Positive impact of traditional rice cropping on geochemical qualities of saline sandy soil in Northeast Thailand

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Keyword: sandy soil acid, rice farmer practice, salinity, pH, reduction, soil column

Abstract

The majority of soils in Northeast Thailand are of low fertility and acidic to depth. Moreover 17% of cultivated soils in the region are affected by salinity that has its origin in saline groundwater that has risen to within 1 m of the soil surface. Traditional rice growing techniques are not well adapted to these kinds of soil constraints that often results in the abandonment of entire fields or areas within fields due to salinization. A study was undertaken to determine the effects of rice cropping on these saline sandy soil with respect to changes in the geochemical attributes of the soil solution and their consequences on soil conservation.

An accurate assessment of geochemical changes and associated mechanisms, including the effects of reducing conditions on soil solution composition, is difficult to undertake under field conditions. Thus we established a laboratory experiment where conditions similar to those in the field could be simulated. Four undisturbed soil columns of 50 cm in height and 24.5 cm in diameter we collected from Northeast Thailand, two of which were saline (S) and two non-saline (NS). Rice was transplanted into one of the columns from each of soil salinity types. The columns were designed to continuously monitor pH, Eh and the chemical composition of solution at three depths namely -7, -24, -40 cm. An increase in pH was observed within the acidic NS column with the pH rising to almost neutrality within the surface horizon. This increase in pH is controlled by iron reduction. At the second depth interval (i.e. -24 cm) manganese reduction control changes in pH along with changes in the partial pressure of CO_2*. The highest increase in pH was measured in the NS columns cropped with rice whilst the smallest increase in pH was observed in the un-cropped S soil. On these sandy soils the production of rice using farmers practices contributes to increases in pH and temporarily controls the expansion of salinity by diluting the salt above the soil. Continued traditional rice cropping contributes to limiting the expansion of degradation on these soils.*

Introduction

Soil salinisation is a global problem that is estimated to affect 6.5% of the earth’s soil surface is (Cheverry et al. 1998). In Northeast Thailand, problems of salinisation and soil degradation have attained an important level (Kohyama et al., 1993). The soils of the region soils are sandy (Mitsuchi et al., 1986; Yuvaniyama, 2001), with very low nutrient supplying capacity (Ragland and Boonpuckake, 1988) and low organic matter (OM) contents (Arunin1986). Around 17% of this area’s soils are affected and a further 108,000 km^2 which is more than twice the size of Switzerland are potentially at risk by the same phenomenon. Upland deforestation leading to a rise of the saline watertables has been the main cause of the increase in soil salinisation (Williamson *et al.*, 1989). This problem is of increasing importance to national stakeholders concerned over their continued use of these soils for agricultural. A decrease in rice production yield due to the occurrence of saline patches could have serious affects on this area’s ability to satisfy the rising food demands of its increasing population (Fukui, 1991; Kono, 1991). Moreover, rice cropping forms a distinct cultural element in communities of northeast that has significant implications on the socio-economic status of the region (Formoso et al., 1997). Hence a decline in rice yields would have serious consequences.

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Salinity issues have been studied for many years in this region of Thailand (Arunin, 1984), (Brinkman et al., 1977). However, there are still unanswered questions on the dynamics of saline patches and the respective soil development. It was therefore decided to study the impact that rice cropping has on these impoverished, sometimes acidic soils that are subject to salinisation. The first results of this study show significant differences in terms of acidity, notably during the dry season, between the saline and non-saline zones. In previous studies Grunberger (2002) observes saline zones having a neutral pH of 6.5-7 and non-saline having a pH of 4.5-5. The discrepancy between pH levels would suggest a modification in behaviour between saline and non-saline patches situated in close proximity to one another (a few metres) on soils of identical origin. Therefore, an evaluation was undertaken using undisturbed columns collected from cultivated and non-cultivated soil with the objective of identifying the effects of traditional rice cropping on soil geochemistry notably the role of plants and salinisation. Since pH is an important indicator of soil quality, variations in pH and Eh are studied in the first months following submersion.

Methods

Experiments were conducted on cultivated plots in Pra Yuhn, near Khon Kaen, Northeast Thailand (16º21′12.744 North and 102º36′29.8″ East).

In the saline patches the exchangeable complex is dominated by sodium. The region has a tropical Savannah climate with a mean annual rainfall of 1,200 mm from May to October. Evaporation is greater than precipitation, except at the height of the rainy season from July to September (Bolomey, 2002). Soil is regularly saturated by solutions of NaCl as the water table rises and conductivity has an average value of 20 dS m^{-1} at a pH of 6.82. The water table is near the soil surface at the end of the rainy season and draws down by 2 m in the dry season.

The study was conducted in the laboratory for optimal control of conditions and ease of monitoring. Four undisturbed soil columns (47 cm high and 24.5 cm in diameter) were tested; two from within the saline patch and two from outside. Rice was planted on one column from each of the two sites. Thus four distinct types were possible; non-saline/non-cultivated C4 (NS NC), non-saline/cultivated C3 (NS C), saline/non-cultivated C1 (S NC) and saline/cultivated C2 (S C).

Efforts were made to reproduce field conditions and ensure that all interventions and measures were conducted in the same way on each column. Measurement and sampling equipment was installed to control the water flow, measure pH and Eh and to study chemical evolution of soil solution. Different measuring equipment was installed at three levels; at 7 cm, less than 24 cm and at 41 cm from surface (Figure 1).

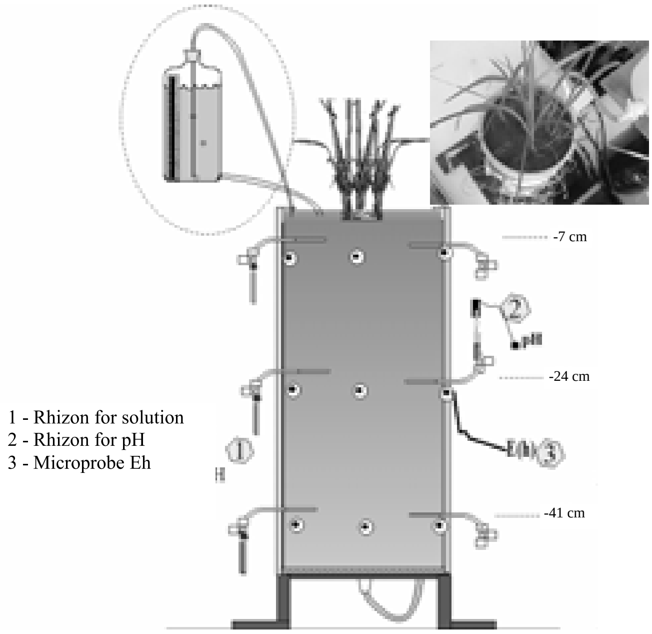

Figure 1. Diagram of a soil column with instrumentation installed to monitoe pH, Eh, chemical composition of the solution, at three depths

The soil has a sandy loam texture (Grunberger, 2002), less than 10% clay content and low, superficial levels of organic matter (OM) (Table 1). The soil was classified as an Ultisols (Roi Et series in the Thai classification system) having a low cation exchange capacity, less than 5 $cmol_c$ kg^{-1} of soil (Table1).

After a week’s saturation, the soil surface of the columns was flooded to a predetermined level using a Marriotte device. Deionised water was used so as to simulate rainwater that under natural conditions irrigates the field plots. Five rice plants were transplanted in two columns to simulate a tuft of plants in the field. Weekly samples of water were taken and analysed. The pH and Eh were measured twice a week, always at the same time.

Studies on reduction in saturated soil and evolution of pH have demonstrated the important roles of microorganisms, certain minerals such as iron and manganese hydroxides and also the partial pressure of CO_2 (p CO_2) (Berthelin, 1998; Ponnamperuma, 1972; Zhi-Guang, 1985; Sumner, 2000).

Table 1. Selected chemical and physical properties of soil collected from Pra Yuhn

Depth (cm)	Interior of the salt patch						External to salt patch					
	Sand %	Silt %	Clay %	CEC ($cmol_c.kg^{-1}$)	pH H_2O	C %	Sand %	Silt %	Clay %	CEC ($cmol_c.kg^{-1}$)	pH 1:5	C %
0-9	66	28	6	1.4	7.0	0.4	55	40	4	2.0	4.4	0.4
15-20	60	34	6	1.5	6.7	0.1	63	31	6	2.0	5.7	0.1
25-35	63	31	6	1.5	6.4	0.0	60	34	5	2.4	5.9	0.0
45-55	48	29	14	4.7	7.5	0.0	44	42	15	2.5	5.6	0.0

Analysis for this study is based on two important equations that characterise the transformation of iron and of manganese when undergoing oxidation and reduction.

Equation 1 shows the stochiometry of the reaction between iron hydroxides (i.e. goethite dissolution) and protons that result in an increase in pH (Chamayou, 1989).

1. $Fe\ OOH + 3H + e = Fe^{2+} + 2H_2O$

where the reduction of Fe (III) to Fe (II) consumes H^+ and causes an increase in pH. Similarly, as for the iron, the reduction of manganese consumes protons (Sigg *et al.*, 1992).

2. $MnO_{2(s)} + 4H^+ + 2e = Mn^{2+} + 2H_2O$

Results

All soil samples show an initial acid pH (Figure 2). This is followed by a rapid reduction in the Eh of the soil profile, reaching as low as -0.35V for the non-saline/cultivated soil column (C3 NS C). For this column the kinetics of reactions was extremely rapid. The pH and Eh of the saline samples (S NC and S C) developed less rapidly. The level of salinity can influence microbial activity by slowing down the development of populations thereby influencing the reduction processes within the soil profile. Iron plays the major role in the in these reaction in the surface horizons of the soil profile, where the presence of Fe (II) is found (Figure 3). This is partly caused by a reduction reaction of Fe (III) to Fe (II) (equation 1).

The presence of ferrous iron is demonstrated by the results of chemical analysis in Table 2.

For the deeper soil layers (24 to 41 cm) the four columns have higher potential for Eh than the surface layer.

Manganese reduction tends to occur before iron in the order of reaction. It appears in the transition phase of soil that is changing from the oxidised to the reduced state (Sumner, 2000). However, only high levels of manganese in the soil profile can produce a significant effect. The abundance of manganese in this soil can be confirmed, due to the presence of nodules of manganese when the soil was sieved. It was also found when analysing the soil solution (Table 2). This confirms that in this soil, manganese is mobilised and precipitates as shown by the oxydoreduction of the soil. As for the iron, the reduction of manganese consumes protons (Equation 2). The influence of Mn is demnonstrated in the depth layers of >24 cm, and is presented in Figure 4. A strong correlation between the presence of Mn in solution and pH development is

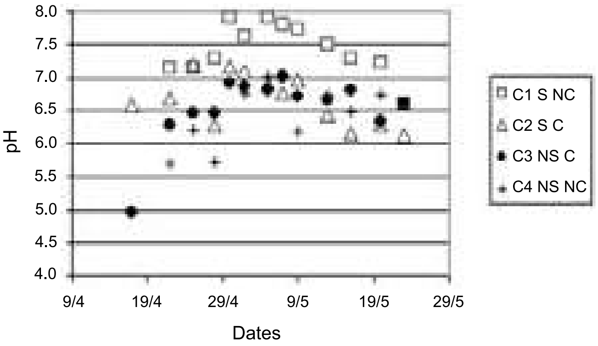

Figure 2. Soil solutions pH development over time at a depth of 7 cm for the four undisturbed columns

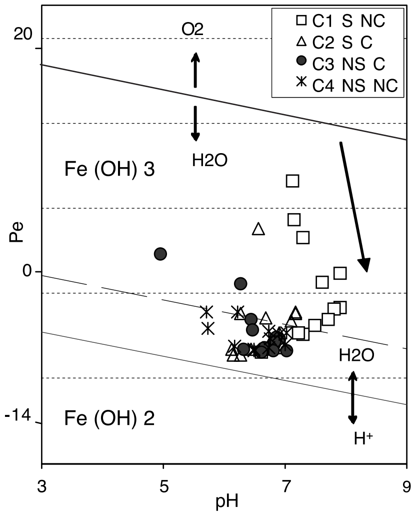

Figure 3. Relationship between pH and pe for soil solutions, of the four columns within the 7 cm layer

Table 2. Soil solutions composition

	Date	Al me/L	Ca me/L	Fe me/L	Mg me/L	Mn me/L	Na me/L	Cl me/L	EC mS/cm	Calculated alkalinity me/L	Analyse alkalinity me/L
C1 S NC -7 cm	22-April	0.04	0.09	0.04	0.86	0.00	2.25	0.98	0.36	1.1	1.9
	25 April	0.11	0.22	0.17	0.18	0.01	6.60	4.13	0.67	2.9	
	29 April	0.56	0.64	0.19	0.50	0.01	13.93	13.05	1.58	1.0	
	06 May	0.97	0.25	0.41	0.11	0.03	8.62	4.06	0.75	5.6	4.9
	13 May	0.67	0.25	0.33	0.07	0.03	8.60	3.54	0.96	6.1	6.4
C2 S C -7 cm	22-April	0.01	0.31	0.22	0.39	0.01	15.23	5.69	1.61	10.2	12.9
	25 April	0.00	0.43	0.17	0.55	0.01	16.64	3.74	2.00	13.3	14.4
	29 April	0.00	0.49	0.11	0.48	0.01	15.99	3.64	1.06	12.7	14.9
	06 May	0.00	1.02	0.32	0.44	0.04	11.98	2.53	1.32	10.5	12.9
	13 May	0.00	1.46	0.67	0.32	0.07	5.84	1.16	0.81	6.4	
C3 NS C -7 cm	22-April	0.00	0.16	0.08	1.20	0.01	4.99	3.46	0.68	0.6	
	25 April	0.00	0.32	0.36	0.84	0.07	5.98	1.26	0.77	4.4	5.4
	29 April	0.00	0.85	1.28	1.28	0.26	8.16	0.93	1.00	9.6	10.4
	06 May	0.00	1.87	0.94	1.13	0.59	9.20	0.71	1.13	12.8	
	13 May	0.00	2.35	0.58	0.76	0.75	9.38	0.63	1.24	12.7	11.9
C4 NS NC -7 cm	15 April	0.01	0.08	0.00	0.33	0.00	2.86	1.71	0.42	-0.1	
	22-April	0.30	0.25	0.09	0.35	0.00	7.76	6.62	0.88	1.6	
	25 April	0.03	0.06	0.15	0.80	0.00	2.98	0.68	0.42	2.1	2.9
	29 April	0.02	0.19	0.54	0.87	0.02	4.54	0.55	0.44	4.6	5.4
	06 May	0.01	0.64	1.95	0.69	0.11	6.60	0.52	0.81	8.9	7.9
	13 May	0.00	1.10	3.17	0.42	0.20	6.91	0.51	0.80	11.3	8.9
	Irrigation water	0.04	0.01	0.01	0.00	0.00	0.17	0.21	0.03	0.0	

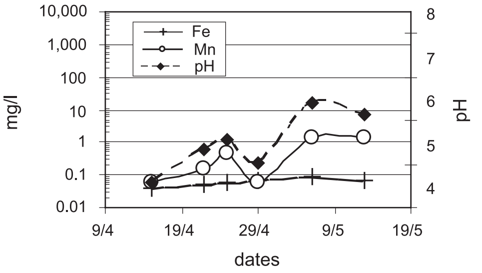

Figure 4. Relationship between the Fe, Mn and pH with time in soil solution from the 24 cm depth interval in treatment C3 C NS

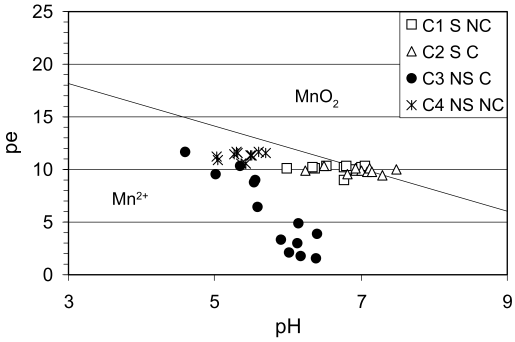

Figure 5. Relationship between pe- pH and the equilibrium line between MnO_2 and Mn^{2+} at 24 cm depth interval for all columns

clearly evident. These observations can be used to construct phase equilibrium diagrams for the different forms of Mn that are present in solution and solid phases, namely, MnO_2 and Mn^{2+} for the profiles at the 24 cm depth interval (Figure 5). Equilibrium between solid and solution phases depends on the log of activity for Mn^{2+} in soil solution and is written in the following way (Sigget al., 1992):

$$4pH + pe + \log(Mn^{2+}) = 43.6$$

Using the Phreeqc simulation model (Parkhurst *et al*., 1999), the activity of Mn^{2+} was calculated for the different soil solutions.

Figure 5, presents the phase diagram for solutions collected from the 24 cm depth interval and demonstrates the influence of reduced conditions on the presence of MnO_2 and Mn^{2+}. This is probably the mechanism controlling the pH and pe of these soils. Alkalinity and the partial pressure of CO_2 interact and control pH. In a closed system, if the pCO_2 increases, the pH diminishes. If however, in this confined medium, the pCO_2 equilibrates with atmosphere after reoxydation, pH will rise (Bourrié, 1978).

In this study, using the Phreeqc model, partial pressure of CO_2 was calculated near the soil surface where alkalinity was measured (Figure 6). The pCO_2 values do not differ with changes in soil salinity. They have values of around 1000 times higher than pCO_2 atmospheric values, which is $10^{-3.5}$atmosphere. Only the C1 S NC column differs, by having a lower pCO_2, closer to the atmosphere's and less alkalinity for this profile. An empirical relation exists which, based on the partial pCO_2 pressure, allows the pH of an iron rich, submersed soil to be calculated;

$$pH = 6.1 - 0.58 \log pCO_2 \text{ (atm)}$$

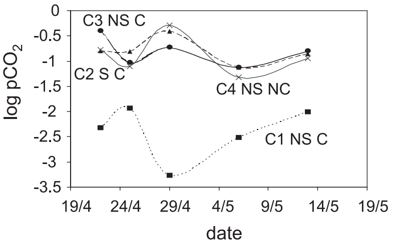

Figure 6. Log of the partial pressure of CO_2 of surface laye for all columns

This relation was derived using measurements made in the field and laboratory. This equation was applied to this study's measurements from soil surface (Figure 7).

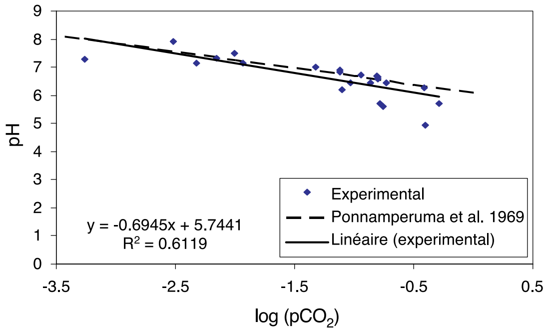

Figure 7. Relationship between predicted pH and the log pCO_2

The relation could be applied to the data of this study. The small differences observed between measured and predicted was probably due to the abundance of manganese in soil and its affect on the control of pH. Subsequent measures made in the field after this first experiment, show similar results on the controlling influence of pH.

Conclusions

In the four soil columns saline, non-saline, with or without plants, pH values of soil solutions converge towards neutrality. The reduction dynamics and pH evolution are related to the availability of carbon provided around the rice roots, to feed the reductive microbial populations. The pH of the soil has an acid tendency before reduction, which changes towards neutrality under the influence of iron and manganese and assures more favourable conditions for the development of rice plants.

The differences of pH values during submerged and dry conditions are important. These cyclic evolutions, which follow the seasons, cannot perhaps bring a return to initial state but may produce a differentiation of pH values. The dissolution of salt through the maintenance of submergence by fresh water on the surface of the rice crop, produces favourable conditions for plant development and rapidly enables reduction to take place. The effect of contact from the rising saline water table under pressure, (Maeght *et al.*, 2005) can also be reduced by dilution in the layer of fresh water.

Traditional rice growing on poor, sandy soil can contribute to temporary pH improvements in soil by rapidly bringing about reduction in the soil surface. It can also assist, during submergence, in controlling the expansion of salinity, by diluting the influx of the rising saline water table in paddy fields. Extensive soil degradation of these impoverished soils can therefore be limited by continuing these traditional rice-cropping methods and in the absence of alternative solutions, should be strongly encouraged.

References

Arunin S., 1984 – Characteristics and management of salt-affected soils in the Northeast of Thailand. Ecology and management of problem soils in asia. 336.

Berthelin J., 1998 – Les microorganismes dans la transformation des minéraux: incidence sur la formation, le fonctionnement et l'évolution des sols. Sol interface fragile. (INRA), 83-91.

Bolomey S., 2002 – The seasonal dynamics of salinity in a small rainfed rice-cropped watershed in Northeast Thailand (Isan).engineer report, 61, multigr.

Bourrié G., 1978, Relations entre le pH, l'alcalinité, le pouvoir tampon et les équilibres de CO_2 dans les eaux naturelles.

Brinkman R., Jongmans A.G. and Miedema R., 1977 – Problem hydromorphic soils in Northeast Thailand.

Chamayou H., 1989 – Les basses physiques, chimiques et minéralogiques de la sciences du sol. 593.

Cheverry C. and Bourrié G., 1998 – La salinisation des sols. Sol interface fragile. 109-126.

Fukui H., 1991 – The rice/population balance in a Northeast Thai village. Nº4, 28, 68-84.

Formoso B., 1997 – Ban Amphawan et Ban Han, Le devenir de deux villages rizicoles du Nord-Est thaïlandais. (eds CNRS éditions), I, 754.

Grunberger O., 2002 – Visite du chantier de UR 067 Thaïlande. Supports d’illustrations, 24, multigr.

Kohyama K. and Subhasaram, 1993 – Salt-afected doils in Northeast Thailand their salinisation and amelioration. Agricultural Development Research Center. Japan International Cooperation Agency, 60 p. multigr.

Kono Y., 1991 – Rainfed rice culture and population growth. nº4, Southeast Asian Studies, 28, 56-67.

Maeght J.L. et al, 2005 – Salinity control by farmers practices in sandy soil. Tropical sandy soils Proceedings, Khon Kaen, Thailand. November 2005, on press.

Mitsuchi M., Wichaidit P. and Jeungnijnirund S., 1986 – Outline of soils of the Northeast Plateau, Thailand. Their characteristics and constraints, ADR, Khon-Kean, Thailand, pp. 64.

Parkhurst D.L., Appelo C.A.J., 1999. User’s guide to Phreeqc (version 2) – a computer program for speciation, batch-reaction, one-dimensional transport, and inverse geochemical calculations. Water-Resources investigations report 99-4256 USGS, Denver, Colorado.

Ponnamperuma F.N., 1972 – The chemistry of submerged soils. Advances in Agronomy, 24, 29-96.

Ragland J., Boonpuckake L., 1988. Fertilizer responses in N.E. Thailand: 1 literature review and rationale. Thai journal of soils fertilisation, Vol. 9, 65-79.

Sigg L., Stumm W. and Behra, 1992 – Chimie des milieux aquatiques. (chimie des eaux naturelles et des interfaces dans l’environnement. (eds 391).

Sumner M.E., 2000 – Handboock of soil science.

Williamson D.R., Peck A.J., J.V.T. and S.A., 1989 – Grounwater hydrology and salinisation in a valley in Northeast Thailand. IAHS.

Yuvaniyama A. 2001 – Managing problem soils in Northeast Thailand. In natural resource management issues in the Korat basin of Northeast Thailand: an overview, edited by. Kam S.P, Hoanh C.T., Trébuil G., Hardy B., IRRI, Limited Proceedings nº7, 147-156.

Zhi-Guang L., 1985 – Oxidation-reduction potential. Physical chemistry of paddy soils. 1-196.

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