked by the observers of the Division. As a result of this field experience a number of changes have been made in the instrument which are all embodied in the description given in this bulletin.

With so many other things to look after in the perfection of the method and of the apparatus, it was found impossible to properly

standardize the electrodes as should have been done throughout the season.

The following table gives the record for three depths from the limestone soil near Lexington, Ky., from July 9 to October 13, together with the daily rainfall during this period. The asterisks indicate the dates on which these electrodes should have been standardized, judging from the character of the season and the variation in the resistance. This will serve to indicate the extent of variation in the resistance which is likely to occur at the several depths and to show how often restandardization should be made, at least during the preliminary study of any soil. It will probably be found as a result of continued study that the plates will need restandardizing only occasionally during the season, except in the case of very heavy rains or after the application of fertilizers. This is a matter, however, that can only be determined from the results of field experiences covering at least two or three seasons. The resistances given in the table are not the actual resistances of the field record, for the actual resistances were as high as three or four thousand ohms. For the sake of comparison, however, with the different electrodes, and in order to bring the data within such a scale that it can be plotted conveniently, the resistances have all been reduced by a constant, and while they are proportionally the same they are not actually the same as the original records.

The electrical resistance of a limestone soil near Lexington, Ky.

	July—			August—				September—				October—			
	3-6 ins.	21-24 ins.	Rain ins.	1-3 ins.	3-6 ins.	21-24 ins.	Rain ins.	1-3 ins.	3-6 ins.	21-24 ins.	Rain ins.	1-3 ins.	3-6 ins.	21-24 ins.	Rain ins.
1					882	937	0.42	1,538	1,109	1,015		883	513	1,059	
2					650	923	1.47	1,684	1,166	1,044		905	516	1,059	trace.
3					678	923		*460	1,147	1,000	0.33	980	548	1,059	
4					716	926		874	1,166	1,015		1,076	566	1,059	
5					776	941		903	1,166	1,015	0.09	1,133	554	1,059	
6					834	926		1,039	1,160	1,015		*1,209	*611	1,059	0.01
7					713	926	0.57	1,153	1,179	1,015		1,287	631	1,044	
8					716	955		1,230	1,185	1,015		1,363	675	1,044	
9	758	1,115	1.59		955			1,307	1,164	1,030		1,287	631	1,059	
10	*910	*1,042			828	955		*1,422	*1,211	*1,030		1,422	739	1,059	
11	917	1,162	0.18		868	955		1,652	1,223	1,030		1,422	784	1,059	
12	917	1,086	0.07	1,018	917	955		1,786	1,268	1,030		1,307	790	1,059	0.12
13	965	1,042		*903	949	955		1,882	1,299	1,030	0.01	537	707	1,059	0.26
14	1,000	1,102		980	956	955		2,036	1,241	1,030					
15	*1,074	*1,115	0.03	1,192	962	955		1,307	1,261	1,030	0.23				
16	853	1,115	0.62	1,211	962	955	0.07	1,403	1,325	1,030	trace.				
17	949	1,102		1,346	962	985		1,384	1,331	1,030	trace.				
18	1,009	1,026		*1,211	*1,000	985		1,499	1,389	1,030					
19	1,089	1,073		1,307	1,013	1,000		1,786	1,376	1,030	0.02				
20	788		1.25	1,538	1,054	985		1,806	1,459	1,030					
21	757	983	2.30	788	1,045	970	0.19	1,998	1,478	1,044	0.01				
22	792	953	1.03	885	1,070	1,015		1,981	1,536	1,044					
23	*643	894	1.02	*461	959	985	0.56	1,960	1,586	1,044					
24	784	923	0.01	632	968	1,000		*1,978	*1,657	1,059					
25	796	953		730	981	1,015		1,981	1,759	1,059					
26	803	953		885	996	1,000		1,998	1,803	1,059					
27	841	894		1,000	1,000	1,000	0.04	1,230	1,771	1,059	0.24				
28	860	923		1,115	1,031	1,015		631	650	1,059	1.49				
29	*910	*967		1,153	1,052	1,015		770	471	1,059	1.76				
30	904	967		*1,363	1,070	1,030		*806	*510	1,059	0.01				
31	806	966		1,346	1,103	1,015									

The asterisk (*) indicates the dates on which the several electrodes should have been standardized.

The accompanying diagram (fig. 6) gives the conductivity corresponding to the resistances in the table. As before stated, it was not practicable to make moisture determinations at the actual depths of the electrodes. A single sample was, however, taken each day of the top 12 inches of the soil. This does not, therefore, correspond to the actual depth of either set of electrodes, although, as a matter of fact, the curves representing these moisture percentages agree very thoroughly with the conductivity of the electrodes at a depth of 3-6 inches below the surface. The period, as a whole, was rather dry and the rains hardly affected the deeper electrodes. The 1-3 inch electrodes show very marked changes with every rainfall, but the soil quickly dries out to an excessive degree, as would be expected. The conductivity of the 3-6 inch electrodes agrees very closely with the moisture curve, although the electrodes represent a depth of only 3 inches while the moisture is based upon a depth of 12 inches. The electrodes, 21-24 inches deep, hardly varied between August 1 and October 13, indicating very slight changes of the moisture at that depth throughout the season.

Considerable work has been done on the effect of water on the electrical resistance of soils as well as upon the influence of salts on the resistance of soils. A method has been devised for the determination of the soluble salt content of soils which is adapted to samples taken from the field. These matters will be presented in another bulletin, which will contain the essential experimental results upon which this method of moisture determination has been based.

The method, as given in the previous pages of this bulletin, requires that the resistances obtained from the measuring instrument be converted into conductivities. In order to facilitate this work a table of reciprocals is given. The use of the table will be readily understood. The resistance is given in the first column to one place of whole numbers and to one place of decimals. The second place of decimals can be obtained from the remaining column, while the third place of decimals can be obtained by subtracting the difference corresponding to the figure found in the table of differences. If the decimal place is moved to the right or left in the resistance, it is moved an equal number of places in the opposite direction in the conductivity taken from the table. Thus,

Resistance of 5 ohms	=	conductivity	0.2
50 "	=	"	.02
500 "	=	"	.002
5,000 "	=	"	.0002

Table of reciprocals, for use in computing the electrical conductivity from the electrical resistance of soils and solutions.

Resistance, ohms.	0	1	2	3	4	5	6	7	8	9	Differences (to be subtracted).								
											1	2	3	4	5	6	7	8	9
1.0	1.0000	9901	9804	9709	9615	9524	9434	9346	9259	9174	8	17	25	33	42	50	58	66	75
1.1	0.9091	9009	8929	8850	8772	8696	8621	8547	8475	8403	7	14	21	28	35	42	49	56	63
1.2	8333	8264	8197	8130	8065	8000	7937	7874	7813	7752	6	12	18	24	30	36	42	48	54
1.3	7692	7634	7576	7519	7463	7407	7353	7299	7246	7194	5	10	15	20	26	31	36	41	46
1.4	7143	7092	7042	6993	6944	6897	6849	6803	6757	6711	4	9	13	18	22	26	31	35	40
1.5	6667	6623	6579	6536	6494	6452	6410	6369	6329	6289	4	8	12	16	20	23	27	31	35
1.6	6250	6211	6173	6135	6098	6061	6024	5988	5952	5917	4	7	11	14	18	21	25	28	32
1.7	5882	5848	5814	5780	5747	5714	5682	5650	5618	5587	3	6	9	12	16	19	22	25	28
1.8	5556	5525	5495	5464	5435	5405	5376	5348	5319	5291	3	6	8	11	14	17	20	22	25
1.9	5263	5236	5208	5181	5155	5128	5102	5076	5051	5025	3	5	8	10	13	15	18	20	23
2.0	0.5000	4975	4950	4926	4902	4878	4854	4831	4808	4785	2	5	7	9	12	14	16	18	21
2.1	4762	4739	4717	4695	4673	4651	4630	4608	4587	4566	2	4	6	8	11	13	15	17	19
2.2	4545	4525	4505	4484	4464	4444	4425	4405	4386	4367	2	4	6	8	10	11	13	15	17
2.3	4348	4329	4310	4292	4274	4255	4237	4219	4202	4184	2	3	5	7	9	10	12	14	15
2.4	4167	4149	4132	4115	4098	4082	4065	4049	4032	4016	2	3	5	6	8	10	11	13	14
2.5	4000	3984	3968	3953	3937	3922	3906	3891	3876	3861	2	3	5	6	8	9	11	12	14
2.6	3846	3831	3817	3802	3788	3774	3759	3745	3731	3717	1	3	4	5	7	8	9	10	12
2.7	3704	3690	3676	3663	3650	3636	3623	3610	3597	3584	1	3	4	5	7	8	9	10	12
2.8	3571	3559	3546	3534	3521	3509	3497	3484	3472	3460	1	2	4	4	6	8	9	10	11
2.9	3448	3436	3425	3413	3401	3390	3378	3367	3356	3344	1	2	4	4	6	8	9	10	11
3.0	0.3333	3322	3311	3300	3289	3279	3268	3257	3247	3236	1	2	3	4	5	6	7	8	9
3.1	3226	3215	3205	3195	3185	3175	3165	3155	3145	3135	1	2	3	4	5	6	7	8	9
3.2	3125	3115	3106	3096	3086	3077	3067	3058	3049	3040	1	2	3	4	5	6	7	8	9
3.3	3030	3021	3012	3003	2994	2985	2976	2967	2959	2950	1	2	3	4	5	6	7	8	9
3.4	2941	2933	2924	2915	2907	2899	2890	2882	2874	2865	1	2	2	3	4	5	6	7	8
3.5	2857	2849	2841	2833	2825	2817	2809	2801	2793	2786	1	2	2	3	4	5	6	7	8
3.6	2778	2770	2762	2755	2747	2740	2732	2725	2717	2710	1	1	2	3	4	4	5	6	6
3.7	2703	2695	2688	2681	2674	2667	2660	2653	2646	2639	1	1	2	3	4	4	5	6	6
3.8	2632	2625	2618	2611	2604	2597	2591	2584	2577	2571	1	1	2	3	4	4	5	6	6
3.9	2564	2558	2551	2545	2538	2532	2525	2519	2513	2506	1	1	2	2	3	4	4	5	5
4.0	0.2500	2494	2488	2481	2475	2469	2463	2457	2451	2445	1	1	2	2	3	4	4	5	5
4.1	2439	2433	2427	2421	2415	2410	2404	2398	2392	2387	1	1	2	2	3	4	4	5	5
4.2	2381	2375	2370	2364	2358	2353	2347	2342	2336	2331	1	1	2	2	3	3	4	4	5
4.3	2326	2320	2315	2309	2304	2299	2294	2288	2283	2278	1	1	2	2	3	3	4	4	5
4.4	2273	2268	2262	2257	2252	2247	2242	2237	2232	2227	1	1	2	2	3	3	4	4	5
4.5	2222	2217	2212	2208	2203	2198	2193	2188	2183	2179	1	1	2	2	3	3	4	4	5
4.6	2174	2169	2165	2160	2155	2151	2146	2141	2137	2132	1	1	2	2	3	3	4	4	5
4.7	2128	2123	2119	2114	2110	2105	2101	2096	2092	2088	0	1	2	2	2	2	3	3	4
4.8	2083	2079	2075	2070	2066	2062	2058	2053	2049	2045	0	1	2	2	2	2	3	3	4
4.9	2041	2037	2033	2028	2024	2020	2016	2012	2008	2004	0	1	1	2	2	2	3	3	4
5.0	0.2000	1996	1992	1988	1984	1980	1976	1972	1969	1965	0	1	1	2	2	2	3	3	4
5.1	1961	1957	1953	1949	1946	1942	1938	1934	1931	1927	0	1	1	2	2	2	3	3	4
5.2	1923	1919	1916	1912	1908	1905	1901	1898	1894	1890	0	1	1	2	2	2	2	3	3
5.3	1887	1883	1880	1876	1873	1869	1866	1862	1859	1855	0	1	1	2	2	2	2	3	3
5.4	1852	1848	1845	1842	1838	1835	1832	1828	1825	1821	0	1	1	2	2	2	2	3	3
5.5	1818	1815	1812	1808	1805	1802	1799	1795	1792	1789	0	1	1	2	2	2	2	3	3
5.6	1786	1783	1779	1776	1773	1770	1767	1764	1761	1757	0	1	1	2	2	2	2	3	3
5.7	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	0	1	1	2	2	2	2	3	3
5.8	1724	1721	1718	1715	1712	1709	1706	1704	1701	1698	0	1	1	2	2	2	2	3	3
5.9	1695	1692	1689	1686	1684	1681	1678	1675	1672	1669	0	1	1	2	2	2	2	3	3
6.0	0.1667	1664	1661	1658	1656	1653	1650	1647	1645	1642	0	1	1	2	2	2	2	3	3
6.1	1639	1637	1634	1631	1629	1626	1623	1621	1618	1616	0	1	1	2	2	2	2	3	3
6.2	1613	1610	1608	1605	1603	1600	1597	1595	1592	1590	0	1	1	2	2	2	2	3	3
6.3	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	0	1	1	2	2	2	2	3	3
6.4	1563	1560	1558	1555	1553	1550	1548	1546	1543	1541	0	1	1	2	2	2	2	3	3
6.5	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	0	0	1	1	1	1	1	2	2
6.6	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	0	0	1	1	1	1	1	2	2
6.7	1493	1490	1488	1486	1484	1481	1479	1477	1475	1473	0	0	1	1	1	1	1	2	2
6.8	1471	1468	1466	1464	1462	1460	1458	1456	1453	1451	0	0	1	1	1	1	1	2	2
6.9	1449	1447	1445	1443	1441	1439	1437	1435	1433	1431	0	0	1	1	1	1	1	2	2
7.0	0.1429	1427	1425	1422	1420	1418	1416	1414	1412	1410	0	0	1	1	1	1	1	2	2
7.1	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	0	0	1	1	1	1	1	2	2
7.2	1389	1387	1385	1383	1381	1379	1377	1376	1374	1372	0	0	1	1	1	1	1	2	2
7.3	1370	1368	1366	1364	1362	1361	1359	1357	1355	1353	0	0	1	1	1	1	1	2	2
7.4	1351	1350	1348	1346	1344	1342	1340	1339	1337	1335	0	0	1	1	1	1	1	2	2

Table of reciprocals, for use in computing the electrical conductivity from the electrical resistance of soils and solutions—Continued.

Resistance, ohms.	0	1	2	3	4	5	6	7	8	9	Differences (to be subtracted).								
											1	2	3	4	5	6	7	8	9
											7.5	1333	1332	1330	1328	1326	1325	1323	1321
7.6	1316	1314	1312	1311	1309	1307	1305	1304	1302	1300	0	0	1	1	1	1	1	2	2
7.7	1299	1297	1295	1294	1292	1290	1289	1287	1285	1284	0	0	1	1	1	1	1	2	2
7.8	1282	1280	1279	1277	1276	1274	1272	1271	1269	1267	0	0	1	1	1	1	1	2	2
7.9	1266	1264	1263	1261	1259	1258	1256	1255	1253	1252	0	0	1	1	1	1	1	2	2
8.0	0.1250	1248	1247	1245	1244	1242	1241	1239	1238	1236	0	0	0	0	1	1	1	1	1
8.1	1235	1233	1232	1230	1229	1227	1225	1224	1222	1221	0	0	0	0	1	1	1	1	1
8.2	1220	1218	1217	1215	1214	1212	1211	1209	1208	1206	0	0	0	0	1	1	1	1	1
8.3	1205	1203	1202	1200	1199	1198	1196	1195	1193	1192	0	0	0	0	1	1	1	1	1
8.4	1190	1189	1188	1186	1185	1183	1182	1181	1179	1178	0	0	0	0	1	1	1	1	1
8.5	1176	1175	1174	1172	1171	1170	1168	1167	1166	1164	0	0	0	0	1	1	1	1	1
8.6	1163	1161	1160	1159	1157	1156	1155	1153	1152	1151	0	0	0	0	1	1	1	1	1
8.7	1149	1148	1147	1145	1144	1143	1142	1140	1139	1138	0	0	0	0	1	1	1	1	1
8.8	1136	1135	1134	1133	1131	1130	1129	1127	1126	1125	0	0	0	0	1	1	1	1	1
8.9	1124	1122	1121	1120	1119	1117	1116	1115	1114	1112	0	0	0	0	1	1	1	1	1
9.0	0.1111	1110	1109	1107	1106	1105	1104	1103	1101	1100	0	0	0	0	1	1	1	1	1
9.1	1099	1098	1096	1095	1094	1093	1092	1091	1089	1088	0	0	0	0	1	1	1	1	1
9.2	1087	1086	1085	1083	1082	1081	1080	1079	1078	1076	0	0	0	0	1	1	1	1	1
9.3	1075	1074	1073	1072	1071	1070	1068	1067	1066	1065	0	0	0	0	1	1	1	1	1
9.4	1064	1063	1062	1060	1059	1058	1057	1056	1055	1054	0	0	0	0	1	1	1	1	1
9.5	1053	1052	1050	1049	1048	1047	1046	1045	1044	1043	0	0	0	0	1	1	1	1	1
9.6	1042	1041	1040	1038	1037	1036	1035	1034	1033	1032	0	0	0	0	1	1	1	1	1
9.7	1031	1030	1029	1028	1027	1026	1025	1024	1022	1021	0	0	0	0	1	1	1	1	1
9.8	1020	1019	1018	1017	1016	1015	1014	1013	1012	1011	0	0	0	0	1	1	1	1	1
9.9	1010	1009	1008	1007	1006	1005	1004	1003	1002	1001	0	0	0	0	1	1	1	1	1

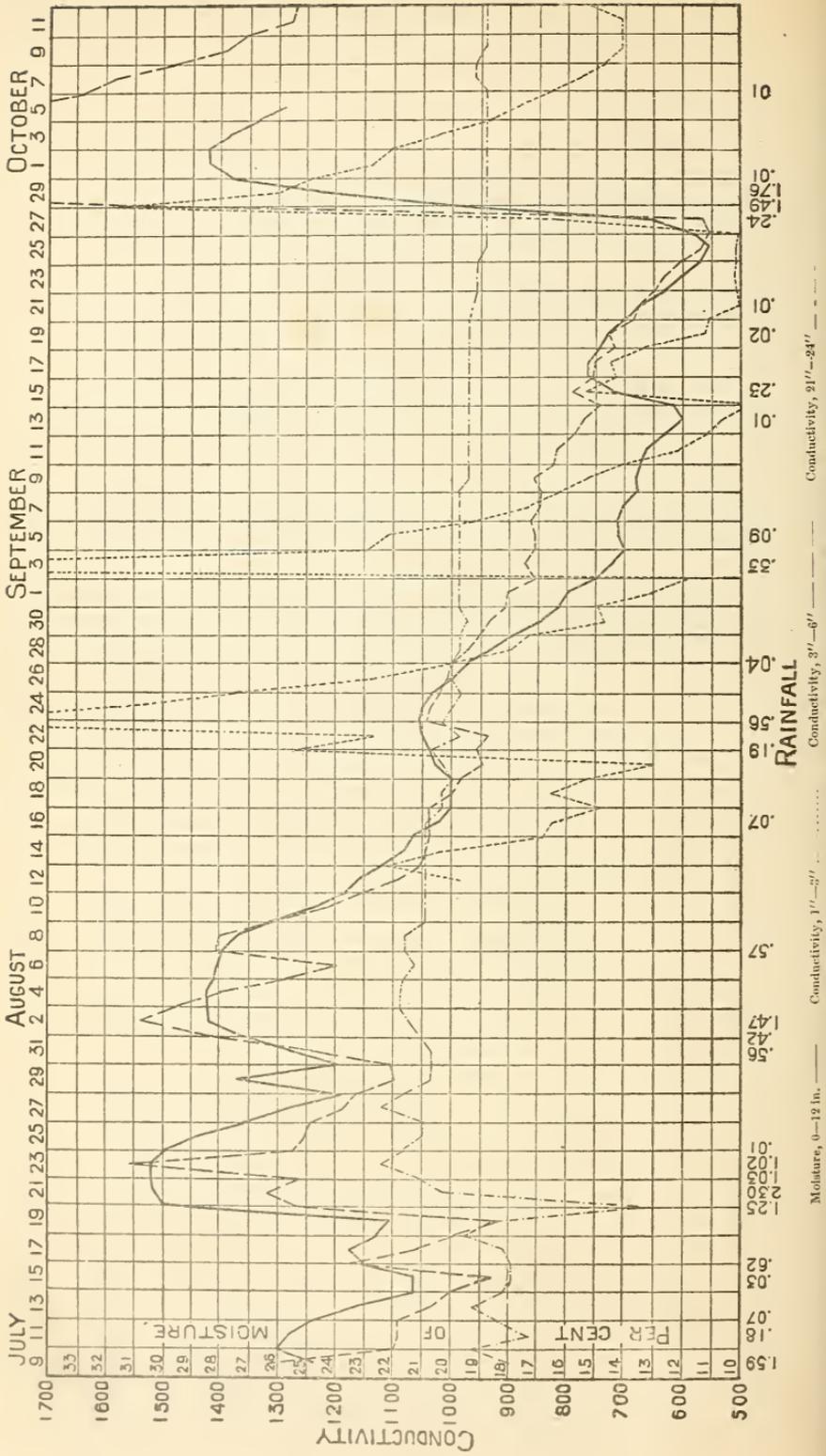


FIG. 6.—Field records of a limestone soil near Lexington, Ky.

