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Full Length Research Paper

Assessment of factors influencing bioelectricity generation in paddy plant microbial fuel cells

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In this study, an experiment has been carried out to produce green energy (bioelectricity) by using paddy plant microbial fuel cells (PMFCs) in soil and observed the various factors which influenced the bioelectricity generation. A total of four buckets filled with the same soil were used with carbon fiber as the electrodes for the test. Rice plants were planted in three of the buckets, with the fourth bucket containing only soil and an external resistance of 100 ohm was used for all cases. It was observed that the cells with rice plants and compost showed higher values of voltage and power density with time. The highest value of voltage showed around 700mV when a rice plant with 1% compost mixed soil was used, however it was more than 95% less in the case of no rice plant and without compost. Comparing cases with and without compost but with the same number of rice plants, cases with compost depicted higher voltage to as much as 2 times. The power density was also 3 times higher when the compost was used in the paddy PMFCs which indicated the influence of compost on bio-electricity generation. Solar radiation, temperature and humidity had also some influences before rice blooms however the organic matter (compost) had the significant influence to the bioelectricity generation.

Keywords: Bioelectricity; Compost; Humidity, Plant microbial fuel cell; Solar radiation, Temperature

INTRODUCTION

Plant MFCs(PMFCs) with living plants are way to get green energy (Moqsud et al. 2014, Striket al. 2008). In PMFCs, plant roots directly fuel the electrochemically active bacteria at the anode by excreting rhizo deposits (Striket al. 2011, D. Schamphelaire, 2008, Kaku et al. 2008, Timmers et al. 2010, Helder et al. 2010). Reed mannagrasshad been used to generate bioelectricity by Strik et al. 2011. A paddy field is a flooded land used for growing rice. In Japan, paddy fields cover 2.5 million hector and occupy more than 50% of the total arable land areas in this country (Ministry of Agriculture, Forestry and Fisheries 2006). When a paddy field is flooded, the soil immediately below the surface becomes anaerobic (Takai, 1969) and a community of anaerobic microbiota (comprised mainly of sulfate-reducing bacteria, iron-reducing bacteria, fermenting bacteria and methanogenicarchaea) is established (Grosskopf et al.1998, Chin et al. 1999). Since a potential gradient is known to be formed between the soil and the flooded water, it was anticipated that an SMFC system could operate in a rice field (Moqsud et al. 2013). Strik et al. 2011 showed an estimated potential electricity production of 21 GJ ha^{-1} $year^{-1}$ (5800 kWh ha^{-1} $year^{-1}$) in Europe by using the PMFCs technology with reed mannagrass plant. The electricity generated in rice PMFCs can be used for small scale electrical appliances as well as to give some lights to the people of the developing world.

Microbial fuel cells (MFCs) are bio-electrochemical transducers that convert microbial reducing power into electrical energy (Bennetto 1990, Allen and Bennetto, 1993,Logan and Regan 2006, Moqsud et al. 2014). They use the available substrates from renewable sources and convert them into harmless by-products with simultaneous production of electricity (Moqsud et al. 2013, Moqsud et al. 2012a). Attempts have been made to apply MFC systems to recover electric power from marine and river beds termed as sediment MFCs (SMFCs) (D. Schamphelaire et al. 2008). These systems utilize the natural potential gradient between the sediment and upper toxic water, and electrons released by the microbial oxidation of organic matter flow from the anode to the cathode through an external circuit. Although the power output from SMFCs is moderate, such levels of output are considered to be sufficient to serve as remote power sources in aquatic environments in where there is no other sources of electricity (Donovan et al. 2011).

The objective of this study is to evaluate the factors which induce bioelectricity generation by using rice plant microbial fuel cells (PMFCs).

MATERIALS AND METHODS

2.1 Experimental set-up

Four buckets (Figure.1) illustrate the test set up for the PMFCs in all cases. Bucket 1was prepared with the same soil without mixing any compost/organic fertilizer but the same number of paddy plants were planted. Bucket 2 and bucket 3 were prepared with compost of 1% and 3% of the total soil (by weight), respectively. Bucket 4 (Figure.1) was prepared in the same way except that a paddy plant was not planted in order to compare the influence of electricity generation; with and without plants. There was no compost

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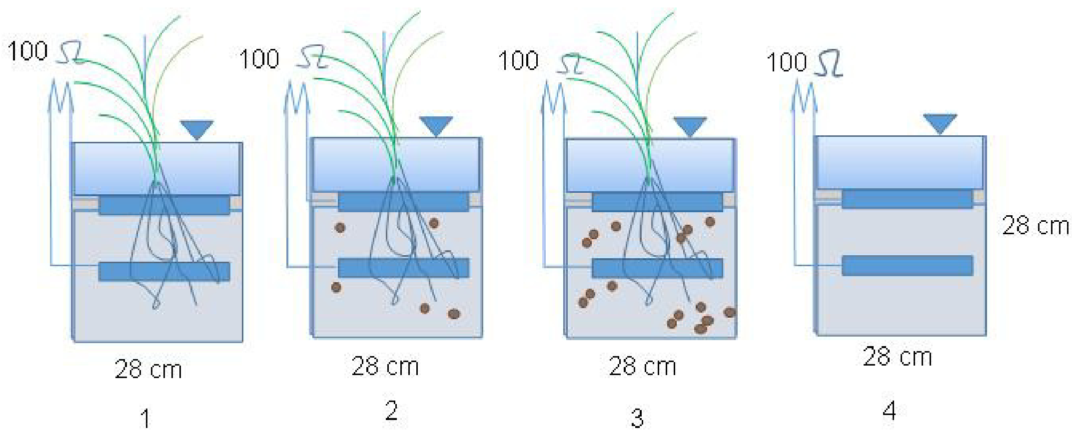

Figure 1: Schematic diagram of experiment with different condition

Table 1: Basic properties of soil and compost used in the experiments

Parameters	Soil	Compost
pH	7.51	6.92
Loss on ignition (%)	7.5	Not measured
Density of soil particles	2.671	Not Measured
Carbon nitrogen ratio	-	20
Moisture content (%)	35	40
Nutrients (N,P,K)	Not detected	N=13%, P=15%, K=20%

mixed in this bucket. Compost was collected from the local office of Japan Agriculture (JA) of Yamaguchi prefecture, which was mainly prepared from kitchen and yard waste for possible use by the local farmers and the chemical properties of this compost were similar with other compost reported in Moqsud et al. 2011. Table 1 gives the details of the materials used in the experiment . For measuring all the parameters (including pH and LOI) the standard methods for soil testing provided by the Japanese Geotechnical Society (JGS) were used.

2.2 Experiments

In brief, 28cm in length and 28cm in diameter plastic buckets were used for the PMFCs during the rice cropping season (from June to September) in the Yamaguchi University engineering campus, Japan. Three replications were used in this experiment. The soil used in the experiments was collected from Yamaguchi prefecture and classified as Onoda soil (pH 7.51 and Organic matter content 7.5 %). The rice plants were planted in the soil in

Table 2: Different parameters for all the six buckets at the starting of the experiment

Parameters	Bucket 1	Bucket 2	Bucket 3	Bucket 4
Soil (kg)	4	4	4	4
Compost (g)	0	40	120	0
pH	7.51	6.99	6.89	7.51
EC (mS/cm)	0.12	0.10	0.11	0.12
LOI (%)	7.5	9.1	9.2	7.5
Paddy (no.)	5	5	5	0
Electrodes	yes	yes	yes	yes

each bucket except for bucket 4. The rice plants used in the experiment were the same rice plants which are used for a famous brand of rice in Yamaguchi Prefecture. A circular shape electrode (both cathode and anode, 50g each) made of carbon fiber (Toray Industries, Tokyo)was used in this PMFCs. The carbon fiber is not only good at conducting electricity with an electrical resistance of 5ohm but also durable and favorable materials for soil environment (Moqsud et al. 2013). The anode area covers around 125cm^2 inside the soil of the PMFCs. The carbon fiber used in this study was designated as T-300 with a density of 1.76 g/cm^3.

The anode was set approximately 5cm below the surface of the soil, while the cathode was placed immediately above the soil surface, but under the water. These electrodes were connected via epoxy-encapsulated wires, and the circuit was completed using an external resister of 100ohm.

2.3 Measurement and method

The voltage across the resister was monitored by the voltmeter everyday at 11 am. Daily solar radiation, temperature and humidity data were collected from the local weather office of Yamaguchi prefecture, Japan.

Polarization curves and power density-current curves were made by using different resisters and internal resistances and power densities were calculated as described elsewhere (Logan 2006). Electrode output was measured in volts (*V*) against time. The current I in Amperes (*A*) was calculated using Ohm's law,

$I= V/R$ (1)

Where *V* is the measured voltage in volts (*V*) and R is the known value of the external load resistor in Ohms (100 ohm in this study). From this, it is possible to calculate the power output *P* in watts (*W*) of the MFCs by taking the product of the voltage and current i.e.

$P= I \times V$ (2)

Current density was calculated using $I = V/aR$ (3)

Where *a* is the electrode area. Normally, the anode area is taken as the electrode area. For example, if the electrode material is rectangle the area will be simply length multiplied by width.

RESULTS AND DISCUSSION

3.1 Variation of voltage generation with time and influence of solar radiation

Figure 2 illustrates the variation of voltage generation with time in rice PMFCs in the soil and the influence of solar radiation on it. It was observed that the voltage values were

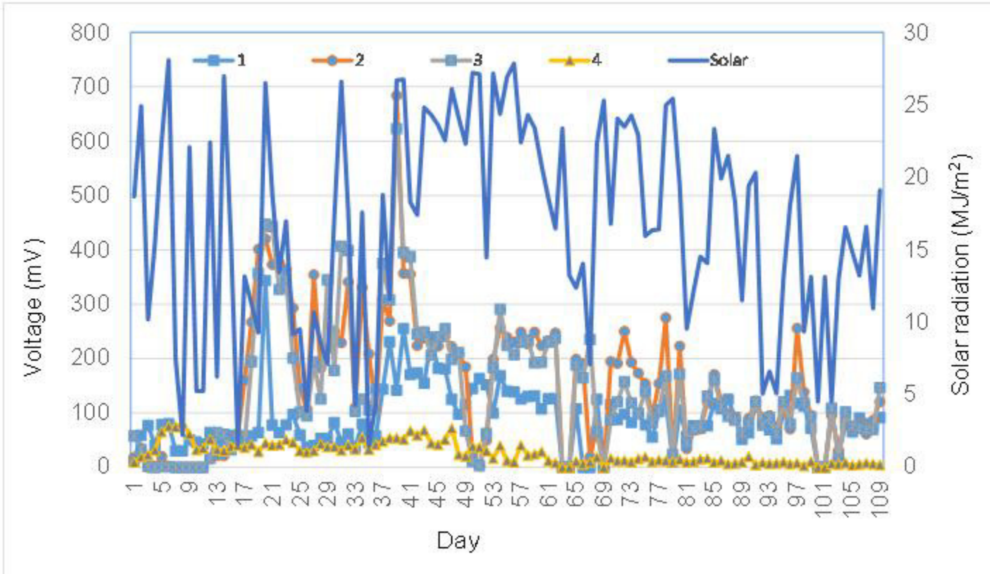

Figure 2: Variation of voltage with duration and influence of solar radiation

higher with paddies than without paddies (by comparing bucket 4 with other buckets). Plants continuously provide an input of organic matter to the soil throughout their plant life (Strik et al. 2011). The peak voltage generated in our study was around 700 mV in PMFC with rice plants and compost (1%).The PMFCs with compost (bucket 2 and bucket 3) showed higher value of voltage than the PMFCs without compost (bucket 1).The general trend of voltage generation was that it increased gradually in the initial stage before becoming constant and finally it started to decrease when the rice plants were ready to be harvested . In initial stage (1-2 weeks)voltage increased gradually and it wasalmost constant and then voltage rised and reached to peak and finally it started to decrease .However, the voltage generation for the case of without paddy plants and compost (bucket 4) was almost constant in all the stages. A small amount of voltage was generated due to the potential difference between the anode and cathode and also probably the phenomenon of organic matter decomposition in the soil.Thus, rice MFC is an ecological solar cell in which plant photosynthesis is coupled to the microbial conversion of organics into electricity. Solar radiation has some effects during the (weeks 2-10) of the experiment. When the solar radiation was high the voltage generation was also high. After the blooming of the rice the correlation of the voltage generation and solar radiation was not so prominent ($r = 0.2$). This type of phenomena was probably due to the food (glucose) produced in the green leaves due to the photosynthesis being used by the rice grain rather than being discharged into the soil.

3.2 Influence of humidity on voltage generation

Figure 3 illustrates the variation of voltage with duration and humidity. It is observed that there is no such significant relation of humidity and voltage generation for all the cases;

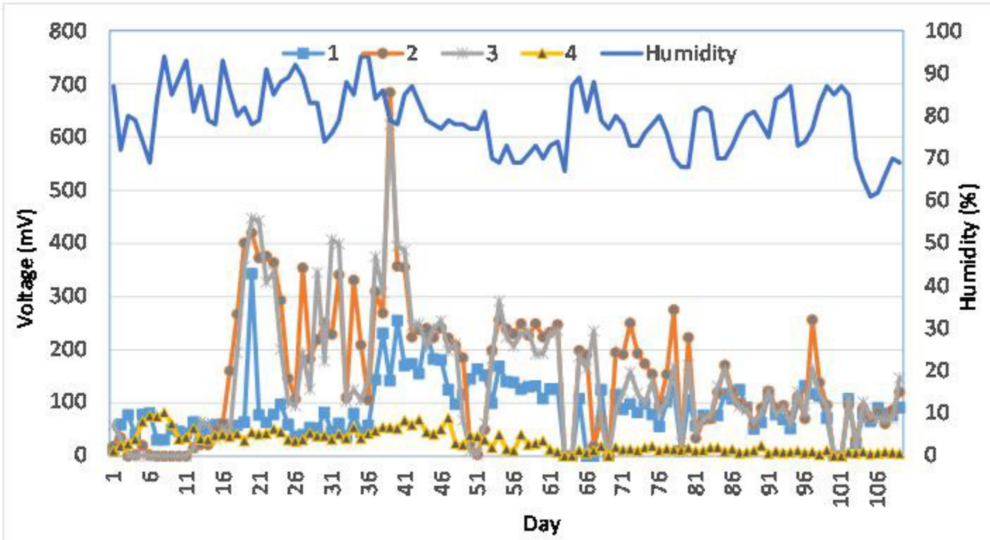

Figure 3: Variation of voltage with duration and influence of humidity

however, a small variation was observed during the initial stage of the experiment. Buckets 2 and 3 (with compost) showed higher values of voltage with higher amounts of humidity. However, after the crops began to bloom the similarity was not so prominent (r = 0.15).Strik et al. 2008 achieved peak voltage around 250mV by using PMFCs of *Glyceria maxima.* Kaku et al. 2008 produced maximum voltage around 300 mV in their PMFCs of paddy plants. Khare and Bundela, 2014 got maximum voltage around 350 mV from food industries waste water. Liu et al. 2013 showed a coupled MFC with *Ipomoea aquatic* plant for constructed wetland method and tried to enhance the voltage generation from waste water and got around 650 mV. The generated voltage in our PMFCs is higher than reported sediment microbial fuel cell (SMFC) as well (D. Schamphelaire et al. 2008).The maximum voltage generation in this study was around 700mV which was the highest so far in PMFCs and MFCs research (Moqsud et al. 2014a, Moqsud et al. 2014, Moqsud et al. 2013, Liu et al. 2013, Strik et al. 2008, Khare and Bundela, 2014).

3.3 Influence of temperature on voltage generation

Figure 4 illustrates the variation of voltage with time and its influence by temperature. It is observed that higher temperature influenced to generate the higher voltage. This type of trend was due to the bacterial activity inside the soil. The bacterial activity increased with the increased temperature. However, it is difficult to separate the influence the solar radiation and temperature at the same time.

3.3 Effect of shading on voltage generation

Figure 5 illustrates the effects of sunlight on the voltage generation in PMFCs. A black plastic sheet was used to

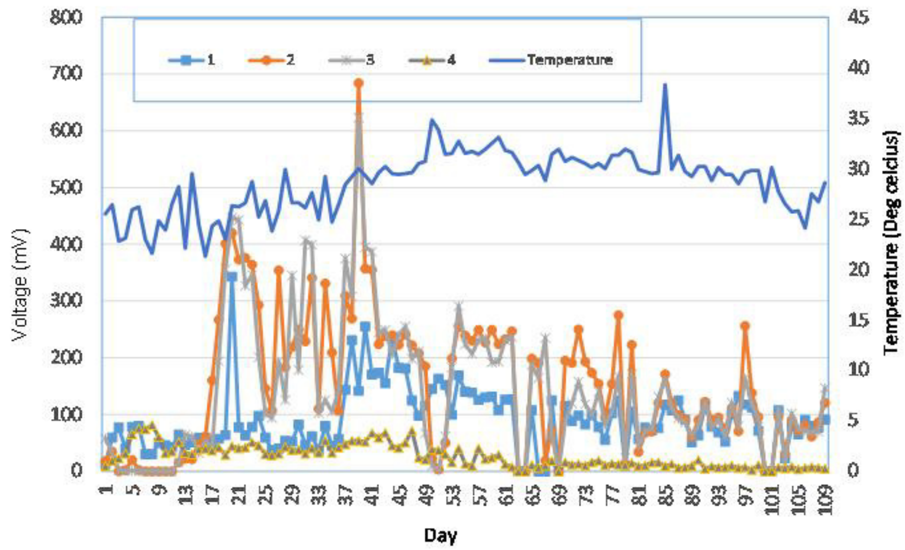

Figure 4: Variation of voltage with duration and influence of temperature

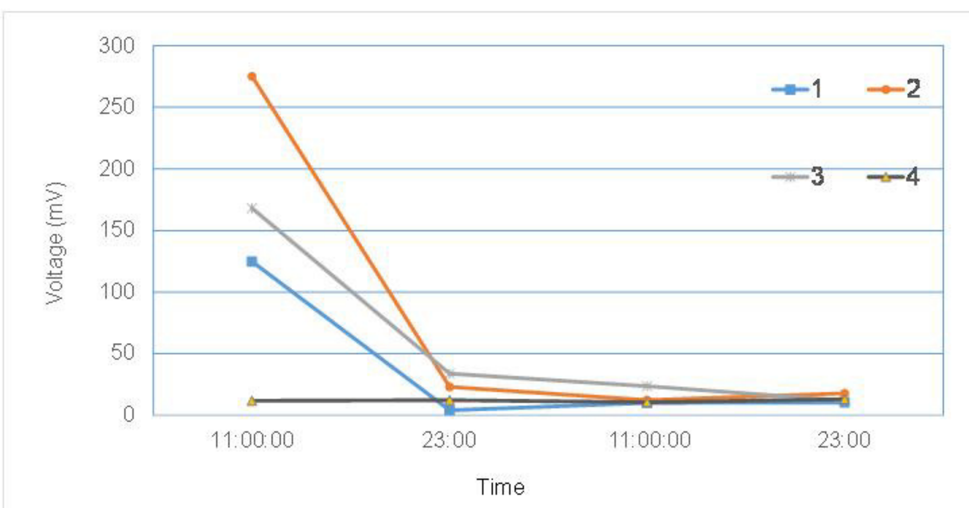

Figure 5: Effect of shading during the experiment

shed 4 buckets after measuring the voltage at 11 am. Different voltages were observed for different buckets. Bucket 2 showed around 280 mV of voltage and bucket 4 showed the minimum voltage of around 10mV before the shading. Then the voltage was measured again at 11 pm at night and 11 am in the morning in the next day (in continuous shading). It was found that the voltage did not change at all after the shedding, either at night time or during day time, for all the 4 buckets. Bucket 4 showed almost constant voltage with shedding and without shedding. It proved that PMFCs are a kind of ecological solar cell in which both plant and solar energy are required.

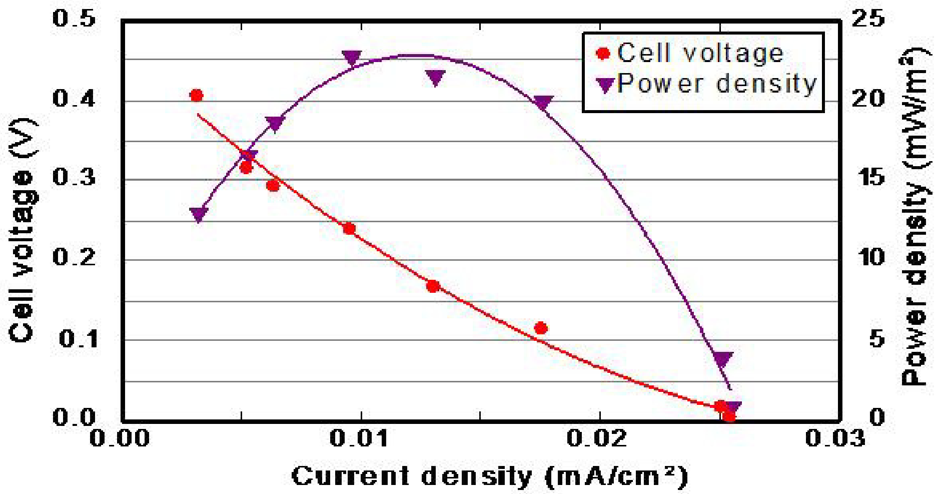

Figure 6: Polarization curve of PMFC during the experiment of Bucket 2 (The polarization curve of all other buckets are similar to the bucket 2)

3.4 Polarization curve for PMFCs

Figure 6 shows the polarization curve of the MFC by using PMFCs in the experiment. A polarization curve is used to characterize current as a function of voltage. The polarization curve shows how well the MFC maintains voltage as a function of the current production. This polarization curve in Fig. 6 was created at 10th week after starting the experiment from bucket 3. The polarization curve for all other buckets displayed similar trends. Thus, only one polarization curve is illustrating in Figure 6. The trend of the polarization curve was very much similar with the polarization curve which was stated in other literature concerning MFCs (Logan, 2006; Moqsud et al., 2014, Moqsud et al. 2013). Figure 5 shows the maximum power density of around 23mW/m^2. The power densities showed an incremental trend with decreasing external resistance and reaches to peak value. After that, the power densities began to fall with increasing current density, which indicated typical fuel cell behavior.

Figure 7 illustrates the specialty of paddy plant microbial fuel cell. It is seen that paddy plant microbial fuel cell can be great benefit for the developing countries in where both food crisis and energy crisis are major hindrances of development. Renewable bio-energy is viewed as one of the ways to alleviate fuel needs of the future and to overcome the crisis of global warming. Rice is grown in almost all of the countries in Asia and many of them are suffering from lack of electricity and hunger as well. Consequently, to use food products such as corn and soybean to produce bio-fuel is not a good idea as it is an unnecessary waste of precious food products for the millions of poor people in these areas.

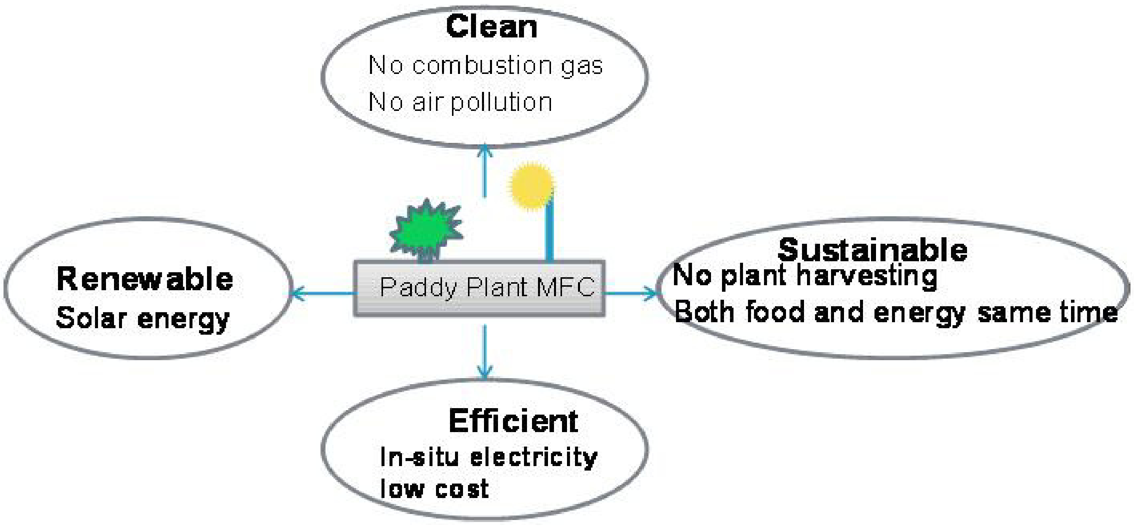

Figure 7: Schematic diagram of the benefit of paddy plant microbial fuel cell in developing countries

CONCLUSIONS

In this study, the factors affecting the bioelectricity generation by using rice plants are discussed. The peak voltage generated in rice PMFCs was around 700 mV with the rice plants when compost was mixed with the soil. The power density became 3 times higher when compost was used .The organic content added by compost gives additional capacity to generate bioelectricity. Thus organic matter influenced the electricity generation more significantly. However, solar radiation, humidity and temperature influenced less significantly after blooming. When the solar radiation and temperature were high the voltage generation was also high. After the blooming of the rice the correlation of the voltage generation and solar radiation was not so prominent (r = 0.2). This type of phenomena was probably due to the food (glucose) produced in the green leaves due to the photosynthesis being used by the rice grain rather than being discharged into the soil.

The additional bioelectricity harvesting did not have any bad influence on the growth of the plant life as the rice bloomed well and harvested well after the experiment. The natural weather parameters as well as additional organic matter have a significant influence on bioelectricity generation in paddy plant microbial fuel cell, however, paddy MFCs can be used for bioelectricity generation both in developed countries as well as electricity-scarce developing countries in the world.

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