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AMELIORATION OF ACID SULPHATE SOILS IN NILWALA RIVER BASIN

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ABSTRACT

Paddy tracts of Nilwala basin has been affected by the implementation of Nilwala Flood Protection and Drainage Project in 1979 due to excessive drainage, and nearly 7000 acres of land is abandoned. The water table goes down to the level of 50 cm below soil surface during dry periods and soil pH falls to 3-4 causing acid sulphate condition. Hitherto several efforts have been made to ameliorate the paddy lands but no economical solution is obtained. The National Science Foundation project to find out the feasibility of using natural hydraulic forces to increase water table to keep the acid sulphate forming minerals at bay and to cultivate rice in these paddy lands. Water table fluctuation in relation to water level in the drainage channel was studied over one year and there was found a very high correlation (r^2=0.985) indicating a possibility of increasing water table by heading up water in the channel. Simulated pot experiment showed that increasing water table to 15 cm below soil surface allows rice to grow effectively, showing plant survival of 112 (53%) compared to 28 (15%) plants in control. Recorded plant height of Bg. 357 variety was 35 cm compared to 22 cm in different treatments and control, respectively. Soil pH also increased to a value closer to 6.0 in the treatment which is conducive for rice cultivation. However, the low values of plant survival and plant heights were due to unusual extreme low rainfall in 2020/21 Maha season compared to 10 years' average.

Keywords: Jarosite, Natural hydraulic forces, Pyrite oxidation, Rice cultivation, Water table.

INTRODUCTION

Nilwala River, the major river in Matara District of Southern Sri Lanka, originates at an altitude of 1,050 m and traversing about 70 km to discharge to Indian Ocean at Matara (Abhayaratna, 1996). Often inundation of the river disturbs the human

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activities creating a chain of socio-economic problems (Delpachitra,1996; Panabokke, 1996; Weerasinghe, 1996; Weerasinghe, et al., 2000; 2015). The Nilwala basin is situated in the wet zone of the country and nearly 90 percent of the area covered by catchment of the river is in Matara District with a paddy area of about 16,000 acres (Abhayaratna, 1996; Fernanda and Suranganie 2009). Frequent flash floods in Nilwala basin are a common occurrence and an effort is taken to mitigate the problem by implementation of Nilwala Flood Protection and Drainage Project (NFPDP) started in 1978 and aimed to provide flood protection to paddy cultivation and achieve higher paddy yields, nevertheless it has created some new problems in the paddy eco- system. Among the new problems was the development of acid sulphate soil conditions in drying period, which arises after changes in the hydrological regime of the locality though the drainage network covering 3960 ha of paddy fields in the downstream was improved from rapid evacuation of floodwater (Delpachitra,1996; Weerasinghe et al., 2015). It is now clear that NFPDP underestimated this factor, and hence the paddy ecosystem undergoes severe stresses (Weerasinghe, 1996; Weerasinghe, et al., 2000; 2015). Problem of acid sulphate soils in the Nilwala ganga area was recommended to carry out a detailed soil survey as a basis for managing the problem (Balasuriya, 1987; Dent, 1987). Later it was confirmed that the problem was due to excessive drainage causing oxidation of Jarosite mineral, which is situated 30-45 cm below, and formation of sulphuric acid and gaseous evolution of H_2S and SO_2, resulted in the formation of acid sulphate soils (ASS) in drying paddy fields, due to pyrite oxidation as experienced in many parts of the world (Dent and Pons 1995, Fanning 2002, Fitzpatrick et al., 2010, Sullivan et al., 2012).

Acid Sulphate formation occurs due to pyrite (mineral, FeS_2) oxidation, when drying fields are exposed to oxygen.

$$FeS_2 + 15/4\ O_2 + 7/2\ H_2O \rightarrow Fe\ (OH)_3 + 2SO_4 + 4H^+$$

The major soil problems encountered in ASS soils are acidity, iron and aluminum toxicity, phosphorous fixation, possible salinity, low base status, nutrient deficiencies of P, K, S and Zn, which are aggravated due to dry spells. (Ponnamperuma, 1972; Ottow et al., 1991). Thus, after implementation of NFPDP, nearly 7000 acres of paddy lands were abandoned and some paddy lands which were cultivated in both seasons of the year are now cultivated once a year. Several groups and research institutes conducted research work during last three decades (1980's onward) to ameliorate acid sulphate conditions and bring back the paddy lands under plough. However, their efforts were not fruitful though some other crops such as cinnamon, coconut, yams etc. are grown under Sorjan system with a provision of irrigation facilities (Balasuriya. personal communication). However, paddy transplanting, fertilizer (Eppawela rock phosphate) application, adaption of more resistant varieties is some of the recommendations from the researchers towards solution of the above problem in Nilwala downstream (Panabokke, 1996; Weerasinghe et al., 2000; Ratnayake et al., 2018).

It was then hypothesized that by bringing water table up in paddy fields and keeping jarosite mineral under reduced conditions, can ameliorate the acid sulphate soil conditions. It was further hypothesized that by heading up water in the drainage channel will bring the water table up in paddy fields through natural hydraulic forces. Thus, the present research was undertaken to investigate the validity of these hypotheses and the possibility of re-cultivating paddy in these acid sulphate affected paddy tracts.

MATERIALS AND METHODS

A pilot area of the drainage channel segment of about 250 m length from NFPDP, where a flat land, consisting of about 5 acre of paddy land affected by acid sulphate soil (Fig. 1) was selected in the Kotawila, Godagama area closer to Agriculture Research Station (ARS), Telijjawila with road accessibility. The only vegetation growing in the site is a plant called “TIKIYA” *(Eliocharis dulcis)*, the only plant that survives under acid saline soil conditions (Balasuriya, 1987).

Figure 1. Area affected by extreme acid sulphate conditions

Soil Sampling

A composite soil sample was obtained, using a soil augur from five randomly selected places at five soil depths; 0-15, 15-30, 30-45, and 45-60 cm, f and the samples were well mixed, and composite 4 samples were prepared for analysis. The pH and EC measurements were taken done by pH and EC meters (1:1 soil-water ratio).

Water table measurements

Forty piezometers were prepared using 1.5-inch diameter S-Lon pipes of 4 feet long and several holes were bored in the lower part of the piezometer to allow the water to enter into the piezometers freely and were installed in the soil up to 3.5 feet depth, in four feet deep holes bored in the uniformly selected positions in the paddy lands using a soil auger.

Water entered into the piezometer through the open end and holes bored and came to equilibrium naturally through hydraulic forces and height of the water column inside the piezometer was measured. The water levels in the piezometers and drainage channel were measured twice a week. Further, pH and EC of the water collected from the piezometers and from the drainage channel was also measured twice a week. Correlation analysis was then carried out between water levels, pH and EC at the end of one-year period.

Simulated pot experiment

Based on the correlations obtained (our second hypothesis) among water levels and other parameters a pot experiment was carried out in a greenhouse at Gannoruwa, Peradeniya, simulating the rainfall received at the site, as other weather parameters in both locations were almost the same, being in wet zone of Sri Lanka. Sixty cm long S-lon pipes of diameter 3 inches (7 pots) and 4 inches (3 pots) were used as pots. Two water table depths; 15 cm below soil surface (Treatment) and 45 cm below soil surface (Control) were used with ten pipes per treatment (10 replicates). The pots were filled with soil collected from the site at five layers: 0-12, 12-24, 24-36, 36-48, 48-60 cm and filled in the same sequence to simulate field conditions and compacted. The required water table depths were achieved by dipping the pots in half barrels filled with water to 45 or 15 cm height, respectively. After two weeks of setting up of the experiment, (allowing the natural hydraulic forces to equilibrate so that the water table in pots reached the same height as outside and also the pH and EC), the pots were seeded with pre-germinated rice seeds of variety Bg.357 at the rate of 25 seeds /pot (3 inches diameter) and 40 seeds/pot (4 Inches diameter). Water depths in half barrels were maintained at 45 and 15 cm, respectively throughout the experimental period.

Experiment was maintained and fertilized as per Department of Agriculture recommendation for 3.5 age group variety until maturity except irrigation. Since the project area was totally rainfed, daily rainfall data from ARS, Tellijjawila was obtained and calculated quantity of water was added on days where rainfall was received (Simulation). Normally the Maha paddy cultivations starts in latter part of October (20 October) in Matara district and the rainfall was simulated in the pot experiment starting from 20 December 2020. EC and pH of soil in pots were monitored once a month and weekly plant population counts and plant heights were recorded throughout the cropping period. The simulated Maha 2020/21 rainfall was given in Table 1.

Table 1. Maha season (2020/21) rainfall in mm received at the site and the rainfall simulation dates in Pot Experiment

Maha season 1920/21 rainfall in mm						
Date	Sept. 2020	October 2020	November 2020	December 2020	January 2021	February 2021
Simulation in Pot Experiment		December 2020	January 2021	February 2021	March 2021	April 2021
1	19.5	0.0	0.0	0.0	0.8	0.0
2	5.1	0.0	0.0	3.7	0.0	0.0
3	0.0	0.0	53.8	0.7	15.0	0.0
4	6.4	0.0	0.0	0.0	3.5	0.0
5	7.6	0.0	14.8	0.0	0.0	0.0
6	28.7	0.0	0.0	0.0	0.0	9.1
7	1.4	12.90	6.0	0.0	0.0	0.0
8	16.6	10.2	72.7	0.0	0.0	0.0
9	6.7	13.5	5.2	0.0	0.9	7.0
10	3.6	18.2	5.2	0.0	0.0	0.0
11	6.7	15.3	4.4	0.0	14.8	0.0
12	17.6	26.7	0.0	2.5	0.7	0.0
13	13.2	0.0	5.9	0.0	1.3	0.0
14	0.7	10.0	65.9	0.0	1.1	0.0
15	9.6	0.0	41.2	24.6	1.1	0.0
16	0.0	0.0	1.7	28.6	12.2	0.0
17	5.4	0.0	18.2	0.0	11.7	0.0
18	7.7	0.0	3.2	0.0	0.0	0.0
19	6.2	0.0	2.1	0.5	0.0	0.0
20	25.9	0.0	1.2	0.0	0.0	0.0
21	22.6	21.9	0.3	14.4	0.6	0.0
22	1.4	4.3	0.0	0.0	0.0	0.0
23	0.0	8.1	0.0	30.4	0.0	0.0
24	43.3	0.0	0.0	0.0	0.0	3.0
25	0.0	14.4	0.0	0.5	0.0	0.0
26	0.0	0.0	0.0	0.0	0.0	0.0
27	0.0	0.0	0.0	0.0	0.0	0.0
28	15.3	0.0	0.0	0.0	0.0	0.0

Maha season 1920/21 rainfall in mm						
Date	Sept. 2020	October 2020	November 2020	December 2020	January 2021	February 2021
Simulation in Pot Experiment		December 2020	January 2021	February 2021	March 2021	April 2021
29	41.2	0.0	0.5	0.0	27.6	-
30	0.0	0.0	6.1	0.0	11.4	-
31		0.0		0.0	0.0	-
Total	312.4	178.0	306.3	105.9	102.7	19.1
	Ten-year average	200	350	150	80	75

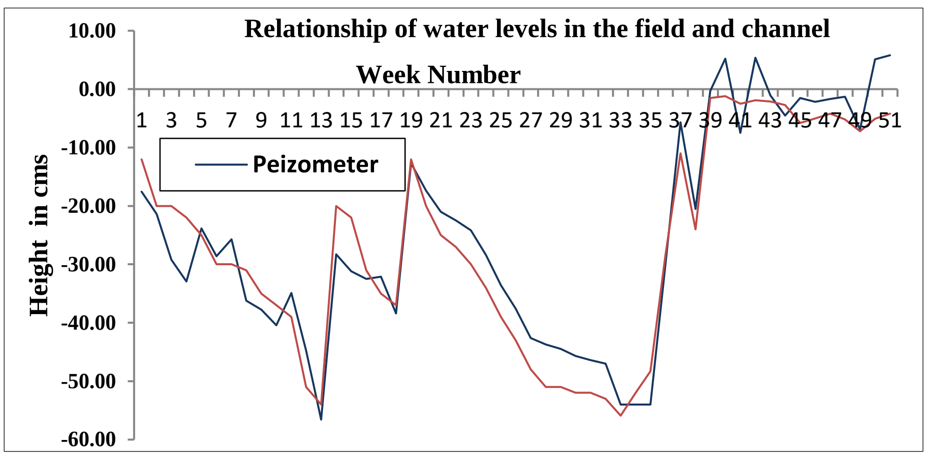
RESULTS AND DISCUSSION

At the onset of the study, composite soil sample was obtained, which includes 20 sub-samples and a representative sample was obtained after thorough mixing and analyzed for pH, organic matter, CEC and EC. Results indicated both pH and EC are in typical conditions of an acid sulphate soil and not conducive for rice cultivation: pH 2.92, EC 11.6 mS/cm, CEC 24.9 cmol/kg and organic matter 4.4%.

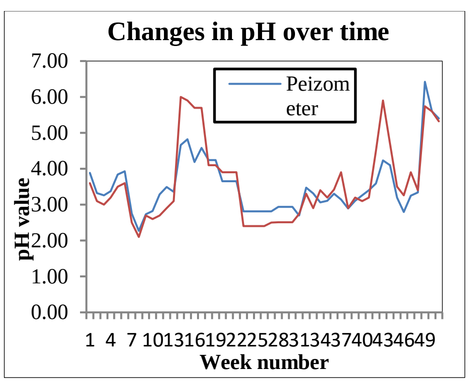
Normally paddy soils are maintained at a reduced condition to bring the soil pH to 7 and EC less than 2.0 mS/cm conducive for rice cultivation. In the project area due to excessive drainage and continuous pumping out of drainage water to sea, drawing down the water table exposing the soil for oxidative processes lead to acid sulphate formation with low pH and high EC.

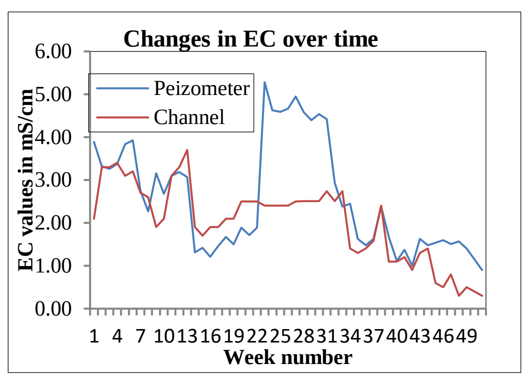
Water table depth in the field and water level in the channel was monitored for a period of one year at 2-week intervals and the data were summerized to weekly averages and presented in the Fig. 2a. It shows the comparative depths for the week 1-51 and weekly variation in water levels, which follows a similar trend. The lower readings in week 14-19 could be attributed to the heavy rainfall (172 mm in November and 128.6 mm in December) in the catchment area inundating the paddy lands and as the rain water from higher elevations in the channel moves down towards the site increasing the water level in the channel and decreasing the water table depth in the paddy fields. These levels in the drainage channel are measured from a reference point marked on a permanent water controlling structure (which is in par with the soil surface of the paddy land) at the highest elevation in channel section of the site.

Correlation analysis of the water table data (Fig. 2a) showed that there is a very high correlation (r^2=0.985), which proved our second hypothesis, where natural hydraulic forces operating in the site and therefore heading up of water in the channel can elevate the water table in the paddy fields, keeping the jarosite oxidation at bay. Further, the changes in pH values between water table depth in the paddy fields and water level in the drainage channel (Fig. 2b) also showed a good correlation (r^2=0.90) throughout experiment period. This also proves that oxidation reduction processes also operational in the site and if we can head up water in the channel then the soil reduction takes place and pH values decrease to acceptable levels for paddy cultivation. Similarly, EC values (Fig. 2c) also showed a good correlation **(**r^2= 0.975) and could be brought to levels acceptable for paddy cultivation.



(a)





(b) (c)

Figure 2. Relationship of water table and water level with changes of pH (b) and EC (c)

Pot Experiment

A simulated pot experiment inside the greenhouse was conducted (Fig. 3) to find out the feasibility to raise a rice crop with increased water table. In this pot experiment Maha 20/21 rainfall of project site was simulated by adding measured quantities of water. However, Maha 2020/21 appears to be exceptionally dry (Table 2) and all of the months except January 2021 the rainfall received was less than 10-year average.

Figure 3. Plant growth after 14 weeks for different treatments

As a result, the plants did not grow to a height of more than 35-40 cm, due to physiological water stress experienced by the rice plants because of low amount of rainfall received and long spells of dry weather and high intra plant competition. Normally Bg 357 rice plant grows to a height of 56 cm (RRDI, Personal communication). Moreover, growth period of the rice plants was also extended by about 7-10 days.

Table 2. Monthly rainfall received during 2020/21 Maha season and ten-year averages

	Rainfall in mm				
	October	November	December	January	February
2020/21 Maha	178	306.3	105.9	102.7	19.1
No. of rainy days	10	18	8	13	3
Ten year average	200	350	150	80	75

Source: Meteorological data, ARS, Telijjawila

Table 2 shows the monthly rainfall in 2020/21 Maha season and in January 2021 only gave slight increase in rainfall above 10-year average. Rainfall data analysis further showed two dry spells of 10 days (October 26–02 Nov.) and 11 days (Nov. 21-29) which coincided with the vegetative phase of the rice crop followed again by another dry spell of 11 days [2021 January 18-28] followed by extremely dry weather in 2021 February with only 3 days of rain (9.1, 7.0 and 3.0 mm) which coincided with panicle development stage of the reproductive phase of rice crop.

This indicates that plants had suffered from physiological stress in the treatment and in control from the acid sulphate conditions in addition to physiological stress. Therefore, one cannot expect a good growth of rice plants - plant height, tillers and panicle size are affected and the plants in the treated pots was reduced to 35 cm in height compared to control where plant height was 22 cm. This difference in height could be attributed to the comparatively favourable growth environment under high water table, keeping the jarosite mineral under reduced conditions.

Plant Population count was also taken at weekly intervals and data represented in Fig. 4. After 9 days after planting seeds of the rice plants were eaten by rats and population was reduced to 210 and 185 plants for treatment and control respectively and the plant count was reduced to 112 and 28 plants respectively at the end of experiment period. Therefore, the survival of plants was 53% and 15% for the treatment and control respectively.

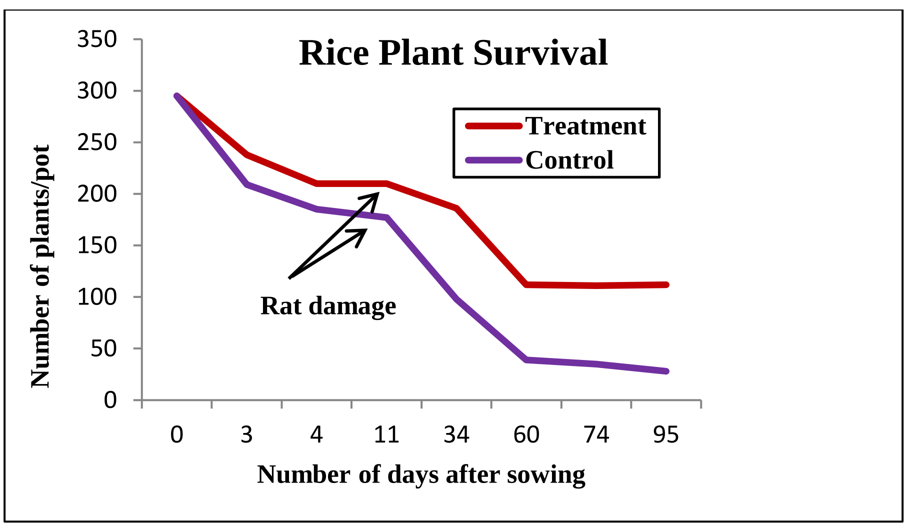


Figure 4. Rice plant survival for different treatments over time

High plant mortality was observed in the control treatment (28 plants) due to development of acid sulphate conditions by oxidation of jarosite and high survival of rice plants in the treatment (112 plants) where water table is within the root zone of rice plants and jarosites are under reduced conditions. Changes in soil pH and EC was monitored in pots and showed water table depth has definite influence on the soil acidity [decreased with increased water table (pH value increase)]. Soil pH value in the treatment increased with time and reaches almost neutrality, which could be attributed to the prevention of Jarosite oxidation and the typical reduced conditions in paddy soils. On the other hand, EC value is also decreased in both treatments.

CONCLUSION

Simulated study concluded that the hypothesis "bringing water table up in paddy fields and keeping jarosite under reduced conditions, can ameliorate the acid sulphate conditions" was found true and under the situation rice can be normally grown in the acid sulphate affected fields of the Nilwala river basin under the condition the water table is maintained at about 15 cm below the soil surface. However, *in-situ* observation i.e., field study is essential to confirm the results and the validity of the hypothesis.

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