A STUDY OF THE EFFECT OF ELECTRIC CURRENT ON CERTAIN CROP PLANTS

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INTRODUCTION

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 lacking in 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 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 a debatable one.

REVIEW OF LITERATURE

Plants are continually subjected to the influence of environmental conditions and forces, and growth is materially affected by many of these conditions, if not by all of them. Variations in temperature, humidity, or light are known to induce marked changes in character and rate of 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 observed that in Europe the potential gradient is highest in midwinter, about 160 volts per meter, and lowest in midsummer, about 70 volts per meter. It is higher in midmorning and midafternoon than at other times of the day. Within a fog the potential gradient may rise to several times its normal value, also clouds of dust may produce large changes, the sign of the charge depending upon the nature of the dust. Clouds other than rain clouds usually have little effect but with the formation of the cumulo-nimbus a very great increase in the potential gradient may occur in a few minutes.

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 electric 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 one year. During this period, which is the rainy season in India, 76.3 centimeters of rain fell. He summarizes his observations as follows: (1) during 71 per cent of the time that charged rain fell the sign was positive, (2) 75 per cent of the electricity brought down by the rain was positive, (3) light rain was more highly charged than heavy rain, (4) all rainfall which occurred at a greater rate than a millimeter in two minutes was positively charged, (5) the potential gradient was more often negative than positive during a rain, (6) no relationship between the sign of the potential gradient and the sign of the electricity of the rain could be detected.

Lemstrom (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. He observes also that the fir trees, by reason of their pointed conformation and needle-like leaves, are particularly adapted to act as "the means through which the electricity goes from the atmosphere into the earth or vice versa." Through experiments made by himself during the Finnish International Polar Expedition of 1882-84 it was shown, Lemstrom asserts, that "Not only do such electrical currentsexist, but these currents were even measured by means of a specially constructed apparatus with metallic points."

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. Lund believes that "we may speak of the apex of the main stem as exhibiting a positive electrical dominance in the tree system", and that this correlation with growth dominance indicates a significant relationship between electrical potential and organic polarity.

Monahan (34) reports the results of systematic observations concerning the effect of trees upon the potential gradient of the air. He made daily readings from April 20 to November 1 with collectors and a Thompson quadrant electrometer. 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. The average daily voltages by months was as follows (in each case the first figure is the voltage for the open air); April, 30.0-30.0; first half of May, 52.0-52.0; last half of May, 44.2-25.3; June, 38.0-21.2; July, 37.3-18.0; August, 54.4-29.6; Sept. 57.0-34.5; first week of Oct. 48.0-40.8; last three weeks of Oct. 19.0-19.0. The sign of the potential was negative throughout. It was noted that the potential was the same in the elm as in the open air until the middle of May when the tree came into full leaf. On August

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 and the sign was nearly always positive.

Crop Experiments Using Modified Atmospheric Potential

In a few cases 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. Sanborn (39) buried wires 10 inches deep and three feet apart across a plot two rods square and connected them at one end with a copper brush mounted on a pole 20 feet high. Crops of various kinds were planted with the rows running at right angles to the direction of the buried wires and extending across an untreated plot also two rods square. Seed yields for the single year of the experiment on the treated plot, as compared to those on the untreated plot, were as follows: plus 67 per cent for oats, plus 41 per cent for beans, and plus 21 per cent for buckwheat. Other crop yields on the treated plot were for potatoes plus 10 per cent, for mangels plus 32 to 115 per cent, and for turnips minus 59 to plus 36 per cent. Apparently no attempt was made to measure the amount of electric current passing between the elevated copper brush and the ground wire.

Many years earlier Basty (1) had used the buried wire and elevated discharge points on his strawberry patch. On the treated area, for one year, he reported a yield 70 per cent greater than on the untreated area. Over a two-year period he obtained, on treated areas one to four square meters in size, increases of 10 to 20 per cent for such crops as potatoes, onions, peas, beans, beets and tomatoes. Basty also investigated the effect of what he calls "petite lightning rods." Although he does not describe these they apparently were pointed rods about one meter long. These were set upright in the ground with the pointed ends uppermost, 16 rods in a plot, two meters square. He reports increases, as a result of this installation of pointed rods, of more than 100 per cent for onions, spinach, hemp, and clover, and smaller increases for other crops. Basty used no replications but he apparently obtained rather consistent increases throughout the range of crops tested.

Stone (43) placed plate electrodes in the opposite ends of greenhouse flats filled with soil. One electrode was connected to a copper brush 47 feet above the ground, the opposite electrode was grounded. A continuous slight current was noted. Several tests with radishes, including 738 plants, resulted in increased yields of tops and roots of 28 per cent. For lettuce, increases of 39 per cent were obtained.

Solly (42), experimental chemist for the Horticultural Society of London, buried copper wires four inches deep and 12 inches apart and connected them with a copper brush 33 feet above the ground. Barley was seeded in rows, one row along side each strand of wire and at a corresponding rate in a near-by control plot. Rate and vigor of growth were observed throughout the season but in this test no differences could be noted.

Grandeau (13), director of the Eastern Agronomy Station in France, investigated the effect on vegetative growth of a reduced atmospheric potential. He grew corn, wheat, and tobacco under wire cages grounded to destroy the normal electrical field. The cages, constructed of iron wire to form a mesh 10 by 15 centimeters, were 1.5 meters high and of sufficient diameter to enclose the plants. On the basis of total green weights, with the controls taken at 100 per cent, the plants enclosed by the cages made the following comparative growth: tobacco 51 per cent, corn 58 per cent, wheat 70 per cent. The test included two plants of tobacco, two of corn and 12 of wheat. Grandeau believed that the effect of trees upon vegetation growing nearby is of the same nature. He reports that the potential gradient, as measured with a Thompson electrometer, is much lower under trees than in the open.

Monahan (33) tested the effect of electrically charged air on the growth of plants. Two lots of 100 seeds each of white clover, onions, lettuce and red clover were germinated in a tight glass case four feet three inches long, two feet nine inches wide, and two feet 11 inches high. Air in this case was kept moist by dripping water and charged every eight hours by a Holtz machine. The charge obtained was sufficient to cause a slight deflection in a Thompson quadrant electrometer. A similar enclosed case was set up for the controls. For the lots tested Monahan obtained an acceleration of germination of 55.4 per cent after 48 hours, 23.1 per cent after 72 hours, and 17.11 per cent after 96 hours. He reports that the growth of tomato plants, corn cotyledons, and bread molds was stimulated by charges of slight intensity. In his work the following year Monahan (34) charged the cases once each day with currents of 140 to 160 volts. The charge was maintained but a few seconds and practically disappeared from the air in 15 minutes. After charging, the cases were kept closed for four hours and then opened for the remaining 20 hours. A comparison including 586 radish plants showed a gain in weight for the treatment of 49.35 per cent for the tops and 51.62 per cent for the roots.

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.

Lemstrom (27) conducted tests of this sort on 10 different fields in as many years. To apply the current for the overhead wires he used a static machine connected at one post with the wires and at the other with the ground. The areas subjected to this sort of treatment were but a few square meters. In nearly all cases the current was applied through most of the growing season except during rainy spells or during the hot part of the day. He observed that treatment during times of hot, bright sunshine was apt to be injurious. Later investigators have obtained similar results in this respect. This injurious result indicates that with his equipment he was able to supply current enough to appreciably affect atmospheric conditions. Lemstrom included in his experiments many kinds of garden and field crops and reports increases of approximately 45 per cent as an average for all tests.

With reference to the sometimes injurious effect of the overhead electrical discharge Priestley (37), botanist at the University of Bristol and later with the University of Leeds, concluded from his study of several groups of experimental data that treated plants give off water more rapidly than untreated ones. He based this conclusion on the fact that in the data studied, plant yields on the treated areas failed to be greater than those on the controls only in dry seasons, and in seasons of extreme drouth were distinctly less than those of the controls.

English investigators have been much interested in the treatment of crops by electricity, especially by means of the overhead network, and have conducted a number of rather elaborate tests. Most of this work was done over the period from 1906 to 1924. Newman (35) at Evesham placed wires 15 feet above the ground and 10 feet apart each way and charged them with a potential of 50,000 to 75,000 volts. He reports a 21 per cent increase in the yield of wheat on three fields over a seven year period. Increased yields for the treatment were obtained every year except during the dry season of 1908. Newman, in cooperation with Sir Oliver Lodge, worked out the details of the necessary electrical equipment and arrangement and since that time the setup has been known as the Lodge-Newman apparatus. About that time Newman was installed as the general manager of the Agricultural Electrical Discharge Co. Ltd.

Blackman (2) summarizes the results of 18 field experiments over a period of six years. Of these tests 14 resulted in increased yields for the electrical treatment. His report includes the result of a three year experiment at the Rothamsted experiment station. Here he used a current of one milliampere at 50,000 volts per acre, six hours a day for six months, and obtained increased yields for barley of 10 to 36 per cent and for clover hay of 34 to 50 per cent. Dudgeon (9) in a test with four varieties of potatoes on eight acres applied current for 413 hours during one season. She reports increases for the treatment ranging from eight to 37 per cent.

Jorgensen and Priestley (17) studied the distribution of the overhead electrical discharge in connection with the Lodge-Newman apparatus. They found that (1) strength of discharges varied as the wind velocity, with other factors probable, (2) maximum current density was of the order 10^{-11} amperes per square centimeter, (3) effect of the discharge was not limited to the area under the wires. They suggested that the use of a screen between the treated area and the control might be of some help in preventing electrical drift. Jorgensen (16) discusses an experiment of Miss Dudgeon's, carried on in 1915, in which she used a wire drift screen as previously suggested by Priestley and himself. A grounded wire screen extending three feet above the charged network was installed between the control and the treated area. Miss Dudgeon's data, as given by Jorgensen, show, for oats, an increased yield on the treated plot of 30 per cent for the grain and 58 per cent for the straw. Electrometer readings showed some leakage past the screen. Hendrick (14), at Aberdeen University, used the Lodge-Newman setup with the wire drift screen. A three year test with oats, barley, hay, potatoes, turnips, and swedes showed no consistent effects on yields resulting from the electrical treatment.

Blackman and Legge (3) conducted pot tests with several crops in the greenhouse and the open for four years, using the overhead discharge. Increased yields were obtained with 23 of the 28 sets of pots. A current of 0.1 times 10^{-10} amperes per plant was as effective as higher currents and less liable to be injurious. Currents of 1.0 times 10^{-8} amperes and higher were definitely harmful.

In contrast to the generally favorable reports from England, France and Finland, concerning the use of the overhead network, are the results of tests conducted in the United States and Germany. Briggs et al (5) conducted experiments with a highly charged network for eight years at the Arlington Farm using an experimental procedure similar to that employed in the English trials. Crops tested included winter wheat, winter rye, corn, and soybeans. Data presented in their report show that the yields for the treatments varied both above and below those for the controls, and that the variations appear to be well within the limits of experimental error. Kühn (22), in a test in Germany, treated eight crops, including four kinds of small grain. The overhead network was placed five meters from the ground and charged with a current of one to two milliamperes at 100,000 volts. From the results obtained at the end of one year Kühn concluded that the electrical treatment was of no value.

Gerlach and Erlwein (12), at Mocheln, treated oats with high tension current applied with overhead network. The treatment was continued 24 hours a day for 45 days on three plots, one of 6136 square meters in area, the other two each 3068 square meters. The season became quite dry and portions of the treated and control areas were irrigated. On the treated plots which were not irrigated the yields were somewhat less than on the corresponding control area, but otherwise the yields were not appreciably affected by the treatment.

In experiments conducted in the biophysical laboratory at Washihgton, D. C., Collins et al (8) treated seedling grain plants with a high voltage direct current of 10^{-9} amperes per plant, discharged from an overhead network. The current was measured with a sensitive galvanometer and maintained constant within a narrow range. The light intensity and amount of water supplied were carefully equalized. The test conducted during the winter of 1924-25 included 48 flats of corn and 24 flats of barley and of these numbers one-half were used as controls. Each flat contained 100 seedlings. Two flats, one treatment and one control, were run at a time. In some cases the treatment was applied only during the day, in others only during the night, and in still others it was applied continuously. Only in the case of the night treatment of corn were significant increases obtained. The measure used was the final mean height of the seedlings per flat.

The following year the test was repeated, running two treatments and two controls simultaneously. The boxes were placed on a rotating platform and watered only at the beginning of the test. The current was applied for from six to ten days and the test was concluded in two weeks after the seeds were planted. This year increases in elongation were determined. The authors conclude that differences due to more rapid loss of water in certain boxes were greater than differences due to treatment. In 1927-28 six flats were started at a time and the four with the most uniform seedlings were chosen for the test. The two flats appearing to be the most nearly equal were paired and the treatment applied to one of the pairs chosen at random. This procedure was repeated five times. To determine the amount of growth green weights were used, cutting all plants in a row simultaneously and placing at once in a closed weighing can. The differences in growth obtainedwere not significant. For one set of flats, two received a comparatively strong current of 75.0×10^{-9} amperes. Here again treated and control plants made practically the same gains.

Crop Experiments Using Soil Electrodes

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.

Ross (38) in 1844 buried a copper plate five feet long and 14 inches wide across the ends of three rows of potatoes and a zinc plate of equal size across the other ends 100 feet distant, and connected the plates by means of a copper wire laid on the surface of the ground. On July 2 the treated potatoes were reported to be about 2½ inches in diameter while those not treated were approximately the size of marrowfat peas. The total weights at harvest apparently were not determined. A year later Solly (42) planted 140 small plots to grains, legumes, flowers, and vegetables. In each of 70 of these plots copper and zinc plates four by five inches in dimensions were placed five inches apart and connected above ground by copper wire. From notes made on rate of germination and comparative vigor he concluded that the treatment was beneficial in 17 cases, harmful in 18, and of no effect in the remaining 35 cases.

Holdefleiss (15) treated sugarbeets and potatoes in the field, selecting areas where the stands were good. Two copper plates, 50 by 80 centimeters in size, were sunk vertically in the soil to a depth of 50 centimeters across the opposite ends of two rows 56 meters long. The plates were connected to the poles of a 14 cell Meidinger battery. In the same fields circuits without battery were set up. In these installations copper and zinc electrodes were buried at the ends of rows so that a distance of 33 meters separated the plates of the pair. Each set of electrodes was connected above ground by a copper wire. The results obtained were summarized as follows: (1) an electric current existed on all treated plots throughout the test, (2) the crops subjected to the current from the battery showed no effect either in growth or yield, (3) both the sugar beets and the potatoes subjected to the current provided by the copper zinc combinations showed increased vigor within 10 days after the beginning of the experiment and increased yields of 15 to 24 per cent.

Wollny (48, 49) laid out five plats, each four meters long by one meter wide, separated from each other by paths 1.2 meters wide and also by boards sunk 25 centimeters in the ground. On plats 1 to 3 a zinc plate was sunk along each side and opposite plates connected as follows: plat 1 with an induction coil operated by three Meidinger cells, plat 2 with a battery of six Meidinger cells, and plat 3 with a battery of three Meidinger cells. On plat 4 a zinc plate was sunk along one side and a copper plate along the other and these connected by a copper wire above ground. Plat 5 was used as the control. Currents in the first three plats were measured frequently by means of a galvanometer and maintained at fairly constant strength by renewing the batteries every three or four weeks. In plat 4 the current was very weak. Of the four square meters in each plat one square meter each was planted to summer rye, summer rape, beans and potatoes. The above described tests were conducted in 1883 and repeated on a somewhat more extensive scale in 1886 to 1887. All plats were harvested and the yields determined. Wollny concludes (1) that the variations in yields were such as to indicate that the effect of the treatment was negligible, (2) the stronger currents might possibly have been harmful, (3) there was a slight indication that the extremely weak current of the copper zinc combination might have been beneficial.

Leicester (25) used flats of soil three feet long and equipped a number of them with the copper zinc combination. In germination trials with several kinds of seeds he noted in every instance a more rapid germination in the treated flats. Watering with a little very dilute acetic acid increased the rate of germination in the treated flats but did not affect those not treated.

In work carried on at Bromberg, Gerlach and Erlwein (12) treated crops with electric current applied through the soil. The field selected for the experiment was divided into seven plots of 200 square meters each and each plot was planted half to barley and half to potatoes. The three plots to be treated were provided with iron plates 20 meters long by 30 centimeters wide and two centimeters thick, sunk in the soil along both sides and charged with current from a nearby electric railway. The current at the plots averaged from 0.2 to 0.4 amperes with a potential of six volts and was applied 24 hours a day from planting to harvest. Yields obtained varied in such a manner as to lead the authors to conclude that the electrical treatment had no effect.

Kövessi (21) in 1907-08 conducted more than 1100 tests with many kinds of herbaceous and woody plants. He used porcelain vessels, each equipped with two platinum electrodes buried in the soil at opposite ends of the vessel. Currents of varying intensities and potentials were provided by Meidinger piles, thermo-electric piles, and dynamo electric machines. In general the effect upon germination and growth was decidedly harmful. Seed in the vicinity of the electrodes germinated weakly or not at all. Results varied with current intensity and potential but were always more or less negative.

Using currents of low intensities, applied by means of electrodes buried in the soil, Stone (43) treated large numbers of radish and lettuce plants. A total of 4671 plants were included in the comparison. The amounts of current used in the different tests ranged from 0.2 to 0.4 milliamperes. Total gains of tops and roots for treated plants compared to controls were as follows: with a weak direct current radishes gained 23.67 per cent, lettuce 22.78 per cent; with a direct current twice as strong radishes gained 34.26 per cent, lettuce 40.76 per cent; with a copper zinc combination providing 0.214 milliamperes radishes gained 58.56 per cent, lettuce 36.48 per cent. The tests with lettuce included only plants which had been transplanted.

Electrical Treatment of Seed and Seedlings

Kinney (18) studied the rate of growth of the root-sprouts of electrically treated seedlings. Glass funnels were filled nearly full of wet sand packed between two copper plate electrodes. Germinated horse beans were placed on the upper surface of the sand and the upper and larger copper plate was pressed down upon them. This plate had 12 perforations and was placed so that the stem sprouts grew upward through the holes. The horse beans, which had radicles two inches long at the beginning of the test, were treated hourly for 30 seconds with a current of two or three volts. The radicles could be observed clearly against the inner surface of the funnel and the growth in length was measured at intervals of 12 hours. Compared to the growth of the radicles of untreated beans in a similar container, the growth of the treated beans, measured in four successive 12 hour periods, was greater by the following per cents: 19.00, 44.95, 42.13, 39.47, in the order given.

Blackman et al (4) studied the effect of a very weak current on the rate of growth of the coleoptile of barley. A direct positive current of the order of 0.5×10^{-10} amperes was applied to the coleoptiles by means of a discharge point two centimeters removed. The roots of the barley seedlings were in nutrient solution. An increased rate of growth was observed, as follows: four per cent the first hour of treatment, five per cent the third hour, and twelve per cent the fifth hour. The increased growth of twelve per cent obtained during the fifth hour was assumed to show after effect as the treatment had been discontinued prior to that time.

Considerable interest has been manifested in the effect of electrical treatment of seed upon germination and subsequent growth. Kinney (18) treated seeds of several crops with currents of voltages varying from a small fraction of a volt to ten or 12 volts. He concluded that the optimum current for the method used was approximately three volts. The moist seed was pressed in a glass cylinder between two plate electrodes, electrified for not more than five minutes, and then placed in a germinator. His summaries show that the rate of germination was accelerated, sometimes as much as 20 per cent, by the optimum treatment and the early growth of the radicles considerably stimulated. He observed, however, that the beneficial effect on growth of the sprouts appeared to be temporary as untreated plants tended to catch up with those treated.

Leighty and Taylor (26) presoaked wheat for two hours in a 3.5 per cent salt solution and then applied current for three and one-half hours at the rate of eight watts per gallon. Treatment was applied in a wooden tank with a sheet iron electrode at each end. The control lots were handled as follows: one lot soaked in salt solution for five and one-half hours, one lot soaked in tap water for five and one-half hours, and one lot dry. After treatment all lots were spread to dry in a greenhouse for two days, then seeded. One-fortieth acre plots were seeded at the rate of seven pecks for the soaked lots and six pecks for the dry lot. Yield averages for two years, with three replications for one year and five for the second year, were as follows: electrically treated 27.0 bushels of grain and 3,884 pounds of straw; soaked in salt solution without electric treatment 25.0 bushels and 3,631 pounds; soaked in water 26.5 bushels and 3,573 pounds; dry lot 28.1 bushels and 3,829 pounds. In at least one year of the test the lot soaked in salt solution without electric treatment germinated quite slowly and showed reduced vigor for some time after sowing.

Lee (23, 24), of the department of Physics at Manitoba Agricultural College, tested the effect of electrical seed treatment. More than 150 trials were made involving tests of different solutions and different amounts and intensities of current, and the most favorable method determined. In 1919 yields were obtained with Marquis seed wheat treated by this method (not described by the author). Yields of grain and straw from the treated seed were 18 bushels and 4800 pounds, from the untreated 14½ bushels and 4,266 pounds. The report states that towards maturity the treated plot showed a slightly ranker growth.

In tests to determine the possible effect of electric currents upon germination, Wheelock (46) treated corn and durum wheat with currents of 0.5 ampers, 1.5 amperes, 2 amperes and 3 amperes, for periods varying from 30 minutes to five hours. In gallon clay jars filled with tap water a metal plate was placed in the bottom and another suspended in the water near the top of the jar. These electrodes were charged with a 110 volt direct current. The seed was immersed in the charged water and a portion removed every 30 minutes. Controls were soaked but not electrically treated. After the treatment all lots were dried, and following an interval of 18 days, were planted in pots in the greenhouse. With the 32 lots of corn and 28 lots of wheat no consistent differences in germination could be observed. In a second series of tests corn and durum wheat were planted 14 hours after treatment, with results similar to those obtained previously.

Studies of the Physiologic Response of Plants

In the experiments described on the preceding pages interest has centered chiefly in the effect of electric current on the rate of growth and yield of the plants under observation. Even by those who claim to have stimulated plant growth, but little systematic effort has been made to discover the physiological basis of plant behavior when so treated. Koernicke (20), in an experiment conducted at the Agricultural College of Bonn-Poppelsdorf, demonstrates the stimulating effect of electric current and presents an explanation of the physiological response to the treatment. In this test highly ionized air, obtained by the spark discharge of a high tension current in a closed tube, from which the objectionable ozone had been removed, was led to the experimental plants. These plants, *Phaseolus multiflorus*, stood in a large, closed glass vessel so that they grew in constantly renewed, ionized air. The degree of ionization of the air in the plant chamber was regularly measured. Treated plants showed considerable increased growth in comparison to the control plants. In many cases they produded leaves with four leaflets instead of the three which are characteristic of the bean. Determinations of the transpiration rate showed that the treated plants transpired 1,554 grams and the controls 1,299 grams of water per square centimeter of leaf surface in five days. To indicate the assimilation rate of carbon and nitrogen, measurements were made of leaf area and dry weight. After 3½ weeks of treatment 35 control plants had a total leaf area of 741.37 square centimeters, as compared to an area of 1431.32 square centimeters for 35 treated plants. The total dry weight of 31 control plants was 19,057 grams, while for 31 treated plants it was 33,655 grams. On the assumption that the comparative use of nutrient salts should be indicated by the pH change of the nutrient solutions in which the experimental plants were grown, determinations of pH were made at the beginning and at the end of the trial period. The pH at the beginning of the test for both lots was 7.05 while at the end it was 6.7 for the controls and 6.5 for the treatments.

Knight and Priestley (19) measured the respiration of germinating seeds and of seedlings under various electrical conditions. Seeds of peas, which had been soaked 24 hours and then placed under a bell jar with controlled temperatures, were treated with a low voltage direct current of from 1.0×10^{-6} to 1.0×10^{-4} amperes. No measurable effect on the formation of carbon dioxide was obtained. Since the resistance of the peas was considerably greater than that of water, they concluded that most of the current must have traversed the water films rather than the peas. In further trials with peas, Brussels sprouts, wheat and rye, high tension currents of 3.0×10^{-6} amperes were used for germinating seeds and of 1.0×10^{-6} amperes for seedlings. No increases in respiration for the treatments could be detected.

In an attempted explanation of the effect of electric current upon plant processes Marinesco (30) 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. These phenomena, perfectly reversible, have been called the electrification of contact. According to Solly (42) this relationship of physical forces was observed as early as 1745 by Boze, professor of physics at Wittemberg, and verified by Nollet in 1746. Marinesco (30,31) compares the ligneous vessels of plants to the above mentioned capillaries. He states that in plants the descending flow of sap is much inferior to the ascending, as the latter includes transpiration, and the relative difference in electromotive force may be measured by the potentiometer. He calls this difference "The potential of filtration." Various plants, including the geranium, were tested by placing two platinum points, one in the root and one in the stem, two centimeters above the soil and a difference of potential was observed of sometimes more than 0.4 volt.

The roots were always positive to the stem. 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.

In the article of July 11, 1932 Marinesco (32) describes the following experiment. Metal plates were placed, plate A above the top and plate B below the roots of a potted geranium, and connected to a battery and rheostat. Platinum points connected to a potentiometer were inserted in the stem and root as described above. The effect of varying degrees of charge upon the metal plates was observed by means of the potentiometer readings and recorded as the potential of filtration. When the difference of potential between the two plates was zero the potential of filtration, designated "The Pf", equalled .010 volt. As the electric field between plates A and B was intensified the Pf increased, becoming 20.0 x .010 volts at a charge of 70 volts per square centimeter. When plate A was charged negatively in relation to B conditions were reversed. A negative charge of five volts resulted in a potentiometer reading of zero and was therefore assumed to stop the flow of sap. A stronger negative charge resulted in a negative Pf and on the same basis was assumed to have caused a reversal of the normal relation between the upward and the downward movement of the plant fluids.

Gelfan (11) in California, studied the electrical conductivity of the protoplasm of the plant Nitella. Using very small electrode points, which could be inserted in a single plant cell without killing it, he applied current from a dry cell. This current, which was assumed to be very small because of the resistance of the small points, had no observable effect upon the protoplasm. With larger electrodes and stronger currents, the protoplasmic streaming stopped when the circuit was closed but when the current was shut off, the streaming resumed in approximately two minutes. He observed that the cessation of streaming appeared to be due to a thickening of the protoplasm and that the mere insertion of the electrodes was apt to cause it. With the use of still stronger currents streaming was not resumed. In this study the conductivity of the protoplasm and of the vacuolar cell sap appeared to be equivalent to that of a 0.04 normal and a 0.07 normal KCl solution, respectively.

Plowman (36), at Harvard University, as the result of studies of the electromotive force in plants, concluded that the spreading of an electric current to all parts of a leaf through which it is flowing, and the distribution of the reaction current which follows, is precisely analogous to similar phenomena in non-living bodies. He passed three volts for one second through a roll of filter paper saturated with solutions of various salts and noted the reaction current with a galvanometer. In each case results were very similar to those obtained with various plants. He found, also, that the plants tested had a normal electric current and that this current might be reduced temporarily.

Effect of Electric Current Upon Soil Micro-organisms

The direct relationship between the producing power of the soil and the numbers and activity of soil bacteria is a matter of record. Waksman (45) observed with soil samples taken from field plots that had been subjected for many years to various fertilizer treatments and cropping systems that the number of soil micro organisms ran nearly parallel to the productive ability of the particular type of soil. Brown (6) made an extensive series of laboratory tests with field soils to determine the relation between productive ability and the bacterial activity within the soil. The results obtained "Permit of the tentative conclusion that bacterial activities involved in the transformation of nitrogenous organic material in the soil bear a very close relationship to the actual crop yields secured on the same soils."

The possible effect of electric current upon bacterial organisms was investigated by Wollny (48) and Stone (44). Wollny, in his experiments with arable soil, placed the samples in U shaped stoppered glass tubes equipped with copper plate electrodes in such a manner that an electrode pressed upon the surface of the soil in each arm of the tube. Insulated wires led from the electrodes to the source of the electric current. Each tube had suitable outlets so that the accumulated carbon dioxide could be withdrawn and the amounts determined. Controls were made in the same manner but without the electrodes. Treatments were continued without interruption for eight days and determinations made at 24 hour intervals. In one test the samples were made up of 80 grams of water and 250 grams of soil. The results expressed as daily averages in volumes of carbonic acid in 1000 grams of soil air were as follows: control, 15.54 volumes; induction current from 2 Meidinger cells, 15.60 volumes; current direct from 2 cells, 14.36 volumes; from one cell, 15.89 volumes. In another test 50 grams of water were added to each 250 gram sample of soil and much stronger currents used. Treatments and results were as follows: controls, 12.45 volumes; induction current from 5 cells, 11.32 volumes; current direct from 5 cells, 11.88 volumes. Wollny concluded that the effect of electric current upon the soil, as measured by the production of carbon dioxide, was not beneficial.

Stone in his experiments on the influence of electricity on bacteria in soils used wooden boxes 8x8x8 inches, inside measurements, filled with a fairly good loam soil. "In the box electrically treated were placed copper and zinc electrodes, each being 8x8 inches in size, and to these were soldered copper wires which were connected, thus forming with the soil a galvanic cell which furnishes a small current approximating the optimum." Stone, in his tests with bacteria in contaminated water, had previously determined this optimum strength to be about 0.1 milliamperes. "The percentage of water in the soil in each box was accurately determined at the beginning of the experiment, and this same percentage maintained throughout by adding sterilized distilled water. The cultures were plated in agar-agar and the usual dilution methods followed. Soil in the boxes was not stirred and the surface became more or less compacted by constant watering." Two tests were conducted, experiment No. 1 from July 13 to August 11 and experiment No. 2 from September 14 to October 16. In the first experiment the bacterial count per gram of soil for the control was 33,470,000 and for the treated soil 37,930,000; two weeks later 28,777,000 and 32,863,000; and at the end of the test the count for the control was 19,294,000 and for the treated soil 35,000,000. In the second experiment the bacterial count at the beginning for the control was 38,047,000 and for the treatment 37,670,000; at the end of the test a month later the counts were 18,720,000 and 26,384,000, respectively.

In a second series of experiments Stone used the same soil-filled boxes but treated one by running 12 wires into the soil from a metal bulb which was given 100 sparks from a Töpler-Holtz machine once a week. In these tests the soil was frequently stirred and the first bacterial counts were made with samples of soil taken a few days after electrical treatment. Bacterial counts for the control and for the treatment were as follows: July 21 control 1,097,000 per gram, treatment

4,506,000; July 31 control 960,000, treatment 15,208,000; August 7 control 1,960,000, treatment 27,756,000.

In tests with sewerage contaminated water and with milk, Stone found that a very weak current of about 0.1 to 0.3 milliamperes 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. With the milk the above increases were obtained by treatments of but 24 to 27 hours. In all cases the bacterial numbers given in this and in the preceding paragraphs were averages of counts made on three or four plates.

PURPOSE OF THE INVESTIGATION

General Statement

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 spite of a very considerable body of evidence to the effect that electric currents do stimulate the growth of plants there is still a real doubt in the minds of many as to the reliability of such results. This scepticism is based partly on the fact that a number of investigators have failed to obtain significantly increased yields with the treatments, and partly on the lack of definite evidence concerning the character of plant response and the underlying causes. Also, it is believed that at least one of the methods used, i.e., that of applying electric current by means of the overhead network, is so expensive and inconvenient as to be without practical value.

The universal existence of electrical phenomena in nature has led a number of scientists and laymen to believe that such phenomena may have a significant role in connection with plant growth, and that an understanding of this role, if one exists, might well aid in the interpretation of some of the facts of plant behavior. Because of the apparent importance of such a possibility, and because of the lack of agreement which exists with respect to the interpretation of results obtained in past experiments, it has been deemed desirable to conduct further trials. The methods used and the results obtained in field and laboratory at Iowa State College will be presented in the following pages.

Problems Investigated

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 three years, 1930-32. A level area approximately 150 by 165 feet in dimensions, of apparently fairly uniform soil was used as a test plot. The field had been in corn in 1929. In late April, 1930, after the corn stubs and other trash had been removed and the ground plowed, 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 four feet apart for the fifth treatment. The wire laying was accomplished by opening a furrow with a common moldboard plow, returning in the same furrow with the plow, and then scooping out the loose dirt with a shovel to a depth of eight inches. A wire laying device developed by C. Vincent of Omaha was attached to the middle shovel of a one horse garden cultivator and the cable laid to a depth of four inches in the bottom of the open furrows. These furrows were then refilled so that the ground was once more level. Similar furrows without cables were opened and refilled at points midway between 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 in width 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 three 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 six inches 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 eight to fourteen 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 Figure 1. All heads were mounted 20 feet above the ground surface on 4"x4" timbers bolted to posts set solidly in the ground. Each head and its connecting wire was insulated from the supporting timber and attached to the south end of one of the underground cables. The poles carrying the collector heads were erected along the south side of the plot about two 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. A cinder road ran along the south side of the plot.

In order to measure at various times the charges collected by the different heads a set of lead wires mounted on insulators were 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.

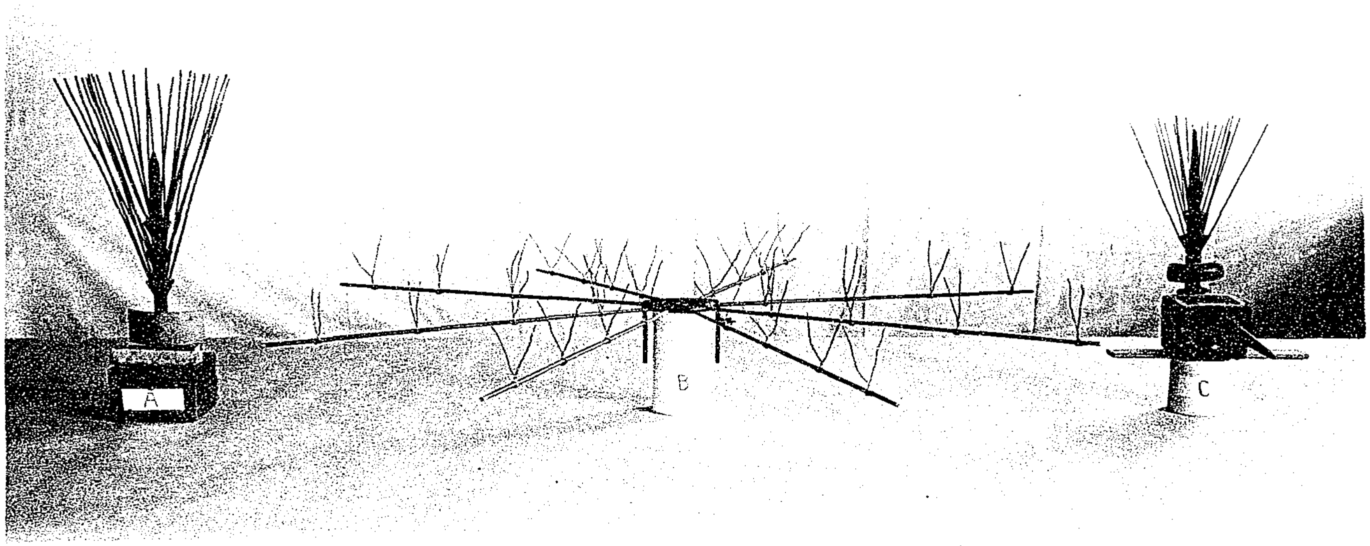

Figure 1. Types of brushes used in the experiment with atmospheric electricity at the Agronomy Farm, 1930, '31, '32. Three brushes of Type A were used, and one each of the others.
Type A - from C. Vincent, Omaha.
" B - from L. W. Butler, Iowa State College.
" C - from Justin Christofleau, La Queue les Yvelines, France.

Crops included throughout the three-year test period were corn, soybeans, garden beets, string beans, Swiss chard, and turnips. For the corn a single cross hybrid was used so that the variation between individual plants might be reduced to a minimum.

These crops were planted in rows three feet four inches apart 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. Three or four border rows of soybeans were planted across the south and north ends of the plot. The arrangement of the experiment is illustrated by figures 2 and 3.

Preliminary germination tests were run each year with all crop seed. All planting was done with a Columbia drill, except the corn, which was dropped by hand two kernels in a place, 12 inches apart, and later thinned to one plant in a place. The plot was cultivated with ordinary horse-drawn cultivators which were turned beyond the margin of the experimental plots. Weeds missed by the cultivator were removed by hand.

Figure 2. Utilization of atmospheric electricity for crops, Agronomy Farm, 1930, '31, '32. South view of experimental field showing the five elevated brushes and instrument house.

Figure 3. Utilization of atmospheric electricity for crops, Agronomy Farm, 1930, looking west across the experimental plots. Left to right - soybeans, beets, chard, turnips, strong beans, corn. Rows extend across the underground wires.

Seasonal soil and climatic conditions

For several years prior to the beginning of the test the part of the field on which the experimental plots were located had received no manure, had grown no legumes, and most of the crop residues had been removed, consequently the soil was rather deficient in organic matter. In 1930 the last rain of any considerable quantity occurred on July 4 so that by the middle of the month the ground had become dry and very hard. The summer was quite hot, the temperature on several days reaching 98^0 or higher during the afternoons, and all crops suffered severely. Corn ears did not fill well on account of unfavorable weather during the pollination period. The crops were somewhat damaged by grasshoppers but poison bran mash was spread twice and the hoppers finally controlled. Yields of beets and chard were not taken in 1930 because of irregular stand due to early cutworm damage.

Prior to the 1931 plantings the plot had been manured and fall plowed so that 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 except the garden beans. The beans became so diseased that this crop was not harvested.

Presentation and discussion of results

In 1930, from June 25 to July 10, the currents were upward, that is, the ground was gaining negative charge, and were of the order of 5.0×10^{-9} ampere. This is about one hundred 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 September 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 extremely 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 that it was difficult to arrive at any definite conclusion as to the general direction of 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} amperes. 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 August 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 September 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 heads were small. The variations between 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 to measure the current through the ground wire by tapping in at junction boxes placed 50 and 100 feet from one of the collectors proved useless. 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 least once each season, shortly before the blossoming period and while the plants were in the full vigor of growth, measurements of height were obtained for the corn, soybeans, and string beans. At no time during the growth of the crops could appreciable 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. At the time the final weights were taken the shelled corn had an average moisture content in 1931 of 9.0 per cent and in 1932 of 9.5 per cent, with variations either way of not more than 0.5 per cent.

Yields of the chard were taken on the basis of the green weight of the tops, and of the turnips and garden beets on the basis of the root weights.

Yields of the crops included in this experiment are presented in Tables I to VII, inclusive. The plot yields are listed in the same order as the field arrangement, progressively from west to east. In a given range each treated plot was situated just east of the corresponding control. The ranges correspond to replications and were numbered consecutively from south to north, range No. 1 being nearest the collectors. Yields from treated plots connected to the Vincent type collector heads are indicated by "A", those to the Butler type head by "B", and those to the Christofleau type head by "C".

An examination of these data shows that in most instances the average yields for the plants in the treated plots were slightly larger than for the controls. The largest differences were obtained with the chard and the beets, the increases averaging approximately seven per cent and nine per cent, respectively. However, a detailed study discloses that 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 being more than 50 per cent, hence average increases

TABLE I. Effect of earth-air electric currents, intensified by means of elevated collector brushes, on yields of corn - dry shelled basis.

Year	Range No. 1		Range No. 2		Range No. 3		Range No. 4	
	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs
1930	5.56	A 7.19	7.00	A 8.00	7.50	A 6.69	*	A 4.00*
	6.13	C 4.31	7.00	C 5.81	5.50	C 8.44	7.25	C 7.81
	5.38	B 2.87*	4.13	B 4.44	8.19	B 7.56	8.16	B 7.00
	4.00	A 4.31	3.69	A 4.75	9.44	A 7.69	8.38	A10.00
	3.75	A 3.31	3.31	A 4.13	5.75	A 5.00	9.00	A 5.87*
	1.44*		1.13*		5.19		3.13*	
Av.	4.96	4.78	5.03	5.43	6.93	7.08	8.20	8.27
Diff. favor treatment		-0.18		0.40		0.15		0.07
1931	15.06	A15.56	15.38	A15.00	5.19*	A 8.25*		
	12.31	C16.87	13.44	C15.25	13.25*	C11.31*		
	14.69	B14.69	15.00	B14.94	13.06*	B15.81		
	11.87	A13.81	18.25	A16.06	15.94	A16.75		
	14.06	A15.81	16.44	A17.25	16.31	A17.00		
	15.06		17.25		15.00			
Av.	13.84	15.35	15.96	15.70	15.75	16.52		
Diff. favor treatment		1.51		-0.26		0.77		
1932**	9.12	A 8.12	7.43	A 7.37	8.25	A 7.12		
	7.56	C 8.25	8.06	C 8.12	6.81	C 6.93		
	8.87	B 8.37	7.25	B 7.69	8.37	B 8.93		
	8.69	A 7.75	9.00	A 8.31	8.00	A 8.43		
	7.37	A 8.31	11.00	A 7.06	8.25	A 9.87		
	9.69		8.19		6.93			
Av.	8.55	8.16	8.49	7.71	7.77	8.26		
Diff. favor								

1930	5.56	A 7.19	7.00	A 8.00	7.50	A 6.69	*	A 4.00*
	6.13	C 4.31	7.00	C 5.81	5.50	C 8.44	7.25	C 7.81
	5.38	B 2.87*	4.13	B 4.44	8.19	B 7.56	8.16	B 7.00
	4.00	A 4.31	3.69	A 4.75	9.44	A 7.69	8.38	A10.00
	3.75	A 3.31	3.31	A 4.13	5.75	A 5.00	9.00	A 5.87*
	1.44*		1.13*		5.19		3.13*	
Av.	4.96	4.78	5.03	5.43	6.93	7.08	8.20	8.27
Diff. favor treatment		-0.18		0.40		0.15		0.07
1931	15.06	A15.56	15.38	A15.00	5.19*	A 8.25*		
	12.31	C16.87	13.44	C15.25	13.25*	C11.31*		
	14.69	B14.69	15.00	B14.94	13.06*	B15.81		
	11.87	A13.81	18.25	A16.06	15.94	A16.75		
	14.06	A15.81	16.44	A17.25	16.31	A17.00		
	15.06		17.25		15.00			
Av.	13.84	15.35	15.96	15.70	15.75	16.52		
Diff. favor treatment		1.51		-0.26		0.77		
1932**	9.12	A 8.12	7.43	A 7.37	8.25	A 7.12		
	7.56	C 8.25	8.06	C 8.12	6.81	C 6.93		
	8.87	B 8.37	7.25	B 7.69	8.37	B 8.93		
	8.69	A 7.75	9.00	A 8.31	8.00	A 8.43		
	7.37	A 8.31	11.00	A 7.06	8.25	A 9.87		
	9.69		8.19		6.93			
Av.	8.55	8.16	8.49	7.71	7.77	8.26		
Diff. favor treatment		-0.39		-0.78		0.49		

* Not included because yields were affected by conditions other than those of the experiment.

** Yields for this year are of the two middle rows only.

Note - "A" indicates yields from plots connected to Vincent type collector heads, "B" to the Butler type head, and "C" to the Christofleau type head. Ranges correspond to replications, the range nearest to the collector heads being designated as "Range No. 1".

TABLE II. Effect of earth-air electric currents, intensified by means of elevated collector brushes, on yields of soybeans - dry weight tops and roots.

Year	Range No. 1		Range No. 2		Range No. 3		Range No. 4	
	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs
1930	7.20	A 6.80	6.50	A 6.50	5.30	A 6.30		
	7.00	C 6.90	7.30	C 6.10	6.00	C 6.80		
	6.30	B 6.00	6.10	B 6.50	5.50	B 6.00		
	7.40	A 8.00	6.00	A 6.20	6.90	A 6.50		
	7.90	A 8.50	6.00	A 8.10	7.20	A 7.40		
	7.50		6.30		7.00			
Av.	7.21	7.24	6.37	6.68	6.31	6.60		
Diff. favor treatment		0.03		0.31		0.29		
1931**	6.56	A 6.81	6.81	A 7.06	6.44	A 6.44	3.38*	A 3.94*
	6.13	C 8.06	6.81	C 7.87	6.63	C 8.06	5.31*	C 6.44*
	6.19	B 5.94	6.69	B 7.25	7.19	B 7.25	6.81	B 6.94
	5.50	A 5.25	7.19	A 6.63	8.19	A 7.19	6.81	A 7.25
	6.06	A 6.06	7.13	A 6.87	8.19	A 8.69	7.31	A 8.38
	7.06		7.25		9.06		9.00	
Av.	6.25	6.42	6.98	7.14	7.62	7.53	7.48	7.52
Diff. favor treatment		0.17		0.16		-0.09		0.04
1932**	12.12	A12.87	13.19	A13.50	13.19	A13.56	10.06	A12.75
	13.12	C12.50	13.44	C13.12	13.87	C13.81	14.44	C13.37
	12.56	B14.69	13.37	B12.93	13.81	B14.44	13.50	B13.75
	14.62	A15.06	12.37	A13.00	14.69	A13.87	13.50	A13.69
	14.50	A14.56	14.87	A14.56	12.87	A13.25	14.75	A15.00
	14.75		15.75		13.12		15.69	
Av.	13.61	13.94	13.83	13.42	13.59	13.79	13.66	13.71
Diff. favor treatment		0.33		-0.41		0.20		0.05

1930	7.20	A 6.80	6.50	A 6.50	5.30	A 6.30		
	7.00	C 6.90	7.30	C 6.10	6.00	C 6.80		
	6.30	B 6.00	6.10	B 6.50	5.50	B 6.00		
	7.40	A 8.00	6.00	A 6.20	6.90	A 6.50		
	7.90	A 8.50	6.00	A 8.10	7.20	A 7.40		
	7.50		6.30		7.00			
Av.	7.21	7.24	6.37	6.68	6.31	6.60		
Diff. favor treatment		0.03		0.31		0.29		
1931**	6.56	A 6.81	6.81	A 7.06	6.44	A 6.44	3.38*	A 3.94*
	6.13	C 8.06	6.81	C 7.87	6.63	C 8.06	5.31*	C 6.44*
	6.19	B 5.94	6.69	B 7.25	7.19	B 7.25	6.81	B 6.94
	5.50	A 5.25	7.19	A 6.63	8.19	A 7.19	6.81	A 7.25
	6.06	A 6.06	7.13	A 6.87	8.19	A 8.69	7.31	A 8.38
	7.06		7.25		9.06		9.00	
Av.	6.25	6.42	6.98	7.14	7.62	7.53	7.48	7.52
Diff. favor treatment		0.17		0.16		-0.09		0.04
1932**	12.12	A12.87	13.19	A13.50	13.19	A13.56	10.06	A12.75
	13.12	C12.50	13.44	C13.12	13.87	C13.81	14.44	C13.37
	12.56	B14.69	13.37	B12.93	13.81	B14.44	13.50	B13.75
	14.62	A15.06	12.37	A13.00	14.69	A13.87	13.50	A13.69
	14.50	A14.56	14.87	A14.56	12.87	A13.25	14.75	A15.00
	14.75		15.75		13.12		15.69	
Av.	13.61	13.94	13.83	13.42	13.59	13.79	13.66	13.71
Diff. favor treatment		0.33		-0.41		0.20		0.05

* Not included.

** Yields for this year are of the two middle rows only.

Note - "A" indicates yield from plats connected to Vincent type collector heads, "B" to the Butler type head, and "C" to the Christofleau type head. Ranges correspond to replications, the range nearest to the collector heads being designated as "Range No. 1."

TABLE III. Effect of earth-air electric currents, intensified by means of elevated collector brushes, on yields of string beans - dry weight tops and roots.

Year	Range No. 1		Range No. 2		Range No. 3	
	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs
1930	0.98	A 1.12	1.22	A 1.23	1.11	A 1.11
	0.95	C 1.07	1.25	C 1.26	1.06	C 1.14
	1.01	B 0.96	1.19	B 1.18	1.06	B 1.14
	0.98	A 0.96	1.06	A 1.05	1.16	A 1.18
	1.06	A 1.16	1.13	A 1.13	1.20	A 1.16
	1.18		1.03		0.73*	
Av.	1.03	1.05	1.15	1.17	1.12	1.15
Diff. favor treatment		0.02		0.02		0.03
1931	1.87	A 2.00	1.75	A 1.94	1.31	A 1.75
	1.81	C 2.13	1.94	C 1.94	1.81	C 1.94
	1.44	B 2.00	1.94	B 1.63	1.94	B 1.69
	2.06	A 1.94	1.75	A 1.44	1.81	A 1.86
	2.00	A 1.94	1.63	A 1.94	1.63	A 1.81
	1.87		1.81		1.94	
Av.	1.84	2.00	1.81	1.63	1.75	1.81
Diff. favor treatment		0.16		-0.18		0.06

* Not included.

Note - On account of poor stand and disease the crop of 1932 was not harvested. "A" indicates yields from plots connected to Vincent type collector heads, "B" to the Butler type head, and "C" to the Christofleau type head. Ranges correspond to replications, the range nearest to the collector heads being designated as "Range No. 1."

TABLE IV. Effect of earth-air electric currents, intensified by means of elevated collector brushes, on yields of turnips - fresh weight of roots.

Year	Range No. 1 Control Lbs	Range No. 1 Treated Lbs	Range No. 2 Control Lbs	Range No. 2 Treated Lbs	Range No. 3 Control Lbs	Range No. 3 Treated Lbs
1930	- *	A15.05	13.13	A13.19	10.72	A10.53
	9.69	C10.76	13.00	C11.25	9.78	C10.78
	11.81	B12.00	9.16	B 9.44	11.53	B10.53
	12.57	A14.31	8.38	A 7.59	13.69	A13.34
	9.78	A 8.03*	8.28	A - *	9.75	A - *
	3.51*		- *		- *	
Av.	10.96	13.03	10.39	10.37	11.09	11.29
Diff. favor treatment		2.07		-0.02		0.20
1931	10.63	A 9.69	10.19	A14.06	8.13*	A12.31*
	9.87	C12.87	13.50	C14.94	13.38	C14.25
	13.44	B13.50	15.38	B14.81	15.06	B13.63
	14.50	A13.19	15.38	A11.81	15.13	A18.25
	17.31	A16.31	13.44	A12.94	15.25	A15.06
	16.44		12.94		15.44	
Av.	13.70	13.11	13.47	13.71	14.85	15.30
Diff. favor treatment		-0.59		0.24		0.45
1932	13.80	A14.00	15.00	A16.00	17.00	A13.50
	12.50	C11.80	15.00	C15.90	14.00	C17.75
	15.00	B14.50	18.00	B19.00	21.00	B11.25
	19.80	A22.60	13.50	A15.50	16.00	A13.60
	19.00	A16.00	13.00	A16.50	14.50	A15.50
	18.00		17.00		19.50	
Av.	16.35	15.78	15.25	16.58	17.00	14.32
Diff. favor treatment		-0.57		1.33		-2.68

* Not included.

Note - "A" indicates yields from plots connected to Vincent type heads, "B" to the Butler type head, and "C" to the Christofleau head. Ranges correspond to replications, the range nearest to the collector heads being designated as "Range No. 1."

TABLE V. Effect of earth-air currents, intensified by means of elevated collector brushes, on yields of Swiss chard - green weights of tops.

Year	Range No. 1		Range No. 2		Range No. 3	
	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs	Control Lbs	Treated Lbs
1931	18.75	A14.81	18.13	A17.87	22.19	A17.38
	6.63	C15.56	12.44	C15.56	24.75	C25.38
	16.50	B18.69	7.31	B 9.94	19.25	B24.75
	15.38	A16.75	12.13	A15.25	26.75	A25.44
	24.38	A26.44	20.13	A14.63	21.25	A25.50
	21.00		19.00		22.94	
Av.	17.11	18.45	14.86	14.65	22.85	23.69
Diff. favor treatment		1.34		-0.21		0.84
1932	12.31	A16.87	13.56	A14.00	18.25	A15.62
	18.62	C18.06	12.43	C12.50	18.19	C25.56
	15.37	B18.31	15.37	B16.50	23.00	B27.87
	18.25	A19.56	16.12	A20.75	17.25	A22.00
	21.25	A16.62	21.00	A19.12	24.50	A23.19
	16.12		15.00		18.62	
Av.	16.99	17.88	15.58	16.57	19.97	22.85
Diff. favor treatment		0.89		0.99		2.88

Note - the crop of 1930 was not harvested on account of poor stand and the dry season. "A" indicates yields from plots connected to Vincent type collector heads, "B" to the Butler type head, and "C" to the Christofleau type head. Ranges correspond to replications, the range nearest to the Collector heads being designated as "Range No. 1".

TABLE VI. Effect of earth-air currents, intensified by means of elevated collector brushes, on yields of beets - fresh weight of roots.

Year	Range No. 1 Control Lbs	Range No. 1 Treated Lbs	Range No. 2 Control Lbs	Range No. 2 Treated Lbs	Range No. 3 Control Lbs	Range No. 3 Treated Lbs
1931	9.19	A 7.19	15.25	A15.25	11.06	A13.94
	6.56	C13.19	13.81	C12.31	15.31	C17.19
	14.81	B 9.63	9.06	B 8.94	14.31	B15.94
	9.19	A10.06	7.44	A10.06	9.87	A12.63
	10.00	A 9.56	9.81	A16.87	12.13	A20.06
	13.56		13.44		13.56	
Av.	10.55	9.93	11.47	12.69	12.71	15.95
Diff. favor treatment		-0.62		1.22		3.24
1932	9.19	A 7.06	5.31	A 5.37	6.44	A 7.31
	7.12	C 5.00	3.50	C 7.00	7.06	C 8.00
	6.44	B 9.31	5.31	B 7.25	7.00	B 4.50
	12.12	A11.00	5.37	A 7.00	4.00	A 4.31
	13.12	A 7.19	5.31	A 7.12	9.00	A 8.00
	2.25		5.31		6.00	
Av.	8.37	7.91	5.02	6.75	6.58	6.42
Diff. favor treatment		-0.46		1.73		-0.16

Note - the crop of 1930 was not harvested on account of poor stand and the dry season. "A" indicates yields from plots connected to Vincent type collector heads, "B" to the Butler type head, and "C" to the Christofleau type head. Ranges correspond to replications, the range nearest to the collector heads being designated as "Range No. 1."

TABLE VII. Summary of three years results - effect of intensified earth-air electric currents on the yields of crops.

	Turnips Fresh wt. of roots (Lbs)			Chard Fresh wt. of Tops (Lbs)		Beets Fresh wt. of roots (Lbs)		Corn Shelled wt. at approximately 10% moisture (Lbs)			Soybeans Cured wt. tops & roots (Lbs)			String beans Cured wt. tops & roots (Lbs)	
	1930	1931	1932	1931	1932	1931	1932	1930	1931	1932 *	1930	1931 *	1932 *	1930	1931
Av. of controls	10.80	13.96	16.20	18.31	17.51	11.58	6.66	6.22	15.07	8.27	6.63	7.05	13.67	1.10	1.79
Av. of Tr.	11.56	13.95	15.56	18.93	19.10	12.86	7.03	6.26	15.75	8.04	6.84	7.11	13.71	1.12	1.86
Diff. favor treat- ments	0.76	-0.01	-0.64	0.62	1.59	1.28	0.37	0.04	0.68	-0.23	0.21	0.06	0.04	0.02	0.07
Percent increase over cks.	7.03	--	-3.95	3.39	9.08	11.05	5.55	0.64	4.51	-2.78	3.16	0.85	0.29	1.82	3.91

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

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 for the yields of the treated plots as compared to those of the controls the following differences: range No. 1, nine increases and six decreases; range No. 2, nine increases and six decreases; range No. 3, 12 increases and three decreases; and range No. 4, three increases and no decreases. These comparisons indicate that the effect of the treatment upon yields was no greater in the experimental areas nearest the source of the currents than in those farther away.

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

Beginning with the winter of 1931 experiments were conducted in field and greenhouse to test the effect upon plant growth of electric current as 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 having inside dimensions 20 x 30 x 4 inches and the small flats 15 x 20 x 4 inches.

On February 13, 1931, eight of the large flats were planted to Iogold oats, one kernel in a place two inches apart each way and one-half inch deep, 126 kernels per flat. The soil used was field soil apparently rather high in organic material.

A copper strip, one and one-half 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 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. 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 midafternoon, 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 February 23 and continued until the grain was in the soft dough stage.

During the time current was being applied bright sparks one or two 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 per cent 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 is shown in Figure 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. To prevent damage by sparrows after the grain had be-

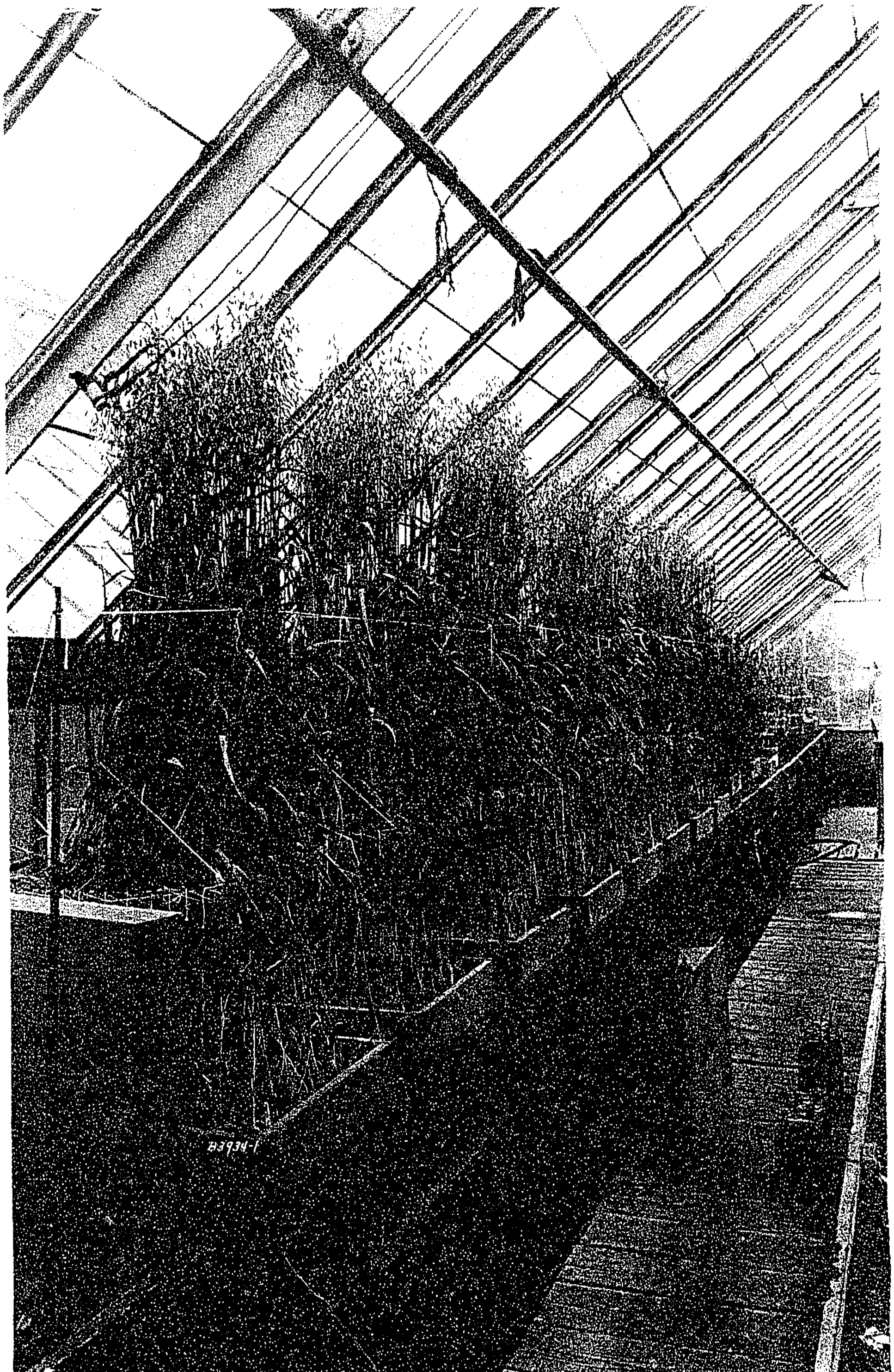

Figure 4. High voltage experiment with oats, 1931; includes six treated lots and two controls. Treated lots received currents at 7,000 to 20,000 volts for a 10 to 15 minute period daily. On this date, May 12, the controls are in the second and sixth locations, counting from the near end.

gun to fill the flats were moved to the middle of the house and the heads covered with mosquito netting. Treatment was continued in this location. Some smutted plants appeared in all flats and these were removed, dried, and the weights included in the total yields. For several days during the latter part of May, when the oats were in the milk, temperatures of more than 100 degrees were recorded in the greenhouse, consequently the grain was light and the yields obtained represent mostly the production of straw.

The oats were harvested by shearing at a height of one inch above the crowns. The product of each flat was placed in a steam heated oven and reduced to a water free basis.

A study of the results shows that the yields of the treated lots varied both above and below the average of the two controls, and that none 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. The obvious conclusion, that the small differences obtained are far from significant, is supported by a statistical analysis of the variance.

Table VIII. Effect of high voltage electric currents, applied to the soil, on the yields of oats - greenhouse experiment 1931.

Treatment	Dry weight grain and straw (Lbs)	Yield compared to average of controls (Per cent)	Per cent increase
7000 volts for 10 min. (neg. charge)	0.88	97.77	-2.23
" " " " " (pos. charge)	0.88	97.77	-2.23
10,000 " " 15 " (neg. charge)	0.85	94.44	-5.57
" " " " " (pos. charge)	0.89	98.88	-1.12
15,000 " " " " (neg. charge)	0.90	100.00	0.00
" " " " " (pos. charge)	0.92	102.22	2.22
Control	0.88	97.77	-2.23
"	0.92	102.22	2.22
Average of controls	0.90	100.00	- --

<u>Greenhouse test with oats using the copper-zinc electrodes combination</u>

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 two 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 milliampere with a potential of one 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, on March 18 were planted each with 126 grains of Iogold oats. 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 six inches in height those in the treated flat were noticeably more vigorous and taller than those of the control. The treated plants headed approximately two days later than the others and the yield at maturity was 12.46 per cent 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 two and one-half 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 experiment, 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, while during the 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 15 x 20 x 4 inches, of which five were to be used as earth cells and five as controls. These were filled with two and one-half 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 whatsoever. It was thought that the above described comparisons might provide leads for further investigation.

The seed oats used throughout were of the Iogold variety and had been treated several months previously with Ceresan. Series No. 1 was planted on January 23 with 126 selected uniform grains per flat, two inches apart each way, and covered one-half 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 1 x 6 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 seven days.

For the control of aphis the house was fumigated as necessary with Nicofume. At the time of the first fumigation, when the plants were about three inches in height, two of the treated lots and one of the controls were burned somewhat by the fumes so that the first leaves turned yellow to a distance of one or two inches back from the leaftips and the growth appeared to be slightly checked. These lots headed 24 to 30 hours later than the others but the yields were close to the averages.

On February 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 later, 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 four days after heading.

The 10 flats of the high fertility series were planted on February 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.

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. After the plants were headed the sun became quite hot at times so that it became necessary to provide partial shade by spattering the roof of the house with lime. The arrangement of the experiment is shown in Figure 5.

The rate of germination, as observed on February 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 micro-organisms, samples of soil, each about a pint in size, were taken from several of the treated and control lots in Series No. 1. A six-inch vertical slice about one inch in width was cut from between the rows, taking roots as well as soil. The composite lots were made up of three samples, one from each end and one from the middle of

Figure 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 flat. Clean glass jars were used as containers, and trowel and hands were cleansed after each sampling. 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.

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 micro-organisms counts are shown in Table IX.

The summary of Table IX shows, for the treatments as compared to the controls, increases in numbers of soil micro-organisms for the earth cells of from 14 to 45 per cent, and for the earth cells supplemented with dry cells increases of more than 100 per cent. These differences seem large enough to indicate a beneficial effect of the electric current. On each successive date the lots of soil were taken from flats not previously sampled, consequently the number of direct comparisons was so small that a statistical analysis was not attempted.

TABLE IX. Effect of electric current, 0.5 to 1.5 milliamperes, on number of micro-organisms in soil of low fertility - greenhouse experiment with oats, 1932

Treatment	Organisms per plate 1	2	3	4	5	Average for 5 plates	Organisms per gram dry soil	Dry wt. soil	Per cent moisture soil
Sampled 4/27, counted 5/2, dilution 1-100,000									
Earth cell plus dry cell -									
copper	59	48	55	49	48	51.8	118,800	43.6	14.7
middle	48	54	61	49	60	54.4	126,200	43.1	16.0
zinc	36	29	22	48	34	33.8	79,700	42.4	17.9
average							108,200		
Earth cell -									
copper	17	21	27	22	35	24.4	55,200	44.2	13.1
middle	18	15	22	13	11	15.8	35,900	44.0	13.6
zinc	33	35	31	35	30	32.8	75,700	43.3	15.4
average							55,600		
Control -									
end	34	31	26	18	14	24.6	55,900	44.0	13.6
middle	18	17	22	21	22	20.0	46,000	43.4	15.2
end	19	18	19	20	17	18.6	43,500	42.7	17.1
average							48,500		
Sampled 5/11, counted 5/16, dilution 1-100,000									
Earth cell plus dry cell -									
copper	34	32	58	57	77	51.6	122,300	42.2	18.5
middle	25	33	30	40	28	31.2	73,400	42.5	17.6
zinc	18	36	22	22	34	26.4	60,300	43.8	14.1
average							85,300		
Earth cell -									
copper	17	15	18	14	23	17.4	40,300	43.2	15.7
middle	25	32	20	36	33	29.2	68,000	42.9	16.5
zinc	36	32	30	29	26	30.6	70,800	43.2	15.7
average							59,700		
Control -									
end	19	15	13	23	9	15.8	37,100	42.6	17.3
middle	20	38	23	24	16	24.2	56,800	42.6	17.3
end	10	8	19	8	17	12.4	29,000	42.8	17.0
average							41,000		
Sampled 5/26, counted 6/2, dilution 1-100,000									
Earth cell No. 1	26	22	16	26	35	25.0	58,500	42.7	17.1
Earth cell No. 2	--	24	26	21	14	21.3	49,800	42.6	17.3
Earth cell No. 3	19	33	15	23	23	22.6	53,000	42.6	17.3
average							53,800		
Control No. 1	25	17	16	30	17	21.0	50,900	41.2	21.3
Control No. 2	10	19	13	13	15	14.0	32,500	43.0	16.3
Control No. 3	10	21	11	14	12	13.6	31,400	43.3	15.4
average							38,300		

SUMMARY - NUMBERS OF MICRO-ORGANISMS

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

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. In two of the four instances samples taken from near the zinc electrodes showed small numbers of organisms, and in two instances large numbers, as compared to those taken from near the copper electrodes. Samples taken from the middles of the same flats showed numbers of organisms in one instance higher, in one instance lower, and in two instances intermediate, as compared to the numbers in the samples from near the electrodes.

The high greenhouse temperatures during much of the heading period quickly brought all lots to maturity. The plants of Series No. 2, though planted two weeks later on richer soil than those of the other series, ripened but a little later and all were harvested on May 2. Harvesting was accomplished by clipping the plants one inch above the crowns. Each lot was rolled in mosquito netting and reduced to a water free basis in a steam heated oven.

The data in Tables X and XI indicate that the yields of oats matured on the soil of low fertility were rather consistently increased by treatment with electric current. In but one case was the yield of an earth cell as low as the average of the controls, and in but one case was the yield of a control as high as the average of the earth cells. The yields from the two flats having a dry cell included in the circuit were somewhat above those of the ordinary earth cells, indicating that the slightly stronger current might have provided an added stimulus. Statistical analysis supports the conclusion 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 per cent 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

TABLE X. Effect of electric current (0.5 to 1.5 milliamperes) on yield of oats (dry weight). Soil of low fertility, greenhouse experiment, 1932.

	Flat No.	Grain gm.	Grain and straw gms.	Against Av. of Control: Grain %	Against Av. of Control: Grain and straw %
Control	1	82.60	217.73	102.61	98.76
"	2	74.13	208.66	92.09	94.65
"	3	79.59	217.73	98.87	98.76
"	4	80.00	213.19	99.38	96.71
"	5	86.20	244.94	107.08	111.11
Averages		80.50	220.45	100.00	100.00
Earth cell	6	84.55	217.73	105.03	98.76
"	7	92.20	240.41	114.53	109.05
"	8	84.75	235.87	105.28	106.99
"	9	93.60	254.02	116.27	115.23
"	10	87.03	222.26	108.11	100.82
Averages		88.43	234.06	109.85	106.17
Earth cell plus drycell	11	94.10	249.48	116.89	113.17
" "	12	93.00	263.09	115.53	119.34
Averages		93.55	256.28	116.21	116.25

TABLE XI. Effect of electric current (0.5 to 1.5 milliamperes) on yield of oats (dry weight). Soil of high fertility, greenhouse experiment, 1932.

	Flat No.	Grain and straw	Against average of controls 3 and 8
		gms	%
Earth cell with $ZnSO_4$	2	276.70	91.73
" " " "	7	258.55	85.71
Averages		267.62	88.72
Earth cell	5	285.77	94.74
" "	10	285.77	94.74
Averages		285.77	94.74
Control with $ZnSO_4$	1	267.62	88.72
" " "	6	272.16	90.23
Averages		269.89	89.47
Control with copper plate	4	322.06	106.77
" " " "	9	294.84	97.74
Averages		308.45	102.25
Control	3	308.45	102.26
"	8	294.84	97.74
Averages		301.64	100.00

beneficial as the yields from the two earth cells receiving no other treatment averaged six per cent lower than those of the controls. On the basis of this rather limited test the possibility that the copper and zinc electrodes might in themselves provide sufficient soluble nutrients to cause increased yields seems rather unlikely.

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 field soil, one part of compost and one part of sand to a depth of three inches. Series No. 2 included 10 of the small flats filled with a mixture composed of four parts 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, the metal strips were but one and one-half inches in width and a dry cell was included in each circuit. Five flats in each series were used as controls. All connections were installed four days before planting.

On December 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.

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 was raised from time to time so as always to provide adequate support. Damage from sparrows during the ripening of the grain was prevented by inclosing the experimental plants with a canopy of mosquito netting. 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 data obtained are presented in table XII.

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

Figure 6a. Earth cell test with oats, 1933. Alternate flats are earth cells, with dry cells included in the circuits, the other flats received no treatment. Photographed April 6.

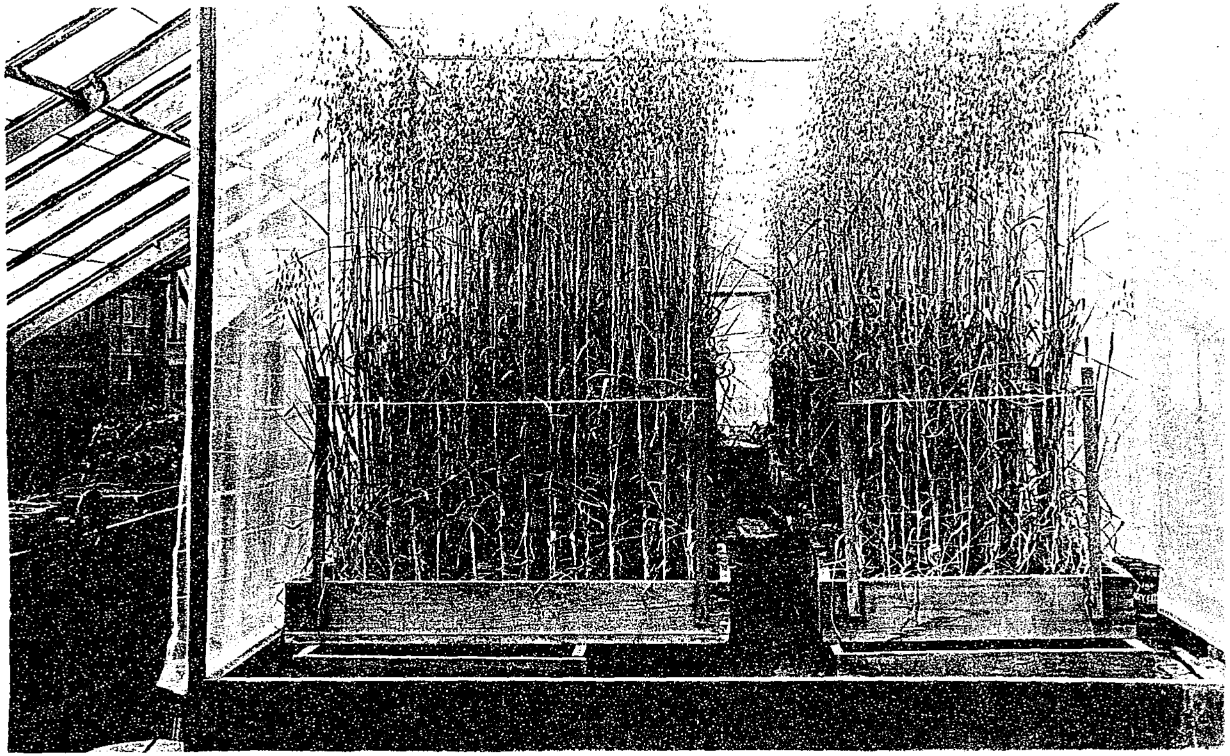

Figure 6b. Same experiment phtoographed May 15, showing enclosure of mosquito netting.

TABLE XII. Current in milliamperes at various dates, in soil of flats planted to oats and equipped with copper-zinc electrode combination. Earth cell treatment, greenhouse, 1933. Readings taken soon after watering unless otherwise stated.

Date	Large flats No.					Small flats No.				
	1	3	5	7	9	1	3	5	7	9
12/29	2.4	2.1	1.7	2.4	2.5	2.6	2.3	2.5	2.2	2.2
12/31	2.1	1.9	1.5	2.1	2.2	2.3	1.9	2.1	1.9	1.8
1/7	1.9	1.6	1.6	1.9	1.9	2.4	2.2	2.5	2.1	1.9
1/10	2.0	1.8	1.7	1.7	2.0	2.3	2.4	2.4	2.1	2.0
1/15	2.2	1.9	1.8	2.0	2.1	2.4	2.4	2.4	2.2	2.2
1/19(before watering)	1.0	0.9	0.8	1.0	1.1	1.3	1.4	1.3	1.0	1.1
(after watering)	2.0	1.8	1.6	1.9	1.9	2.2	2.1	2.2	2.1	2.1
1/26(before watering)	0.7	0.7	0.8	0.9	0.9	1.0	0.9	1.1	1.0	0.9
(after watering)	1.2	1.2	1.2	1.3	1.5	1.8	1.6	1.7	1.6	1.7
*1/31(before watering)	1.3	1.3	1.2	1.3	1.6	1.8	1.4	1.5	1.7	1.8
(after watering)	2.0	2.0	1.8	1.9	2.3	2.8	2.3	2.5	2.5	2.6
2/4 (before watering)	1.1	0.9	1.0	1.0	1.1	1.6	1.0	1.2	1.3	1.5
(after watering)	1.9	1.8	1.7	1.9	2.0	2.8	2.3	2.7	2.5	2.8
2/11(24 hrs after watering)	1.5	1.6	1.8	1.5	1.9	2.5	2.5	2.4	2.7	2.2
2/18(24 hrs. after watering)	1.8	1.7	1.8	2.1	2.5	3.2	2.8	3.2	2.9	2.5
2/25	2.2	2.2	2.5	2.5	3.4	3.8	2.9	2.8	2.7	2.6
2/28(24 hrs. after watering)	1.5	2.0	2.5	2.1	3.0	2.8	2.0	2.2	1.5	1.6
3/2 (before watering)	0.9	1.3	1.1	1.5	1.9	1.9	1.3	1.2	0.9	1.0
(after watering)	2.0	3.0	3.3	2.7	3.1	3.3	2.9	2.5	2.3	2.3
3/9 (24 hrs. after watering)	1.5	2.1	2.2	1.5	2.7	3.1	2.3	1.8	1.8	1.8
3/13(before watering)	0.8	1.3	1.7	1.2	1.0	1.3	1.1	1.0	1.1	1.0
3/20(before watering)	1.1	1.9	2.1	1.5	1.1	1.7	1.3	1.6	1.2	1.2
3/27(before watering)	1.3	1.9	2.0	1.8	2.1	2.5	2.0	2.2	1.5	1.2
4/2	2.2	2.7	2.5	3.0	3.9	3.7	3.6	4.4	3.6	2.8
4/9	2.2	3.0	1.5	2.6	3.0	3.6	3.5	3.0	3.0	2.5
4/13	2.4	4.2	3.4	2.4	3.0	3.7	3.1	4.1	3.0	2.9
4/18	4.0	4.0	3.2	3.2	3.8	3.8	3.8	4.0	4.0	3.9
4/20(50 hrs. after watering)	2.5	2.4	2.0	1.8	2.0	1.9	1.7	1.9	2.3	2.0
4/28	3.0	4.0	3.5	3.0	3.5	4.0	3.5	4.7	4.6	3.2
5/2	2.0	2.7	2.8	2.2	3.0	2.8	2.8	3.6	3.0	2.3
5/15(24 hrs after watering)	3.7	3.3	4.5	3.0	4.0	4.5	4.2	4.5	4.0	3.5

* On January 30 an additional dry cell was placed in each circuit.

watering operation resulted in almost 100 per cent increases in the amounts of current. During much of the time, especially toward the end 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.

After the crops had been harvested final measurements of current were made on all of the treated flats. The data obtained are presented in Table XIII.

TABLE XIII. Final measurements of current in earth cell flats after harvesting oats. Readings taken May 24, 1933.

Flat No.	Before watering I_e MA (1)	I_t MA (2)	E_b v (3)	E_e v (4)	E_t v (5)	After watering I_e MA (6)	I_t MA (7)	E_b v (8)	E_e v (9)	E_t v (10)
L_1	0.40	1.95	2.84	0.57	3.41	1.35	*3.60	1.41	0.84	3.68
L_3	.50	2.30	2.82	.78	3.60	1.20	*3.00	1.40	.93	3.75
L_5	.55	2.70	2.82	.72	3.54	1.15	*2.30	1.41	.83	3.65
L_7	.45	2.40	2.84	.66	3.50	1.10	*2.95	1.42	.80	3.64
L_9	.75	3.75	2.80	.70	3.50	1.40	*3.80	1.40	.81	3.61
S_1	0.20	0.95	2.79	0.74	3.53	0.75	3.60	2.79	0.73	3.52
S_3	0.30	1.40	2.79	0.76	3.55	0.95	4.80	2.79	.70	3.49
S_5	.20	.90	2.79	.80	3.59	1.00	4.20	2.79	.87	3.56
S_7	.55	2.80	2.80	.68	3.48	1.50	*4.25	1.40	.76	3.56
S_9	.50	2.80	2.85	.62	3.46	1.40	*4.00	1.43	.77	3.61

Symbol	Meaning
e.c.	Earthcell
I_e	Current with e.c. only
I_t	Current with e.c. and 2 dry cells
E_b	Voltage of dry cells
E_e	Voltage of e.c.
MA	Milliamperes
v	Volts
E_t	Total voltage of e.c. and dry cells in series
S	Small flats
L	Large flats

Column (5) = sum of columns (3) and (4).
Column (10) = sum of columns (8) and (9).

*Current I_t using two dry cells in series with e.c. was too large to measure with milliammeter used. Only one dry cell was used to determine E_e, (Column 10).

Seeding was accomplished by pressing the grains to a depth of one-half inch in the moist soil and filling each small cavity compactly with freshly mixed soil.

TABLE XIV. 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 - 9AM	12/31 - 11AM	98
Remainder " "	" 12AM	" 3PM	99
Series 2	" 3PM	" 6PM	99

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

A count of the numbers of tillers was made by rows across each flat, each row being nine plants long and six plants long in the large and the small flats, respectively. The row nearest the zinc electrode is designated as Row No. 1.

TABLE XV. Number of tillers (oats) by rows on February 4, earth cell treatment greenhouse 1933. Averages for all flats.

Treatment	Row No.	Large flats	Small flats	Treatment	Row No.	Large flats	Small flats
5 treated		per flat		5 controls		per flat	
flats	1	10.2	3.4		1	8.6	3.0
	2	5.2	2.2		2	6.4	2.2
	3	6.8	0.8		3	5.8	3.0
	4	5.2	1.4		4	4.2	2.0
	5	4.2	1.2		5	6.4	0.8
	6	3.8	1.0		6	5.2	0.8
	7	3.0	1.0		7	3.4-	1.2
	8	4.4	0.6		8	3.0	0.6
	9	4.6	1.8		9	2.4	1.0
	10	4.0			10	0.8	
	11	4.6			11	1.0	
	12	2.6			12	2.0	
	13	2.0			13	2.6	
	14	2.8			14	2.0	
	Totals	63.4	13.4			53.8	14.6
Av. No. tillers per plant		0.507	0.248			0.43	0.252

TABLE XVI. 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

Note: An examination of the stand on this date, Feb. 4, showed that in Series No. 1 four of the lots had a perfect stand of 126 plants and no lot had less than 124 plants, while Series No. 2 had a perfect stand of 54 plants thruout. Total number of plants obtained, in Series No. 1 - 1251 out of a possible 1260, in Series No. 2 - 540 out of a possible 540.

While the data indicate a definite trend in numbers of tillers, always in the same direction in each flat, this difference will be noted in the controls as well as in the treatments. Since the same end of each flat was always to the outside of the bench, in order to facilitate electrometer readings, 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 both series the variations between individual flats were so large as to indicate that the differences in numbers of tillers with respect to treatments is not significant. While flat No. 5 in Series No. 1 had many more tillers than any other, an inspection of the yield records shows that, for some unaccountable reason, its yields of roots, straw and grain were, with respect to each item, materially lower than those of any other lot.

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 obtained are recorded in Table XVII.

TABLE XVII. Comparative time of heading (oats), earth cell treatment, greenhouse 1933.

Treatment	Flat No.	Large flats 4/13	Large flats 4/16	Small flats 4/13	Small flats 4/16
Treated	1	1	30	0	5
	3	0	30	0	5
	5	0	40	0	5
	7	5	80	0	5
	9	3	40	1	10
Averages		1.8	44.0	0.2	6.0
Controls	2	1	30	0	5
	4	1	30	0	5
	6	0	40	0	5
	8	3	70	0	5
	10	0	40	0	4
Averages		1.0	46.0	0	4.8

From the data presented it is apparent that the treatment with electric current has neither advanced nor retarded the time of heading.

Shortly after the complete emergence of the heads a considerable number of blasted spikelets was 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 obtained are recorded in Table XVIII.

TABLE XVIII. Numbers of blasted spikelets (oats) earth cell treatment, greenhouse 1933. Counts made on two rows per flat.

Treatment	Flat No.	Large flats *row A	Large flats row B	Small flats row A	Small flats row B
Treated	1	86	47	33	36
	3	66	47	34	24
	5	66	48	34	29
	7	120	61	46	50
	9	156	46	50	52
Totals		494	249	197	191
Controls	2	68	67	33	45
	4	71	52	35	48
	6	56	56	40	43
	8	63	50	34	53
	10	164	77	28	48
Totals		422	302	170	237

* Of the rows on which the counts were made the row nearest the outher edge of the bench is designated as A and the row nearest the center of the bench as B.

Study of these data indicates 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. Because of the systematic rotation of the flats as described in the experiment of 1932, the large flats, during much of the flowering period, were located opposite each other on one-half of the bench and the small flats opposite each other on the other part of the bench. The large flats extended almost halfway across so that the inside ends of opposite flats almost touched, consequently the plants in row B were subjected to considerably different environmental conditions than those of row A at the outer edge of the bench. A considerable space intervened between the inside ends of the small flats, hence the growing conditions for the outer and the inner ends of these flats probably were not much different. The much larger number of the blasted spikelets in the A rows than in the B rows of the large flats indicates that the variation in numbers of these spikelets may be due mainly to environmental conditions.

For the counts of micro-organisms 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 XIX and XX.

TABLE XIX. Numbers of soil micro-organisms, series No. 1, earth cell treatment, greenhouse, 1933.

Flat No.	Organisms per plate 1	2	3	4	5	Av. for 5 plates	Organisms per gram dry soil	Dry wt. soil gms.	Per cent moisture soil	Current m.a.
Sampled 3/19, counted 3/25, dilution 1-100,000										
1*	31	67	38	33	40	41.8	97,900	42.7	17.1	1.1
2#	44	53	58	46	58	51.8	121,300	42.7	17.1	
3*	67	59	45	41	64	55.2	131,400	42.0	19.0	1.9
4#	37	30	37	33	34	34.2	81,400	42.0	19.0	
5*	46	42	63	56	45	50.4	124,400	40.5	23.4	2.1
6#	38	41	36	38	41	38.8	91,500	42.4	17.9	
7*	36	45	42	48	46	43.4	103,300	42.0	19.0	1.5
8#	45	37	41	31	33	37.4	87,600	42.3	18.2	
9*	41	30	29	46	42	37.6	88,100	42.7	17.1	1.1
10#	37	49	43	59	41	45.8	106,500	43.0	16.3	
Av. of treatments (1-3-5-7-9)							109,000			
Av. of controls (2-4-6-8-10)							97,800			
Per cent increase over controls							11.4			
Sampled 4/27, counted 5/2, dilution 1-100,000										
1*	20	16	19	15	29	19.8	45,300	43.7	14.4	2.5
2#	19	16	23	17	6	16.2	35,800	45.2	10.6	
3*	20	12	20	19	18	17.8	41,400	43.0	16.3	2.4
4#	11	14	13	14	17	13.8	32,100	43.0	16.3	
5*	21	20	20	23	22	21.2	49,900	42.5	17.6	2.0
6#	11	12	20	15	13	14.2	32,100	44.2	13.1	
7*	17	15	21	23	20	19.2	43,600	44.0	13.6	1.8
8#	18	13	29	28	20	21.6	49,000	44.1	13.4	
9*	16	10	18	20	20	16.8	38,100	44.1	13.4	2.0
10#	12	13	10	11	20	13.2	29,300	45.0	11.1	
Av. of treatments (1-3-5-7-9)							43,700			
Av. of controls (2-4-6-8-10)							35,700			
Per cent increase over controls							22.4			

* Treated
# Control

TABLE XX. Numbers of soil micro-organisms, series No. 2, earth cell treatment, greenhouse, 1933.

Flat: No.	Organisms per plate 1	2	3	4	5	Av. for 5 plates	Organisms per gram dry soil	Dry wt. soil gms.	Per cent moisture soil	Current m.a.
				Sampled 3/13, counted 3/18, dilution 1-10,000						
1*	283	367	291	352	368	332	76,300	43.5	14.9	1.3
2#	72	211	296	289	279	229	51,600	44.4	12.6	
3*	496	440	424	509	454	465	109,400	42.5	17.6	1.1
4#	350	242	358	251	292	299	68,700	43.5	14.9	
5*	434	302	350	353	356	359	83,100	43.2	15.7	1.0
6#	317	361	320	357	X	339	77,000	44.0	13.6	
7*	375	346	271	361	182	307	71,100	43.2	19.7	1.1
8#	389	383	420	334	351	375	86,200	43.5	14.9	
9*	246	325	342	283	235	286	65,700	43.5	14.9	1.0
10#	176	320	337	346	315	299	68,400	43.7	14.4	
	Av. of treatments (1-3-5-7-9)						81,100			
	Av. of controls (2-4-6-8-10)						70,400			
	Per cent increase over controls						15.2			
				Sampled 5/2, counted 5/8, dilution 1-100,000						
1*	21	20	23	30	34	25.6	60,000	42.7	17.1	1.9
2#	35	36	32	28	37	33.6	75,700	44.4	12.6	
3*	23	34	19	34	22	26.4	61,700	42.8	17.0	1.7
4#	17	36	24	24	28	25.8	60,300	42.8	17.0	
5*	23	31	32	27	20	26.6	61,900	43.0	16.3	1.9
6#	15	20	18	15	7	15.0	33,300	45.1	10.9	
7*	24	21	20	34	21	24.0	55,800	43.0	16.3	3.0
8#	19	15	21	17	19	18.2	41,400	44.0	13.6	
9*	23	32	23	24	27	25.8	58,800	43.9	14.0	2.0
10#	14	14	18	11	15	14.4	32,000	45.0	11.1	
	Av. of treatments (1-3-5-7-9)						59,600			
	Av. of controls (2-4-6-8-10)						48,500			
	Per cent increase over controls						22.8			

* Treated
# Control

In this study of the effect of electric current upon the numbers of soil micro-organisms, the increases, averaging approximately 18 per cent, 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 no consistent differences in amount of growth could be observed. Each lot was rolled in mosquito netting and reduced to a water free basis. The roots of each lot were washed and dried, and yields determined. Yields of grain, straw, and roots are shown in Table XXI.

TABLE XXI. Effect of electric current of low intensity (copper-zinc electrode combination) on yields of oats, greenhouse experiment, 1933. Dry weight in grams per flat.

Series	Grain		Straw		Roots		Total	
	Tr.*	Ck.*	Tr.	Ck.	Tr.	Ck.	Tr.	Ck.
Small flats 15"x20"	56.3	57.3	126.5	116.6	47.0	49.0	229.8	222.9
	57.9	60.3	125.0	127.3	44.0	44.0	226.9	231.6
	61.9	58.7	134.2	115.0	45.0	49.0	241.1	222.7
	56.8	56.2	116.6	117.6	36.0	45.0	209.4	218.8
	58.1	59.9	115.2	116.9	48.0	50.0	221.3	226.8
Total	291.0	292.4	617.5	593.4	220.0	237.0	1128.5	1122.8
Av. Yield per flat	58.2	58.5	123.5	118.7	44.0	47.4	225.7	224.6
% increase over cks.	-0.5		3.9		-7.7		0.5	
Large flats 20"x30"	95.2	105.2	214.3	212.9	75.0	83.0	384.5	401.1
	100.5	95.9	222.9	204.5	71.0	71.0	394.4	371.4
	93.9	105.6	211.5	222.3	56.0	65.0	361.4	392.9
	98.0	96.5	220.6	213.0	63.0	73.0	381.6	382.5
	98.3	94.3	220.3	215.5	67.0	76.0	385.6	385.8
Total	485.9	497.5	1089.6	1068.2	332.0	368.0	1907.5	1933.7
Av. Yield per flat	97.2	99.5	217.9	213.6	66.4	73.6	381.5	386.7
% increase over cks.	-2.3		2.0		-10.8		-1.3	

* Tr = treated
Ck = control

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 averages for each series shows, for the treated flats, a slightly less yield of grain and a slightly increased yield of straw, the variations between individual flats were so large as to indicate that the results for the grain and the straw can not be considered conclusive.

With reference to the yields of roots the data show that in eight of the ten treated flats the root weights were less than the mean weights of the controls. While the differences are not large, the consistently lower root yields from the treated flats indicates 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 two gram samples of the straw and roots were used and determinations made by the Kjeldahl method. Results of these analyses are shown in Table XXII.

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

TABLE XXII. Per cent total nitrogen in grain, straw and roots (oats), earth cell treatment, greenhouse, 1933.

GRAIN				STRAW				ROOTS			
Treatments		Checks		Treatments		Checks		Treatments		Checks	
Plot	Total N %	Plot	Total N %	Plot	Total N %	Plot	Total N %	Plot	Total N %	Plot	Total N %
				Series No. 1							
1	1.84	2	1.84	1	.417	2	.421	1	1.23	2	1.30
3	1.87	4	1.90	3	.412	4	.431	3	1.32	4	1.32
5	1.88	6	1.84	5	.451	6	.382	5	1.32	6	1.39
7	2.08	8	2.04	7	.421	8	.417	7	1.23	8	1.38
9	1.77	10	1.94	9	.392	10	.451	9	1.25	10	1.44
Av.	1.89		1.91		.419		.420		1.27		1.37
				Series No. 2							
1	1.69	2	1.70	1	.402	2	.363	1	1.37	2	1.39
3	1.61	4	1.61	3	.343	4	.372	3	1.30	4	1.39
5	1.64	6	1.65	5	.372	6	.378	5	1.41	6	1.40
7	1.62	8	1.68	7	.339	8	.349	7	1.26	8	1.34
9	1.68	10	1.65	9	.363	10	.363	9	1.28	10	1.39
Av.	1.65		1.66		.364		.365		1.32		1.38

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.

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 Iogold oats. The oats was planted with a hand drill in rows running north and south, six 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 in width. For the treated plots the copper-zinc electrode combination was installed. The metal strips, each 40 inches long and two inches wide, were pressed into the soil to a depth of about three 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 ten plots six dry cells in series were included in each circuit while the remaining ten 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 one inch in height. The arrangement of the field with the locations of the high and the low treatments, also the intervening controls, is shown by Figure 7.

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. The following meter readings are indicative of current intensities during the experiment.

	April 22 m.a.*	June 23 m.a.	June 28 m.a.	June 30 m.a.
High treatment	20-55	8-15	5-12	5-12
Low treatment	12-30	3-10	2-8	2-8

*milliamperes

Counts of soil micro-organisms, 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 Tables XXIII to XXVI, inclusive.

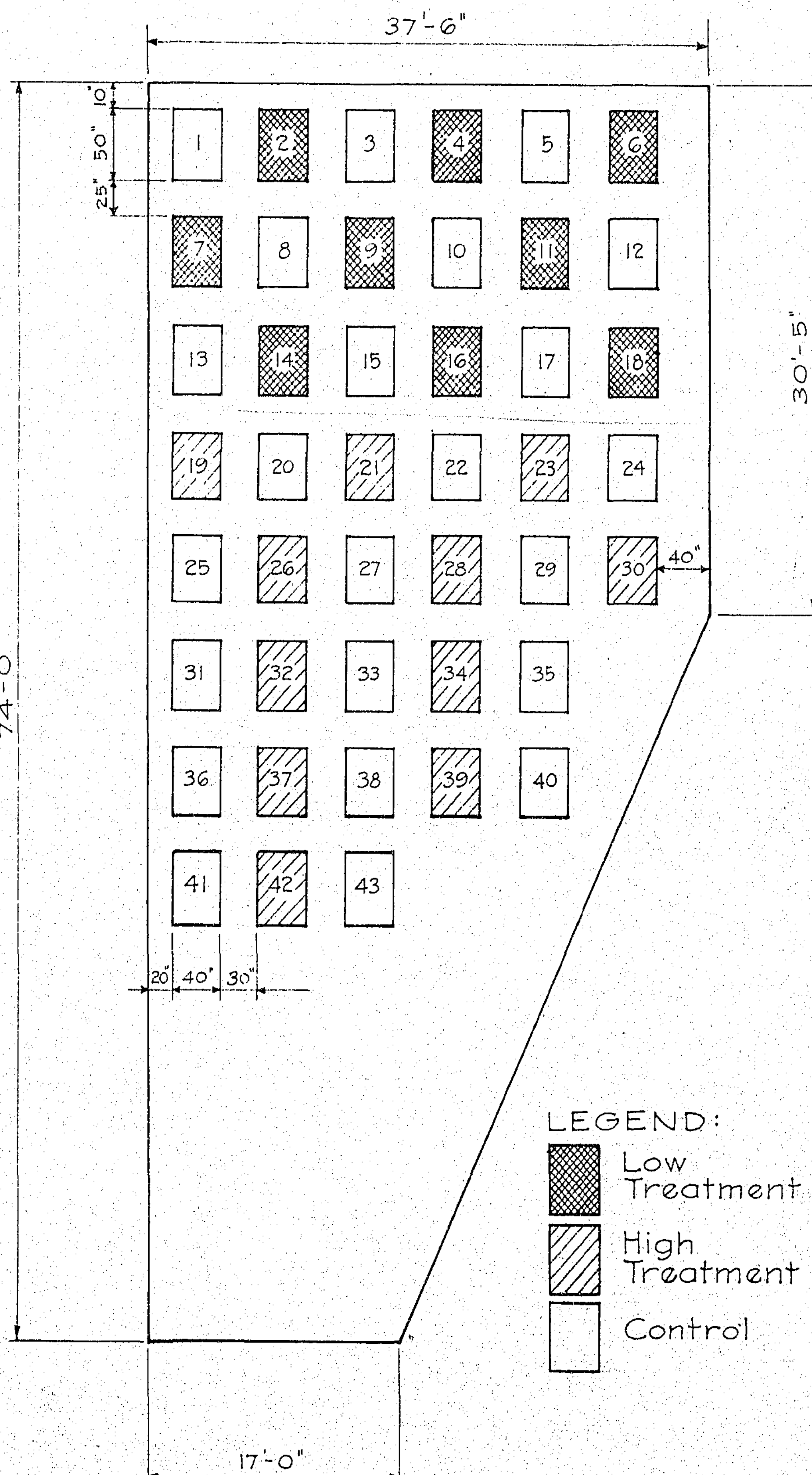

Figure 7. Planting plan of earth cell experiment, copper-zinc electrode combination, with oats, College Field, 1932.

TABLE XXIII. Effect of electric current (copper zinc electrode combinations supplemented with dry cells) on numbers of soil organisms and yields of oats, College Field, 1932.

Plot No.	Control: Nos. soil organisms 000 per gm.	Control: Crop yield gms.	Plot No.	Light Treatment: Nos. soil organisms 000 per gm.	Light Treatment: Crop yield gms.
1	*	680.4	2	108	621.4
3	76	662.3	4	93	725.7
5	85	743.9	6	88	753.0
8	68	653.2	7	98	712.2
10	100	675.9	9	103	653.2
12	*	734.8	11	110	684.9
13	*	712.2	14	129	671.3
15	100	694.0	16	89	689.5
17	92	689.5	18	94	771.1
20	122	607.8	19	92	671.3
	Control			**Heavy Treatment**	
20	122	607.8	21	121	616.9
22	83	644.1	23	83	725.8
24	*	771.1	26	128	762.0
25	*	698.5	28	127	784.7
27	139	612.4	30	93	662.3
29	82	712.2	32	*	771.1
31	*	771.1	34	*	707.6
33	*	666.8	37	99	698.5
35	*	707.6	39	99	825.6
36	100	698.5	42	*	721.2
38	108	725.8			
40	113	716.7			
41	*	734.8			
43	*	762.0			

*Not sampled.

TABLE XXIV. Numbers of soil micro-organisms - summary of Table XXIII.

Treatments	June 23 No of samples	June 23 Bacteria per gm.	June 23 Comparative per cents	June 28 No of samples	June 28 Bacteria per gm.	June 28 Comparative per cents	June 30 No of samples	June 30 Bacteria per gm.	June 30 Comparative per cents
Low Treatments	3	96,300	118.89	4	100,800	120.00	3	104,000	107.77
Corresponding Cks.	2	81,000	100.00	2	84,000	100.00	2	96,500	100.00
High Treatments	3	115,700	104.71	2	102,000	99.51	2	99,000	92.52
Corresponding Cks.	2	110,500	100.00	2	102,500	100.00	3	107,000	100.00
All Treatments	6	106,000	110.65	6	101,200	108.82	5	102,000	99.22
All Checks	4	95,800	100.00	5	93,000	100.00	7	102,800	100.00

	No. of samples	Bacteria per gram	Comparative per cents
Average all low treatments	10	100,400	115.14
Average all corresponding cks.	6	87,200	100.00
Average all high treatments	7	105,600	98.97
Average all corresponding cks.	7	106,700	100.00
Average all treatments	17	103,000	106.30
Average all checks	16	96,900	100.00

TABLE XXV. Yield of grain and straw - summary of Table XXIII.

Treatment	No. plots	Average yield	Yield compared to checks
		GMS	%
All treatments	20	711.4	101.79
All checks	23	698.9	100.00
Low treatments	10	695.4	101.46
Corresponding cks.	10	685.4	100.00
High treatment	10	727.6	102.58
Corresponding cks.	13	709.3	100.00

TABLE XXVI. Effect of electric current (copper-zinc electrode combination supplemented with dry cells) on percentage total nitrogen in oats, College Field, 1932.

Plot: No.:	Grain % n.	Straw % n.	Plot: No.:	Grain % n.	Straw % n.
	Controls			Light Treatment	
1	1.844	0.308	2	1.800	0.345
3	1.947	0.359	4	2.018	0.345
5	1.869	0.286	6	1.891	0.271
8	1.844	0.292	7	1.916	0.336
10	1.922	0.351	9	1.916	0.292
12	1.785	0.358	11	1.785	0.305
13	1.779	0.292	14	1.850	0.344
15	1.807	0.300	16	1.894	0.314
17	1.910	0.308	18	1.894	0.308
20	1.791	0.300	19	1.822	0.257
Av.	1.850	0.315		1.879	0.312
	Controls			Heavy Treatment	
20	1.791	0.300	21	1.735	0.292
22	1.807	0.322	23	1.763	0.314
24	1.878	0.365	26	1.835	0.271
25	1.850	0.264	28	1.894	0.292
27	1.835	0.249	30	1.981	0.330
29	2.040	0.308	32	1.735	0.257
31	1.866	0.300	34	1.850	0.300
33	1.807	0.365	37	1.704	0.235
35	1.910	0.314	39	1.966	0.330
36	1.866	0.257	42	1.791	0.308
38	1.807	0.264			
40	1.966	0.308			
41	1.850	0.235			
43	1.894	0.264			
Av.	1.869	0.294		1.825	0.293
Av. for all controls	1.864	0.303	Av. for all treatments	1.852	0.302

It is apparent that the results of this experiment fail to show significant differences due to the treatment with electric current. There is a slight indication, however, that the currents used may have been too strong since with the lower treatment an average increase of 15 per cent in the number of soil micro-organisms was obtained, while with the high treatment the number was slightly decreased. But little reliance can be placed upon such a conclusion as the variations in the individual counts were so large as to render insignificant the slight average differences obtained. For example, the number of soil organisms per gram dry soil in treated plot No. 9 was 103,000, while in plots Nos. 8 and 10, the controls on either side, the numbers were 68,000 and 100,000 respectively. Again, in treated plot No. 28 the number was 127,000, while in plots No. 27 and 29 the numbers were 139,000 and 82,000 respectively.

A comparison of treatments and controls with respect to crop yields and percentages of total nitrogen shows that the average differences were so slight as to be negligible, especially in view of the rather large variations in the individual determinations. For the plots receiving the light treatment, the crop yields, as shown in Table XXIII, varied from 621.4 grams to 771.1 grams, while the yields of the corresponding group of controls varied from 607.8 grams to 743.9 grams. The yields of the plots receiving the heavy treatment varied from 616.9 grams to 825.6 grams, and for the controls from 607.8 grams to 771.1 grams. The nitrogen analyses, presented in Table XXVI, show that both the grain and straw of treated plot No. 28 were higher in percentage of total nitrogen than control No. 27, and lower than control No. 29. The data on percentage of total nitrogen presents a number of similar examples.

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 micro-organisms, samples of soil were treated with different intensities of current and the effect 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 two to five inches below the surface in an old alfalfa field. After air drying for 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 the taking of the experimental samples the moisture content of the air-dry soil was determined by reducing 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 per cent by adding 40 cc. of a nutrient solution. The nutrient solution had been prepared by adding to each 40 cc. of distilled water two 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 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 Edison storage batteries. On account of high resistance in the circuits, possibly due to imperfect contact between the soil and the electrodes, it was necessary to use considerable voltage in order to obtain the currents desired. 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 inches in diameter, projecting through holes bored in opposite sides about three-fourths inch above the bottoms. The ends of the electrodes intended to be in contact with the soil projected one-half inch beyond the inner walls and were sealed in place to prevent leakage. The three bottles in each group were connected in series, as illustrated in Figure 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 CO_2 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 per cent KOH. From each soil flask the CO_2 laden air was drawn

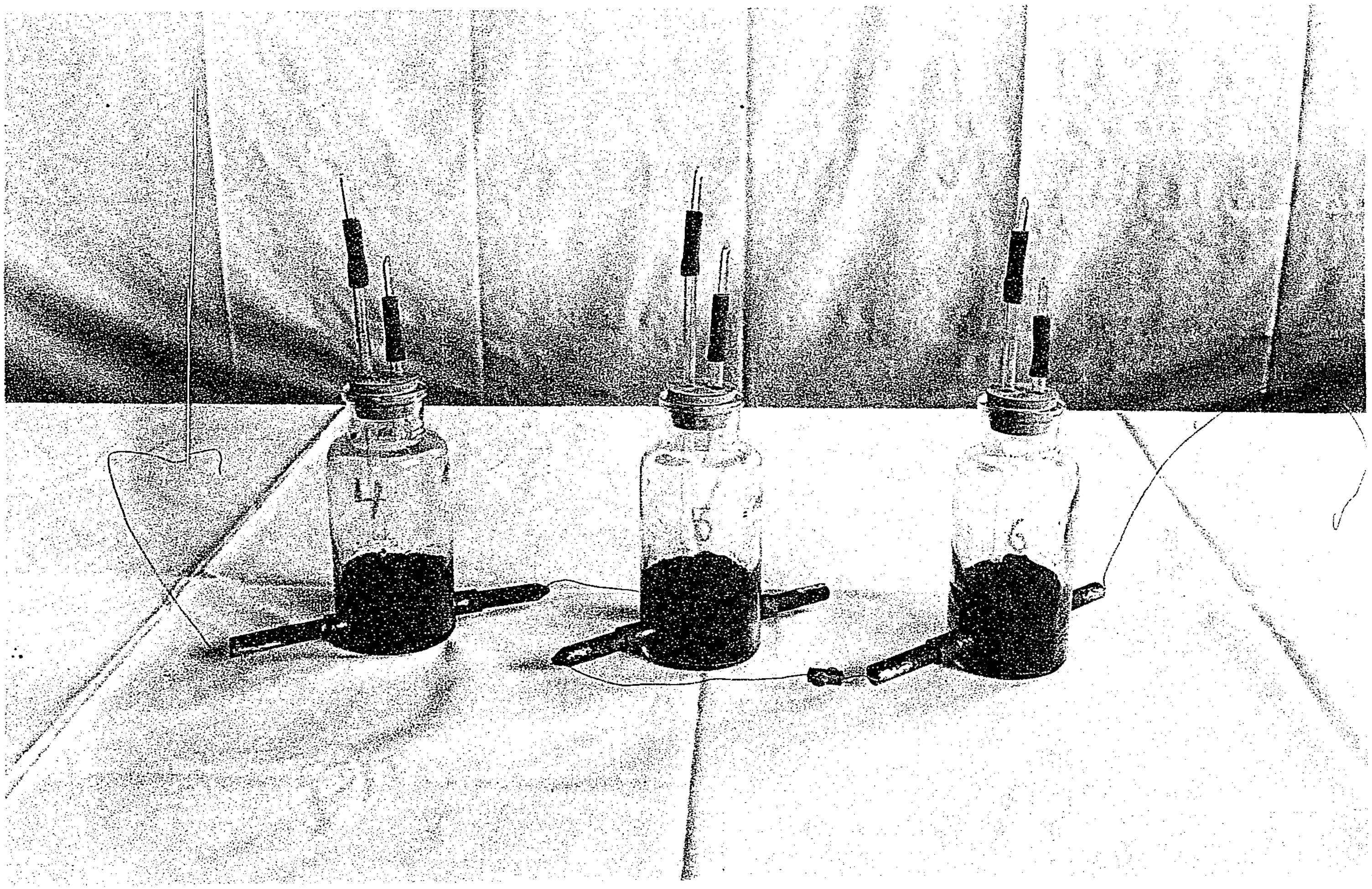

Figure 8. Group of three 200 gram (dry weight) samples of soil in gas bottles wired in series for treatment with electric current. Part of experiment to measure effect of electric current on CO_2 formation in soil.

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, ten cc. of $BaCl_2$ 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 CO_2 were made at the end of each eight-hour period for the first day, and at the end of each 24-hour period for the next two days. The results of this experiment are presented in the Tables XXVII and XXVIII.

In Table XXVIII the symbol "F" in each case represents the ratio of the greater to the smaller mean squares. The degree of significance for each factor is indicated by comparing "F" with the appropriate figures from Snedecor's (41) tables for the values of "F". In certain cases the "F" values obtained in this experiment are higher than the highly significant tabular values of the 1% order.

On the basis of these data , a high degree of significance must be attached to the variation between treatments, indicating that the numbers or activities of soil micro-organisms, as measured by the evolution of carbon dioxide, have been affected appreciably by electric current. The "F" value of 46.94, representing the variation between treatments, is many times larger than the 1% tabular value of 6.01. That the effect of such treatment is independent of the time the readings were

TABLE XXVII. Effect of electric current of different intensities on the formation of CO_2 in soil. Milligrams CO_2 per 200 grams of soil.

	Mg. CO_2 at 8 hrs.	Mg. CO_2 at 16 hrs.	Mg. CO_2 at 24 hrs.	Mg. CO_2 at 48 hrs.	Mg. CO_2 at 72 hrs.	Sums
			Controls			
Rep.* 1	83.6	109.5	158.2	230.2	173.0	754.5
" 2	126.9	152.5	158.4	225.3	175.8	838.9
" 3	104.8	140.5	150.4	226.0	171.4	793.1
Sums	315.3	402.5	467.0	681.5	520.2	2386.5
			Light Treatment--0.1 milliampere			
Rep. 1	121.5	140.1	167.4	225.5	204.3	858.8
" 2	122.9	145.7	182.2	210.2	233.8	894.8
" 3	137.2	161.2	177.3	271.2	199.4	946.3
Sums	381.6	447.0	526.9	706.9	637.5	2699.9
			Heavy Treatment--10-15 milliampere			
Rep. 1	102.9	101.2	111.8	76.3	83.6	475.8
" 2	77.9	88.0	117.7	112.5	168.5	564.6
" 3	68.3	76.0	66.9	56.7	78.2	346.1
Sums	249.1	265.2	296.4	245.5	330.3	1386.5

*Replication.

TABLE XXVIII. Analysis of variance in amounts of CO_2. Data from Table XXVII.

Source of variation	Degrees of freedom	Mean Square	Values of 'F'
Total	26		
Between means of treatments	2	52,282.21	46.94**
Between means of time	2	119,268.30	107.09**
Interaction -treatment and time	4	2,017.80	1.81*
Unaccounted for	18	1,113.74	

** Highly significant
* Not significant

taken is indicated by the fact that the "F" value for interaction between treatment and time is smaller than the barely significant 5% tabular value.

The comparative amounts of carbon dioxide obtained at the end of each interval are shown in Figure 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. Apparently, much of the significance for the variation between treatments must be due to the relatively small amounts of carbon dioxide formed in the soil treated with the stronger 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. However, a study of the data for the weak treatment and for the controls shows the following differences: (1) the amounts of carbon dioxide obtained during each of the five successive periods were definitely larger for the weak treatment; (2) for each of the successive eight hour periods of the first 24 hours the rate of carbon dioxide evolution was somewhat accelerated by the weak treatment.

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.

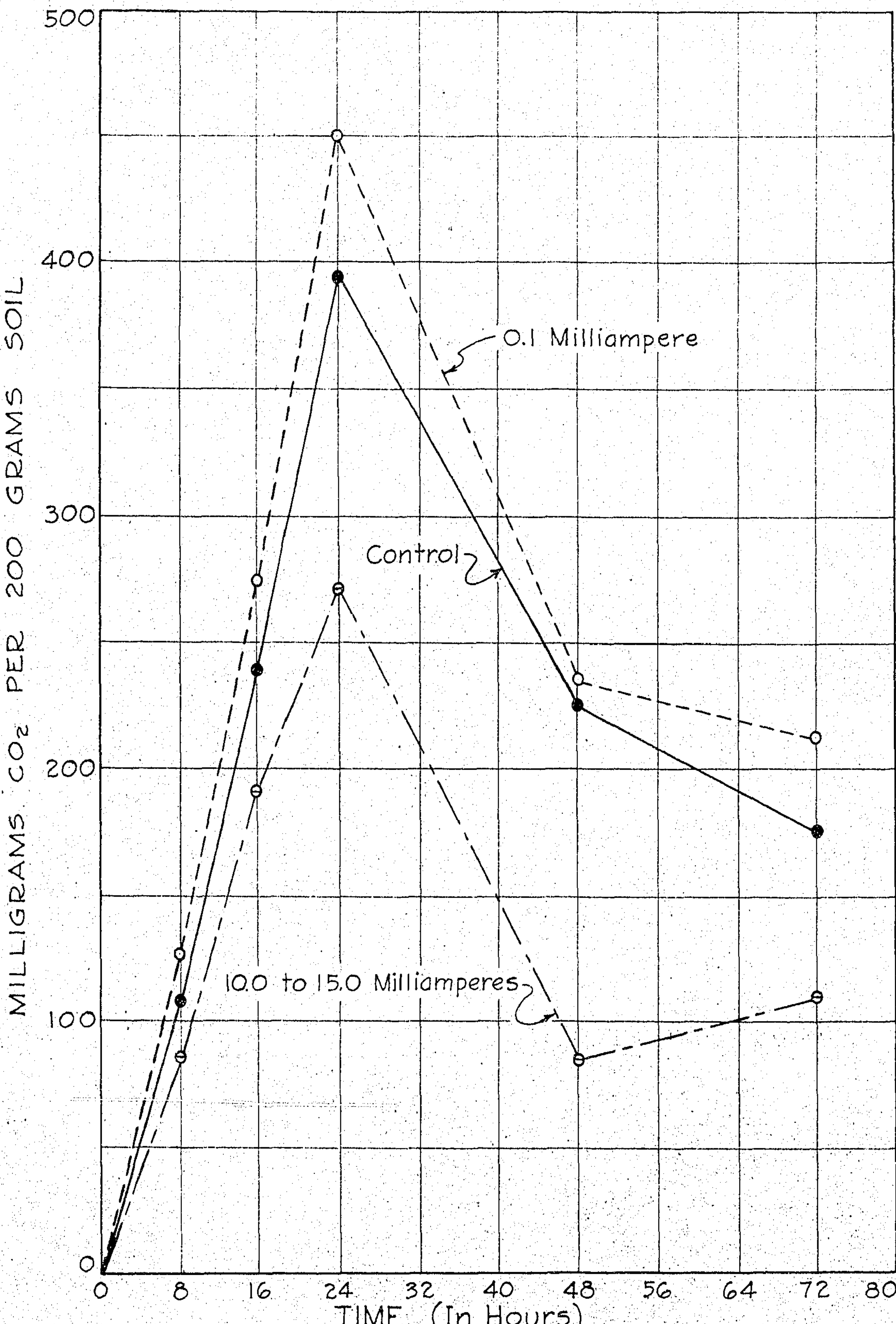

Figure 9. Effect of electric current on CO_2 formation in soil.

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 under observation.

The study of plant response has been confined to measurable features of growth and development, such as rate of germination, time of maturity, analyses of total nitrogen, and yields of grain and straw. Considerable attention was devoted to one of the environmental problems, namely, the effect of the electric currents used upon the numbers and activity of the micro-organisms in the treated root areas. The response was measured by determining the relative numbers of organisms and also the amounts of carbon dioxide evolved.

The results with the earth-air currents indicated, under the conditions of this experiment, that the currents obtained by means of the installation of elevated metal brushes connected with buried wires transversing the root areas of field crops were of so little effect that the method must be deemed quite impractical. In fact, the yield differences measured in these comparisons were so slight and the direction of variation was so erratic that the possibility of either a stimulating or a depressing effect, due to the currents obtained, seems doubtful. Furthermore, it appears probable that the minute electric currents passing through the elevated brushes were not led from the bases of the poles outward into the field for any effective distance but leaked off into the soil within a maximum distance of six feet from the point where the conductor entered the ground. This conclusion is supported by calculations based on physical formulae including the observed strength of current, and also on the fact that the intensity of the currents measured in the soil and along the buried conductor at various distances from one of the collectors seemed to bear no relation to the intensities measured at the base of the pole. During the course of this three year experiment a wide range of seasonal conditions was encountered, the first year being extremely hot and dry and the third year providing an abundance of rain and generally favorable growing weather.

The experiments with the copper-zinc electrodes combination, 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 results with oats which indicate that the growth of plants may be affected by electrical currents of low intensity.

In the first year of the greenhouse test significant increases in yields were obtained from the treated lots except where grown on soil of high fertility. This exception is one which might be expected, since the high fertility soil in itself apparently provided such favorable growing conditions that further stimulus could not produce measurable response. In five of the seven treated lots of the low fertility series the current applied was very weak, being of the orderof 0.5 milliampere, and was merely that current induced as the result of the difference in potential between the copper and zinc electrodes. With the two lots having a dry cell included in the circuit and subjected to current of approximately 1.5 milliamperes the increases obtained were larger, indicating that somewhat stronger currents might be still more effective, a deduction which was not supported by further trials.

For the greenhouse experiment of the second year one or more dry cells were included in the circuit for each treated lot and current intensities in all flats, while generally of the order of from 1.0 to 2.0 milliamperes, at times ranged as high as 4.0 milliamperes. In this experiment the yields of grain and straw were not significantly increased, in fact, the grain yields of the treated lots were slightly less than those of the controls. It seems possible that too high an amperage was used, and this inference is supported by the fact that in the case of the roots the yields and per cent total nitrogen were significantly less for the treated lots than for the controls.

In the field trials the copper-zinc electrodes combination with dry cells included in the circuits provided a wide range in current intensities. In the low series treatment the intensities varied between 2 and 30 milliamperes, depending on the dryness of the soil and the condition of the batteries, and in the high series between 5 and 55 milliamperes. Since the current was not confined in the field soil as in the greenhouse flats, it was free to follow the usual curved pathway of the lines of force and consequently the intensity per unit of cross-section area was obviously not in the same proportion to the recorded intensity in the two experiments. However, neither of the two general levels of current intensity which were used in this field trial proved to be effective, as the differences obtained for the plant yields, nitrogen analyses, and numbers of soil organisms were so small as to be without significance.

With the exception of the determinations made in connection with the field test, a rather definite and constant relationship between electrical treatment and numbers of soil micro-organisms was observed throughout the series of experiments. In the 1932 greenhouse experiment a comparison of 24 samples by means of laboratory counts showed increases for the electrically treated lots of 14 to 123 per cent, and of 15 to 23 per cent 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. Since the positive correlation between numbers of soil micro-organisms and the productivity of the soil has been well established it may be concluded that possible variations in plant growth resulting from the application of electric current are at least partly due to the effect of such treatment upon these organisms.

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