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The Effect of Electric Current on Certain Crop Plants

BY CHARLES S. DORCHESTER

AGRICULTURAL EXPERIMENT STATION
IOWA STATE COLLEGE OF AGRICULTURE
AND MECHANIC ARTS

R. E. BUCHANAN, Director

FARM CROPS SUBSECTION

AGRONOMY SECTION

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CONTENTS

| | Page |
|---|------|
| Summary | 3 |
| Previous studies of the effect of electric current on plant growth | 6 |
| Natural earth-air currents | 6 |
| Crop experiments using modified atmospheric potential.... | 7 |
| Crop experiments using soil electrodes..... | 8 |
| Electrical treatment of seed and seedlings..... | 8 |
| Studies of the physiologic response of plants..... | 8 |
| Effect of electric current on soil microorganisms..... | 9 |
| Purpose of the investigation..... | 10 |
| Experimental | 10 |
| Utilization of atmospheric electricity..... | 10 |
| Application of current to the root areas by means of electrodes | 16 |
| Greenhouse test with oats using high voltage currents.. | 16 |
| Greenhouse test with oats using the copper-zinc electrodes combination | 19 |
| Field test with oats using the copper-zinc electrodes combination | 30 |
| Effect of electric current upon the formation of carbon dioxide in the soil | 31 |
| Literature cited | 35 |

SUMMARY

In this investigation the primary object has been to study the possible effect of weak electric currents, similar to those existing in nature, upon plant growth and certain phases of the environment. The experiments have been of two types: (1) Those using the earth-air currents collected and discharged by means of elevated metal brushes, and (2) those using currents generated as the result of differences in potential between buried, aerially connected, copper and zinc electrodes, sometimes augmented by dry cells placed in the circuits. In both types the currents developed have been applied to the root areas of the plants.

1. Currents obtained by means of the installation of elevated metal brushes connected with buried wires transversing the root areas of field crops apparently had little effect on yields. Yearly averages show a variation from the controls with corn of -2.78 to $+4.51$ percent; with soybeans of $+0.29$ to $+3.16$ percent; with turnips of -3.95 to $+7.03$ percent; with chard of $+3.39$ to $+9.08$ percent; with beets of $+5.55$ to $+11.05$ percent; with string beans of $+1.82$ to $+3.91$ percent.

2. Currents passing through the elevated metal brushes during fair weather changed direction frequently and were of the order of from 5.0×10^{-10} amperes to 1.0×10^{-9} amperes. During unsettled weather the currents varied greatly, both in direction and magnitude, the highest value being of the order of 200×10^{-9} amperes.

3. The intensities of the currents measured in the soil and along the buried conductor at various distances from one of the elevated brushes seemed to bear no relation to the intensities measured at the point where the conductor entered the soil.

4. The application of currents ranging in intensity from 7,000 to 20,000 volts to the roots of oats in greenhouse flats did not produce significant variations in yields of grain and straw. The yields of the treated lots varied both above and below the average of the controls, and none yielded more than the higher control. The high voltage currents were applied for 15 minutes each day throughout the growing period.

5. The greenhouse treatments in which an electrode of copper and one of zinc were buried at opposite ends of the soil area to be treated, and connected aerially by copper wire, produced significant increases in yields of oats the first year of the experiment. Currents measured were of the order of from 0.5 to 1.5 milliamperes. The second year of the experiment, the grain and straw yields were not increased by treatment with electric current, while root yields were significantly decreased. For this test one or two

dry cells were included in the circuit for each treated lot, and current intensities ranged as high as 4.0 milliamperes.

6. In the field trials with oats the copper-zinc electrodes combination, with dry cells included in the circuits, provided current intensities ranging from 2.0 to 55.0 milliamperes but failed to affect the yields significantly.

7. In the comparisons using the copper-zinc electrodes combination, the percentage of total nitrogen of oats apparently was not affected by treatment with electric current.

8. With the exception of the determinations made in connection with the field tests, a rather definite relationship between electrical treatment and numbers of soil microorganisms was observed throughout the series of experiments. In the 1932 greenhouse experiment, a comparison of 24 samples showed increases for the electrically treated lots of 14 to 123 percent and of 15 to 23 percent for 20 samples in 1933. Further proof was provided by the carbon dioxide determinations, a weak current of 0.1 milliampere producing appreciable increases in amounts of carbon dioxide formed and a relatively strong current of 10 to 15 milliamperes resulting in pronounced decreases.

The Effect of Electric Current on Certain Crop Plants

BY CHARLES S. DORCHESTER¹

The possible effect of electric current upon the growth of plants has been the object of various types of research for more than 150 years. Solly (42) states that the earliest work was done by Dr. Maimbray of Edinburgh in 1746. According to this account Maimbray electrified two myrtles during the month of October and found that they put forth small branches some inches in length, and even came into blossom. Other myrtles which were not electrified made no such development; consequently he concluded that the difference in behavior was due to the effect of the electric current.

Apparently the first treatment of crops was attempted by the abbe Bertholon in France about 1870. Basty (1) relates that Bertholon treated various garden plants by sprinkling with electrified water. A gardener, standing on a slab of insulating material in a wagon, carried a sprinkling can electrified by means of a wire leading to a static machine. "By means of this process, strange for the times, the good abbe Bertholon, who was considered something of a sorcerer, obtained salades of an extraordinary size."

Prior to 1900 many of the investigators on the subject of the electrical treatment of plants reported rather sensational increases in plant growth and yields, but for the most part their tests were limited in scope and obviously lacked exactness. In recent years many phases of this problem have been studied by English, French, Finnish, German and American observers and scientific investigators. A number have reported apparently significant increases in crop yields resulting from treatment with electric current, others have found little or no difference. Among these later trials, which, in most instances, appear to have been conducted under carefully controlled conditions, the majority show significant yield increases for the electrical treatment.

In the few experiments where the effect of electric current upon the physiologic functions of plants has been investigated, the results obtained have failed to provide a satisfactory explanation for yield

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differences. Until significant responses of plant functions to the influence of electric current have been demonstrated it would seem that the whole matter of increased plant yields by such treatment must remain debatable.

PREVIOUS STUDIES OF THE EFFECT OF ELECTRIC CURRENT ON PLANT GROWTH

NATURAL EARTH-AIR CURRENTS

That plant life is surrounded in the atmosphere and in the soil by a continual play of electric currents has been demonstrated by several investigators. Wilson (47) observed that on a clear day the ground is negatively charged while the lower atmosphere is positively charged, and that the positive potential gradient increases with height at the rate of 100 volts per meter. He found that in the upper atmosphere this rate of increase falls off until, at something less than 10 kilometers, the potential has become independent of the height. The average current from the air to the earth in clear weather was found to be approximately 2.0×10^{-16} amperes per square centimeter.

Wilson further relates that during showers and thunder storms the charge at the ground may be either positive or negative, and changes sign frequently. At such times the vertical electrical force often exceeds 10,000 volts per meter and the exchanges of electric charge between earth and air are much larger than in fair weather. These changes occur not only as lightning discharges but also by means of (1) a continuous conduction current between the thundercloud and the ground and (2) small charges carried by individual drops of rain.

Simpson (40), in India, developed an instrument for measuring the electrical charge of rain and made observations from April to September for 1 year. From his experiments he concluded that rain usually carries a measurable electric charge.

Lemström (27) calls attention to the rapid and succulent growth of crop plants in the far North. He is not willing to ascribe this rapidity of growth entirely to the longer day but asserts that it must be at least partly due to the highly electrical state of the atmosphere in the northern regions. In support of this view he states that in a study of sections of fir trees from different latitudes he has found a pronounced variation in periods of yearly growth which corresponds fully with the periods of the sun spots and the auroras. A comparison of sections of large trees from the polar regions of 67 degrees north latitude with sections of trees from a more southerly latitude of about 60 degrees shows that this periodic variation in yearly growth is much more pronounced in the northern trees.

Lund (28, 29) measured the relative potential of the growing points of the Douglas fir and found that the apical leader of the

fir had an electric charge which was positive in sign (in the external circuit) when compared to any of the leaders on the side branches. He observed also that the growing tip of any lateral branch was positively charged in relation to the trunk at the base of the tree.

Monahan (34) reports the results of systematic observations concerning the effect of trees upon the potential gradient of the air. A collector was placed in an elm 40 feet above the ground somewhat above the widest spread of branches and another at an equal height in the open air, and voltages were measured daily from April 20 to Nov. 1. After the elm came into full leaf, the potential was definitely lower than in the open air. On Aug. 1 a collector was placed 12 feet above the ground near the top of a small Norway spruce. Daily readings taken here showed that the potential was very much lower than in the elm.

CROP EXPERIMENTS USING MODIFIED ATMOSPHERIC POTENTIAL

In a few instances attempts have been made to intensify, within a definite area, the natural exchange of electric current between the earth and the atmosphere and to measure the effect on plant yields. Basty (1), Sanborn (39) and Solly (42) buried wires in the root areas and connected these wires with elevated metal discharge points. Basty and Sanborn apparently obtained pronounced increases in yields on the treated areas but Solly observed no differences.

Stone (43) placed electrodes in the opposite ends of greenhouse flats filled with soil and connected one electrode to an elevated copper brush, the other to the ground. He noted a continuous slight current and obtained, as the result of several tests, increases of 28 to 39 percent in the yields of radishes and lettuce.

Grandeau (13) grew a few plants of corn, wheat and tobacco under wire cages grounded to destroy the normal electrical field. His comparisons indicated reduced yields of from 50 to 70 percent. Monahan (33) observed that electrically charged air, used under greenhouse conditions, apparently hastened germination and plant growth.

Treatment of crops by means of an overhead wire network, highly charged, has been tested by several investigators. In all cases the network was supported on insulated posts so that the discharge could reach the plants and the earth only through the atmosphere.

Lemström (27) conducted tests of this sort on 10 different fields in as many years. He included many kinds of garden and field crops and reports increases of approximately 45 percent as an average for all tests. Blackman (2), in England, summarizes the results of 18 field experiments over a period of 6 years. Of these

tests 14 showed definitely increased yields for the electrical treatment. Other English investigators, Blackman and Legge (3), Dudgeon (9), Jorgensen (16), Jorgensen and Priestley (17), and Newman (35) report similar results.

Briggs et al (5) conducted experiments with a highly charged network for 8 years at Arlington Farm, using an experimental procedure similar to that employed in the English trials but conclude that the variations appeared to be well within the limits of experimental error. Kühn (22), Gerlach and Erlwein (12), in Germany, and Hendrick (14), in Scotland, as the result of field trials, conclude that the electrical treatment was of no value.

In experiments conducted in the biophysical laboratory at Washington, D. C., Collins et al (8) treated seedling grain plants with a high voltage direct current discharged from an overhead network. After an extensive and apparently carefully conducted test, he concludes that the differences in growth obtained were not significant.

CROP EXPERIMENTS USING SOIL ELECTRODES ¹

The effect, upon plant growth, of electricity applied through the soil has been studied in a group of tests characterized by the use of plate electrodes placed one at each end of the seedbed. The current used in these tests must pass through the trial plots from one electrode to the other.

Using currents of low intensities ranging from 0.2 to 0.4 milliamperes, Stone (43) treated large numbers of radish and lettuce plants and obtained increased yields of from 22 to 58 percent. Experiments conducted by Gerlach and Erlwein (12), Holdefleiss (15), Kövessi (21), Leicester (25), and Wollny (48, 49) indicate that currents similar in intensity to those used by Stone may be beneficial, and that currents of higher intensities may produce neutral, or even harmful, results.

ELECTRICAL TREATMENT OF SEED AND SEEDLINGS

In studies of the effect of electric current as applied to seedlings, Blackman et al (4) and Kinney (18) observed a distinct acceleration in the rate of growth. According to Leighty and Taylor (26) and Wheelock (46), the electrical treatment of seed, previous to planting, had little or no effect upon subsequent germination or yield, while Lee (23, 24) reports an increase of 25 percent in the yield of wheat.

STUDIES OF THE PHYSIOLOGIC RESPONSE OF PLANTS

The physiologic basis of plant behavior, as affected by treatment with electric current, has been studied in a few instances. Koernicke (20) grew beans in a glass compartment filled with highly ionized air, constantly renewed. He reports that, in comparison with the controls, treated beans transpired more rapidly,

had a larger leaf area and a greater dry weight, and used a greater amount of the salts from the nutrient solution. Knight and Priestley (19) studied the rate of respiration of germinating seeds and seedlings as affected by treatment with low and high voltage direct currents. No differences were observed.

Marinesco (30, 31, 32) states, in substance, that the application of an electromotive force to the ends of a bundle of capillary tubes plunged into an electrolytic solution induces a displacement of liquid through all the tubes. Conversely, an ionic solution forced through the tubes produces at their ends an electromotive force. He compares the ligneous vessels of plants to capillary tubes and states that since, due to transpiration, the ascending flow of sap is much greater than the descending flow, a measurable difference in electromotive force should result. In his experiments, various plants were tested by placing a platinum point in the root and one in the stem two centimeters above the soil. A difference of potential was observed of sometimes more than 0.4 volt. He concludes that this difference of potential may be used as a measure of the comparative rate of upward flow of the sap and that, conversely, an applied difference of potential should affect sap flow.

EFFECT OF ELECTRIC CURRENT UPON SOIL MICROORGANISMS

Brown (6) and Waksman (45) observe that bacterial activities involved in the transformation of nitrogenous organic material in the soil bear a direct relationship to the crop yields obtained. Assuming that the apparent response of plants, in many experiments, to applications of electric current might be due to the effect of the treatment on the activity of soil microorganisms, Wollny (48) treated samples of arable soil with electric currents of varying intensities and measured the evolution of carbon dioxide. His results indicate that the weakest current may have slightly stimulated bacterial activity, but that the stronger currents were harmful.

Stone (44) buried a copper and a zinc electrode in the opposite ends of small boxes filled with soil and connected the electrodes aeriaily, thus forming with the soil in each box a galvanic cell with a current of approximately 0.1 milliampere. Sterilized distilled water was added at intervals during the experiment. Bacterial counts taken on the first, fourteenth and twenty-eighth days in two successive experiments indicated a relative increase of 40 to 80 percent in numbers of organisms per gram of soil for the treatments as compared to the controls. In tests with sewerage contaminated water and with milk, Stone found that a weak current of 0.1 to 0.3 milliampere increased the bacterial counts over the controls as much as 10 to 20 times with the water, and with the milk as much as 40 to 60 times.

PURPOSE OF THE INVESTIGATION

A study of previous investigations indicates that the problem of the possible effects of electric current upon plant growth may be divided into the following phases: (1) the determination of the relationship between electric currents and plant growth; (2) the amount of current for greatest stimulus, assuming that a stimulating effect exists; (3) the character of plant response and the underlying causes; and (4) the most effective method of applying treatment. Methods of treatment previously studied may be grouped as follows: (1) application to the root areas by means of underground wires or by plate electrodes, and (2) application to the atmosphere and to the plants themselves by means of overhead network.

In outlining the present experiments it seemed logical to use electric currents similar in intensity and amount to those existing in nature during moderate weather, and to apply them by the simplest method which, in past trials, had given reasonable promise of being effective. Such conditions, i. e., weak continuous currents and simplicity, seemed best fulfilled by those methods which apply electric charges to the root areas. It was decided, therefore, to study the effect on plant growth of slight electric currents applied to the root areas by means of underground wires and by plate electrodes. This plan of using slight currents was followed throughout with the single exception of a limited greenhouse study of the effect of high voltages on oats. Results obtained were to be measured in the form of plant yields and analyses. As the experiment progressed, it appeared desirable to investigate the effect of electric current upon the activity of soil organisms, and this phase was studied in some detail. The following experimental trials and data obtained are submitted as a contribution to a more complete understanding of the relationship between the plant and its environment.

EXPERIMENTAL

UTILIZATION OF ATMOSPHERIC ELECTRICITY

METHODS

The experiment utilizing atmospheric electricity was conducted at the Agronomy Farm for 3 years, 1930-32. A level area, approximately 150 by 165 feet, of apparently fairly uniform soil was used as a test plot. The field had been in corn in 1929. In late April, 1930, the underground wiring was installed and the collector heads were set up. Seven strand, No. 22 copper radio cable was laid entirely across the plot in a direction parallel to the magnetic axis of the earth and approximately 12 inches below the surface. Four lines were laid 30 feet apart, one for each of four treatments, and three lines 4 feet apart for the fifth treatment. Furrows without cables were opened and refilled at points midway between

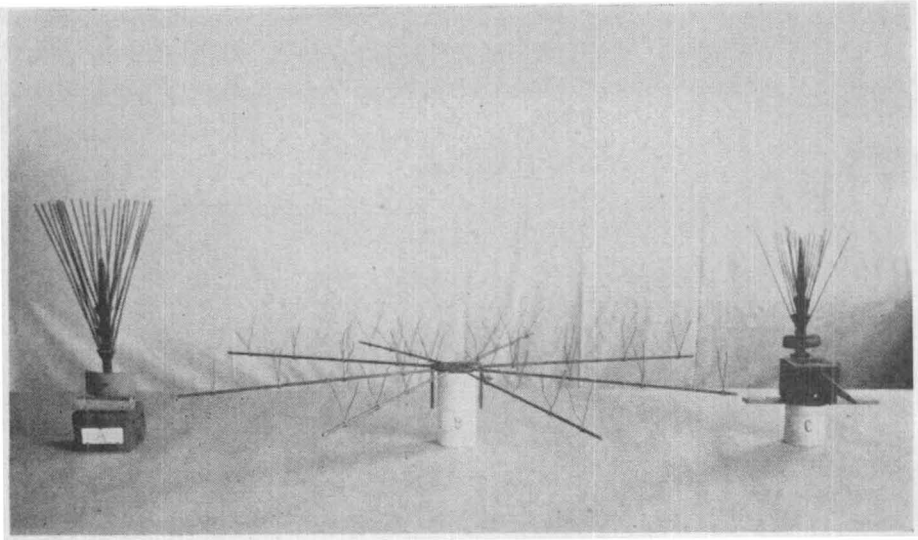


Fig. 1. Types of brushes used in the experiment with atmospheric electricity at the Agronomy Farm, 1930, 1931, 1932. Three brushes of Type A were used and one each of the others.

Type A—from C. Vincent, Omaha.

Type B—from L. W. Butler, Iowa State College.

Type C—from Justin Christofleau, La Queue les Yvelines, France.

each of the wire lines to insure the same degree of tillage in the controls as in the treated plots.

On the basis of the cable arrangement described above, the experimental field was divided into five treated plots extending north and south, each 12 feet wide and placed so that one of the buried copper cables extended exactly beneath its middle. Six control plots of like width were located, one between each two of the treatments and one outside of each of the two outer treatments. The 11 experimental areas were separated by border plots 3 feet wide.

The apparatus used for collecting the charge from the atmosphere consisted of one original Christofleau (7) apparatus and four variations, three of the Vincent type and one of our own. These were essentially brushes of wires on an iron standard, the brushes containing from 18 to 27 wires. The wires varied in length from approximately 6 to 18 inches and were so arranged on the standard that the tops of the wires were about even. The diameters of the brushes varied from 8 to 14 inches. Our design was slightly different, consisting of six brass bars 18 inches long, radiating from a central plate and carrying several copper wires projecting upward. The three types of brushes used are illustrated in fig. 1. All heads were mounted 20 feet above the ground surface. Each head and its connecting wire were insulated from the supporting timber and attached to the south end of one of the underground

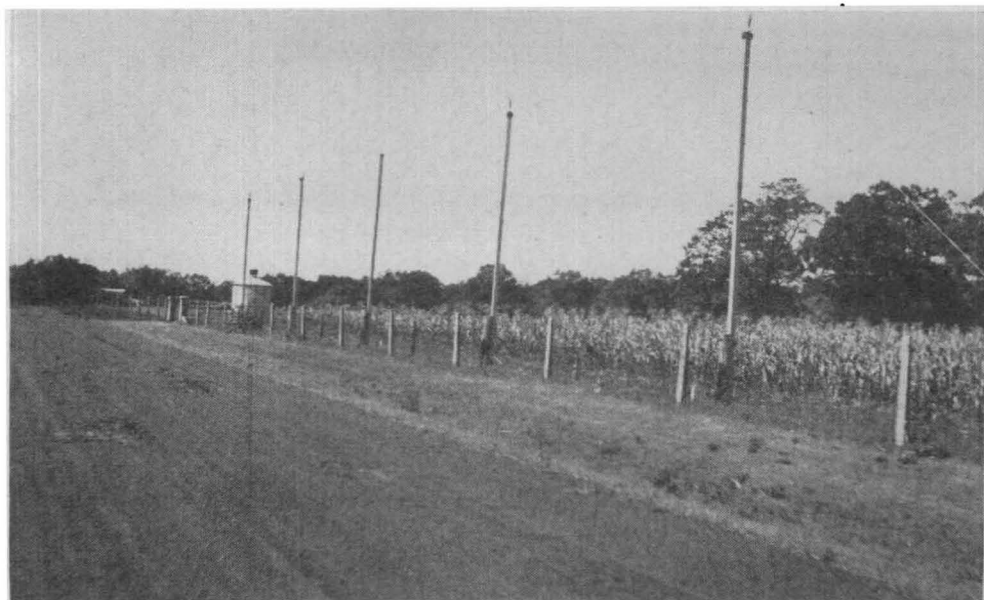


Fig. 2. Utilization of atmospheric electricity for crops, Agronomy Farm, 1930, 1931, 1932. South view of experimental field showing the five elevated brushes and instrument house.

cables. The poles carrying the collector heads were erected along the south side of the plot about 2 feet inside a woven wire fence. There were several tall soft maples within 160 feet of the elevated brushes but at this distance it was thought that they would not materially affect the results.

In order to measure at various times the charges collected by the different heads a set of lead wires mounted on insulators was set up along the line of supporting poles and connected through a series of switches to one plate of a high grade mica condenser, the other plate being connected to the ground wires. A high sensitivity Leeds and Northrup ballistic galvanometer was used to measure the charges collected. Another Leeds and Northrup type R high sensitivity galvanometer was installed to measure the current directly when the charges were large enough to produce appreciable deflections. The measuring instruments were housed in a small sheet-iron building.

Crops included throughout the 3-year test period were corn, soybeans, garden beets, string beans, Swiss chard and turnips. These crops were planted in rows at right angles to the direction of the underground wires so that each crop extended east and west across the entire series of 11 experimental plots. Each replication, of which there were at least three, included four rows of corn and four of soybeans in block, and one row each of the other crops. The arrangement of the experiment is illustrated by figs. 2 and 3.



Fig. 3. Utilization of atmospheric electricity for crops, Agronomy Farm, 1930, looking west across the experimental plots. Left to right: Soybeans, beets, chard, turnips, string beans, corn. Rows extend across the underground wires.

SEASONAL CONDITIONS

In 1930 the last rain of any considerable quantity occurred on July 4, so that by the middle of that month the ground had become dry and very hard. The summer was quite hot, the temperature on several days reaching 98 degrees or higher during the afternoons, and all crops suffered severely.

Prior to the 1931 plantings the plot had been manured and fall plowed, so the seedbed was in excellent condition. The weather was dry and hot through midsummer, but the crops came through in fair condition, and yields were obtained on all. In 1932 the season, with its fairly abundant rainfall, was generally favorable to all crops.

PRESENTATION AND DISCUSSION OF RESULTS

In 1930, from June 25 to July 10, the currents were upward, that is, the ground was gaining a negative charge, and were of the order of 5.0×10^{-9} ampere. This is about 100 times the average fair weather current as given by Wilson (47) but, as points were used here as dischargers, larger currents were to be expected. During the interval from July 11 to Sept. 6, after which time the readings were discontinued, the currents were generally downward and smaller, being of the order of 5.0×10^{-10} ampere. Through midsummer a few sprinkles of rain occurred, these being so ex-

tremely light as but momentarily to dim the brilliance of the sun. At such times large increases of current were noted, and the direction of the current, in contrast to that prevailing immediately before and after the disturbance, was upward.

In 1931 the value of the currents measured during fair weather was about the same as obtained in 1930, or of the order of magnitude of 5.0×10^{-10} ampere. There was more variation of direction than in the preceding season, so it was difficult to arrive at any definite conclusion as to the general direction of the current in fair weather. Although the summer was very dry, several showers occurred, and at such times the currents varied greatly, both in direction and magnitude. In one case, for example, the current varied from 5.0×10^{-9} ampere downward through zero to 100.0×10^{-9} ampere upward, then back through zero to 200.0×10^{-9} ampere downward, and back to zero at the close of the observations.

Up to June 21, 1932, when the current readings for the season were started, there had been a great deal of rain, and the rainy weather continued until July 10. During this time the current was much larger than in either of the previous years, being of the order of 3.0×10^{-9} ampere. The weather from July 11 to 31 was generally hot and dry with an occasional light shower. Through this period the current was of about 2.0×10^{-9} ampere and, contrary to the results obtained in 1930, the direction was generally upward. The first half of August, especially Aug. 6 to 17, was characterized by cloudy weather with frequent thunder showers. The currents during this time varied from 5.0×10^{-9} ampere upward to 55.0×10^{-9} ampere downward. The latter half of the month was mostly clear with currents of about 1.0×10^{-9} ampere upward, and similar conditions prevailed until Sept. 15 when the readings were discontinued.

Galvanometer readings were taken for each collector head, but the variations in the amounts of current for the individual collectors of the Vincent type were often greater than those measured for the different types, and the amount of charge collected was, therefore, considered to be independent of the kind of collector used.

An attempt was made to measure the current through the ground wire by tapping in at junction boxes placed 50 and 100 feet from one of the collectors. The currents measured here were many times those obtained at the base of the collector post. The condition of the ground was such that the electromotive force generated between points at opposite sides of a box was great enough to mask any effect due to the collectors which might conceivably be present at the above distances.

Each year observations were made comparing treatments and controls with reference to (1) rate of emergence of crop plants above ground, (2) vigor and rapidity of growth, and (3) time of maturity. At no time during the growth of the crops could appre-

TABLE 1. SUMMARY OF 'THREE YEARS' RESULTS—WITH AND WITHOUT INTENSIFIED EARTH-AIR ELECTRIC CURRENTS.

| | Turnips, fresh wt. of roots (lbs.) | | | Chard, fresh wt. of tops (lbs.) | | Beets, fresh wt. of roots (lbs.) | |
|--------------------------------|--|-------|-------|---------------------------------------|-------|--|------|
| | 1930 | 1931 | 1932 | 1931 | 1932 | 1931 | 1932 |
| Av. of controls..... | 10.80 | 13.96 | 16.20 | 18.31 | 17.51 | 11.58 | 6.66 |
| Av. of tr..... | 11.56 | 13.95 | 15.56 | 18.93 | 19.10 | 12.86 | 7.03 |
| Diff. favor treatments..... | 0.76 | -0.01 | -0.64 | 0.62 | 1.59 | 1.28 | 0.37 |
| Percent increase over cks..... | 7.03 | | -3.95 | 3.39 | 9.08 | 11.05 | 5.55 |

| | Corn, shelled wt. at approximately 10% moisture (lbs.) | | | Soybeans, cured wt. tops and roots (lbs.) | | | String beans, cured wt. tops and roots (lbs.) | |
|-----------------------------------|---|-------|--------|---|--------|---------|--|------|
| | 1930 | 1931 | 1932 | 1930 | 1931 | 1932 | 1930 | 1931 |
| Av. of controls..... | 6.22 | 15.07 | * 8.27 | 6.63 | * 7.05 | * 13.67 | 1.10 | 1.79 |
| Av. of tr..... | 6.26 | 15.75 | 8.04 | 6.84 | 7.11 | 13.71 | 1.12 | 1.86 |
| Diff. favor treatments | 0.04 | 0.68 | -0.23 | 0.21 | 0.06 | 0.04 | 0.02 | 0.07 |
| Percent increase over cks..... | 0.64 | 4.51 | -2.78 | 3.16 | 0.85 | 0.29 | 1.82 | 3.91 |

*Two middle rows only. Corn and soybeans planted in 4-row plots, other crops planted in 1-row plots.

cial differences of any kind be noted. In order to obtain yields on the basis of a fairly uniform moisture content, the ear corn, soybean plants and string bean plants were reduced to a uniform air dry basis.

Average yields of the crops included in this experiment are presented in table 1.

An examination of these data shows that in most instances the average yields for the plants in the treated plots were, in general, slightly larger than for the controls. The largest differences were obtained with the chard and the beets, the increases averaging approximately 7 and 9 percent, respectively. However, the variations in the individual plot yields were large, consequently small differences in average yields would not be significant. Probably because of the nature of the crops, the yields of the chard and of the beets were extremely variable; in some cases the fluctuations between contiguous plots were more than 50 percent, hence average increases much larger than those obtained would be required in order for the differences to be deemed significant.

Considering the very low intensities of the average currents obtained, which were of the order of 3.0×10^{-9} ampere or less, and recognizing the natural tendency of these currents to leak from the

underground wires near the points where the wires entered the soil, it seems obvious that the greatest effect upon crop yields should occur in the range nearest the bases of the collector timbers, i. e., in range No. 1, and that the effect should uniformly decrease in the ranges progressively farther away. Analysis of the yearly averages on this basis shows that the yield variations in range No. 1 are such as to be well within the limits of experimental error.

Since measurements of the intensities of current for the individual collector heads indicated that the variations in the intensities were independent of the type of collector used, no attempt was made to analyze the corresponding yield data.

APPLICATION OF CURRENT TO THE ROOT AREAS BY MEANS OF ELECTRODES

From 1931 to 1933, inclusive, experiments were conducted in field and greenhouse to test the effect upon plant growth of electric current applied to the root areas by means of plate electrodes. The character of these tests may be indicated in a preliminary way as follows:

- (1) Greenhouse tests with oats using high voltage currents applied for short periods daily from germination to maturity.
- (2) Greenhouse tests with oats using the slight continuous currents of the copper-zinc electrode combination supplemented in some cases by one or more dry cells.
- (3) Field tests with oats using the copper-zinc combination supplemented by batteries of dry cells providing relatively strong currents.
- (4) Laboratory tests for the rate of evolution of carbon dioxide, using slight and moderate continuous currents.

GREENHOUSE TEST WITH OATS USING HIGH VOLTAGE CURRENTS

For the various electrical experiments which were to be run in the greenhouse, 15 large and 10 small cypress flats were used. The large flats had inside dimensions of 20x30x4 inches and the small flats 15x20x4 inches.

On Feb. 13, 1931, eight of the large flats were planted to Iogold oats, one kernel in a place 2 inches apart each way and $\frac{1}{2}$ inch deep, 126 kernels per flat. The soil used was field soil apparently rather high in organic material.

A copper strip, $1\frac{1}{2}$ inches wide and 30 inches long with a covered copper conducting wire attached at the middle by solder was buried lengthwise down the middle of each of six flats. Each strip was placed on edge and shoved down into the soil until completely buried. The remaining two flats were reserved as controls. The current was provided by means of five cell Edison batteries with a

Two Edison batteries were used in order that two flats could be treated simultaneously, and the circuits were set up so that one flat would receive current of positive sign and the other would receive current of negative sign. Treatment was applied once daily in mid-afternoon, two flats receiving approximately 7,000 volts from two cells for 10 minutes, two flats receiving 10,000 volts from three cells for 15 minutes, and two flats receiving 14,000 to 20,000 volts for 15 minutes. The daily treatments were begun on Feb. 23 and continued until the grain was in the soft dough stage.

During the time current was being applied, bright sparks 1 or 2 millimeters long could be drawn from the plants by means of the fingertip or other conductor. Accidental contact of the leaves with those of another flat developed sparks with resultant destruction of plant tissue at that point. In order to prevent leakage of current from one flat to another along the bench while treatment was being applied, each flat rested upon strips of copper which could be grounded. These strips were insulated from the wood of the bench by heavy rubberized paper. During the process of treatment all flats except the two actually receiving current were protected from stray currents by grounding the copper strips.

Stands of 93 to 95 percent were obtained in all flats. The plants appeared thrifty at all times and attained a height of approximately 4½ feet at maturity. The method of supporting the plants in erect position and the general arrangement of the experiment are shown in fig. 4. Because of the extreme weight of the boxes and the difficulty of keeping the insulation in place, the relative position of the flats was changed but two or three times during the course of the experiment. Some protection was provided at one end by a box placed on edge and at the other by a flat of oats not in the test.

The oats were harvested by shearing at a height of 1 inch above the crowns. The product of each flat was reduced to an oven dry basis.

Table 2 shows that the yields of the treated lots varied both above and below the average of the two controls, and that none

TABLE 2. YIELDS OF OATS WITH HIGH VOLTAGE ELECTRIC CURRENTS APPLIED TO THE SOIL—GREENHOUSE EXPERIMENT, 1931.

| Treatment | Dry weight grain and straw | Yield compared to average of controls | Percent increase |
|--|----------------------------------|---|---------------------|
| | (lbs.) | (percent) | |
| 7000 volts for 10 min. (neg. charge) | 0.8 | 97.7 | -2.2 |
| 7000 volts for 10 min. (positive charge) | 0.8 | 97.7 | -2.2 |
| 10,000 volts for 15 min. (negative charge) | 0.8 | 94.4 | -5.5 |
| 10,000 volts for 15 min. (positive charge) | 0.8 | 98.8 | -1.1 |
| 14,000 volts for 15 min. (negative charge) | 0.9 | 100.0 | 0.0 |
| 14,000 volts for 15 min. (positive charge) | 0.9 | 102.2 | 2.2 |
| Control | 0.8 | | |
| Control | 0.9 | | |
| Average of controls | 0.9 | 100.0 | |

yielded more than the higher control. While the lots receiving currents of lesser intensities, i. e., 7,000 and 10,000 volts, showed consistent reductions in yields, the fact that the lots receiving the greatest intensities, i. e., 14,000 to 20,000 volts, yielded as much as the controls indicates that the treatments were not harmful. The variations in yields corresponding to the positive or negative sign of the charge are greater in no instance than the difference between the yields of the two controls. That the small differences obtained are not significant is shown by a statistical analysis of the variance.

GREENHOUSE TEST WITH OATS USING THE COPPER-ZINC ELECTRODES COMBINATION

In the late winter of 1931, as a preliminary test, one of the large flats was equipped with a copper-zinc electrode combination to form what shall be, for convenience, designated as an "earth cell." The electrodes used were thin strips 2 inches wide and 20 inches long with a length of covered copper wire soldered to one end of each. A strip of copper and a strip of zinc were pressed into the soil at opposite ends of the flat, the copper wires mounted on hard rubber posts along one rim of the box and joined by tubular set screw connectors. Such an arrangement formed with the moist soil a galvanic cell which provided a small current of approximately 0.5 milliamperes with a potential of 1 volt. The amount of current varied somewhat during the test and the variation was in direct proportion to the amount of moisture in the soil. This "earth cell," and a similar flat which was to be used as the control, were planted to Iogold oats on March 18. The soil with which the flats were filled was similar to that used in the high voltage experiment.

From the time the plants were about 6 inches in height those in the treated flat were noticeably more vigorous and taller than those in the control flat. The treated plants headed approximately 2 days later than the others and the yield at maturity was 12.46 percent larger than the yield of the plants in the control flat.

While the results obtained from the preliminary earth cell test could not be considered conclusive on account of the small number of comparisons, the method of treatment appeared promising and it was decided to continue this type of experiment on a more extensive scale.

Experiment in 1932.—In January, 1932, two series of experiments with the earth cells were started. For series No. 1 a soil mixture of rather low fertility was used. Twelve of the large flats were filled to a depth of $2\frac{1}{2}$ inches with a soil mixture composed of four-fifths field soil and one-fifth sand. Seven of these flats were equipped with the copper-zinc electrodes in the manner described in the preliminary test, except that with two of the seven flats a dry cell was included in the circuit. Measurements taken with a Weston milliammeter indicated, at the beginning of the experi-

ment, currents in the ordinary earth cells of 1.0 to 1.5 milliamperes and in those supplemented with a dry cell of 2.0 to 2.5 milliamperes. During most of the test period, beginning with the time when the roots had apparently formed somewhat of a mat, the currents indicated were of the order of 0.5 milliamperes and 1.5 milliamperes, respectively. A fairly constant degree of current intensity was maintained by replacing the dry cells as often as was necessary. Five similar flats without electrodes were included as controls.

Series No. 2 included 10 small flats, inside dimensions 15x20x4 inches, of which five were to be used as earth cells and five as controls. These were filled with 2½ inches of a comparatively rich soil mixture composed of one-third each of field soil, compost and sand. In order to test the possible effect of zinc as dissolved from the zinc electrodes in the earth cells, two of the controls and two of the earth cells were treated with a solution of zinc sulfate at the rate of 50 pounds per acre. This treatment was applied 15 days after the plants were up. To test the possible effect of copper, a copper strip was buried at one end of each of two controls. Of the remaining four flats, two were given no treatment. It was thought that the above described comparisons might provide leads for further investigation.

The seed oats used throughout were of the Logold variety. Series No. 1 was planted on Jan. 23 with 126 selected uniform grains per flat, 2 inches apart each way, and covered ½ inch deep. The flats were placed, six on each side, on the wide center bench of the greenhouse and supported on a double wooden track of 1x6-inch strips set on edge in the sand. In order that all lots might be subjected to fairly uniform growing conditions, the series was rotated systematically in a clockwise direction, all flats being moved two places to the right once every 7 days.

On Feb. 18 all lots in series No. 1 were reduced to a uniform stand of 113 plants per flat. Toward the last of March the oats in this low fertility series appeared to be suffering from the low nutrient level and on March 31 were fertilized at the rate of 100 pounds of NaNO_3 and 75 pounds of KH_2PO_4 per acre. The required amounts of these salts were dissolved in 1200 cubic centimeters of distilled water and applied with a fine sprinkler at the rate of 100 cc. of the solution per flat. This treatment was repeated on April 12 at the rate of 50 pounds of NaNO_3 and 75 pounds of KH_2PO_4 per acre, and on April 23 at the rate of 150 pounds of NaNO_3 and 75 pounds of KH_2PO_4 per acre. This final treatment was applied 4 days after heading.

The 10 flats of the high fertility series were planted on Feb. 6 with 54 grains per flat. The stand obtained was reduced to a uniform number of 50 plants per flat. On the richer soil of this series the plants grew rankly and produced much straw with but little grain.



Fig. 5. Earth cell test with oats, 1932. Alternate flats are equipped with the copper-zinc electrode combination. Two lots have additional current supplied by a dry cell. The high fertility lots are at the far end of the bench.

The house was visited at least twice daily, the temperature checked and the plants watered sufficiently to keep them growing well. It was possible to keep the temperatures below 70 degrees F. during the early part of the experiment. The arrangement of the experiment is shown in fig. 5.

The rate of germination, as observed on Feb. 11 when the young plants were emerging from the soil, was approximately equal for all lots. Observations on the time of heading April 19 failed to disclose consistent differences between treated and control plants.

For the study of the effect of electric current upon the numbers of soil microorganisms, samples of soil, each about a pint in size, were taken from several of the treated and control lots in series No. 1. A 6-inch vertical slice about 1 inch in width was cut from between the rows, taking roots as well as soil. Composite lots were made up of three samples, one from each end and one from the middle of the flat. In the laboratory, samples 50 grams in size were thoroughly shaken in distilled water and the usual dilution methods followed. The final dilutions were plated in replications of five upon the sodium albuminate agar culture made up according to directions given by Fred and Waksman (10). Determinations of moisture content were made by reducing lots 100 grams in size to oven dryness.

TABLE 3. NUMBER OF MICROORGANISMS IN SOIL OF LOW FERTILITY
WITH ELECTRIC CURRENT, 0.5 TO 1.5 MILLIAMPERES—
GREENHOUSE EXPERIMENT WITH OATS, 1932.

| Treatment | Number of organisms | | Percent moisture soil |
|--|---------------------|-------------------|-----------------------|
| | Average 5 plates | Per gram dry soil | |
| Sampled 4/27, counted 5/2, dilution 1-100,000 | | | |
| Earth cell plus dry cell— | | | |
| copper..... | 51.8 | 118,800 | 14.7 |
| middle..... | 54.4 | 126,200 | 16.0 |
| zinc..... | 33.8 | 79,700 | 17.9 |
| average..... | | 108,200 | |
| Earth cell— | | | |
| copper..... | 24.4 | 55,200 | 13.1 |
| middle..... | 15.8 | 35,900 | 13.6 |
| zinc..... | 32.8 | 75,700 | 15.4 |
| average..... | | 55,600 | |
| Control— | | | |
| end..... | 24.6 | 55,900 | 13.6 |
| middle..... | 20.0 | 46,000 | 15.2 |
| end..... | 18.6 | 43,500 | 17.1 |
| average..... | | 48,500 | |
| Sampled 5/11, counted 5/16, dilution 1-100,000 | | | |
| Earth cell plus dry cell— | | | |
| copper..... | 51.6 | 122,300 | 18.5 |
| middle..... | 31.2 | 73,400 | 17.6 |
| zinc..... | 26.4 | 60,300 | 14.1 |
| average..... | | 85,300 | |
| Earth Cell— | | | |
| copper..... | 17.4 | 40,300 | 15.7 |
| middle..... | 29.2 | 68,000 | 16.5 |
| zinc..... | 30.6 | 70,800 | 15.7 |
| average..... | | 59,700 | |
| Control— | | | |
| end..... | 15.8 | 37,100 | 17.3 |
| middle..... | 24.2 | 56,800 | 17.3 |
| end..... | 12.4 | 29,000 | 17.0 |
| average..... | | 41,000 | |
| Sampled 5/26, counted 6/2, dilution 1-100,000 | | | |
| Earth cell No. 1..... | 25.0 | 58,500 | 17.1 |
| Earth cell No. 2..... | 21.3 | 49,800 | 17.3 |
| Earth cell No. 3..... | 22.6 | 53,000 | 17.3 |
| average..... | | 53,800 | |
| Control No. 1..... | 21.0 | 50,900 | 21.3 |
| Control No. 2..... | 14.0 | 32,500 | 16.3 |
| Control No. 3..... | 13.6 | 31,400 | 15.4 |
| average..... | | 38,300 | |

In connection with this study an effort was made to determine the possible effect of the zinc and copper electrodes upon the numbers of organisms in the nearby soil areas. For this purpose three separate samples were taken from some of the treated lots, one each from near the zinc and copper electrodes and one from the middle of the flat. The results of the soil microorganisms counts are shown in table 3.

TABLE 3—Continued.
SUMMARY—NUMBERS OF MICROORGANISMS

| Treatment | Date sampled | No. of flats sampled | No. of samples | Organisms per gram dry soil | Increase over controls (percent) |
|-------------------------------|--------------|----------------------|----------------|-----------------------------|----------------------------------|
| Earth cell plus dry cell..... | 4/27 | 1 | 3 | 108,200 | 123.09 |
| Earth cell..... | 4/27 | 1 | 3 | 55,600 | 14.64 |
| Control..... | 4/27 | 1 | 3 | 48,500 | |
| Earth cell plus dry cell..... | 5/11 | 1 | 3 | 85,300 | 108.05 |
| Earth cell..... | 5/11 | 1 | 3 | 59,700 | 45.60 |
| Control..... | 5/11 | 1 | 3 | 41,000 | |
| Earth cell..... | 5/26 | 3 | 3 | 53,800 | 40.47 |
| Control..... | 5/26 | 3 | 3 | 38,300 | |

The summary of table 3 shows, for the treatments as compared to the controls, increases in numbers of soil microorganisms for the earth cells of from 14 to 45 percent, and for the earth cells supplemented with dry cells increases of more than 100 percent. These differences seem large enough to indicate a stimulating effect of the electric current. On each successive date the lots of soil were taken from flats not previously sampled. For the four treated flats sampled so as to test the possible effect of the zinc and the copper electrodes on the number of organisms in the nearby areas of soil, the results fail to show consistent differences.

The high greenhouse temperatures during much of the heading period quickly brought all lots to maturity. The plants of series No. 2, though planted 2 weeks later on richer soil than those of the other series, ripened but a little later and all were harvested on May 2. The data in tables 4 and 5 indicate that the yields of oats matured on the soil of low fertility were rather consistently increased by treatment with electric current. Apparently a still greater stimulus was provided by the slightly stronger currents in the circuits including dry cells. Statistical analysis indicates that the differences in favor of the treatment are significant.

Comparisons of yields obtained on the soil of high fertility do not seem to warrant the forming of definite conclusions, but the following differences may be noted: (1) the applications of zinc sulfate appear to have been harmful, as the yields of the four lots to which it was applied, including lots with and without electric current, were from 8 to 15 percent lower than those of the controls receiving no zinc sulfate; (2) the effect of the copper plate was negligible; (3) the effect of the electric treatment was not beneficial, as the yields from the two earth cells receiving no other treatment averaged 6 per cent lower than those of the controls.

Experiment in 1933.—The following winter, 1932-33, the greenhouse test with the copper-zinc electrodes combination was repeated. Ten of the large flats, to be designated as series No. 1, were filled with a soil mixture composed of five parts of field soil,

TABLE 4. YIELD OF OATS (DRY WEIGHT) ON SOIL OF LOW FERTILITY.
EARTH CELL ELECTRIC CURRENT (0.5 TO 1.5 MILLIAMPERES)—
GREENHOUSE EXPERIMENT, 1932.

| | Flat No. | Grain gms. | Grain and straw gms. |
|-------------------------------|-------------|---------------|----------------------------|
| Control..... | 1 | 82.60 | 217.73 |
| Control..... | 2 | 74.13 | 208.66 |
| Control..... | 3 | 75.59 | 217.73 |
| Control..... | 4 | 80.00 | 213.19 |
| Control..... | 5 | 86.20 | 244.94 |
| Averages..... | | 80.50 | 220.45 |
| Earth cell..... | 6 | 84.55 | 217.73 |
| Earth cell..... | 7 | 92.20 | 240.41 |
| Earth cell..... | 8 | 84.75 | 235.87 |
| Earth cell..... | 9 | 93.60 | 254.02 |
| Earth cell..... | 10 | 87.03 | 222.26 |
| Averages..... | | 88.43 | 234.06 |
| Earth cell plus dry cell..... | 11 | 94.10 | 249.48 |
| Earth cell plus dry cell..... | 12 | 93.00 | 263.09 |
| Averages..... | | 93.55 | 256.28 |

one part of compost and one part of sand to a depth of 3 inches. Series No. 2 included 10 of the small flats filled with a mixture composed of four parts of field soil, one part of compost and one of sand. It was planned to have two distinct levels of soil fertility but due to an error the percentage of compost in series No. 2 was not increased sufficiently and probably little difference in fertility was obtained.

Five flats in each series were equipped with the copper and zinc strips as described in the experiment of the previous year. In the experiment for this year, however, a dry cell was included in each circuit. Five flats in each series were used as controls. All connections were installed 4 days before planting.

In order to prevent the lodging which might result from the frequent moving of the flats and the top-heavy growth characteristic of greenhouse plants, an adjustable network of light cord was constructed for each flat. Each network was stretched from corner posts and raised from time to time so as always to provide adequate support. Figures 6a and 6b show the arrangement of the experiment.

In this experiment rather systematic observations on the amounts of current were taken throughout the period of the test, using a Weston milliammeter. The current readings, taken before and after watering, show a large variation in amounts of current due to the moisture content of the soil. At no time was the soil of any flat dry enough to cause wilting of the plants, yet the addition of water resulted in almost 100 percent increases in the amounts of current. During much of the time, especially toward the end

TABLE 5. YIELD OF OATS (DRY WEIGHT) ON SOIL OF HIGH FERTILITY, EARTH CELL ELECTRIC CURRENT (0.5 TO 1.5 MILLIAMPERES) WITH VARIOUS AUXILIARY TREATMENTS—GREENHOUSE EXPERIMENT, 1932.

| | Flat No. | Grain and straw |
|---|----------|-----------------|
| Earth cell with ZnSO ₄ | 2 | gms. 276.70 |
| Earth cell with ZnSO ₄ | 7 | 258.55 |
| Averages..... | | 267.62 |
| Earth cell..... | 5 | 285.77 |
| Earth cell..... | 10 | 285.77 |
| Averages..... | | 285.77 |
| Control with ZnSO ₄ | 1 | 267.62 |
| Control with ZnSO ₄ | 6 | 272.16 |
| Averages..... | | 269.89 |
| Control with copper plate..... | 4 | 322.06 |
| Control with copper plate..... | 9 | 294.84 |
| Averages..... | | 308.45 |
| Control..... | 3 | 308.45 |
| Control..... | 8 | 294.84 |
| Averages..... | | 301.64 |

of the growing period, the amounts of current used in this experiment were considerably greater than the 1.5 milliamperes used in the heavier of the 1932 treatments.

On Dec. 27 all flats were planted to Iogold oats, at the rate of 126 grains for the large flats and 54 grains for the small flats. The individual grains had been selected for uniformity in size and freedom from discoloration and were from a sample which had been treated with Ceresan. A preliminary germination test had shown a strong and healthy growth.

The rate of germination in and between flats was very uniform and no differences whatever could be observed as a result of the electrical treatment.

Counts of the numbers of tillers by rows within each flat indicated a definite trend in amount of tillering always in the same di-

TABLE 6. RATE OF GERMINATION OF OATS IN FLATS RECEIVING CURRENT AND IN CONTROLS. EARTH CELL TREATMENT, GREENHOUSE, 1933.

| Flat No. | Date covered | Date of emergence | Hours elapsed |
|---------------------------|--------------|-------------------|---------------|
| 4 and 5 (series 1)..... | 12/27— 9 am | 12/31—11 am | 98 |
| Remainder (series 1)..... | 12/27—12 am | 12/31— 3 pm | 99 |
| Series 2..... | 12/27— 3 pm | 12/31— 6 pm | 99 |



Fig. 6a. Earth cell tests with oats, 1938. Alternate flats are earth cells, with dry cells included in the circuits. The other flats received no treatment. Photographed April 6.

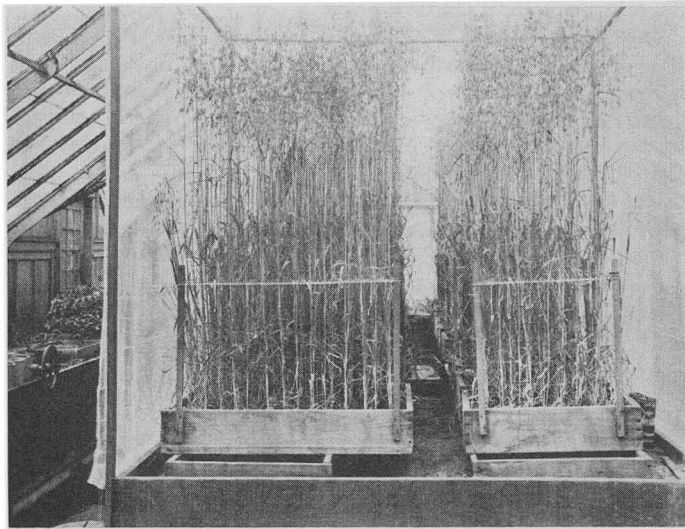


Fig. 6b. Same experiment photographed May 15, showing enclosure of mosquito netting.

TABLE 7. NUMBER OF TILLERS (OATS) PER FLAT ON FEB. 4, EARTH CELL TREATMENT, GREENHOUSE, 1933.

| Treatment | Flat No. | | | | | | | | | |
|--------------------------------|----------|----|----|----|-----|----|----|----|----|----|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 5 large flats—treated | 39 | | 57 | | 128 | | 55 | | 36 | |
| 5 large flats—controls | | 78 | | 46 | | 60 | | 50 | | 34 |
| 5 small flats—treated | 15 | | 6 | | 17 | | 2 | | 27 | |
| 5 small flats—controls | | 14 | | 7 | | 11 | | 9 | | 31 |

rection. Since this trend was noted in the controls as well as in the treatments, it is apparent that these differences must have been due to environmental conditions other than those provided by the treatment. A comparison of numbers of tillers per flat between the treatments and the controls is favorable to the treatments in the case of the large flats, but with the small flats no differences are apparent.

In connection with the study of the effect of the treatment on the rate and amount of growth, observations were made with respect to the approximate time of emergence of the heads. Counts were made on the basis of the number of plants showing terminal spikelets above the boot. The data indicate that the treatment with electric current had no effect on the time of heading.

Shortly after the complete emergence of the heads, many blasted spikelets were noted in all lots. Counts were made of the numbers of these spikelets in two corresponding rows in each lot, using in all flats the second row from each end. The data indicate that apparently there is no correlation between the treatment and the number of blasted spikelets. While there was considerable variation in the number of blasted spikelets for individual flats, the differences within the treated or the control groups were as large as the differences between any pair of treated or control flats.

For the counts of microorganisms, the methods of sampling, dilution and plating were the same as those used in the experiment of the previous year. Results are shown in tables 8 and 9.

In this study of the effect of electric current upon the numbers of soil microorganisms, the increases, averaging approximately 18 percent, obtained in the soil of the treated lots seem a rather definite indication of the favorable effect of the electric current. However, examination of the data discloses large variations between individual flats of both the treated and the control groups. In a number of instances the numbers of organisms for the controls were considerably larger than for the treated flats. A statistical study applying the analysis of variance indicates that the differences obtained in this test were not significant.

All lots were harvested by clipping as previously described. At this time the heights of all lots varied from 52 to 54 inches, and

TABLE 8. NUMBERS OF SOIL MICROORGANISMS, SERIES NO. 1,
EARTH CELL TREATMENT, GREENHOUSE, 1933.

| Flat No. | No. of organisms per gram dry soil | Percent moisture soil | Current m. a. |
|----------|------------------------------------|-----------------------|---------------|
| | Sampled 3-19 | | |
| 1 | 97,900 | 17.1 | 1.1 |
| 2 | 121,300 | 17.1 | |
| 3 | 131,400 | 19.0 | 1.9 |
| 4 | 81,400 | 19.0 | |
| 5 | 124,400 | 23.4 | 2.1 |
| 6 | 91,500 | 17.9 | |
| 7 | 103,300 | 19.0 | 1.5 |
| 8 | 87,600 | 18.2 | |
| 9 | 88,100 | 17.1 | 1.1 |
| 10 | 106,500 | 16.3 | |
| | Av. of treatments (1-3-5-7-9) | | 109,000 |
| | Av. of controls (2-4-6-8-10) | | 97,800 |
| | Percent increase over controls | | 11.4 |
| | Sampled 4-27 | | |
| 1 | 45,300 | 14.4 | 2.5 |
| 2 | 35,800 | 10.6 | |
| 3 | 41,400 | 16.3 | 2.4 |
| 4 | 32,100 | 16.3 | |
| 5 | 49,900 | 17.6 | 2.0 |
| 6 | 32,100 | 13.1 | |
| 7 | 43,600 | 13.6 | 1.8 |
| 8 | 49,000 | 13.4 | |
| 9 | 38,100 | 13.4 | 2.0 |
| 10 | 29,300 | 11.1 | |
| | Av. of treatments (1-3-5-7-9) | | 43,700 |
| | Av. of controls (2-4-6-8-10) | | 35,700 |
| | Percent increase over controls | | 22.4 |

TABLE 9. NUMBERS OF SOIL MICROORGANISMS, SERIES NO. 2,
EARTH CELL TREATMENT, GREENHOUSE, 1933.

| Flat No. | No. of organisms per gram dry soil | Percent moisture soil | Current m. a. |
|----------|------------------------------------|-----------------------|---------------|
| | Sampled 3-13 | | |
| 1 | 76,300 | 14.9 | 1.3 |
| 2 | 51,600 | 12.6 | |
| 3 | 109,400 | 17.6 | 1.1 |
| 4 | 68,700 | 14.9 | |
| 5 | 83,100 | 15.7 | 1.0 |
| 6 | 77,000 | 13.6 | |
| 7 | 71,100 | 19.7 | 1.1 |
| 8 | 86,200 | 14.9 | |
| 9 | 65,700 | 14.9 | 1.0 |
| 10 | 68,400 | 14.4 | |
| | Av. of treatments (1-3-5-7-9) | | 81,100 |
| | Av. of controls (2-4-6-8-10) | | 70,400 |
| | Percent increase over controls | | 15.2 |
| | Sampled 5-2 | | |
| 1 | 60,000 | 17.1 | 1.9 |
| 2 | 75,700 | 12.6 | |
| 3 | 61,700 | 17.0 | 1.7 |
| 4 | 60,300 | 17.0 | |
| 5 | 61,900 | 16.3 | 1.9 |
| 6 | 33,300 | 10.9 | |
| 7 | 55,800 | 16.3 | 3.0 |
| 8 | 41,400 | 13.6 | |
| 9 | 58,800 | 14.0 | 2.0 |
| 10 | 32,000 | 11.1 | |
| | Av. of treatments (1-3-5-7-9) | | 59,600 |
| | Av. of controls (2-4-6-8-10) | | 48,500 |
| | Percent increase over controls | | 22.8 |

TABLE 10. EFFECT OF ELECTRIC CURRENT OF LOW INTENSITY (COPPER-ZINC ELECTRODE COMBINATION) ON YIELDS OF OATS (DRY WEIGHT)—GREENHOUSE EXPERIMENT, 1933.

| Series | Grain | | Straw | | Roots | | Total | |
|------------------------------------|-------|------|-------|-------|-------|------|-------|-------|
| | Tr.* | Ck.* | Tr. | Ck. | Tr. | Ck. | Tr. | Ck. |
| | gms | gms | gms | gms | gms | gms | gms | gms |
| 5 small flats (ave) | 58.2 | 58.5 | 123.5 | 118.7 | 44.0 | 47.4 | 225.7 | 224.6 |
| Percent increase over cks. | -0.5 | | 3.9 | | -7.7 | | 0.5 | |
| 5 large flats (ave) | 97.2 | 99.5 | 217.9 | 213.6 | 66.4 | 73.6 | 381.5 | 386.7 |
| Percent increase over cks. | -2.3 | | 2.0 | | -10.8 | | -1.3 | |

* Tr—treated
* Ck—control

no consistent differences in amount of growth could be observed. Each lot was rolled in mosquito netting and reduced to an oven dry basis. The roots of each lot were washed and dried, and yields determined. Yields of grain, straw and roots are shown in table 10.

Study of the data for the yields of the treated flats as compared to the controls fails to reveal consistent differences except for the yields of roots. While the differences are not large, the consistently lower root yields from the treated flats indicate that the amount of electric current used in this experiment has been harmful to root growth. This conclusion is supported by statistical analysis.

For the determinations of total nitrogen in the grain, straw and roots, representative samples were ground in a Wiley mill. One gram samples of the grain and 2 gram samples of the straw and roots were used and determinations made by the Kjeldahl method. Results of these analyses are shown in table 11.

A study of the nitrogen analyses with respect to the averages and the individual items within the treatments shows that there are no consistent differences in the percentages of total nitrogen in the grain or in the straw. There does appear to be a consistent reduction in the total nitrogen in the roots of the treated lots, and this conclusion is supported by statistical analysis of the data.

TABLE 11. PERCENT TOTAL NITROGEN IN GRAIN, STRAW AND ROOTS (OATS), EARTH CELL TREATMENT, GREENHOUSE, 1933.

| Series | Grain | | Straw | | Roots | |
|-------------------------------|---------|---------|---------|---------|---------|---------|
| | Treated | Control | Treated | Control | Treated | Control |
| | % | % | % | % | % | % |
| 5 small flats (ave) | 1.89 | 1.91 | .419 | .420 | 1.27 | 1.37 |
| 5 large flats (ave) | 1.65 | 1.66 | .364 | .365 | 1.32 | 1.38 |

FIELD TEST WITH OATS USING THE COPPER-ZINC ELECTRODE
COMBINATION

During the season of 1932 the electrode method of applying weak electric currents to plants was tested under field conditions. A level plot, 74 by 36 feet in size, of apparently uniform soil, was selected in College Field and on April 8 drilled to logold oats. The oats were planted in rows running north and south, 6 inches apart. This area was laid out with 20 treated and 23 control plots, each 40 inches wide and 50 inches long, with intervening buffer strips 30 inches wide. For the treated plots the copper-zinc electrode combination was installed. The metal strips, each 40 inches long and 2 inches wide, were pressed into the soil to a depth of about 3 inches at the ends of the 50-inch plots. Each control and treatment, therefore, included eight grain rows 40 inches long.

For the treatments, two levels of current intensity were used. With 10 plots, six dry cells in series were included in each circuit, while the remaining 10 received the current from three dry cells per plot. Later, as the meter readings dropped, the number of cells was increased to eight and four, respectively, and on June 10 all cells were replaced. During the progress of the experiment the cell groups were enclosed in rain proof boxes. All treatments were installed on April 22 when the plants were approximately 1 inch in height. The arrangement of the field with the locations of the high and the low treatments, also the intervening controls, is shown in fig. 7.

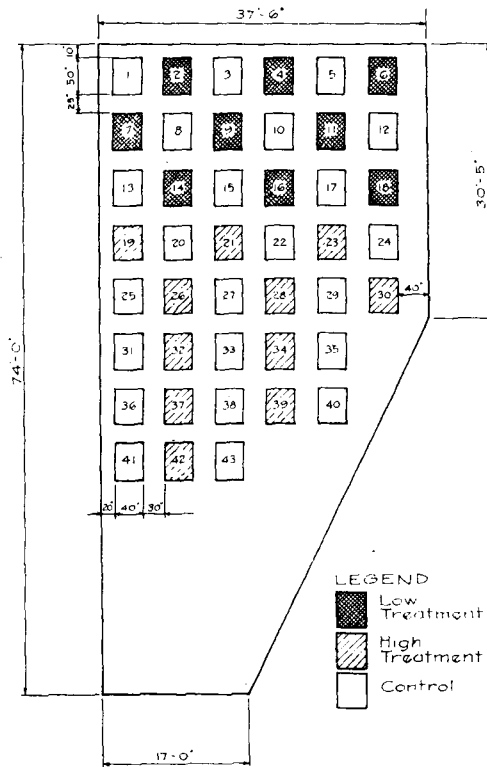


Fig. 7. Planting plan of earth cell experiment, copper-zinc electrode combination, with oats, College Field, 1932.

The season was favorable for growth and the crop grew well. Ripening progressed normally, and the quality was good. During the growth and ripening period no differences as the result of treatment could be observed.

Counts of soil microorganisms, yields of grain and straw, and analyses of total nitrogen were obtained as in the greenhouse test. The experimental plots were harvested on July 7. For the harvesting a braced frame was constructed with two parallel prongs 50 inches long and 40 inches apart, and the limits of the area to be harvested were determined by thrusting the prongs across the rows at the ground from one end to the other of the plot. The results are presented in table 12.

TABLE 12. EFFECT OF ELECTRIC CURRENT (COPPER-ZINC ELECTRODE COMBINATIONS SUPPLEMENTED WITH DRY CELLS) ON NUMBERS OF SOIL ORGANISMS, OATS CROP YIELDS AND PERCENT TOTAL NITROGEN, COLLEGE FIELD, 1932

| Treatment | Number of plots | Crop yield in grams | % total nitrogen | | Soil organisms per gram |
|---------------|-----------------|---------------------|------------------|-------|-------------------------|
| | | | Grain | Straw | |
| High*..... | 10 | 727.6 | 1.825 | 0.293 | 105,000 |
| Controls..... | 14 | 709.3 | 1.869 | 0.294 | 106,000 |
| Low..... | 10 | 695.4 | 1.879 | 0.312 | 100,000 |
| Controls..... | 10 | 685.4 | 1.850 | 0.315 | 87,000 |

*Note: The following meter readings in milliamperes are indicative of current intensities during the experiment: April 22, high 20-55, low 12-30; June 23, high 8-15, low 3-10; June 28, high 5-12, low 2-8; June 30, high 5-12, low 2-8.

The results of this field experiment indicate that the treatment with electric current did not appreciably affect the percentage of total nitrogen nor the numbers of soil organisms. The crop yields on the treated plots were somewhat higher than on the controls, but statistical analysis indicates that the differences are not significant.

THE EFFECT OF ELECTRIC CURRENT UPON THE FORMATION OF CARBON DIOXIDE IN THE SOIL

In order to investigate further the possible effects of slight electric currents upon the numbers of soil microorganisms, samples of soil were treated with different intensities of current, and the effect was measured in terms of carbon dioxide formation. Since carbon dioxide is produced by nearly all types of these organisms, the amounts evolved can be assumed to indicate rather definitely the combined effect of the number and activity of the organisms in the soil studied. This test was conducted in May and June, 1934.

The soil used was a Clarion loam taken from 2 to 5 inches below the surface in an old alfalfa field. After air drying several days the soil was pulverized with mortar and pestle, screened through a 20-mesh sieve and spread out for further drying. Just prior to

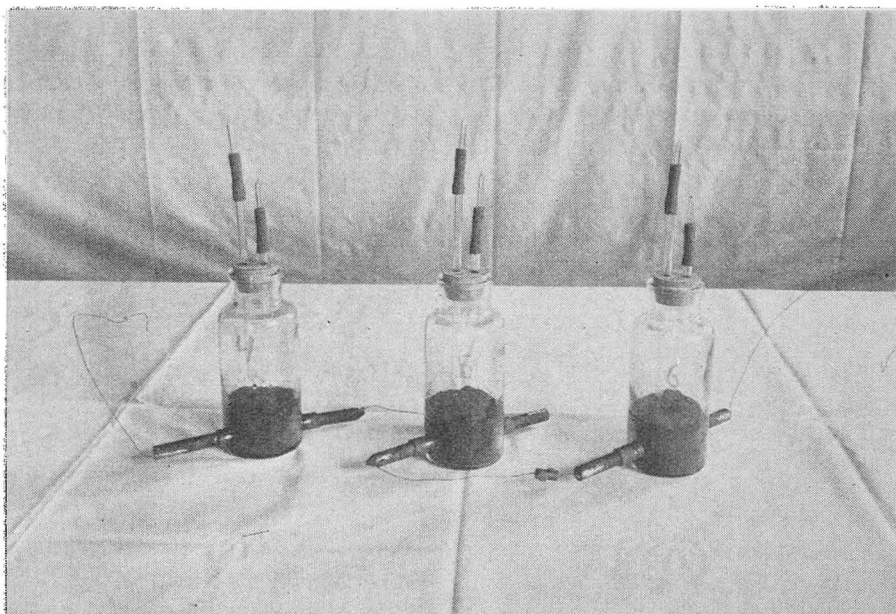


Fig. 8. Group of three 200-gram (dry weight) samples of soil in gas bottles wired in series for treatment with electric current. Part of experiment to measure effect of electric current on CO_2 formation in soil.

the taking of the experimental samples, the moisture content of the air-dry soil was determined by reducing it to oven dryness.

Each experimental sample, consisting of 200 grams of the thoroughly mixed, air-dry Clarion loam, was weighed into a 500 cc. gas bottle and the moisture content raised to approximately 21 percent by adding 40 cc. of a nutrient solution prepared by adding to each 40 cc. of distilled water 2 grams of cane sugar and 0.6 grams of ammonium sulfate.

Nine experimental samples of soil, in groups of three samples each, were used for the test. One group was subjected to a current of 10-15 milliamperes, the second group received approximately 0.1 milliampere, and the samples of the third group were used as controls. The heavier current was obtained from a direct current generator and the lighter from storage batteries. Treatments were continuous and were applied throughout the full period of the test, except during the time necessary for drawing off the carbon dioxide.

The gas bottles for the treated samples were equipped with two carbon electrodes, 0.5 inch in diameter, projecting through holes bored in opposite sides about $\frac{3}{4}$ inch above the bottoms. The ends of the electrodes intended to be in contact with the soil projected $\frac{1}{2}$ inch beyond the inner walls and were sealed in place to prevent leakage. The three bottles in each group were connected

TABLE 13. ANALYSIS OF VARIANCE IN AMOUNTS OF CO₂ IN SOILS TREATED WITH DIFFERENT INTENSITIES OF ELECTRIC CURRENT.

| Source of variation | Degrees of freedom | Mean square |
|-------------------------------------|--------------------|-------------|
| Total..... | 26 | |
| Between means of treatments..... | 2 | 52,282.21* |
| Between means of time..... | 2 | 119,268.30* |
| Interaction-treatment and time..... | 4 | 2,017.80** |
| Error..... | 18 | 1,113.74 |

* Highly significant.

** Not significant.

in series, as illustrated in Fig. 8, and placed in the proper circuit. Each bottle was stoppered with a two-hole rubber stopper equipped with glass tubes to which were attached short lengths of rubber tubing. During the treatment these openings were closed with tightly fitting solid glass rods. One of the two glass tubes in each bottle extended to a point just above the surface of the soil, the other terminated just below the stopper.

For the aspiration of the carbon dioxide, the soil flasks were connected to 500 cc. suction flasks containing from 20 to 80 cc. of approximately 0.5N KOH, the amount used depending on the length of time elapsed since the previous determination. Each suction flask was equipped with a tower containing approximately 18 inches of glass beads, so that during aspiration the KOH, which was drawn up into the tower, would have the maximum absorption rate. Suction, applied at the upper ends of the towers, was provided by a water pump. The CO₂ free air, which was led to the soil flasks during the aspiration process, had been drawn first through a 30-inch tower of glass beads kept moist with constantly circulating NaOH, and then through two gas-washing bottles in series filled with 35 percent KOH. From each soil flask the CO₂ laden air was drawn into a suction flask and bubbled through the KOH in the tower.

At the end of the aspiration period the beads were washed from the absorption towers into their respective flasks with distilled water, 10 cc. of BaCl₂ for each 20 cc. of KOH were added, and the solution titrated against 0.1070N HCl. The experiment was continued for 72 hours and determinations of CO₂ were made at the end of each 8-hour period for the first day, and at the end of each 24-hour period for the next 2 days. The results of this experiment are presented in table 13.

Table 13 indicates that the numbers or activities of soil microorganisms, as measured by the evolution of carbon dioxide, have been affected appreciably by electric current. That the effect of

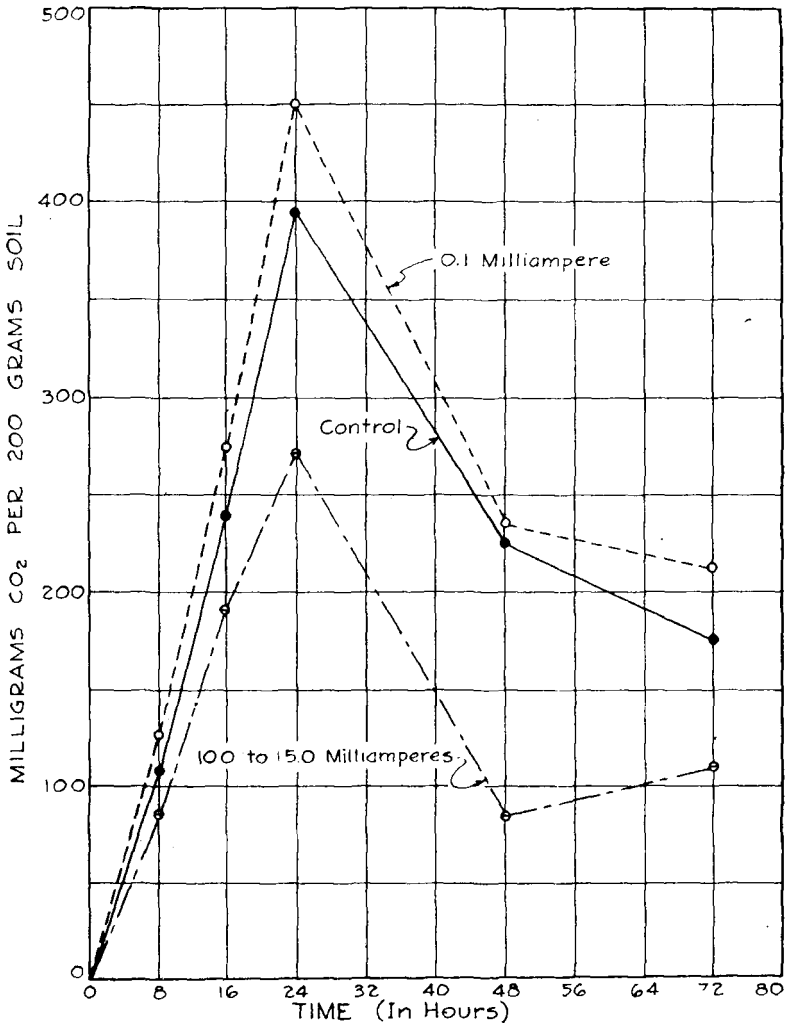


Fig. 9. Effect of electric current on CO₂ formation in soil.

such treatment is independent of the time the readings were taken is indicated by the fact that the interaction between treatment and time is not significant.

The amounts of carbon dioxide obtained at the end of each interval are shown in fig. 9. A comparison of the three curves in this figure shows that the depressing effect of the stronger current was considerably greater than the stimulating effect of the weak current. Analysis of the variations in the means of the weak

treatment and of the controls indicates that the stimulating effect of the weak current is of doubtful significance.

For all treatments, much larger amounts of carbon dioxide were obtained for the first 24-hour period than for the succeeding intervals, a result which probably was due in part to the early but temporary effect of the nutrient solution.

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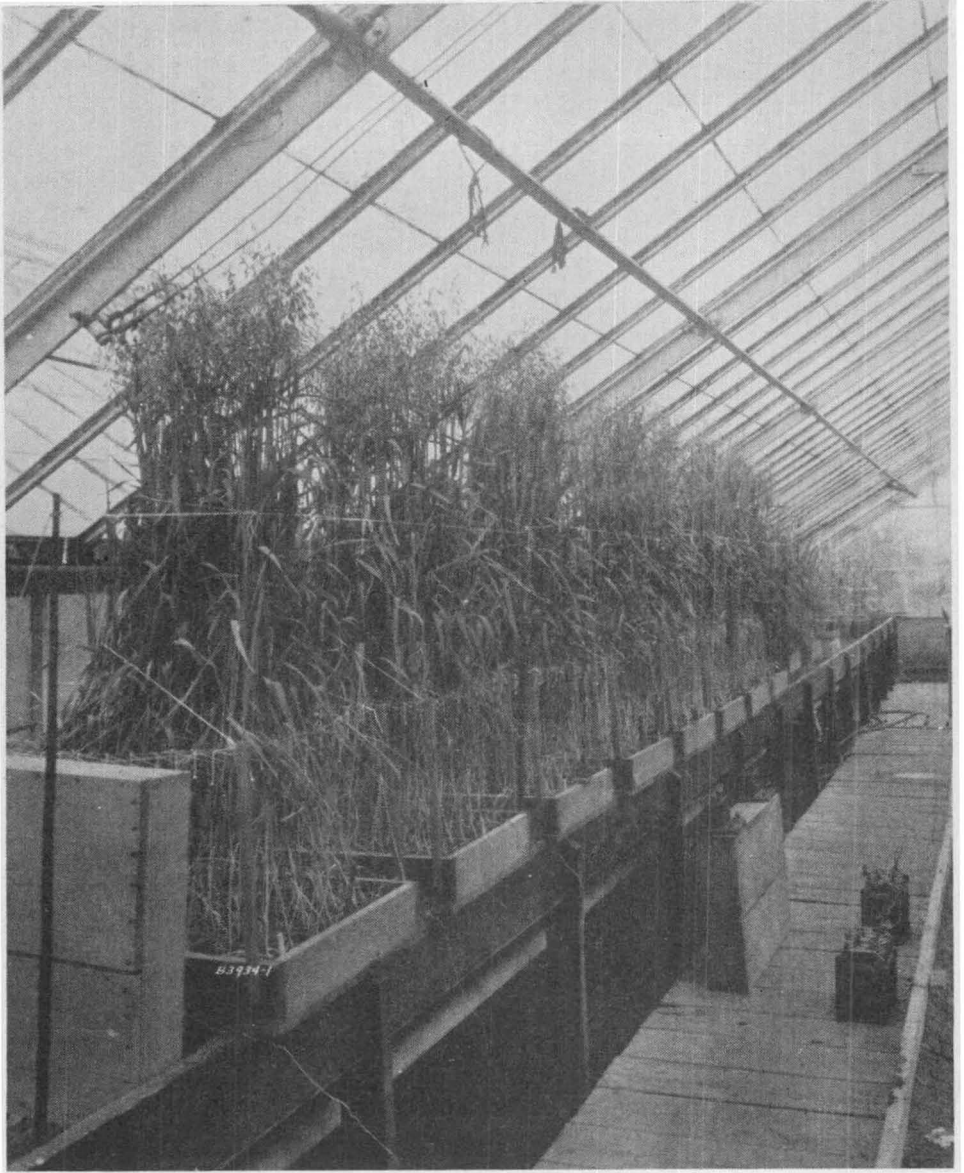


Fig. 4. High voltage experiments with oats, 1931; includes six treated lots and two controls. Treated lots received currents at 7,000 to 20,000 volts for a 10- to 15-minute period daily. On this date, May 12, the controls are in the second and sixth locations, counting from the near end.

potential of 1.2 volts per cell. This current was stepped up by placing a Ford induction coil in the circuit between the battery and the insulated flat so that the flats which were given the maximum treatment received a charge of from 14,000 to 20,000 volts.