

STUDIES IN ELECTRO-CULTURE. PART I. INTRODUCTION.

By K. Venkata Giri, T. J. Mirchandani and V. Subrahmanyam.

Investigations carried out in different parts of the world during the past half-century leave little doubt regarding the possibility of increasing crop-production by treating plants with electricity under favourable conditions. The factors affecting the efficacy of the treatment are however, so many, and the conditions so difficult to control, that although many workers have obtained almost phenomenal increases in crop-yields, several have reported to the contrary, often the same authors working under apparently identical conditions. The information so far obtained is not sufficient to be usefully applied in standardising any one of the various methods of treatment described as successful.

Treatment with electric light and the accompanying radiations.—Irradiation by electric arc or mercury-vapour lamps was tried by many of the earlier workers as a means of hastening maturity in uncertain seasons and for stimulating flower and fruit production in nurseries and green-houses. Hervé-Mangon (1861), Walkoff (1866), Siemens (*Nature*, 1880, 21, 438, 456) and several later workers observed that photosynthetic activity proceeded in electric light just as efficiently as in sunlight. Dorsey (*Electrotech. Z.*, 1914, 35, 236) experimenting with hothouse plants found that certain crops like lettuce were favoured by treatment with electric light while others like radish were not. Hayden and Steinmetz (*Gen. Elec. Rev.*, 1918, 21, 232) observed that in artificial light, the rates of maturing and ripening of plants can be nearly doubled. In more recent years it has been recognised that both the arc and the mercury vapour lamps are not quite satisfactory because of their high but spasmodic intensity and their colour, which are somewhat injurious to plants. Harvey and Hendricks (*Bot. Gaz.*, 1924, 77, 330) have investigated the limiting intensities and periods of exposure for a variety of crops. Mathews (*Electro-Farming*, 1928) found gas-filled filament lamps to be highly satisfactory.

It is difficult to state from the foregoing observations whether the beneficial effects noticed by previous workers were due to the light radiations, or to the ionisation of the air, or to any one of the attendant gaseous products like ozone, particularly when the source of illumination was an electric arc. Moreover, during the lighting, the major part of the electrical energy is dissipated as heat and the attendant rise in temperature would, no doubt, have influenced the vegetative growth as

well as the maturation of the greenhouse plants under experiment. Further knowledge regarding the mechanism of plant stimulation is therefore required before the process can be applied economically to obtain increased crop-production.

Utilisation of atmospheric electricity.—The treatment consists in conducting the energy from an elevated collector to either an electrode in the soil or discharge points above plants. Abbé Bertholon (1783) devised an apparatus, the electro-vegetometer, which consisted of a number of metal points supported above as in a lightning conductor leading below to an iron bar with a number of discharge points. By growing plants under the discharge points, he obtained highly satisfactory results with a large variety of crops. The plants thus treated made better vegetative growth and gave higher yields of the desired crops than those untreated (cited from Priestly, *Proc. Bristol Nat. Soc.*, 1907, 1, 193). Grandeau (*Compt. rend.*, 1878, 78, 60, 265, 939) adduced further evidence in favour of utilising atmospheric electricity by studying the development of big trees in forests and the consequent smothering of the smaller ones. He also demonstrated that plants protected from atmospheric electricity by overhead wire-netting did not develop properly and gave yields which were hardly 50 per cent. of those from plants grown in the usual way.

Abbé Bertholon's method found considerable favour in France where, in a modified form, it came to be known as the 'geomagnetifère' system. Treatment of plants with atmospheric electricity did not find much favour in either Britain or America.

With the scanty literature now available on the subject, it is difficult to state whether the method has possibilities of extensive application. The precise nature and mechanism of stimulation observed by Bertholon, Grandeau and others has yet to be understood. In view of the fact that thunderstorms in the tropics are frequent and often intense, it is possible that in India, concentration of atmospheric electricity over plants may lead to highly beneficial results. Further systematic study of the subject is, however, needed before the method can be safely advocated for use by farmers.

Earth currents.—Several workers in different countries have observed beneficial effects as the result of using earth-plates of dissimilar metals connected by conductors. The soil between the plates then becomes an electrolyte and a weak current flows through it giving the necessary stimulus to the growing plants. Speschnew (cited from *Gen. Elec. Rev.*, 1915, 18, 14) obtained increased yields from various plants by the above treatment. Rauson and Le Baron (*Elec. World*, 1906, 47, 1067) buried plates of copper and zinc at the opposite ends of lettuce beds and noted that the low voltage (0.5 V.) and current (0.4–15.0 milliamps) flowing between the

plates quickened the development of leaves so that the crops attained marketable size a week earlier than they otherwise would. An objection to this method suggested that although the previous workers obtained somewhat satisfactory results, it is possible that minute quantities of the metals passing into the soil either as rust or solution may ultimately prove toxic to the plants and poisonous to the consumers; thus leading to greater loss and trouble than the small advantage gained by earlier harvest.

Priestly (*Proc. Bristol Nat. Soc.*, 1907, 1, 190) repeated the treatment under carefully controlled conditions and obtained not only healthy early crops, but also increased yields, amounting to 33 per cent. over the control in the case of beans.

Like some of the earlier methods, the one described above has not been tried extensively owing to the overwhelming popularity of overhead discharge methods; but it deserves further systematic study because of its cheapness, there being no expense additional to the outlay on metal plates. Moreover, in view of the findings of Hissinck (*Internat. Mitt. Bodenkunde*, 1922, 12, 81) and others regarding base-exchange in soils, it is hardly possible that any more than traces of the toxic metals will pass into the growing plants. Earth-plates made of metals other than copper and zinc, preferably such cheap ones as occupy distant positions in the electromotive series, may be tried. It is also possible that by enclosing the plates in small earthenware pots, (a) loss due to rusting or action of salts in the soil may be minimised, and (b) chances of even minute quantities of the metals passing into the plants may be obviated.

The method of passing current from external sources through the soil has not, so far, met with much support. The treatment is stated to be more expensive than most others: scientific opinion regarding its utility is also somewhat conflicting. Cook (*Electrician*, 1898, 41, 787) observed that the earth-current helped to increase the rate and proportion of seed-germination in the soil, but had no effect on either plant-development or crop-yield. Kövessi (*Compt. rend.*, 1912, 154, 289) trying the same method, noticed that an earth-current was inimical to the germination of seeds. Gerlach and Erlwein (*Elektrochem. Z.*, 1910, 17, 31) passed a 6-V. current (0.2 - 0.4 amp.) between iron electrodes buried at the opposite ends of barley and cabbage rows but derived no advantage from the treatment. Dorsey (*Electrician*, 1913, 72, 442) tried the earth-current method at different voltages and current strengths, but was unable to obtain any significant increase in crop-yield. Peaslee (*J. Elec. Power and Gas*, 1914, 32, 69) passed direct as well as alternating current of lower density than those used by previous workers between carbon electrodes and obtained

highly satisfactory, all-round increase in his crops. He obtained the best results at a power consumption of 0.5–0.6 W. per cu. ft.: there was earlier and increased percentage of seed-germination, more rapid and luxuriant vegetative growth with healthier and richer crop, especially of roots, as compared with the untreated plants. He reported that after treatment with direct current, the increase in the yield of cauliflower was about 150 per cent. and that of radish, over 400. Alternating current was also useful, but not so efficacious as the direct one. Many methods of earth-current treatment which are claimed to be improvements on the previous ones have been patented in recent years, but most of them have not been either described properly or tried extensively enough to warrant public confidence in their efficacy (Phoenix, *J.I.E.E.*, 1929, 67, 1296).

It may be inferred from the instances cited above that although earth-currents have not always proved favourable, yet there are certain hitherto obscure conditions leading to increased crop returns. Definite knowledge with regard to the scientific basis of the treatment, with special reference to the response given by the different types of soils under various systems of cultivation and manuring is still lacking; and further work on the standardisation of procedure with individual crops is required.

Overhead discharge.—Passage of silent or glow discharge from overhead antennæ to the soil has been tried extensively in various countries and may, after being standardised, prove to be one of the cheapest methods of electro-culturing plants. The method has been studied in the laboratory as well as on the field. It offers considerable possibilities of success, though the results reported by various workers and, often, by the same workers in different seasons, have not been consistently satisfactory. The earlier experiments of Lemstrom (*Electricity in Agriculture and Horticulture*, 1904) were remarkably successful: increased yields ranging from 45 to 100 per cent. for various crops were noted. The results of the later trials by Lodge and Newman (*J.I.E.E.*, 1914, 52, 333) were not so satisfactory, but held out promise of being useful under properly controlled conditions. Gerlach and Erlwein (*loc. cit.*) who followed the technique suggested by Lemstrom observed no difference between their treated and untreated plants: indeed, they found alternating current to be injurious to plant-growth. Stahl (*Elec. World*, 1911, 58, 1549) on the other hand, found the overhead D.C. discharge to be an inexpensive method of quickening crop production. Gloede (*Elec. Rev. West. Elec.*, 1911, 59, 975) obtained increased yields of flowers and fruit as the result of mild overhead discharge. He also noted that his electro-cultured fruits were sweeter than the untreated ones. Dorsey (*Electrotech. Z.*, 1914, 35, 236) observed that the yields from the treated plants though high on the average, were not consistent. Peaslee

(*loc. cit.*) obtained generally enhanced yields from plants receiving nightly overhead discharge, but noted that the seasonal variations influenced considerably the quality and yields obtained. Britton (*Electrician*, 1918, 80, 641) carried out a similar series of trials and observed that the plant response to overhead discharge was highly inconsistent and that the yields differed from those of the controls by +23.5, +153.0 and -7.5 per cents. respectively. Hein (Phoenix, *loc. cit.*) experimented with brush discharges at 20,000 V. and obtained satisfactory increase in yields.

Since 1918, the Electro-culture Committee of England have investigated the various factors influencing plant response to electro-culture, particularly by the method of overhead discharge, and have noted the most suitable voltage, current density, height of the aerial, spacing between the wires, time and duration of discharge, treatment of the soil and certain of the physiological effects of the discharge (Interim Reports of the Electro-culture Committee, 1918-29; Blackman, *J. Agric. Sci.*, 1924, 14, 240; Blackman and Legge, *J. Agric. Sci.*, 1924, 14, 264). Contrary to the earlier findings, alternating current was observed to be just as efficient as direct, and even superior to it in certain cases.

The field experiments were pursued through many seasons and at various centres, the technique being improved at every stage to minimise adventitious errors, but the results proved inconsistent. In the same season, with apparently the same treatment, satisfactory plant response was observed at some centres and almost none at others: the results at the same centres in successive seasons were also inconsistent. The meteorological conditions doubtless influenced the crop returns, but they were not entirely responsible for the discordant results from electro-cultured plants. The soil conditions also appeared to affect the results unaccountably. Recently, Blackman and his co-workers carried out some carefully planned experiments at Rothamsted and elsewhere, but the results were highly erratic, casting doubt on the practical significance of the observations collected so systematically and patiently during many years past.

The foregoing observations, though somewhat discouraging, only emphasise the need for further work. There are obviously certain hitherto unsuspected factors affecting the success of overhead treatment, and these must be ascertained before further progress can be achieved.

Electrical treatment of Seeds, Seedlings and Plants.

Fry's patented method of activating seed (*U. S. Pat.*, 1,106,039) consists in packing them between metallic electrodes in a 10 per cent. solution of a nitrate, or ammonium sulphate or any one of the soluble

salts which are commonly used as fertilisers, then passing current from the main for a number of hours, after which the seeds are taken out, dried and supplied to farmers. Dunn (*Elect. Rev.*, 1919, 84, 89) reported the process to be highly useful in hastening germination and stimulating tillering. The advantages claimed could not be confirmed by other workers in England; Sutton, who carried out extensive series of trials, concludes that the method is of doubtful value and does not justify the expenses involved (cited from Phoenix, *loc. cit.*).

Favourable reports regarding the possibilities of seed-treatment have been received from Australia, however. Bennett's method (*B.P.* 268,291) consists in rolling seeds, previously soaked in water to soften the cuticle, with a cylindrical vacuum tube containing a Tesla coil. By its adoption the benefits of increased germination percentage, greater yield and improvement in quality have been claimed for a variety of crops. The method has not been sufficiently tried outside Australia, and further trials under a variety of soil and climatic conditions are required before it can be adopted extensively.

Nehru (*Proc. Indian Sci. Congress*, 1930, 38) energised a variety of seeds by passing high tension electric sparks (1,000—10,000 V.) over them for 5 to 10 minutes. As the result of the treatment he obtained quicker germination, better growth, increased yields and resistance to certain plant diseases and insect pests.

Energising plants by passing an electric current through them does not appear to have met with much success: Marx, who passed current through *Elodea canadensis* soaked in water observed no marked benefit, but noted frequent depression in development (*Ann. Bot.*, 1929, 43, 163).

The foregoing examples show that further study of seed and plant-energising is required before any of the processes can be applied extensively. The effect of the current on the various chemical constituents and the enzymes of the seed has to be studied. The influence of the treatment on assimilation and respiration, and various vegetative and reproductive activities of the growing plants have also to be clearly understood before a rational application of any one of the different methods of energising can be adopted successfully.

High Frequency Currents.—Bennett's method (*loc. cit.*) of seed-energising has been already described. Benedetti (*Atti R. Accad. Lincei*, 1926, 4, 324) studied the effect of electromagnetic fields oscillating at high frequencies on some germinating seeds and noted that under suitable conditions the treatment hastened seed-germination and favoured the development of seedlings. Mezzadroli and Vareton studied the effect of short-wave astral rays on the germination of seeds and the growth of plants, but did not obtain encouraging results (cited from *Int. Rev.*

Agric., 1929). Homberger (*Bull. Agric. Intelligence*, 1930, 11, 1430) observed that unlike high tension currents, those of high frequency have no harmful effects on plants. Experiments conducted in America at 10,000 V. and a frequency of 200,000 per sec. gave increases in yield amounting, in certain cases, to 75 per cent. The treated plants were also noted to be richer in chlorophyll than the untreated, and the method is obviously quite promising.

Nehru (*Proc. Indian Sci. Congress*, 1930, 38) has recently observed that the soil can also be energised by a 'tickler' or a discharge tube through which air is pumped and sparked at the orifice; the conical nozzle is driven into the soil at different positions and the sparked air pumped for 2-5 minutes at a time. He combines this treatment with that of seed-energising which has already been described, and obtains satisfactory results. The method appears to be promising and deserves more extended investigation in both the laboratory and the field. The details are at present somewhat elaborate and difficult for the average farmer to follow, but it is possible that the technique could be simplified and the details standardised to render the method more easily workable.

The nature of the action of electricity on plants.—The mechanism of the action of electricity on plant life is still not properly understood. Numerous theories have been propounded by various authors from time to time, but most are discordant. From his studies on forest trees, Grandeau (*loc. cit.*) concluded that atmospheric electricity is just as essential to plant-development as sunlight, air and water; he could not explain its role but was convinced of its necessity for plant life. Pollacei (*Atti Inst. Bot.*, 1905, 2, 7) observed increased assimilation of carbon dioxide and plant nutrients resulting from an electric discharge over plants. Bach (*Compt. rend.*, 26, 479) obtained evidence that formaldehyde is generated in the atmosphere through which an electric discharge passes and argued that for this reason electrical treatment is beneficial. Euler (*Ber.*, 1904, 37, 3415) repeated Bach's work, but could not detect formaldehyde. Various other authors detected ozone with various active ions, and attributed to them the action of electricity on plant-growth. Lemström (*loc. cit.*), Priestly (*loc. cit.*), Escard (*Rev. Gen. Sci. pur et app.*, April 30, 1913), Peaslee (*loc. cit.*) and many other workers have studied the botanical significance and the physiological effects of electric discharge on plants, but their investigations have not thrown much light on the precise mechanism of the action. Waller (*Proc. Roy. Soc.*, 1901, B, 162, 129) studied the electrical results of light on plants and observed that the leaves exhibit electromotive effects and after-effects amounting to fractions of a volt depending on the extent of illumination. He also noted that the chloroplasts are concerned in the development of electromotive force in the plants. Using extremely sensitive instruments of his own design, Bose (e.g., Plant response as a means of physiological investigation,

1906) has demonstrated that every phase of activity in plant life is associated with changes in the electrical properties of the various tissues, and may at times even result in a flow of current.

The foregoing observations no doubt suggest that external electrical stimulus is likely to play a part in influencing plant development and activity. They do not however indicate the biochemical mechanism by which the simpler physiological processes like photosynthesis, respiration, assimilation and translocation of nutrients are effected. Stone (cited from *Bull. Agric. Intell.*, 1921, 12, 262) observed that following a discharge through the space above an area of soil, the bacterial numbers become sixfold. Mathews (*loc. cit.*), who carried out extended field trials for many years, inclines to the view that electrical energy helps to stimulate the assimilation of nitrogen by plants, an observation which indirectly accords with that of Stone, because increased numbers of bacteria will lead to greater release of plant food, particularly nitrogen, in available form from the soil. The Electro-culture Committee (Interim Reports, 1920-29, Nos. I-X) after an extended series of trials at many centres and spread over several years have come to the conclusion that electro-culture has no effect on the plant response to nitrogen: indeed, they found that nitrogen in excessive amounts is definitely unfavourable to the discharge. They also noted that a high phosphate content actually depresses the yield from electro-cultured plants, but that the injurious effect is reduced in presence of higher amounts of potash and nitrogen. Reporting on his experiments in 1922 (fifth report of the Electro-culture Committee, 1923, 17) Blackman concluded that electrical energy has practically no effect on the vegetative activity of the plant, but influences the reproductive activity to a considerable extent. Thus, although the yield of grain from electro-cultured barley was generally higher than that from the untreated seed, the total dry weight of plant was practically the same in both the cases. He also observed that there was no increase in the total number of flowers, but that the electro-cultured plants had fewer sterile flowers than the control. Moreover, the treated plants carried fewer seconds or shrivelled grains, and the weights of grain were individually and totally greater than those from the control plants. The foregoing observations are somewhat discordant with those of the previous workers, many of whom have stated that one of the most marked effects of electro-culture is the increased tillering and vegetative growth.

Haynes (*Sci. Progress*, 1923, 18, 223) suggests that change of reaction in the tissue-fluids and increased permeability of membranes are the causes of electrical stimulation. His observations are suggestive, but do not help to explain the peculiar variations that have been noted with regard to both plant-development and crop-yields from season to season on the same experimental areas. Thus they cannot explain the

remarkably striking observations of Britton (*loc. cit.*) who obtained yields varying from + 153.0 to - 7.5 per cent. as compared with the untreated plots. Several authors have considered the effect of electricity to be indirect, but have not adduced sufficient evidence to support their theories. On the other hand, Blackman, Legge and Gregory (*Proc. Roy. Soc.*, 1924, 95, 214) observed that the development of the coleoptile of barley was greatly stimulated by passage of very low density current (10,000 V., 0.5×10^{-10} amp.) and noted that the effect persisted for 4 hours after treatment. Changing the current direction produced the opposite effect, and they infer that the effect was due to the direct action of the current itself, and not to any of the products of the discharge. Studying the effect of electric discharge on the respiration of barley, Middleton (*Ann. Bot.*, 1927, 41, 345) observed this to be increased by about 30 per cent. in ionised air. The degree of stimulation varied with the extent of ionisation. The trials also showed that the effect was due to the active ions themselves and not to any of the products of ionisation. Whimster (*Ann. Bot.*, 1927, 41, 357) came to a similar conclusion from his study of the rates of assimilation and respiration of *Pelargonium zonale*: he also observed that the stimulus continued for appreciable lengths of time even after removing the ionised air from around the plants.

It has already been pointed out that the season plays an important part in determining the success or failure of electro-culture. This influence is determined by the time and extent of rainfall, humidity, hours of bright sunshine, maximum and minimum temperatures. Any or all of such factors may determine the plant response to electro-culture; it is therefore desirable to study the effects of the different climatic factors individually and to ascertain which of them is individually responsible and to what extent. In this connection, the observations of Höstermann (*Electrotech. Z.*, 1910, 31, 294) regarding the beneficial effect of foggy weather deserve further systematic study from the chemical as well as biological point of view.

It has been noted by several workers that in certain seasons the electro-cultured plants failed, while the control developed normally. Such results could not have been due merely to unfavourable weather detracting from the beneficial effects, for then the control plots should have yielded less than the electro-cultured ones. The observations suggest that changes in one or more of the seasonal factors actually determine whether electro-culture will be beneficial or not in a particular season. It is also possible that when the treatment is given on a number of days in succession, the effect is favourable on certain days and unfavourable on others.

Our knowledge of the biochemical aspect of electro-culture with reference to both soil and plant is still obscure. Extension of Stone's

observation regarding increase in bacterial numbers (*loc. cit.*) will show whether the transformation of plant nutrients proceeds alike in all soils when subjected to the influence of electric discharge. Study of changes in the nature and numbers of different other forms of microflora should also prove useful. Important biochemical processes such as oxygen absorption and carbon dioxide evolution, ammonification and nitrification should be followed to ascertain whether changes in the composition and character of microflora are accompanied by the hastening of such processes. The study of the biochemical response of the plant will help to explain (a) the significance of the treatment, (b) the causes of the abnormally high or low yields observed in some cases and (c) the nature of the resistance offered by the electro-cultured plants to certain fungus diseases as well as insect pests.

The observations of the Electro-culture Committee appear to suggest that the treated plants do not respond to manurial treatment, particularly to artificials. It is still not definite whether such observations would apply to different types of organic manures as well as to the different soils commonly met with under the tropical conditions. When these are favourable, depletion of minerals and nitrogen from the soil would no doubt follow. Since the extent of availability of such nutrients is a limiting factor in crop-production, it may be inferred that although the electro-cultured plant did not respond to nitrogen and phosphate in the trials carried out by Blackman and his co-workers, it would do so under more depleted conditions of the soil such as may be expected after a succession of crops without adequate manuring.

Many of the earlier workers have observed that electro-culture is not beneficial when applied in bright sunlight. Lemström found night treatment to be useful. Henrici (cited from Whimster, *loc. cit.*) observed that ionisation of air aided assimilation in dull weather, but retarded it in bright sunshine. Blackman and his co-workers found the morning hours to be suitable for the treatment, but noted that the night discharge was of doubtful value and might even prove harmful to plant-growth. All the previous workers are agreed that treatment during periods of severe drought, or bright sunshine, or heavy rain should be avoided as they are likely to affect plant-development. The time of treatment is of only relative significance however. Thus, 6 a.m. which is mentioned by Blackman to be a suitable hour for England may be brightly sunny and even hot in a tropical country. It is therefore desirable to define the time in terms of sunshine intensity, cloudiness or otherwise, temperature and relative humidity rather than by the clock.

The conditions leading to increased assimilation by electro-cultured plants have not, so far, been studied systematically.

Whimster (*loc. cit.*) observed that when the leaves of *Pelargonium zonale* are placed in ionised air, assimilation is not increased appreciably, but that the respiration is hastened by over 80 per cent. It is however doubtful whether the above observation is applicable to the whole plant. Field trials by several workers show that under favourable conditions increased assimilation resulting in all-round plant-development may be expected; and further study of the various factors such as degree of ionisation of air, relative humidity, intensity of light and concentration of carbon dioxide on assimilation and translocation is required.

Several authors have stated that electro-cultured crops are superior in quality to those untreated, but various analyses have not so far shown anything abnormal with regard to the chemical composition of the former. Recent investigations on the digestibility and nutritive values of different food materials have shown, however, that the chemical composition is often apt to be misleading. Animal experiments with regard to the relative growth-promoting qualities of the treated as well as untreated crops should therefore be conducted to settle this question. It is probable that at least some of the electro-cultured products may possess better taste and flavour than those untreated, and appeal by such qualities to consumers: others may be rich in vitamins and contain minute quantities of the various growth-promoting substances which add to the food-value of such materials. If the electro-cultured materials possess such qualities, they will be more desirable than the untreated ones in spite of the uncertainty of success attending the methods practised at present. The high prices commanded by superior quality should more than compensate for any possible loss due to depression in yield. This aspect of the subject also deserves systematic study.

In the present series of investigations, it is proposed to (a) study some of the more fundamental problems suggested in the foregoing pages and thereby ascertain the nature and extent of the various influences affecting plant-development during electro-culture, and (b) standardise a system of treatment that will increase the yield of crops of the desired quality under various conditions of soil and climate, with special reference to those of India.

*Departments of Biochemistry and Electrical Technology,
Indian Institute of Science,
Bangalore.*

[Accepted, 7-7-31.]