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An Innovative Approach for Amelioration of Acid Sulphate Soils in Nilwala River Basin

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Abstract
Paddy tracts of the Nilwala basin have been affected by acid sulphate soils through the implementation of the Nilwala Flood Protection and Drainage Project in 1979. Nearly 7000 acres of lowland paddy lands were abandoned. In these lands, the water table goes down to the level of 50 cm below the soil surface during rainless periods, and soil pH falls to 3-4, causing acid sulphate conditions. Hitherto, several efforts have been made to ameliorate the paddy lands, but none of the solutions were either economical or farmer acceptable. An innovative preventive approach instead of curing where feasibility to increase water table and to keep the jarosie mineral under reduced conditions using natural hydraulic forces was tested. Water table fluctuation in relation to water level in the drainage channel was studied over one year, and a very high correlation (r2=0.985) indicated the possibility of increasing the water table by heading up water in the drainage channel. Simulated greenhouse pot experiment revealed that increasing the water table to 15 cm below the soil surface allowed rice plants to grow normally. The recorded plant survival was 112 (53% survival) compared to 28 (15% survival) plants in control. The Recorded mean plant height of Bg. 357 variety was 35.5 cm compared to 23.0 cm in d treatment and controls, 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 height were due to unusual low rainfall received in the 2020/21 maha season compared to the 10- year average.

Keywords: Jarosite, Natural Hydraulic Forces, Pyrite Oxidation, Acid Sulphate Soils, Rice Cultivation, Water Table.

Introduction

The major river in Matara District of Southern Sri Lanka, known as Nilwala River originates at an altitude of 1,050 m and traversing about 70 km downstream to discharge to Indian Ocean at Matara [1]. Very often inundation and flash floods of the river basin disturbs the human activities creating a chain of socio-economic problems [2-6]. Whole of Nilwala basin is situated in the wet zone of the country and nearly 90 percent of the catchment area of the river is in Matara District with a paddy area of about 16,000 acres [1,7]. Fffors undertaken to mitigate the frequent flash floods in Nilwala basin by the implementation of Nilwala Flood Protection and Drainage Project (NFPDP) which started in 1978 aimed flood protection to paddy cultivation and to achieve higher paddy yields. Nevertheless, it has created some new problems in the paddy eco- system in the basin. Among the new problems was the development of acid sulphate (AS) soils in drying period, which arises with the changes in the hydrological regime of the locality, though the drainage network developed covering 3960 ha of paddy fields in the downstream was improved for rapid evacuation of floodwater (Delpachitra,1996; Weerasinghe et al., 2015). It is now clear that NFPDP underestimated the drainage factor, and hence the paddy ecosystem underwent severe stresses [2,5-6]. Problem of acid sulphate soils in the Nilwala ganga area was lead to carrying out a detailed soil survey as a basis for managing the problem [8-9]. Later it wasconfirmed that the problem was due to excessive drainage causing oxidation of Jarosite mineral, which is situated 30-45 cm below the soil surface and formation of sulphuric acid and gaseous evolution of H2S and SO2. The formation of AS soils in drying paddy fields, due to pyrite oxidation has experienced in many parts of the world [10-14].

Acid Sulphate formation occurs due to pyrite (mineral, FeS2) 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 associated with AS soils are acidity, iron and aluminum toxicity, phosphorous fixation, possible salinity, low base status, nutrient deficiencies of P, K, S and Zn, which are further aggravated during dry spells. [14-15]. 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 brought down to once a year paddy cultivation affected the economy of more than 15000 farmer families.
Several groups and research institutes conducted research work during last four decades (1980's onward) to ameliorate acid sulphate conditions and bring back the paddy lands under the plough. However, their efforts were not fruitful though some crops other than paddy, such as cinnamon, coconut, yams etc. are grown under Sorjan system with a provision of irrigation facilities (Balasuriya. personal communication). Other recommendations such as paddy transplanting, fertilizer (Eppawela rock phosphate) application, adaption of more resistant varieties are solutions forwarded for curing purposes though they are either not economical or farmer friendly to eliminate ASS problem in Nilwala downstream [3-4,16]. Hitherto none of the research groups or researchers used preventive approaches to resolve the AS soil problem in the region.

Alternatively, innovative approach where preventive measures to be taken for developing AS soils instead of working out ameliorative measures, are hypothesized for this study. It was further hypothesized that by heading up water in the drainage canal can bring up the water table in paddy fields through the activation of natural hydraulic forces .The idea of bringing water table up is to keep the AS soils forming Jarosite mineral under reduced conditions.

Thus, the present research was undertaken to investigate the validity of these hypotheses with the objectives of;

- Removing the acid sulphate soil formation
- Stopping emanation of toxic gases and health hazards
- Cultivating paddy in these ASS paddy tracts.

Materials and Methods

A pilot area of the drainage channel segment of about 250 m length from NFPDP, consisting of about 5 acre of paddy land affected AS soils (Figure 1) was selected in the Godagama area closer to Agriculture research Station (ARS), Telijjawila with road accessibility. The only vegetation growing in the site is a

Figure 1: Area Affected By Extreme Acid Sulphate Conditions

Figure 2: "TIKIYA PLANT " (Eliocharis dulcis),

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, 60-75 cm 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).The pH and EC measurements are also taken from individual sampling depths The standard Electrical

Conductivity (EC) meter and a standard pH meter where a pH electrode and a reference electrode and measured the potential difference between the electrodes is used for taking measurements.

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. They were installed in the experimental site up to 3.5 feet depth, in selected positions in the paddy lands using a soil auger. Water entered into the piezometer came in to equilibrium naturally through hydraulic forces and height of the water column inside the piezometer and drainage canal was measured at regular intervals, twice a week. Further, pH and EC of the water collected from the piezometers and the drainage channel was also measured twice a week. Correlation analysis was then carried out between water levels to know the behavior of natural hydraulic forces and , 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 designed and carried out in a greenhouse at Gannoruwa, Peradeniya, simulating the soil and 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 experimental 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 levels: 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). Water addition was simulated by strictly adhering to the quantity and the frequency of rainfall in the project site. 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.

Plant height analyses were carried out using one-way analysis of variance (ANOVA) using the Minitab software package (Minitab 19.1) with three replicates.

Table 1: Maha season (20/21) rainfall in mm received at the site and the rainfall simulation dates in Pot Experiment

Maha season 2020/21 rainfall in mm						
Date	**September2020**	**October 2020**	**November2020**	**December2020**	**January 2021**	**February 2021**
Simulation in Pot Experiment		**December 2020**	**January 2021**	**February 2021**	**March 2021**	**April 2021**
1	19.50	0.00	0.00	0.00	0.80	0.00
2	5.10	0.00	0.00	3.70	0.00	0.00
3	0.00	0.00	53.80	0.70	15.00	0.00
4	6.40	0.00	0.00	0.00	3.50	0.00
5	7.60	0.00	14.80	0.00	0.00	0.00
6	28.70	0.00	0.00	0.00	0.00	9.10
7	1.40	12.90	6.00	0.00	0.00	0.00
8	16.60	10.20	72.70	0.00	0.00	0.00
9	6.70	13.50	5.20	0.00	0.90	7.00
10	3.60	18.20	5.20	0.00	0.00	0.00
11	6.70	15.30	4.40	0.00	14.80	0.00
12	17.60	26.70	0.00	2.50	0.70	0.00
13	13.20	0.00	5.90	0.00	1.30	0.00
14	0.70	10.00	65.90	0.00	1.10	0.00
15	9.60	0.00	41.20	24.60	1.10	0.00
16	0.00	0.00	1.70	28.60	12.20	0.00
17	5.40	0.00	18.20	0.00	11.70	0.00
18	7.70	0.00	3.20	0.00	0.00	0.00

19	6.20	0.00	2.1	0.50	0.00	0.00
20	25.90	0.00	1.20	0.00	0.00	0.00
21	22.60	21.90	0.30	14.40	0.60	0.00
22	1.40	4.30	0.00	0.00	0.00	0.00
23	0.00	8.10	0.00	30.40	0.00	0.00
24	43.30	0.00	0.00	0.00	0.00	3.00
25	0.00	14.40	0.00	0.50	0.00	0.00
26	0.00	0.00	0.00	0.00	0.00	0.00
27	0.00	0.00	0.00	0.00	0.00	0.00
28	15.30	0.00	0.00	0.00	0.00	0.00
29	41.20	0.00	0.50	0.00	27.60	-
30	0.00	0.00	6.10	0.00	11.40	-
31		0.00		0.00	0.00	-
Total	312.4	178.0	306.3	105.9	102.7	19.1
Ten year average	200	350	150	80	75	

Table 2: Monthly rainfall and the number of rainy days 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

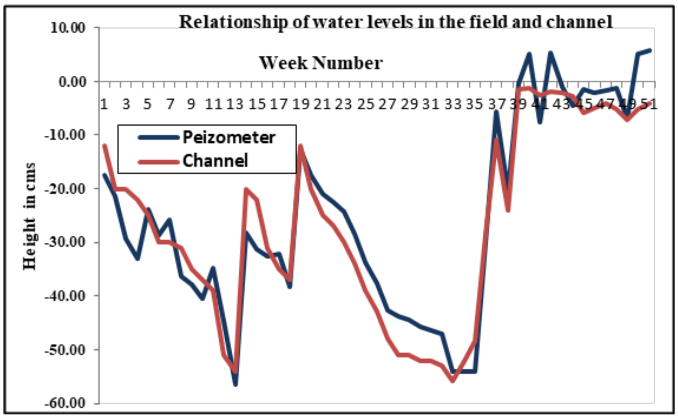
[Source: Meteorological data, ARS, Telijjawila]

Results and Discussion

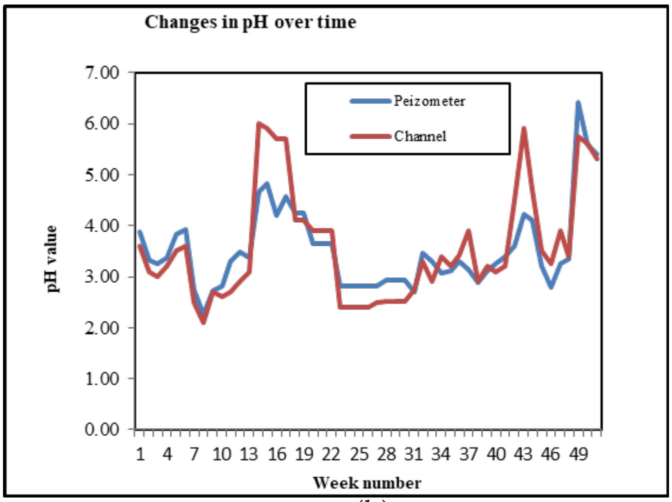
Composite soil sample obtained, which includes 20 sub-samples and a representative sample was obtained after thorough mixing and analyzed for pH, organic matter, CEC and EC. Results indicated both pH and EC are in typical conditions of an AS soils and not conducive for rice cultivation where pH -2.92, 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 closer 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 canal 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 canal moves down towards the site increasing the water level in the canal and decreasing the water table depth in the paddy fields. These levels in the drainage canal are obtained from the NFPDP project office where they maintain the water level continuously.

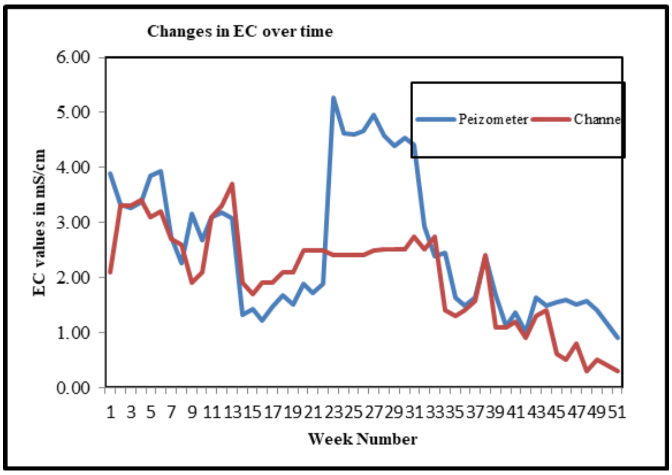
Correlation analysis of the water table data (Fig. 3a) showed that there is a very high correlation ($r2=0.985$), which proved our second hypothesis, where natural hydraulic forces operating in the site and therefore heading up of water in the canal can elevate the water table in the paddy fields, keeping the jarosite oxidation under reduced condition, thereby preventing the AS soil formation. Further, the changes in pH values between water table depth in the paddy fields and water level in the drainage channel (Fig. 3b) also showed a good correlation ($r2=0.90$) 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. 3c) also showed a good correlation ($r2= 0.975$) and could be brought to levels acceptable for paddy cultivation.



(a)



(b)



(c)

Figure 3: 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. 4) 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.

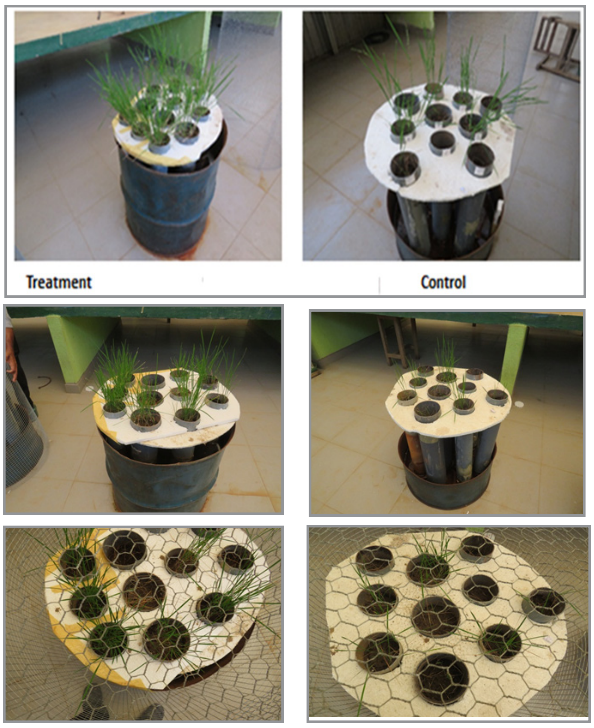


Figure 4 : Plant growth after 4, 8 and 14 weeks after seeding in different treatments

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 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 AS 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 favorable 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. 5.

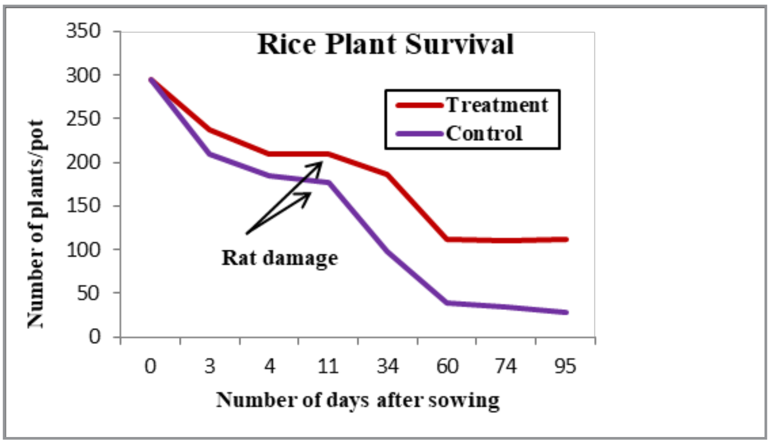


Figure 5: Rice plant survival in different treatments.

Nine 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 further 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.

Table 3: Plant height at weekly intervals (average of 10 replicates)

Date	Plant height in Cms	
	Treatment	Control
04.12.2020	11.1 a	15.7 a
11.01.2121	9.2 b	13.2 b
18.01.2021	18.0 a	14.5 b
25.01.2021	18.6 a	15.7 b
01.02.2021	18.3 a	16.4 a
08.02.2021	21.5 a	15.8 b
15.02.2021	22.3 a	17.4 b
22.02.2021	26.9 a	18.8 b
01.03.2021	27.6 a	19.8 b
08.03.2021	30.3 a	21.9 b
16.03.2021	31.5 a	21.8 b
29.03.2021	34.0 a	22.5 b
05.04.2021	35.5 a	23.1 b
SE	1.57	

High plant mortality was observed in the control treatment (28 plants) due to development of AS 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. 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.

Plant height was also monitored and presented in Table 3 at weekly intervals. Data shows there was significant differences between treatment (35.5 cm) and control (23.0). However, normal plant height of Bg 357 in good soils without any stress was recorded as 80.0 cms (RRDI, personal communication). The reduced plant height (35.5 cms) observed in treatment could be attributed to poor rainfall received during maha 20/21 season which was less than 10 year average and simulated in the pot experiment. Therefore, the rainfall received was not enough for possible wash away of acid sulphate conditions. Further, the plant height in the control treatment was still lower (23.0 cms) and attributed to acid sulphate conditions which was further aggravated by reduced rainfall.

Results discussed above shows very clearly that the natural hydraulic forces are behaving normally within the site making it possible that innovative preventive approach can be applied successfully in the amelioration of AS soils in the Nilwala Basin. Therefore this approach which is highly cost effective (as there is no any additional expense for amelioration of AS soils) compared to the curative approach which was experimented for last 3-4 decades without much success. Therefore, if the initial capital expenditure for constructing water control devices to maintain water level at suitable height level by the respective government the farmer do not need to incur additional cost factor for cultivating AS soils, hence cost effective and farmer acceptable. However, this innovative preventive approach need to be tested out in- situ and proven the hypothesis before necessary recommendations are made. Moreover, the soils in the experimental site in the Nilwala basin belongs to Palatuwa series of Half bog-soils, which is taxonomically Typicsulfaquents and according to FAO classification it is Thionic fluvisols. Therefore, further studies on this innovative preventive approach is necessary in other soil types and environments to confirm the achievements in this study.

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 through innovative preventive approach" was proved successful and under the situation rice can be normally grown in the AS 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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