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PLANT BIOELECTROPOTENTIAL AND ITS ORIGIN

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A d.c. electric potential termed as plant bioelectropotential (BEP) is generated in a plant body. It is monitored by a simple circuit comprising of a calomel reference electrode in the root vicinity, a thin platinum electrode inserted into any part of a plant and a high impedance ($\simeq$ 1012-Ω) voltmeter.

Bioelectropotential measurements have been made under varying conditions of respiration of germinating seeds and of photosynthetic activity of Hydrilla Verticillata. On the basis of the experimental evidences it has been concluded that the plant BEP originates as a result of various redox couples of the electron transport processes of the respiration and photosynthesis.

INTRODUCTION

A plant is a product of its own environment. The other living things on earth depend on the plant kingdom. In fact various energy sources like coal and petroleum products are of bio-origin only. The soil possesses redox potential and pH which are used to assess the quality of the soil. Since a plant grows on the soil one would expect the same electrochemical parameters in the plant also. The d.c. electric potential generated in a plant body is termed as the bioelectropotential (BEP) of the plant. An electrochemical instrumentation system has been developed [1] to monitor the plant BEP. The basic technique in this system is the placement of a thin (250 μ) platinum probe into any part of a plant and a silver-silver chloride or calomel reference electrode in the root vicinity with a high impedance voltmeter connected to two electrodes as shown in Fig. 1 to measure the potential.

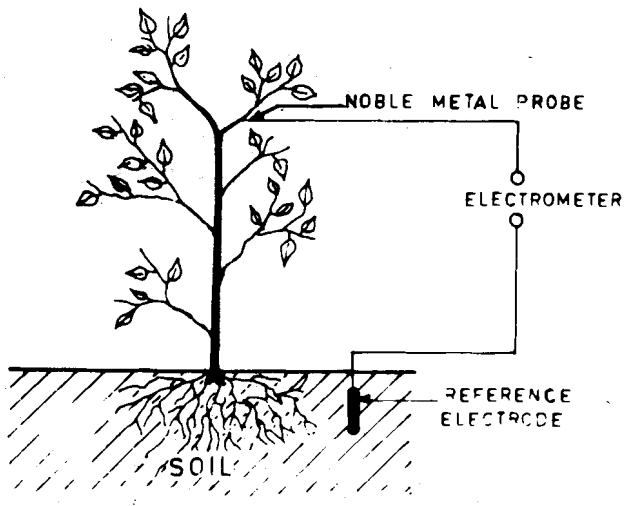

Fig.1

In cotton under field condition, a regular variation in potential with time has been observed [1] and the time history of the potential variation has been termed as Electrophytogram (EPG). The long term potential variation is related to the combined water status of a plant and its root environment. The water status refers to the total water content and free energy status of water, In-vivo cyclic voltammetric studies [2] on cotton plant prove the absence of any active redox couple in the plant apoplast electrolyte contributing to the plant BEP. The present authors carried out potential measurements [3] on a number of plants like mango, chilli, tomato, banana etc. and the following observations have been made.

(1) The plant BEP is invariably positive with respect to the reference electrode kept in the soil in the root vicinity.

(2) The numerical value is as high as 700 mV for plants like plantain.

Electrophytograms of germinating seeds and Hydrilla under different photosynthetic activity conditions have been recorded. The nature of the Electrophytograms and other observations reveal to certain extent that the plant BEP originates as a result of various electron transport reactions of the respiration process. Although the photosynthesis involves a large number of electron transporting active redox couples, it does not seem to influence the plant BEP.

EXPERIMENTS AND RESULTS

A groundnut seed is placed in a moist soil bed taken in a petridish. A thin platinum wire (250 μ thick) is inserted into the seed and a calomel electrode is kept in the vicinity of the germinating seed. EPG is recorded continuously until the seedling with fully developed leaves is formed and the same is shown in Fig. 2.

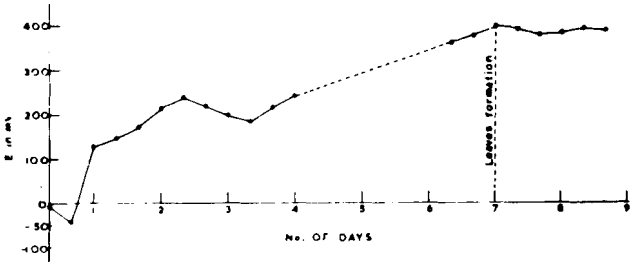

Fig.2: E P G of germinating groundnut seed

Similarly, the EPG for germinating pea seed is shown in Fig.3

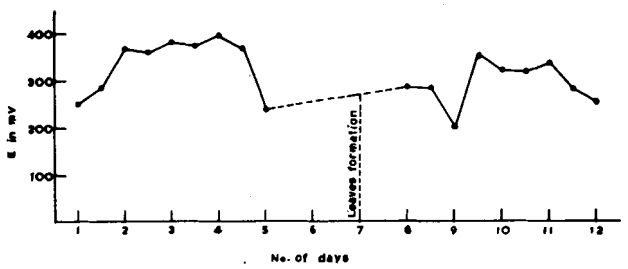

Fig.3: E P G of germinating pea seed

Hydrilla verticillata is a submerged water plant whose photosynthetic activity can be altered suitably by altering the experimental conditions. Further, since it is a submerged water plant, its oxygen evolution due to photosynthesis could be monitored with the help of the experimental set up shown in Fig. 4

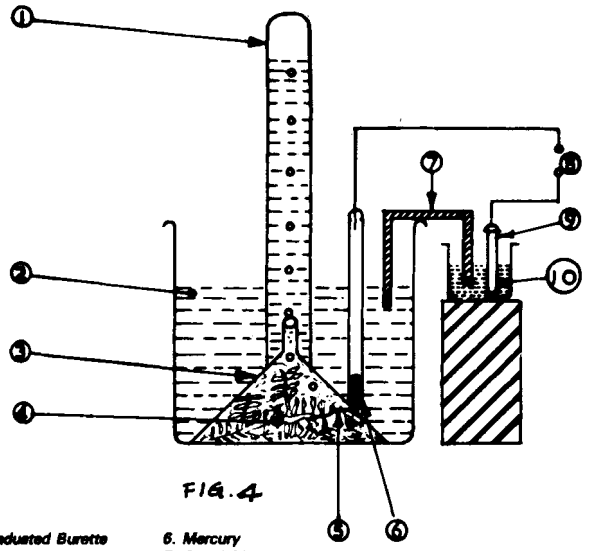

FIG. 4

1. Graduated Burette
2. Water
3. Glass Funnel
4. Hydrilla
5. Pt Electrode
6. Mercury
7. Salt Bridge
8. Electrometer
9. Reference Electrode
10. Satd. KCl Solution

Recording of the EPG and measurement of the volume of oxygen could be done simultaneously. When the experimental set up is kept inside the laboratory, the EPG, oxygen evolution and temperature variations are shown in Fig. 5. In the bright sunlight the variations are shown in Fig. 6. When the temperature is above 40°C the oxygen evolution practically stops. As the temperature is controlled around 30°C the oxygen evolution continues with the normal variation of the BEP as shown in Fig. 7. The temperature is maintained around 30°C by periodical replacement of a portion of water with ice or ice water.

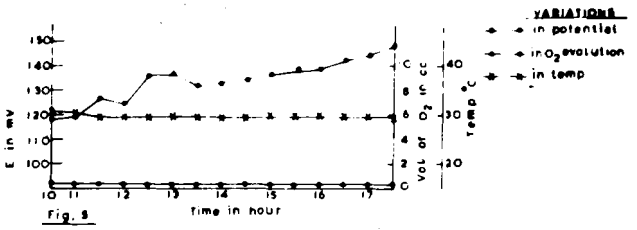

Fig. 5

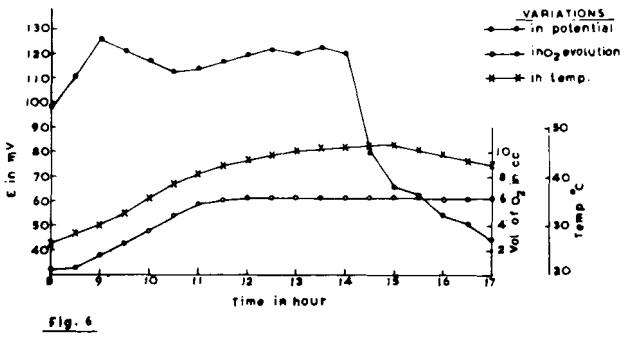

Fig. 6

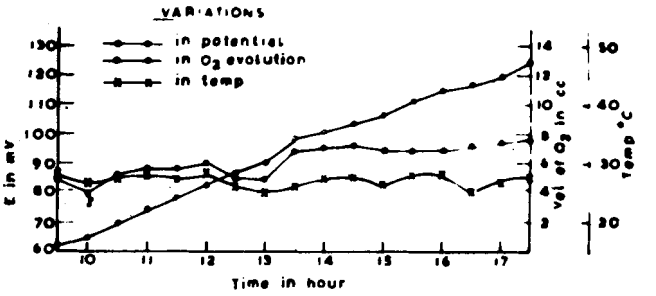

Fig 7

When the temperature is maintained at about 30°C by the environment itself, say due to cloudy weather, the oxygen evolution continues as indicated in Fig. 8. Addition of sodium bicarbonate

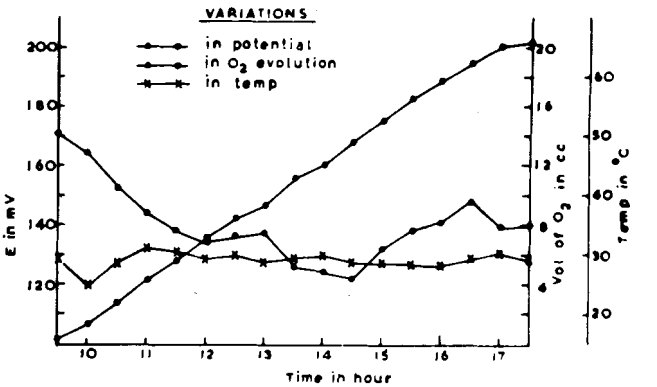

Fig. 8

(1.0 g/lit) to water into which Hydrilla is immersed and control of temperature around 30°C enhances the rate of oxygen evolution considerably in the presence of bright sunlight as illustrated in Fig.9. In the absence of sunlight the oxygen evolution is minimum even with sodium bicarbonate addition as clearly indicated in Fig.10. With sodium bicarbonate addition and in the presence of bright sunlight the volume of the oxygen evolved is constant above 40°C and that could be very clearly seen in Fig. 11. Water is boiled and then cooled to remove the dissolved carbon dioxide and bicarbonates. This carbon dioxide-free water, when used in the experimental set up, does not produce oxygen evolution even in the presence of sunlight as shown in the Fig. 12.

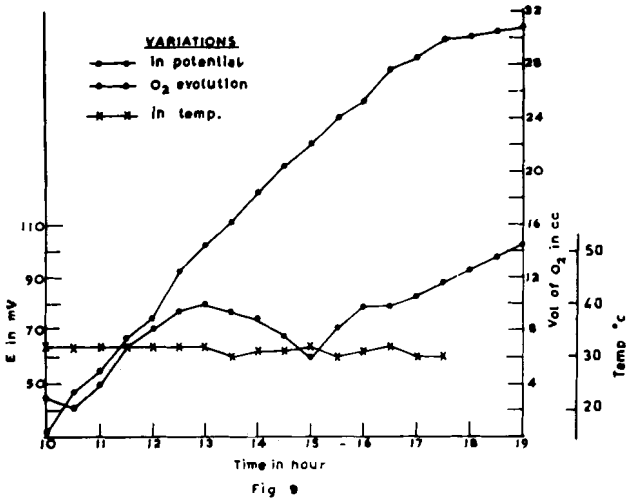

Fig 9

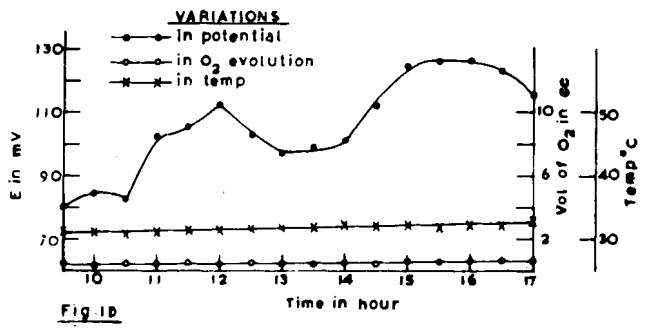

Fig 10

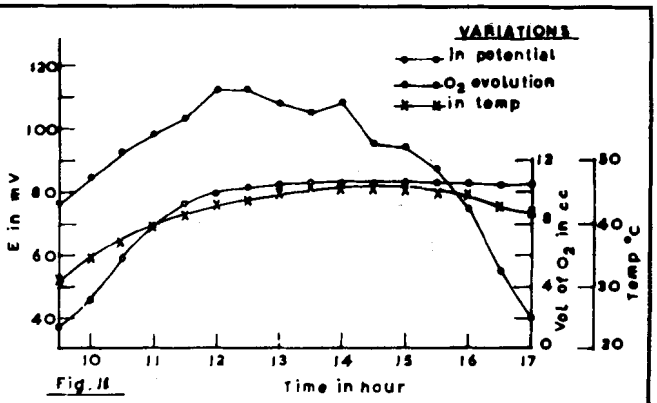

Fig. 11

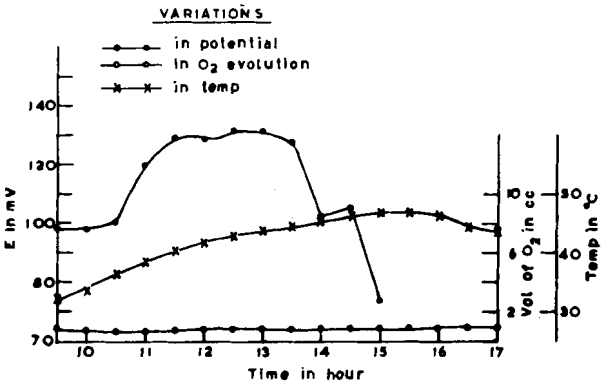

Fig. 12

DISCUSSION

The energy producing process in any living organism is the process of respiration in which the fuel carbohydrate is oxidized with oxygen to carbon dioxide and water. In the process of this oxidation, oxygen is reduced electrochemically to water as per the following reaction:

$$\tfrac{1}{2}\, O_2 + 2\, H^+ + 2e^- \longrightarrow H_2O$$

The oxygen reduction takes place in the inner mitochondrial membrane. When one molecule of glucose is completely broken down to CO_2, twenty four numbers of protons and the same number of electrons are generated. These electrons and protons are transported to oxygen through a series of redox couples present in the inner mitochondrial membrane. The different redox couples with their standard redox potentials (E°) versus normal hydrogen electrode (NHE) at pH 7 are given in the following Table:

NADH represents the reduced form of nicotinamide ademine dinucleotide (NAD), U_{QH_2} is the reduced form of Ubiquinone (U_Q) and cyt stands for cytochrome. Fe^{3+} and Fe^{2+} represent the oxidized and reduced forms of cytochromes. The electron transfer is spontaneous during respiration under a potential difference of 1.4 V. The electron flow is similar to that in an electrochemical power source. The anode redox couple is NAD/NADH and the cathode redox couple is O_2 / H_2O.

Photosynthesis in plants is the transformation of the energy of the electromagnetic radiation into the energy of organic molecules viz. carbohydrates. The overall photosynthetic reaction that takes place in the thylakoid membrane of the chloroplast is

$$6\, CO_2 + 6\, H_2O\, (12H^+ + 12e^- + 6\, [O]) \longrightarrow C_6H_{12}O_6 + 6\, O_2$$

When light falls on green leaves, the following actions take place successively in the thylakoid membrane.

Active redox couple	NAD / NADH	→	U_Q / U_{QH_2}	→	Cyt b (Fe^{3+}) / Cyt b (Fe^{2+})	→	Cyt C (Fe^{3+}) / Cyt C (Fe^{2+})	→	O_2 / H_2O
E° in volts	−0.32		0.08		0.1		0.28		0.82

(1) Photolysis of water

$$H_2O \xrightarrow[Mn^{++}]{h\nu} 2H^+ + 2e^- + \tfrac{1}{2}O_2$$

(2) Electron transport from P_{680} Chlorophyll to P_{700} chlorophyll which is termed as photosystem II (PSII).

(3) Electron transport from P_{700} chlorophyll to NADP to form NADPH which is known as photosystem I (PSI).

During photosynthesis electrons from H_2O / O_2 couple are transported through plastoquinone, Cytochrome, Plastocyanin (Photosystem II) to ferridoxin (Photosystem I). Ferridoxin, in turn, releases its acquired electrons to NADP to form NADPH. The energy released during the electron transport is stored in the form of ATP. In the absence of light, CO_2 is converted to carbohydrate. In order to produce one mole of fructose-6-phosphate (F6p), 12 moles of NADPH and 18 moles of ATP are needed according to the following reaction:

$$6\,CO_2 + 18\,ATP + 12\,NADPH \longrightarrow F6P + 12NADP + 18ADP + 17Pi$$

Thus the respiration and photosynthesis in plants continuously generate active redox couples. The BEP sensed by the platinum electrode is merely the mixed potential of various redox couples. Depending upon the environmental conditions the plant physiological activity must change and so is the plant BEP. It has been found that the BEP varies with time in all the plants. The end reactions in respiration and photosynthesis are the reduction of O_2 and $NADP^+$.

$$O + 2e^- + 2H^+ \longrightarrow H_2O$$

$$NADP^+ + 2e^- + H^+ \longrightarrow NADPH$$

Since these reactions are reduction reactions, the measured potentials must be positive with respect to calomel reference electrode. It has been found to be so in all the BEP measurements.

In a dry seed the biological activity is practically low. The respiration is minimum and there is practically no photosynthesis. When the seed is placed in a moist soil bed it starts slowly respiring. If the plant BEP is contributed by the electron transport process of the respiration, the magnitude of the BEP measured on the germinating seed must be low initially and increase with time. The EPGs of germinating groundnut seed and pea seed in Figs. 2 and 3 are very well in agreement with the expected variations. The figures show that the potential attains maximum value when the germination is complete.

Essential requirements for photosynthesis are sunlight, CO_2, water and chlorophyll of the chloroplast. Absence of the sunlight leads to very low rate of photosynthesis as indicated in Fig. 5. When the temperature reaches beyond 40°C the oxygen evolution completely stops as shown in Fig.6. This may be due to the fact that chlorophyll would have been affected by high temperature or the reaction may be temperature sensitive. Maintaining the temperature around 30°C leads to continuous photosynthetic activity as shown in Figs.7 and 8. Addition of sodium bicarbonate enhances the rate of photosynthesis considerably as indicated in Fig.9. Sodium bicarbonate addition has no effect in the absence of sunlight as could be seen in Fig.10. In the presence of bright sunlight and with sodium bicarbonate addition practically there is no photosynthesis beyond 40°C as depicted in Fig. 11.

In all the three categories of study viz. minimum photosynthetic activity (Figs. 5, 10 and 12), normal photosynthetic activity (Figs. 6, 7 and 8) and enhanced photosynthetic activity (Fig. 9), the EPG of Hydrilla is quite normal and apparently there is no remarkable change in the nature of the EPG. These experiments give the impression that the redox couples of photosynthesis do not have any influence over the plant BEP.

During respiration electrons move from NAD/NADH couple (E° = -0.32 V) to O_2 / H_2O couple (E° = 0.83 V) through various redox couples. This is a spontaneous process releasing energy which is stored in the form of ATP molecules. On the contrary, photosynthesis is the reverse of respiration and is a non-spontaneous process and it must take place under the influence of external energy (solar energy). The apparent deviation of the experimental evidences may be due to this endergonic nature of the photosynthetic electron transport.

CONCLUSION

The BEP generated in a plant is a mixed potential of various redox couples produced during the electron transport of the respiration process as evidenced by the EPGs of germinating seeds. The experimental evidences relating to photosynthesis show that the plant BEP is not influenced by the photosynthetic activity. Perhaps it may be due to the endergonic nature of the photosynthetic electron transport. However, the study [4] on the influence of intensity of light and inhibitors of photosynthesis on photo-induced bioelectropotentials and intensity of photosynthesis of leaves of higher plants show that the d.c. electrical signals in plants are very much influenced by the photosynthesis.

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