EM Bio-Generator for Amending Sodic Groundwater

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Abstract: *The groundwater in the Indus basin contributes around 35 percent of the total water available for agriculture on 17 million hectares. Water quality of 60 percent area of the basin is marginal to brackish in quality. The use of sodic or saline-sodic groundwater contributed to secondary sodification. Therefore, farmers have to use gypsum as an amendment, which has very low solubility, and thus its use is not cost effective without public sector subsidy. The Sulfurous Generator technology requires high initial investment of around US$ 25,000 with higher operational cost. The research studies were conducted to design and build a EM Bio-generator with initial investment of US$300-400 for a farm size of 10 hectares. The propagability of EM is extremely high and EM 1 can be extended in three phases using ratio of 1:1:20 (EM:Molasses:Water). Therefore, one litre of EM 1 can be extended in three phases to 22, 484 and 10648 litres of extended-EM, super-extended EM and supra-extended EM, respectively. A pH of 4.0 can be achieved after 3-4 days of detention. After the first cycle, the whole process can be completed in 3 days in summer and 7-8 days in winter season. The supra-extended EM was used to amend sodic groundwater using a ratio of 1:100 (EM:Water) which reduced one unit of pH i.e. from 9.5 to 8.5 and reaction was stable for 44 days with further reduction in pH. The amended water will further help to manage the sodic soil. In fact, the acid forming character of EM is very encouraging because improvements in soil productivity would be an added benefit in addition to amending sodic water. The techno-economic analysis indicated that once the microbial mass is built in the soil, much less EM will be required to amend the sodic water. Comparative studies of EM with other traditional amendments like gypsum and sulfuric acid were conducted. The initial results indicated that low solubility of gypsum is a major limitation in having chemical reaction in soil because of heavy depths of water required for leaching. The waterlogging problem, scarce water resources and high pumping cost do not permit farmers to use additional amounts of freshwater for leaching. Apparently, the EM amended water would not require extra leaching because monsoon rains can provide leaching. Furthermore, gypsum also add salts in soils which are already high in salinity, whereas total solids of EM are all organic based and thus would not add much towards salinity of soil. Lysimeter studies reveal that by lowering down one unit of pH of sodic water through addition of Supra-extended EM, there was 70.54 percent decrease in soil SAR build up as compared to control (29.9 percent). The potential of EM Bio-generator is immense especially for semi-arid and arid environments where calcareous soils having pH of 8.0 or more are very common. The acidic nature of EM would be a blessing for future agriculture using marginal groundwater and still soil quality can be managed on sustainable basis. Although, there is a resistance from traditional scientists in accepting the technology farmers have already started using it at their own cost in an environment where almost every intervention including chemical fertilizers were introduced with a subsidy from the government. This is the encouraging aspect of the Bio-generator in Pakistan. Future research would be directed towards integrated systems including biogas and amending*

saline groundwater.

Introduction

Agriculture sector contributes 25 percent to the gross domestic product of the country and provides job opportunities for 55 percent of the labor force. It also accounts for 80 percent of the total export earnings of the country (GOP 1998a). Irrigation plays a predominant role as it provides major agricultural productions within 16.4 million hectares (mha) of the Indus basin (GOP 1998b). The irrigated area has increased from 9.1 mha in 1947 to about 18 mha in 1998. The cropping intensity has increased from 60 percent in 1947 to 120 percent in 1998. This four-fold increase was mainly due to increase in water availability from both surface and groundwater sources (GOP 1998b). By the end of 80s, several signals suggested that the period of agricultural output growth was over, with the productivity per unit of land of the main crops becoming stagnant or even following a decreasing trend (GOP 1998b; World Bank 1994; Bandaragoda and Firdousi 1992).

The main source of water is the Indus basin irrigation system, one of the largest and oldest contiguous systems in the world. The system fed by glacier and snowmelt and rainfall primarily outside the Indus plains, records average annual flows of about 171 billion m^3 (WSIPS 1990). However, the flows exhibit considerable variation, both annually and seasonally. The maximum and minimum annual flows were 231 and 124 billion m^3 during 1959-60 and 1974-75, respectively. The average summer season flow of 142 billion m^3 is over five times the average winter season flow of 27 billion m^3 (Ahmad 1989; Mohtadullah et al. 1991).

Although, the existence of groundwater does not increase total water availability, it is an important mechanism for delivering water to farmer under a flexible system of operation. A vast aquifer of variable quality exists under the Indus plain, recharged by natural precipitation and river flows and becoming increasingly saline the farther it is from recharge sources. It is harnessed through tubewells, open wells, and Karezes. There are around 484,000 tubewells in the country, pumping about 48 billion m^3 (GOP 1998b). The groundwater in the Indus basin contributes around 35 percent to the total water available for agriculture and water quality of 60 percent area is marginal to brackish (World Bank 1997).

Although investments in drainage have been significant in Pakistan during the last two decades, waterlogging still affects large tracts of land, with more than 22 percent of the total gross command area of the Indus basin irrigation system having water-table within 1.5 m (World Bank 1994). Salinity and sodicity also constrain farmers and affect agricultural production. These problems are further exacerbated by the use of poor quality groundwater (Kijne and Kuper 1995). In fresh groundwater areas, excessive pumping by private tubewells leads to mining of the aquifer (NESPAK 1991). The government has initiated Salinity Control and Reclamation Projects (SCARP) during 60s to control waterlogging and salinity but the use of saline-sodic and sodic groundwater resulted into secondary salinization (Rehman et al. 1997). Furthermore, due to continued pumping of deep groundwater, there has been serious concerns regarding deterioration of groundwater quality because of the intrusion of brackish water into the freshwater zone. The continued use of marginal quality groundwater also resulted into recycling of salts in the groundwater (Aslam 1997).

The irrigation and drainage issues and options have been identified for Pakistan's water sector (World Bank 1994) and adopted by the government of Pakistan as basis for the formulation of the National Drainage Programme (NDP). The NDP emphasized the need for research in developing more sustainable solutions for managing marginal quality groundwater. The WRRI-NARC in collaboration with IIMI-Pak, WAPDA and Sweetwater Farming Inc. USA tested the Sulfurous Generator and now the technology is available for use in Pakistan (EASE and Sweetwater 1998). The initial capital and operational cost is high and resource-poor farmers can't afford the use of the imported machine in Pakistan until it is indigenized and the cost is drastically reduced. The price as quoted by Messers Sweetwater Farming Inc. USA is around Rs. 1.2 million. Furthermore, the question regarding sustainability of chemical reaction is still unanswered, because physical improvements in sodic or saline-sodic soils are not possible only through the use of the sulfurous amended water.

The chemical amendments like sulfuric acid and gypsum are commonly used to amend sodic water. The handling of sulfuric acid is difficult due to danger of mishaps and low solubility of gypsum requires higher detention time. The economics is also not favourable without subsidy from the government. Furthermore, similar to the sulfurous generator, the sustainability of chemical reaction of these amendments is also questionable to manage the soil quality on long-term basis.

Biological approaches were used for reclamation and/or management of salt affected lands (Sandhu and Malik 1975; Qureshi et al. 1982; Ahmad and Pietro 1985; Malik et al. 1986; Sandhu et al. 1988; Aro et al. 1988; Barret-Lennard and Qureshi 1998). These efforts were mainly restricted to the use of Kallar grass and plantation of *Eucalyptus* and A*triplex* species to manage the salt affected lands where traditional agriculture is not possible.

EM is an abbreviation for "effective microorganisms", or more accurately, for the group comprising a heterogeneous collection of effective microorganisms that affect the world of nature in a positive manner and coexist harmoniously in a liquid state. EM comes in four varieties, which, for convenience, are numbered EM 1 to 4. Each type has distinct features and properties. EM 2 features mainly gram-positive actinomyces; the major content of EM 3 is photosynthetic bacteria, and of EM 4, lactic bacteria and yeasts. EM 1 exhibits all the properties found in EM 2 to 4. EM 1 is the latest formulation and was used in the development of the Bio-generator. The term EM used in the paper thus refers to EM 1.

The research hypothesis is that biological reactions are more sustainable than chemical reactions. Moreover, there is a possibility to make these reactions cost-effective as the propagability of EM is expected to be much higher than any other reaction. The initial work done by the WRRI-NARC produced very promising results (Ahmad et al. 1997), and thus there was a strong justification to initiate systematic research on this priority research theme, where technology of EM Bio-generator produced would have direct impact on profitability of agriculture and environmental sustainability.

Materials and Methods

The methodology for experimentation was developed considering the procedures normally used for water quality management. The basic assumption was that once propagability of EM is possible in water it would also be effective in soil. The pH of solute is important in maintaining the soil sodicity.

Mixing Ratio and Detention Time

The mixing ratio and detention time are two parameters affecting the size and cost of the

Bio-generator. Three mixing ratios of 1:1:20, 1:1:50 and 1:1:100 for Extended EM:Molasses:Water were selected for the trial to identify optimal mixing ratio for propagation of EM. The pH criterion of 4.0 is used to standardize the detention time.

Propagability of EM

The study on propagability of EM was designed to evaluate the detention time under given temperatures: a) room temperature; and b) constant temperature of 45^{o}C. Three replications were used. The criterion of pH was used to determine the detention time. The pH of the Basic EM is around 3.5. Therefore, for the propagability of EM, pH criterion of 4.0 is used.

The extended EM was prepared using a ratio of 1:1:20 for Basic EM:Molasses:Water. This mixing ratio was used, as it was most effective in reducing the detention time.

After achieving the pH of 4.0, the study was continued to evaluate the life of the extended EM, if pH is maintained at 4.0 or less. The life of 30 days is sufficient because after 30 days another irrigation can be applied to a period when critical mass of microbial organisms is maintained in soils.

Propagability of Extended EM

The study on propagability of extended EM was designed to evaluate the detention time under given temperatures: a) room temperature; and b) constant temperature of 45^{o}C. Three replications were used. The criterion of pH was used to determine the detention time. The pH of the extended EM is around 4.0. Therefore, for the propagability of extended EM, pH criterion of 4.0 is used, so that the quality of propagated extended EM is same as extended EM. This propagated material is named as super-extended EM.

The super-extended EM was prepared using Extended EM:Molasses:Water in a ratio of 1:1:20. The objective was to propagate the extended EM so that 22 liters can be further extended to 484 liters.

After achieving the pH of 4.0, the study was continued to evaluate the life of the super-extended EM, if pH is maintained at 4.0. The life of 30 days is sufficient because after 30 days another irrigation can be applied to a period when critical mass of microbial organisms is maintained in soils.

Propagability of Super-Extended EM

The study on propagability of super-extended EM was designed to evaluate the detention time under given temperatures. Three replications are used. The criterion of pH was used to determine the detention time. The pH of the super-extended EM is around 4.0. Therefore, for the propagability of super-extended EM, pH criterion of 4.0 is used, so that the quality of propagated super-extended EM is same as extended EM. This propagated material is named as supra-extended EM.

The supra-extended EM was prepared using Super-Extended EM:Molasses:Water in a ratio of 1:1:20. The objective was to propagate the super-extended EM so that 484 liters can be further extended to 10648 liters.

After achieving the pH of 4.0, the study was continued to evaluate the life of the supra-extended EM, if pH is maintained at 4.0. The life of 30 days is sufficient because after 30 days another irrigation can be applied to a period when critical mass of microbial organisms is maintained in soils.

Comparison with Traditional Amendments

After completing the trials on propagability of EM, a comparative study was designed to evaluate the performance of supra-extended EM with the traditional amendments like gypsum and sulfuric acid. Following treatments were used.

- Control treatment using water only to document changes, if any;
- Application of gypsum to water using Gypsum: Water in a ratio of 0.6:100.
- Application of supra-extended EM to water using Supra-Extended EM: Water in a ratio of 2.4:100.
- Application of supra-extended EM and gypsum to water using Supra-Extended EM:Gypsum:Water in a ratio of 1.2:0.3:100.
- Application of sulfuric acid to water using H_2SO_4: Water in a ratio of 0.007:100.

These five treatments were used to evaluate the effectivity of supra-extended EM in comparison with the traditional amendments of gypsum and sulfuric acid. The solubility of gypsum is a serious concern, whereas application of acid is hazardous. Furthermore, any addition of gypsum to the soil will further add salts in soils, which are already saline to a varying extent. Therefore, supra-extended EM was also used to improve solubility of gypsum.

Evaluation of the Effects of Supra- extended EM Amended Sodic Water on Soil Physico-chemical/Chemical Properties

A lysimeter study (3 replications), with no leaching provision, was conducted to evaluate the performance of Supra-extended EM (SAR 14.1; RSC 4.02 and pH 3.90) amended water for three levels of pH (8.5, 8.0, 7.5) and the control (sodic water of pH 9.0). Treatments used were as follow.

- Sodic water (control; pH 9.5)
- Supra- extended EM amended, sodic water with pH reduction of 0.5
- Supra- extended EM amended, sodic water with pH reduction of 1.0
- Supra- extended EM amended, sodic water with pH reduction of 1.5

The parameters were recorded after 2 months. Soil moisture was maintained at Field Capacity. Equal quantity of normal soil was taken in all lysimeters and water was applied according to the experimental treatments, when needed.

Results and Discussion

Propagability of EM

The incredible character of EM is its high propagability, which makes it possible to develop Bio-generator for amending sodic groundwater. The concept of extended EM introduced by Higa (1998) and Hussain et al (1998) was the starting point for conducting research in further propagability of EM.

An irrigation of 75 mm/ha requires 750,000 of water (or 304000 l/acre). If we use extended EM to reduce the pH of groundwater from 9.5 to 8.5, we require about Rs. 14000 to 17000 (US$ 280 to 340) /ha per irrigation. This is not economical for field application. Therefore, two additional phases of extended EM were developed to reduce the cost and named as super-extended and supra-extended EM.

Detention Time

The major limitation faced in the process of EM propagation was the detention time for microbial propagability to achieve a pH level of 4.0. Therefore, three mixing ratios of EM:Molasses:Water were evaluated to reduce the detention time on one hand and sustain the microbial action on the other hand. The extended EM was used for propagation and termed as super-extended EM. The non-saline and non-sodic groundwater was used. The detention time of 2, 6 and 11 days was observed for three selected mixing ratios of 1:1:20, 1:1:50 and 1:1:100, respectively, for Extended EM:Molasses:Water (Table 1). The pH criterion of 4.0 is used to standardize the detention time. It is not practical to use mixing ratio of more than 1:1:20. The quality of EM used for this study was very good because even at temperature of 15-20^{o}C**,** the detention time of 2 days was achieved. If the quality is good, ratio of 1:1:50 can also be used.

Table 1. Comparison of Mixing Ratios of Extended EM:Molasses:Water for Propagability of Extended EM in Groundwater of pH 7.9 at Temperature of 15-20^{o}C.

Days Since Start of the Experiment	pH of Three Selected Ratios of Super-Extended EM (Extended EM:Molasses:Water)		
	1 : 1 : 20	1 : 1 : 50	1 : 1 : 100
0	5.22	6.08	6.55
1	4.30	5.48	6.29
2	**3.96**	4.57	5.80
4	3.76	4.09	4.43
6	3.60	**3.96**	4.18
7	3.41	3.80	4.11
11	-	3.75	**4.00**
14	-	3.64	3.85
23	-	3.55	3.85

The mixing ratio of 1:1:20 was further used with sodic groundwater of 9.5 pH. The detention time of 4, 4 and 3 days was observed for extended EM, super-extended EM and supra-extended EM, respectively, at a temperature of 45^{o}C (Table 2). The detention time at temperatures lower than 45^{o}C was quite large. Therefore, for propagation of EM with sodic groundwater, higher temperatures are required. The quality of recently produced EM in Pakistan was also a concern as the reaction was not stable at lower temperatures.

Table 2. Propagability of Three Selected Phases of EM in Sodic Groundwater of pH 9.5 at Temperature of 45^{o}C

Days Since Start of the Experiment	pH of Three Selected Phases of Extended EM		
	Extended EM	Super-Extended EM	Supra-Extended EM
0	6.16	6.32	6.13
1	5.37	4.83	4.65
2	4.38	4.41	4.13
3	4.11	-	**3.91**
4	**4.05**	**4.00**	3.87
5	3.94	3.92	-
7	3.88	3.84	3.81
10	3.81	-	3.70
12	3.82	3.78	-
44	3.80	3.73	3.67

Phases of EM Propagation

The Basic EM (EM1) can be further propagated using a mixing ratio of 1:1:20 (BasicEM:Molasses:Water) and termed as extended EM. The sodic groundwater of 9.5-9.6 pH was used for this experiment. The detention time was about 4 days at a temperature of 45 °C to achieve pH of 4.0 and microbial dry matter mass of 0.1-0.15 percent.

The extended EM can be further propagated using a mixing ratio of 1:1:20 (Extended EM:Molasses:water) and termed as super-extended EM. The detention time was about 4 days at a temperature of 45°C to achieve pH of 4.0 and microbial dry matter mass of 0.1 to 0.15 percent. The mixing provided similar results at room temperature of around 25°C indicating options to adjust environmental variability.

The super-extended EM can be further propagated using a mixing ratio of 1:1:20 (Super Extended EM:Molasses:water) and termed as supra-extended EM. The detention time was about 3 days at a temperature of 45°C to achieve pH of 4.0 and microbial dry matter mass of 0.1 to 0.15 percent. The mixing provided similar results at room temperature of around 25°C indicating options to adjust environmental variability.

Stability of Propagated EM

The propagability trials with sodic groundwater were continued for about 44 days for the three phases of EM propagation. The pH of the propagated material was maintained in the range of 3.67-3.82 (Table 2), which is a good indicator that the process of propagation is stable at 45°C. Therefore, for a crop of around 100 days two irrigation, will be sufficient to maintain the soil health, if sufficient food for microbial propagation is available in the soil.

Amending the Sodic Groundwater

The amount of supra-extended EM required for reducing pH of 1.0 unit of the sodic groundwater ranges between 7500 to 9000 litres. The cost of this amount would be around Rs. 386 to 465 per hectare (Rs. 156 to 188 or US$ 3 to 4 per acre). This is an affordable cost and it is expected that two irrigations (pre-sowing and first irrigation) would help to maintain soil physical, chemical and biological health. For slightly sodic water, one irrigation per season would be sufficient.

Managing Soil Health for Tropical Plants

The country is trying to successfully introduce tea plantations in the wet mountains and plantation of tropical fruits like pineapple, coconut, etc. in the coastal area. These plants require acidic environment and therefore large quantities of sulfur are being used. The use of chemicals is not safe as the wet mountains drain water in to the Indus River System. The initial trials made for tea plantations were very encouraging where foliar and soil applications along with mulching of dry tea leaves helped to maintain the soil pH of around 6 or even less. The EM propagability trials with freshwater of 7.9 pH requires a detention time of 2-4 days for the three phases of propagation (Table 3).

Table.3. Propagability of Three Selected Phases of EM in Ground Water of pH 7.9 at Temperature of 15-20^{o}C

Days Since Start of the Experiment	pH of Three Selected Phases of Extended EM		
	Extended EM	Super-Extended EM	Supra-Extended EM
0	3.80	5.22	4.42
1	3.42	4.30	4.23
2	4.09	**3.96**	-
3	-	3.84	**3.75**
4	**4.07**	3.76	3.33
7	4.07	3.41	3.26
8	3.91	3.41	3.10
13	3.75	-	-
19	3.54	-	-

Managing Sodic Soils

In case freshwater is available then supra-extended EM can also be used for managing the sodic soils by applying irrigation of less than 7 pH. Water with acidic pH will help to manage the sodic soils.

Table 4. Comparison of Three Selected Amendments using Gypsum, Supra-extended EM and Sulfuric Acid for Amending Sodic Groundwater of pH 9.6 at Temperature of 8-12^{o}C

Days Since Start of the Experiment	Control Water Only		Gypsum :Water (0.6:100)		Supra-Extended EM: Water (2.4:100)		Supra-Extended EM: Gypsum:Water (1.2:0.3:100)		H_2SO_4:Water (0.007:100)	
	EC	pH	EC	PH	EC	pH	EC	pH	EC	pH
0	2.04	**9.60**	2.42	**9.43**	2.56	**8.60**	2.89	**8.49**	2.19	**8.63**
5	2.10	9.51	2.55	7.64	2.54	7.98	3.19	7.67	2.26	8.28
10	2.13	9.42	2.84	7.29	2.55	7.38	3.38	6.82	2.32	8.41
15	2.10	9.25	3.22	7.35	2.74	7.10	3.65	6.53	2.30	8.60
20	2.10	9.24	3.30	7.35	2.76	7.20	3.95	6.53	2.28	8.74
25	2.09	9.26	3.49	7.39	2.88	7.09	4.05	6.41	2.41	8.79
30	2.11	**9.26**	3.49	**7.40**	2.88	**7.06**	4.09	**6.33**	2.42	**8.74**

EC in mS/cm (dS/m),

Comparison with Other Traditional Amendments

The acceptance of EM is still a question in the country as specialists have serious concerns about the viability of this material. However, the Pakistani farmers have performed much better as they started using the material without any governmental support. The scientists still believe that there is no substitute for the traditional amendments. Therefore, a trial was conducted to compare the supra-extended EM with gypsum and sulfuric acid.

Sodic groundwater of 9.6 pH was used for five treatments of: a) control water only; b) gypsum:water with a ratio of 0.6:100; c) supra-extended EM:water with a ratio of 2.4:100; d) supra-extended EM:gypsum:water with a ratio of 1.2:0.3:100; and f) sulfuric acid:water with a ratio of 0.007:100.

The solubility of gypsum is low as instantaneous reduction in pH of only 0.17 units was observed. However, a reduction in pH of 2.0 units was observed after 10 days and continued to 30 days. The supra-extended EM performed tremendously better than gypsum as instantaneous reduction in pH of 1.0 unit was observed, whereas it was reduced to 2.2 units after 30 days. The reaction was stable both for gypsum and supra-extended EM (Table 4).

Further improvements were observed, when supra-extended EM and gypsum were used conjunctively, but the dose of each was reduced to half. The instantaneous reduction in pH of 1.11 units was observed which was highest in all the treatments. It was further decreased to 3.27 units after 30 days, which was also highest among all the treatments. This shows that EM and gypsum co-exist. Thus supra-extended EM can be used for increasing the solubility of gypsum, if needed. Otherwise supra-extended EM is the most economical and safe amendment (Table 4).

The sulfuric acid performance was strange. The instantaneous reduction of 0.97 units in pH was observed. However, this reduction after 10 days could not be sustained. Commercial grades of sulfuric acid were used, which are commonly used by farmers for reclamation purposes. The poor performance of sulfuric acid shows that claims made in the past by the scientists need further validation regarding the effectivity of sulfuric acid over gypsum (Table 4).

The supra-extended EM performed in a similar pattern with groundwater of 7.4 pH Gypsum did not perform positively. The response of sulfuric acid was also not positive, as the reaction was not stable. Therefore, for managing acidic environment of soils for tea and other tropical fruit plants, only EM is effective with freshwater (Table 5).

Table 5. Comparison of Three Selected Amendments using Gypsum, Supra-extended EM and Sulfuric Acid for Groundwater pH of 7.4 at Temperature of 8-12^{o}C

Days Since Start of the Experiment	Control Water Only		Gypsum: Water (0.4:100)		Supra-Extended EM:Water (1.2:100)		Supra-Extended EM: Gypsum: Water (0.6:0.2:100)		H_2SO_4: Water (0.014:100)	
Days	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**	**EC**	**pH**
0	0.66	**7.40**	1.03	**7.55**	1.08	**6.31**	1.24	**6.16**	0.67	**6.44**
5	0.68	7.98	1.77	7.66	1.10	6.09	1.83	5.98	0.80	6.68
10	0.66	7.99	1.92	7.55	1.12	5.78	2.04	5.71	0.81	7.21
15	0.59	8.05	2.09	7.60	1.13	5.68	2.15	5.82	0.80	7.54
20	0.53	8.17	2.17	7.78	1.11	5.58	2.23	5.52	0.78	8.01
25	0.52	8.15	2.26	7.86	1.19	5.38	2.29	5.18	0.85	8.05
30	0.52	**8.14**	2.28	**7.83**	1.17	**5.31**	2.28	**5.10**	0.85	**8.02**

EC in mS/cm (dS/m).

Sustaining Soil Quality

Initial Lysimeters studies, conducted to evaluate the effect of Supra-extended EM amended sodic water (1 ml Supra: 100 ml sodic water to lower down one unit pH) which revealed that soil quality can be managed on sustainable basis (Fig. 1, 2 and 3). Data (Table 7 & 8) indicated that by lowering down one unit of pH of sodic water through addition of Supra EM there was 70.54 percent decrease in soil SAR build up as compared to control (29.9). There was significant decrease in pH except control. This management trend towards neutral pH will help for an efficient availability of essential macro as well as micronutrients required for plant growth. Furthermore soil EC can be managed on sustainable grounds based upon the fact that total salts of EM are all organic based and thus don't add much towards salinity of soil. Long term study is still under progress. The techno-economic analysis indicated that once the microbial mass is built in the soil, much less EM would be required to amend the sodic water.

Table: 6. Soil, Sodic Water and Supra-Extended EM Chemical Composition Used for Lysimeter Study

	pH	EC (ds/m)	SAR	RSC	CO_3	HCO_3	Cl	Na	Ca+Mg	Mg
Soil	8.1	3.49	4.72	-	-	27.5	3.6	14.9	20	2.0
Irrigation water	9.0	3.12	17.07	6.02	1.25	9.97	10.08	27.53	5.20	1.73

Table 7. Evaluated Effect of Supra-extended EM Amended Sodic Water on Soil Physico-chemical/Chemical Properties at 0-15 cm-depth

Soil irrigated with	pH	ECe (dS/m)	SAR	% Decrease over Control
Sodic water of **9.0 pH (control)**	8.47	8.13	29.9	-
Supra EM amended sodic water of **8.5 pH**	8.19	5.18	15.2	49.16
Supra EM amended sodic water of **8.0 pH**	7.65	3.63	8.81	70.54
Supra EM amended sodic water of **7.5 pH**	7.31	5.35	15.27	48.93

Table 8. Evaluated Effect of Supra-extended EM Amended Sodic Water on Soil Physico-chemical/Chemical Properties at 15-30 cm-Depth

Soil Irrigated with	pH	ECe(dS/m)	SAR
Sodic water of **9.0 pH (control)**	8.47	4.23	15.30
Supra EM amended sodic water of **8.5 pH**	8.19	4.66	12.91
Supra EM amended sodic water of **8.0 pH**	7.65	3.30	8.48
Supra EM amended sodic water of **7.5 pH**	7.31	5.1	12.76

Engineering the Technology

The techno-economic feasibility of EM propagability encouraged the research team to engineer the technology of Bio-generation so that it can be linked with tubewell irrigation system for amending sodic or saline-sodic groundwater.

The design of the Bio-generator requires three fermenters. The first fermenter is for extended EM and the size is kept larger than required so that it is also available to farmers for use in foliar applications, compost making and small-scale irrigation to mulched plants.

The size of the second and third fermenters would depend on farm size and streamsize available. Further, the quality of tubewell water has to be considered in the design exercise. However, for standardization of design, a farm size of 10 ha (25 acres) is assumed as a unit design and the specifications are:

- The generator is considered as a unit generator if it provides material for one acre on per day basis to complete irrigation to a farm of 10 ha in 25-30 days. Thus production of about 10000 litres of supra-extended EM would be required after every 3rd day.

- The sizes of fermenters required are:

  - First Fermenter of 50 litres
  - Second Fermenter of 500 litres
  - Third Fermenter of 10000 litres

- First two fermenters can be built using black UV stabilized polyethylene tanks manufactured in Pakistan.

- Third fermenter can be built considering the irrigation system. For surface irrigation, the third fermenter can be built using masonry tank of 4m x 3m x 1.1m and should be constructed on the ground surface to have a system of gravity flow to the watercourse or bio-fertigation tank (Figure 1). Manual pump can be used to transfer super-extended EM to the supra-extended EM fermenter.

- In case of piped flow systems, the supra-extended EM can be injected in the pipe using EM injectors. For shallow pumping systems, the EM supply can be linked directly with the suction line of the pump. The size of the third fermenter will depend on the discharge of the pumping system (Figure 2).

- Cost of the Bio-generator for a farm size of 10 ha would vary between Rs. 15000 to Rs. 20,000 (US$ 300 to 400). The command area can be increased to 25 ha if only one irrigation would be required per crop season.

Future Thrusts

The future research of Bio-generator would be focussed to integrate the concept of groundwater amendment with fertigation and biogas. Ultimately, the economics will be much more favourable through integrated management of groundwater and bio-fertigation including biogas and slurry management. The enrichment of Bio-fertigation and enhancement of soil quality are the ultimate objectives. Therefore, the biogenerator design will evolve during the pilot-scale-testing phase for the integrated system.

The other areas where Bio-generator would be required and pilot-scale testing will be initiated are: a) freshwater aquaculture using sodic groundwater; and b) cultivation of tea with amended irrigation water to reduce and maintain soil pH in tea growing areas. The probing trials for initial testing have already been initiated at the National Tea Research Institute, Shinkiari and Fisheries Research Institute, NARC, Islamabad. These studies will be expanded in future.

The initial trials of fertigation conducted at NARC indicated that enrichment of bio-fertigation is possible using EM and around 60 percent increase is possible in major nutrients (NPK) availability. The systematic trials for enrichment of bio-fertigation will be carried out during 2000.

In the large scale integrated systems, efforts are underway to design the biogas systems for livestock and crop farmers to produce bio-gas for pumping of shallow groundwater using energy efficient pumps and old Japanese car petrol engines.

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