Test of Electrical Method of Determining Soil Moisture

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The importance of having a reliable method of determining the amount of soil moisture has been recognized by the formost agriculturalists for a long time. Knowing this many of our exoerimenters have tried to find some accurate method by which they might determine the amount of moisture in the soil. Various methods by different experimenters have been proposed for this purpose but with very little success. In 1885 the New York station buried brick in the ground and taking them up and weighing from day to day. they hoped to be able to determine the amount of moisture, but this proved to be unreliable as well as inconvenient. Later porous terra cotta was tried but with no better results. Finally a graduated tube was let down in the ground and water allowed to flow through a small opening in the bottom into the soil. it being assumed that the drier the soil the faster the flow, and that the quantity which flows out in a certain time will have some ratio to the amount of water in the soil. While this method was supposed to be accurate, yet it has never been entirely satisfactory.

At the present time the universal method in use is to take samples of soil from the field at the desired depths and weighing, then after drying at a temperature of 110° to 130°C from eighteen to twenty four hours, it is weighed again, and the percent of moisture calculated. While this method is most relied upon at present, yet it has been found from long experience that owing to the inequalities of a field and the difficulty of taking representative samples, it is not accurate for a single determination to within two or three percent of the actual amount determined by a large number of duplicate samples. On account of the unreliableness and inconvenience of this method, Whitney and others of the United States Department of Agriculture, undertook to devise an electrical resistance method which they hoped to make more reliable and convenient.

The possibility of using the resistance of an electrical current passing through the soil was suggested to Whitney by the fact that telephones and telegraph lines must be thoroughly grounded and kept in moist soil in order for the lines to work in dry seasons, the resistance being too great for the current to pass if the soil around the terminals becomes too dry. By experiments it was found that the current varied with the moisture content of the soil, the drier the soil the greater the resistance, and by measuring the resistance and comparing it with the actual per cent of moisture. A table can be constructed from which the percentage of moisture may be read directly if the resistance in Ohms is known.

Working upon this principle Whitney used the Wheat Stone bridge method, with a few alterations for convenience, for measuring the resistance.

He used an alternating current with a watch reciever telephone to indicate when a balance is obtained.

With this apparatus Whitney proceeded as follows; the resistance ti be measured is attached by means of lead wires to the binding posts in one arm of the bridges.this resistance is known as the unknown resistance. In the other arm of the bridge a known resistance is attached. As the electrical resistance of salt solution varies with the temperature.it becomes necessary to know the temperature of the soil at the place where the resistance was taken.and to make corrections for the influence of temperature.

This difficulty Whitney overcame by using a compensating cell for for the unknown resistance. The cell used consists of a small glass tube about 3.5 millimeters internal diameter.with small platinum electrodes in each end. The tube is filled with a salt solution consisting of 90 per cent of four-fifths normal chloride solution and commercial alcohol. This solution has the same temperature coefficient as the soil. The electrodes are about 8 inches apart having attached to them lead wires and arranged so that they may be put closer or farther apart in order to vary the resistance if necessary. As the temperature varies in the soil and the resistance changes.the resistance of the cell changes which compensates for the error in the resistance due to the temperature.

The electrodes finally adopted consisted of carbon plates. 3 in. long 3/8 of an inch wide and 3/16 of an inch thick. Each electrode was copper plated on one end and an insulated copper wire soldered to the plating of a length sufficient to read above the surface of the ground.

After the carbons have the wires attached they are soaked in distilled water to remove all salts or acids that may have accumulated during the plating and soldering. These electrodes are then set in the ground in such a way as to make as near a perfect contact with the soil as possible. The soldered parts and exposed wires, together with all of the copper plating must be insolated.

Several sets of ele trodes are put in different depths in the same field and readings can be made from day to day.

As has already been said the resistance is influenced by the temperature and soluble salts as well as the amount of moisture. The temperature effect is eliminated by the use of the temperature cell, using it for the unknown resistance in one arm of the bridge. Now as the salt content is liable to change during the season on account of heavy rains and drying out of the soil it becomes necessary to standardize the field electrode from time to time, by taking samples of soil and evaporating them to determine the actual moisture content.

When the electrodes are buried samples of soil in the immediate vicinity are taken at the depths corresponding to each set of electrodes. These samples are taken in brass tubes and put in tin boxes and moisture evaporated and the actual percent of moisture calculated. Some time$ later when the resistance has changed enough to indicate that a change in moisture content has taken place, another set of samples is taken; the same as the a-bove and treated in the same way.

From this data a table is constructed or a curve may be plated from which the percent of moisture can be read directly if the resistance in ohms is known.

In our tests of the electrical method of ascertaining the amount of moisture in the soil, the otdinary carbons purchased from the Manhattan electric light plant were used as electrodes. They were cut into lengths of about 2 1/4 to 4 inches and were 1/2 inch in diameter. One end was cut tapering. On the other end the wire was fastened in the following manner: a 1/8 inch hole was bored into the end of the carbon to a depth of from 3/4 to 1 inch. Then another hole of the same size was bored from the side joining the vertical hole from one side only. A wire was put into the vertical hole and manipulated so that it came out of the side hole whence it was bent over and soldering metal put into the hole making a firm and good contact. Gutta percha was then put over the soldered part and wrapped with insolating tape. Also all bare parts of the wire were insolated. To remove the grease and other foreign substances from the carbons they were washed in a strong solution of caustic potash, rinsed in distilled water, and then heated in a flame. The apparatus of putting the carbons into the ground was quite a simple yet efficient instrument. A hole one inch in diameter was made with a brass tube to the depth to which the top of the carbon was calculated to be. The carbons were then inserted by means of a round stick in the center of the end of which was made a hole 1/8 inch deep and large enough to receive the end of the carbon and in the center of this hole was made another hole 1/8 inch in diameter and bored slanting so that it came out at the side 1/2 foot distance from the same end. The wire was then put through the small hole and the carbon, which was cut tapering was forced into the ground or hard soil, thus making close contact. The stick was then pulled out and carbon left in the soil. Three carbons were put at the same depth in an isosceles triangle the bases being regarded as 1 foot apart and sides 2 feet apart. They were put 1/2 foot, 1 1/2 feet, 2 1/2 feet, 3 1/2 feet, 4 1/2 feet, and 5 1/2 feet deep respectively. After laboring in vain for some time to get the resistance of the soil by the wheat stone bridge method using a direct current. - unable to strike a point where the galvanometer did not move - we attached the two lead wires from the electrodes to a Weston galvanometer and found that the battery action of the carbon electrodes was strong enough to throw the needle off the scale. The strength of the current varied with different pairs of carbons. One pair was found to be nearly neutral. In all cases a reversion of the electrodes on the poles of the galvanometer caused a deflection of the needle to the other side. Similar electrodes were then put into tap water and a deflection was again produced. In the laboratory a test was made using distilled water in which case scarcely no deflection was produced on the galvanometer.

Two silver dollars were then taken as electrodes. Lead wires were soldered on one side and then thoroughly insolated with gutta percha. When these were buried in the soil a deflection was produced but not so strong as with the carbon electrodes. Two copper plated electrodes produced also a slight deflection.

The current produced by the carbon electrodes was strong enough so that the make and break on the wheat stone bridge could be easily heard with the telephone receiver and only when we used the alternating current could a zero point be found.

An attempt was then made to find two electrodes which would exactly counter balance each other by connecting positive and positive together but did not succeed in getting such a combination as in every case a slight or large deflection was produced.

We failed several times to make a temperature cell which would have the same temperature coefficient as the soil. One was constructed as follows: A gkass tube about 12 inches long was filled with soil and thoroughly saturated with rain water. Two carbons about 2 1/2 inches long were used as electrodes; about 3/4 of an inch of each electrode on one end was copper plated and on this portion was soldered the copper lead wires which passed through a rubber cork. When the correct resistance was obtained by getting the proper distance between the electrodes, the tube was sealed up tightly. The resistance, however, was found to vary more than could be ~~ac~~ accounted for by change of temperature. At first it was 907 ohms resistance and three weeks later it was 2150 ohms resistance. This change may be due to the effect of the tube standing vertically after the first reading was taken and that, perhaps, the dirt being heavier than the water it settled to the bottom of the tube thus making some change in the soil particles and also a change in the resistance as shown by above figures. Also in this cell a battery action was noticed. The resistance was measured by the alternating current as polarization took place immediately with the direct current. Some other methods were tried in regard to making a temperature cell. First we took some samples of soil of different depths and allowed to stand saturated with distilled water for 48 to 60 hours, then filtered off the water again. It was found that the resistance was nearly infinite or the same as distilled water. When heated it was found that the resistance was slightly decreased. Then we took some soil on which we poured distilled water and boiled for several hours together. The resistance was slightly lower than before. To this solution we added a small amount of salt decreasing the resistance very much. It was supposed that by taking a solution of the soil in this manner we would be able to get a cell of the same temperature coefficient as that of the soil but it was found that very little if any of the salts were dissolved. The experiment would seem to indicate that the salts in the soil are very slow to dissolve.

In view of the fact that a current was produced by the buried carbons, it was suggested that this current could be used to measure the soil moisture. Since we have that $C := \frac{E}{r + r'}$ where c = the current and r and r' are = to the external and internal resistance respectfully it would seem to follow that E or the EMF and the internal resistance (r') vary in-directly with the amount of moisture, because, since the internal resistance (r') decreases with the amount of moisture. because, since the amount of salts in the soil seem to be fixed it follows that the more the moisture the weaker the solution and the drier the soil the stronger the solution and the less the internal resistance and the greater the current. Now since C and the EMF can be found and (r) the external resistance remains constant the value of (r') the internal resistance ~~remains~~ can be found. Working upon the above hypothesis we proceeded as follows:

A line was put up from the physics building in which is a very sensitive Roland's galvanometer. to the eledtrodes. A distance of perhaps 750 feet. Connections with the lead wires from the galvanometer were made as follows: A wooden block 2×4×4 was taken and into which was bored two 3/8 inch holes 1/2 inch deep. Fastened to the block were the two terminals of the line so that each end was held permanently in the hole by means of insolating knobs. This block could be moved about to the various electrodes as desired and the lead wires from the electrodes together with the terminals of the line were put into the holes which were nearly filled with mercury. Thus giving an almost perfect contact. Readings were then taken and instead of calculating the internal resistance or the current as was intended the deflections on the galvanometer were taken as the deflections are proportional to the strength of the current.

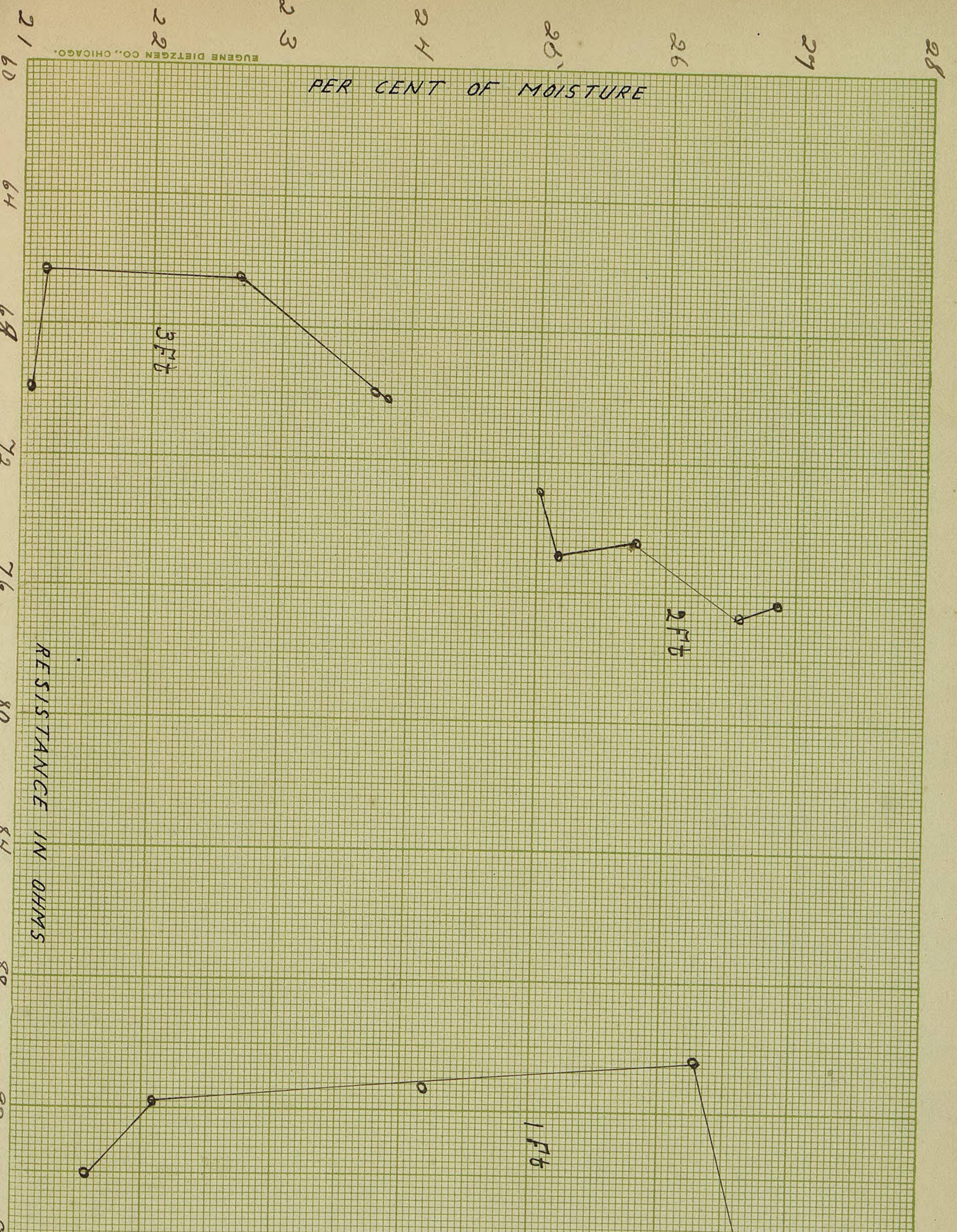
Below is the result of readings taken every day for one week of continued dry weather on the Roland's galvanometer and with an alternating current produced by a sechometer which is an instrument for converting a direct current into an alternating current and back to a direct current. Instead of a telephone receiver a Weston Galvanometer was used.

Depth of Electrode	Percent of Moisture	Galvanometer Deflect.	Resistance.
1/2 ft.	19	1.5	219.5
"	19.9	3	216.4
"	16.8	4.2	228.9

Depth of Electrode	Per cent of Moisture	Galvanometer Deflect.	Resistance.
1/2 ft.	12	1.05	241.3
"	14.1	4.85	247.7
"	10.4	5.15	252.1
1 ft	21.6	9.1	94.2
"	24.7	9.	97.6
"	26.3	10.1	90.8
"	22.1	10.5	93.8
"	24.2	10.1	91.3
"	22.1	10.4	91.9
2 ft.	26.6	1.	76.9
"	26.9	1.7	76.5
"	25.1	.5	75.1
"	25.8	.95	74.6
"	25.	00	73.1

Depth of Electrodes.	Percent of Moisture	Galvanometer Deflection	Rrsistance.
3 ft.	23.8	9.	70.5
"	21.1	8.6	70.8
"	23.7	8.5	70.
"	22.7	8.6	66.6
"	21.2	8.2	66.5

It will be seen from the above data taken with Roland's galvanometer that it was impossible to construct regular curves as was expected from the hypothesis stated. From the curves and data there seems to be no relation between the strength of current, internal resistance of the soil battery and the moisture content. In the data for 1/2 foot the deflection seems to get greater as the moisture decreases, but as can be seen on close examination there is no rrgularity, showing that other factors influence the internal resistance besides moisture. The 19 and 12 per cent moisture gave practically the same. Deflection, for 10.4 per cent moisture was 5.15 cm. The next day with practically the same moisture, the deflection was 18 cm. while 2 days later and after a 4 inch rain the deflection was 20 cm. In the two feet depth the deflection for 25.1 per cent moisture is even less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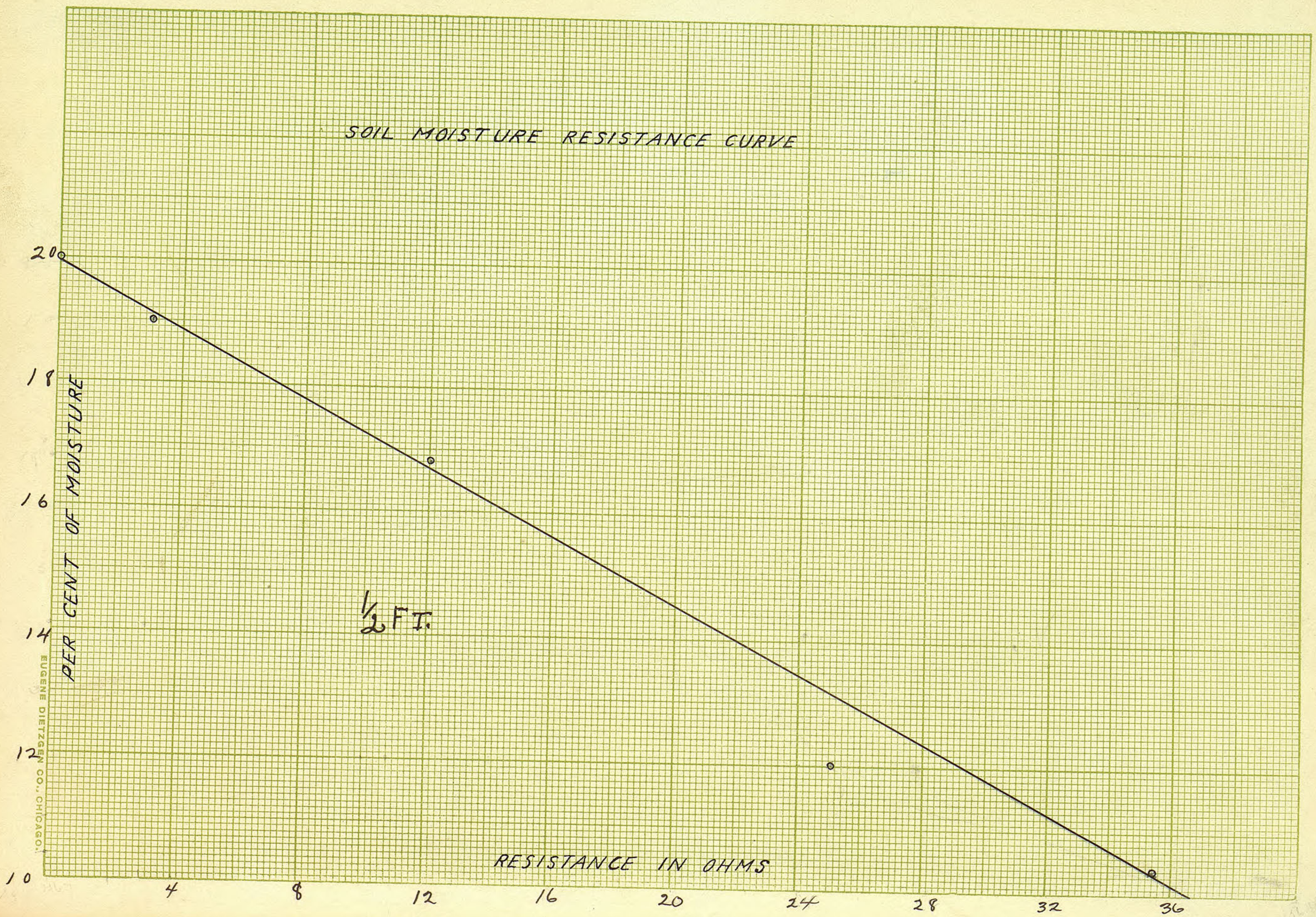
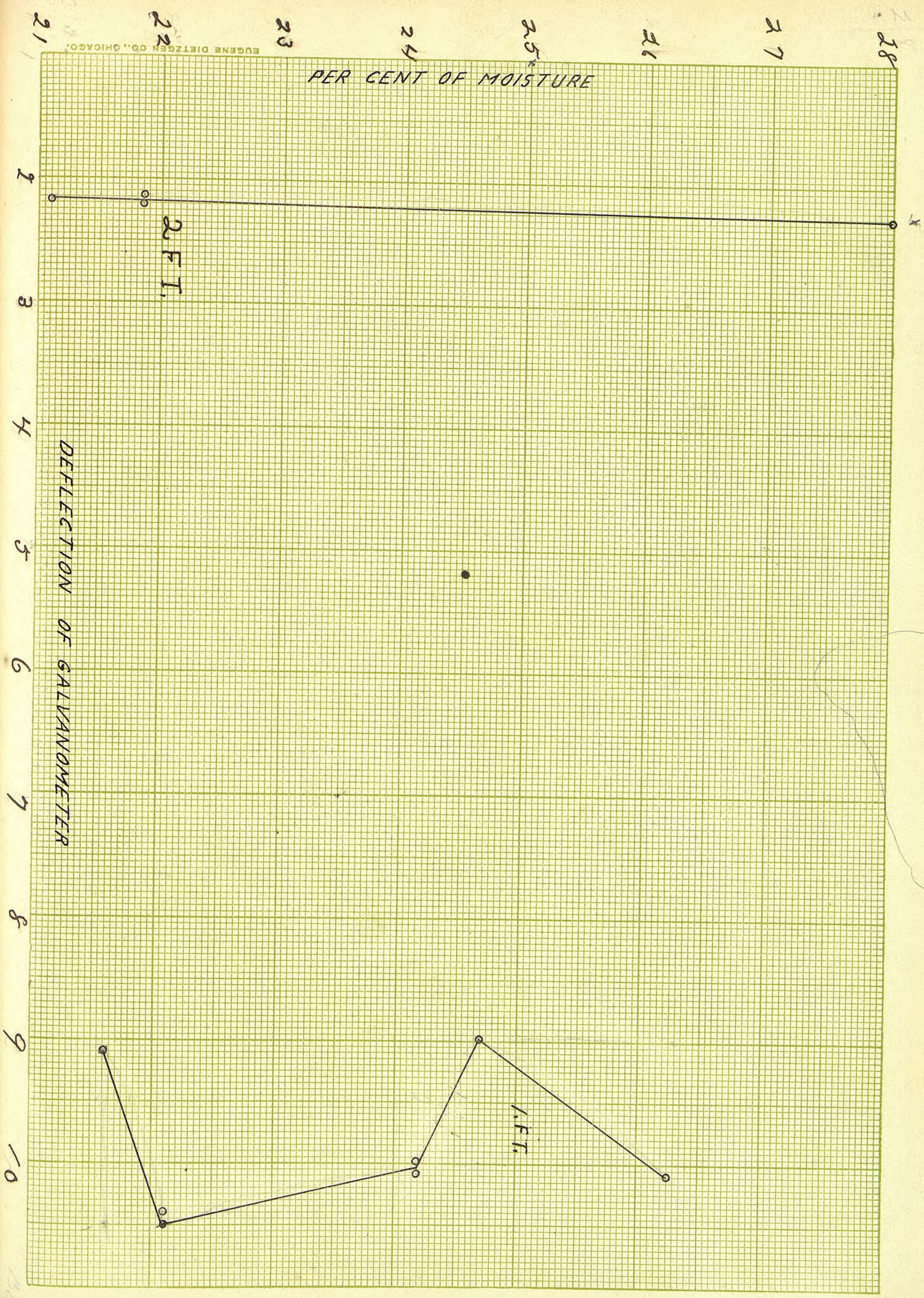
PER CENT OF MOISTURE
21
22
23
24
25
26
27
28
RESISTANCE IN OHMS
60
64
68
72
76
80
84
88
92
96
100
3 Ft
2 Ft
1 Ft



SOIL MOISTURE RESISTANCE CURVE
PER CENT OF MOISTURE
RESISTANCE IN OHMS
1/2 FT.
20
18
16
14
12
10
4
8
12
16
20
24
28
32
36
EUGENE DIETZGEN CO., CHICAGO.


PER CENT OF MOISTURE
21
22
23
24
25
26
27
28
DEFLECTION OF GALVANOMETER
1
2
3
4
5
6
7
8
9
10
2 FT.
1 FT.

than that for 26.9 per cent moisture while the 25.1 per cent should give the greatest deflection.

From the data for the resistance as determined with the sechometer and Weston galvanometer it will be seen that as with the Roland's galvanometer there seems to be no near relation between the resistance and the per cent of moisture. In the data for 1/2 foot there seems to be a regularity as indicated by the curve but upon close observation it will be seen that the curve did not follow all points.and that one instance there was a wide variation. In the one and three feet it will be seen that the resistance for the larger percent of moisture was greater than the resistance for the smaller per cent of moisture while the reverse should be true if Whitney's statements are true.

From our observations there seems to be too many factors to influence the resistance to make this method reliable. The battery action no doubt increases the difficulty of determining the resistance. To overcome this polarization Whitney used the alternating current and a telephone receiver in connection with the Wheat Stone Bridge. We found that a variation of from 1 to 2 cm could not be avoided and this being the case the result must be uncertain. For instance a known resistance of 1000 ohms as used by Whitney,with a variation of 1 to 2 cm, gives the following rates

25:1000::75:x and 24:1000::77:x. Where 25 and 75 are arms of the bridge and x the unknown resistance. In the first ratio x is equal to 4000 ohms, in the second with a variation of 2 cm the unknown resistance is equal to 3348 ohms or a difference of 652 ohms which if the method were reliable in other respects would cause too wide a variation. Another obstacle which would decrease the reliability, especially in cultivated soil, is the contacts of electrodes and the compactness of the soil before and after rain. In our tests we found the resistance decrrased by packing the soil between the electrodes.

Another fault may be that the electrodes are placed in single places and as was the case in our test certain electrodes received much greater portion of moisture in a heavy dashing rain than in a steady rain on account of the electrodes being where water accumulated as it was shed from the surrounding surface, in this case the salts around the electrodes receiving the heavy soaking would leach out and the electrodes would have to be standardized after every heavy rain.

Again in soils rich in salts where a long continued drought occurs there is a tendency for the salts to collect in the surface 2 or 3 inches and in this case there would be a gradual decrease in resistance due to the movement of the salts near the top. After a heavy rain these salts leach out and are carried down into soil so that one time there may be a layer of soil near the top rich in salts and at others after a heavy rain it may be found 10,20 or30 inches below the surface. In this case it is easily seen that the electrodes would have to be standardized after each rain or in case of irrigated land after each soaking.

Taking into account then,the results of the sechometer readings; the insensibility of the telephone as compared with the Weston galvanometer; the liability of salts leaching from around certain electrodes after a heavy rain;the contact and compactness of soil before and after a heavy rain; the movement of salts near the surface after a long continued drought and the probable effect of the battery on the alternating current we can not indorse the accuracy of this method as claimed by Whitney.