PD-AAW-681

AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D.C. 20523

DATE: 8/31/87

MEMORANDUM

TO: AID/PPC/CDIE/DI, room 209 SA-18

FROM: AID/SCI, Victoria Ose

SUBJECT: Transmittal of AID/SCI Progress Report(s)

Attached for permanent retention/proper disposition is the following:

AID/SCI Progress Report No. 2.A-22
Final

Attachment

3 cy

PD-AAW-681
2A-22

Final Report

for

USAID Project DAN-5542-G-SS-2098-00

REDOX CHEMISTRY OF THE ACID SULFATE SOILS OF THAILAND

from

Dr. W. H. Patrick, Jr.
Laboratory for Wetland Soils and Sediments
Center for Wetland Resources
Louisiana State University
Baton Rouge, Louisiana 70803

Participants

1. Laboratory for Wetland Soils and Sediments

   Dr. W. H. Patrick, Jr. - Principal Investigator

   Dr. R. P. Gambrell - Co-principal Investigator

   Dr. C. J. Smith - Co-principal Investigator

   P. A. Moore, Jr.

2. Department of Agriculture of Thailand

   Deputy Director General Ampol Senanarong 2528

   Dr. Chob Kanureugsa

   Sunchai Satawathanont

   Jirapong Prasittikhet

3. Department of Land Development of Thailand

   Director General Anunt Komes 3488

   Charoen Charoenchamratcheep

   Arunee Yuvaniyama

   Jumpol Yuvaniyama

4. Soil Science Department of Kasetsart University

   Dr. Piya Duangpatra, Department Head

   Dr. Tassanee Attanandana

   Jiraval Pechayapisit 5236

During the last three years, research on USAID project Dan-5542-G-SS-2098-00, "Redox Chemistry of the Acid Sulfate Soils of Thailand" has been conducted both in the U.S. and in Thailand with the specific purpose of elucidating the physico-chemical processes which control the release of plant toxins and nutrients in these soils. This project was based on the premise that soil redox, pH and salinity conditions strongly effect the activities of both toxic and beneficial soil contituents. By understanding the individual or collective effects of these parameters on soil chemical processes, it will be possible to develop management strategies allowing increased productivity of these soils.

One of the most important aspects of this study has been the exchange of ideas and information between the American and Thai scientists involved. The agencies participating in this project were; 1) the Laboratory for Wetland Soils and Sediments at Louisiana State University, 2) the Department of Agriculture of Thailand, 3) the Department of Land Development of Thailand, and 4) the Soil Science Department of Kasetsart University located in Bangkok, Thailand. During the course of this study five Thai scientists received advanced training in recently developed experimental methods in wetland soil chemistry at the Laboratory for Wetland Soils and Sediments located at LSU. Two of the visiting scientists from Thailand enrolled in the Louisiana State University graduate school and are currently completing the requirements for receiving their Ph.D. degrees in Agronomy. Concurrently, an American graduate student conducted research for one year in Thailand and a fully equipped laboratory was established in Thailand with the sole purpose of investigating the particular problems associated with acid sulfate soils.

Dr. Tasnee Attanandana of the Soil Science Department of Kasetsart University was the first Thai scientist involved in this project to train at the Lab for Wetland Soils and Sediments at Louisiana State University. Following her return to Thailand she set up a soil chemistry lab equipped with a series of the microcosms as described by Patrick (1966) which were provided by this grant. Jiraval Pechayapisit, a Thai graduate student in the Soil Science Department at Kasetsart University working in conjunction with Dr. Attanandana, utilized these microcosms to study the amelioration of acid sulfate soils for rice production for her masters thesis. Some of the results of their research have subsequently been published (Attanandana et al., 1985).

The two Thai graduate students working towards degrees at Louisiana State University are Sunchai Satawathananot and Jirapong Prasittikhet, both of which are affiliated with the Department of Agriculture of Thailand and working in conjuction with Dr. Chob Kanureugsa and Dr. Ampol Senanarong. Along with completing the coursework necessary for their degrees, these students have conducted several laboratory experiments on the redox-pH chemistry of acid sulfate soils utilizing the microcosm systems as cited earlier.

The research conducted at Louisiana State University by Jirapong Prasittiikhet has focused on the effects of redox potential and pH in acid sulfate soils on nutrient uptake and growth of two rice varieties which have been identified as sensitive and tolerant to acid sulfate soil conditions. Mr. Prasittikhet utilized the microcosm system adapted by Reddy, Jugsujinda, and Patrick (1976) to conduct three growth chamber experiments on five common rice topsoils of the Central Plain of Thailand. Two of these soils, Bangkok and Ratchaburi series are non-acid marine soils, while the remaining three, Mahapot, Rangsit, and

Rangsit very acid phase series are acid sulfate soils with acidity as a limiting factor to rice production.

In the first experiment conducted by Mr. Prasittikhet the soils were preincubated under controlled acidity conditions at pH's of 3.5, 4.0, 4.5, 5.0 and 5.5. These pH's are believed to be within the critical range in which excess amounts of toxins accumulate in the soil solution at concentrations which are deleterious to plant growth. Redox potentials were not controlled in this study, but were monitored for the duration of the experiment. Labelled nitrogen compounds were used in order to study the fate of applied fertilizer nitrogen. Other chemical constituents investigated in this study were aluminum, calcium, iron, magnesium, mangenese, molybdenum, potassium, sodium, sulfate and zinc. At the end of the experiment, samples of the soil suspensions were analyzed for water soluble, exchangeable and reducible metals, and N-15 content. Dry matter and nutrient uptake by the rice plants was also determined at harvest. Metal analysis of soil and plant fractions was conducted utilizing an inductively coupled argon plasma emission spectrometer (ICAP). Anion analysis of plant extracts were obtained by ion chromatography. Total nitrogen content of soils and plants were determined using the micro-kjeldahl digestion prodecure, with N-15 analysis via mass spectrometer.

The second experiment Mr. Prasittikhet conducted utilized the same controlled microcosm systems, rice varities and soils described previously, with controlled redox potentials. Redox conditions investigated corresponded to oxidized (Eh = +500 mV), moderately reduced (Eh = +250 mV), reduced (Eh = +50 mV) and highly reduced (Eh = -100 mV) conditions. The techniques of soil and plant analysis utilized were as in experiment 1.

In the third experiment, Mr. Prasittikhet studied nine combinations of controlled redox and pH conditions corresponding to redox potentials of +500 mV, +250 mV, and +50 mV with pH's of 3.5, 4.5 and 5.5. The techniques of soil and plant analysis were as described above.

The results of Mr. Prasittihket's research indicated that the growth of the rice plants was affected by both redox potential and pH, with dry matter production increasing with increasing pH and highest under moderately reduced (Eh = +250 mV) conditions. Redox and pH were also found to affect iron availability in these soils, whereas manganese availability was governed solely by redox potential and aluminum solely by pH. Plant analysis indicated that the tolerant variety generally had lower concentrations of iron and aluminum and higher concentrations of phosphorus than the sensitive variety. A copy of Mr. Prasittikhet's dissertation containing the final results of these experiments will be sent to USAID on completion.

The research conducted by Sunchai Satawathananot at Louisiana State University has dealt with the redox, pH and ion chemistry of acid sulfate soils. During the course of this project, he has conducted seven experiments on acid sulfate soil chemistry. The soils used in these experiments were: 1) Rangsit very acid phase (Sulfic Tropaquept), 2) Rangsit (Sulfic Tropaquept), 3) Mahapot (Sulfic Tropaquept), 4) Bang Pakong (Typic Sulfaquept) and 5) Bangkok (Typic Tropaquept) series.

In the first experiment Mr. Satawathananot studied the kinetics of Eh, pH, and ion availability in the four soils described above amended with three levels of rice straw. The results of this study indicated that the absence of oxygen in these soils following flooding lead to an increase in pH and water soluble iron and manganese, whereas Eh and aluminum concentrations were found to decrease under anaerobic conditions. Increasing levels of organic matter were found to enhance

the effects of reduction. In extremely acid soils, reduction was found to be retarded.

In the second experiment conducted by Mr. Satawathananot the four soils were preincubated under very reduced conditions and Eh was augmented in a step-wise fashion at 100 mV intervals until the soils were completely oxidized. Samples were taken for water soluble and exhangeable metals in the soil slurry at each Eh interval after steady state conditions had been achieved. The process was then repeated from oxidized to reduced conditions. The results of this experiment showed that water soluble iron and manganese increased with decreases in redox potential. The Bang Pakong soil, a potential acid sulfate soil, had much higher levels of available iron and manganese than the other soils studied. The relationships found between available iron and manganese as a function of Eh were different when soils were taken from reduced to oxidized conditions as compared to that found when oxidized soils were reduced, forming a hystersis pattern.

In the third experiment conducted by Mr. Satawathananot both Eh and pH were controlled. The redox levels investigated in this experiment corresponded to 600, 400, 250, 100 and -100 mV. The pH levels studied were 3.5, 4.0, 4.5, 5.0, 5.5, 6.0. 6.5 and 7.0. Samples were taken for water soluble and exchangeable metals after each Eh-pH combination had been allowed to reach steady state for approximately two weeks. Ferrous and ferric iron was analyzed by colormetric techniques.

In the fourth experiment, the soils were incubated in cores under submerged conditions, with and without additional organic matter in order to study the kinetics of profile development in acid sulfate soils with respect to Eh-pH and metal chemistry. After the soils bad been allowed to incubate for 0.1, 1, 2, 4, 8 and 16 months, the Eh-pH

profiles were determined and the soils were sectioned (5 to 10 mm thickness) for extraction of metals.

In the fifth experiment, the profiles of Eh-pH and ionic constituents were determined as above for the Rangsit very acid phase soil which had been amended with lime. Lime applications were chosen for this study that corresponded to aerobic soil pH values of 4.0, 4.5, 5.0, 5.5 and 6.0. Redox potential, pH and ion profiles were determined at 0.5, 1, 2, 4, and 8 months. Phosphorus fractionation of the cores was determined according to the method of Chang and Jackson (1957).

In the sixth experiment the diffusion of labelled iron and manganese compounds was studied utilizing the Rangsit soil series. In this study the diffusion cells consisted of a 3 cm layer of soil amended with $^{59}FeCl_2$ and $^{54}MnCl_2$ corresponding to activities of ^{59}Fe and ^{54}Mn of .05 and 0.02uCi/g untagged soil, respectively, overlain by 5 cm of non-tagged soil. After the soils were flooded for 0.1, 0.5, 1, 2, 4 and 6 months they were sectioned horizontally into 5 mm layers. Activities of ^{59}Fe and ^{54}Mn from the soil solution and exchangeable fraction of each layer were determined utilizing an auto-gamma counter.

In the final experiment conducted by Mr. Satawathananot, the mineralization of ^{14}C-tagged organic matter was investigated in suspensions of the Rangsit soil under varying redox conditions. The Eh levels investigated in this study were 0, 200, 400 and 600 mV. After each redox level had been maintained for approximately two weeks, ^{14}C-tagged ground maize was introduced. Decomposition of the plant material was evaluated by trapping the evolved $^{14}CO_2$ in NaOH and subsequently determining ^{14}C activity by liquid scintillation. Preliminary results of this study indicate that mineralization was highest under intermediately reduced conditions. A copy of Mr.

Satawathananot's dissertation containing the final results of these experiments will be sent to USAID upon completeion.

The other visiting scientists from Thailand who received advanced training in soil chemistry techniques at the Lab for Wetland Soils and Sediments were Charoen Charoenchamratcheep, Arunee Yuvaniyama, and Jumpol Yuvaniyama; all of whom work for the Thai Department of Land Development in conjunction with Dr. Anunt Komes.

The American graduate student that conducted research in Thailand was Philip Moore. He studied trace metal behavior in acid sulfate soils, while working with Dr. Tassanee Attanandana at Kasetsart University and Jumpol Yuvaniyama at the Department of Land Development. Mr. Moore conducted three experiments of acid sulfate soils from Thailand.

The first experiment was a field study conducted on acid sulfate soils in the Central Plains region of Thailand. In this study, 134 sites comprising a wide range of acidity conditions were sampled from farmers' fields and research stations from May until October in 1984. Trace metal availability in these soils was assessed by analytical extraction techniques and uptake by rice. Approximately 80 different rice varieties were sampled in this study. Each site was sampled when the rice crop was at the panicle initiation stage of growth (about one to two months after flooding). Soil pH, Eh, and salinity were measured by electrochemical methods. Trace metal analysis was conducted utilizing an inductively coupled argon plasma emission spectrometer. Anion analysis was accomplished by ion chromatography.

The second experiment was a growth chamber study utilizing 50 soils collected from the previous study and the R.D. 23 rice variety. In this study, changes in redox potential and pH were monitored on a weekly basis throughout the growing season. Trace metal availability was

determined by analytical extraction techniques at the time of transplanting and at harvest. Dry matter production and metal uptake by the plants was also evaluated.

The third experiment was a micronutrient fertility trial of acid sulfate soils. In this study, dry matter production and rice yields were determined under greenhouse conditions from five acid sulfate soils (Bangkok, Sena, Rangsit, Rangsit very acid phase, and Rangsit very acid phase plus lime) amended with micronutrients. The micronutrients investigated in this experiment were boron, copper, iron, manganese, molybdinum, silica, and zinc.

The results from Mr. Moore's research in the field and growth chamber experiments indicated that goethite (FeOOH) was the solid phase of iron controlling the oxidation-reduction process in these soils. In order to test this hypothesis, theoretical redox potentials were calculated from pH and iron activity data utilizing the Nernst equation for the reduction of goethite. The predicted Eh values found from this technique were highly correlated ($R=.91$, $p<.001$) with observed values, indicating that goethite is the dominate electron acceptor in flooded acid sulfate soils.

Iron was also found to play an important role in governing the availability of trace metals in these soils. Water soluble iron was found to be highly correlated with water soluble As, B, Cd, Cr, Mn, Mo, Ni, and Pb. This relationship is thought to be due to the release of occluded and coprecipitated metals from oxidizied iron compounds such as goethite following flooding.

Although extremely low pH's and elevated levels of water soluble and exchangeable iron and manganese were found in many soils, mortality of rice was found only in soils with high levels of aluminum. Critical toxicity values for water soluble aluminum in the field and growth

chamber experiments were 63 and 130 ppm, respectively. The large difference in the critical values found under field and growth chamber conditions was probably due to inadequate phoshorus levels in the field. Water soluble and exchangeable aluminum were inversely related to pH, with large quantities measured below pH 4.4. Dry matter production and soil pH were found to be positively correlated in the growth chamber study.

In the micronutrient fertility trial, a response to Si was observed in the Rangsit very acid phase that was limed. Since this soil had the highest levels of water soluble iron, it was hypothesized that the addition of Si improved the oxidizing power of the roots, causing decreased iron uptake. This hypothesis will be tested when the trace metal analysis of the leaves has been completed. A copy of Mr. Moore's dissertation containing the final results of these experiments will be sent to USAID upon completion.

Dr. Nico van Breemen of the Soil Science and Geology Department of Agricultural University in Wageningen served as a consultant in this project. Dr. van Breemen has conducted extensive field and laboratory investigations on acid sulfate soils and proved to be a very valuble collaborator in this study. During the course of this project he traveled both to Thailand and the U.S. in order to provide recommendations on research techniques.

The results from the research funded by this grant will be submitted to journals for publication. We expect to publish approximately ten articles from this research.

Literature Cited

Attanandana, Tasnee, Jiraval Pechayapisit, and W. H. Patrick, Jr. 1985. Factors affecting amelioration of the oxidized potential acid sulfate soil for rice cultivation. Proc. of Intl. Sem. Environmental Factors in Agricultural Production, Thailand, pp. 413-421.

Chang, S. C., and M. L. Jackson. 1957. Fractionation of soil phosphorus. Soil Sci. 84:133-144.

Patrick, W. H., Jr. 1966. Apparatus for controlling the oxidation-reduction potential of waterlogged soils. Nature 212:1278-1279.

Reddy, C. N., Aroon Jugsujinda, and W. H. Patrick, Jr. 1976. System for growing plants under controlled redox potential-pH conditions. Agronomy Journal 68:987-989.

A PROGRESS REPORT
TO
WILLIAM H. PATRICK, JR.

The Principal Investigator of the Project:
"Redox-pH Chemistry of Acid Sulfate Soils"

Reported by
Sunchai Satawathananont

As some parts of research work on the study of Redox-pH-Ion chemistry of acid sulfate soils of Thailand have been assigned to my responsiblilty since August 1982, I have already finished all of my experimental work. The works that are currently going on are data processing and the writing of dissertation and papers for publication. My subproject under the main project is named "Redox, pH, and Ion Chemistry of Acid Sulfate Rice Soils in Thailand" which this will become the title of my dissertation as well. The subproject is composed of six main experiments and one supplementary study. The brief description of each experiment will be summarized in the next sections.

In the experiments, four acid sulfate soils plus a check soil brought from Thailand were used in this study. Each soil represents different class. The breif descriptions of the soils are as follows:

Series	Class	pH	Classification
1. Rangsit very acid (Rs-a)	Extremely acid soil	3.5-3.9	Sulfic Tropaquept
2. Rangsit (Rs)	Severely acid soil	4.0-4.4	Sulfic Tropaquept
3. Mahaphat (Ma)	Moderately acid soil	4.3-4.6	Sulfic Tropaquept
4. Bang Pakong (Bg)	Potentially acid soil	5.5-6.5 (oxidized) 1.8-2.5 (reduced)	Typic Sulfaquent
5. Bangkok (Bk)	Non-acid-sulfate marine soil	5.0-6.0	Typic Tropaquept

EXPERIMENT I. Kinetics of Redox Potential, pH, and Aqueous Ions in O_2-free, Stirred Suspension of Acid Sulfate Soils.

Four acid sulfate soils as referred to earlier were employed in this experiment. Two hundred grams of the soils, with 1:9 weight-by-weight soil-water ratio, was stirred in a closed 3-necked flask. Each soil was set by two replicates. The changes of Eh, pH and dissolved ions with time were investigated under three different treatments:

(1) without additive organic matter.
(2) with 0.5% additive rice straw.
(3) with a different percent of additive rice straw.

Eh and Ph were measured with time for extracting the dissolved ions. The ions were then determined by the ICAP.

The results can be summarized that O_2-free submerged conditions, pH

and water soluble Fe and Mn increase whereas Eh and Al decrease with time. The more organic matter added, the more the Eh decreases and the pH, Fe, and Mn increases. The extremely and the pre-oxidized potentially acid sulfate soils tend to retard reduction more than the other two soils.

EXPERIMENT II. Ion Chemistry in the Suspension of Acid Sulfate Soils Under Controlled Redox Potential.

This experiment was conducted with the four acid sulfate soils and one non-acid-sulfate marine soil. The soils were submerged and pre-incubated, with 0.5% rice straw, for two months. The Eh was then adjusted from the lowest reduction to the highest oxidation with a 100 mV interval. At the steady state under a given Eh, the samples were taken and extracted for water soluble and ammonium-acetate extractable ions in N_2 atmosphere. The same process but backwards form the most oxidized to the most reduced were also established.

The results show that an increase in Eh brings about a decrease in water soluble and extractable Fe and Mn of the five soils and vice versa. At the same Eh level the potential acid sulfate soils has much more water soluble and extractable Fe and Mn than the other four soils. For the red→ox and ox→red curves of either Fe or Mn both water soluble and extractable versus Eh are not likely to be superimposed; they tend to be hysterisis pattern.

EXERIMENT III. Ion Chemistry in the Suspension of Acid Sulfate Soils under Controlled Eh and pH.

The study was done with the four acid sulfate soils. The Factorial Experiment in Split Plot was designed. The Eh of the soils suspensions was assigned into the main plot and was controlled in either of the constant values of 600, 400, 250, 100, and -100 mV. pH was assigned into the subplot and was varied, in a specific Eh, from pH 3.5 to 7.0 with 0.5 unit intervals. At the steady state of each Eh-pH combination (about 2 weeks) the sample was taken up to extract for water soluble and extractable ions and the extract was analyzed by the ICAP. For iron, the reducing technique was employed to determine Fe^{2+} and Fe^{3+} by using spectrophotometer.

For this experiment the data have been processed so far, however, the illustration in the graphs can be indicated here:

(1) The 3-dimension bar chart of Eh, pH, and concentrations of Fe, Mn, Al, Si, and P.
(2) The 3-dimension bar chart of Eh, pH, and the percentages of Fe^{2+} and Fe^{3+}.
(3) The correlation of either Eh or pH to Fe, Mn, Al, Si.
(4) The pe and pH versus log activity of Fe or Mn (+2pH).

EXPERIMENT IV. Profiles of Eh, pH, and Ionic Constituents in Acid Sulfate Soils Incubated in Cores under Submerged Condition

The four acid sulfate soils and the non-acid-sulfate marine soil were incubated in cores under submerged condition with and without

additive organic matter. At the time periods of 3 days and 1, 2, 4, 8, and 16, months, the Eh and the pH profiles were run, and the soil was sectioned by layers of 5 to 10 mm thick. Under the N_2 atmosphere, the soils were extracted by water and later followed by NH_4OAc. Various ionic constituents in the extracts were run by the ICAP. In this experiment another two counterpart sets were used for studying kinetics of Eh and pH profiles.

The results of this experiment will be included in the next report.

EXPERIMENT V. Profiles of Eh, pH, and Ionic Constituents of Limed Extremely Acid Sulfate Soil Incubated in Cores under Submerged Condition.

Rangsit very acid soil, with known aerobic lime requirement rates at pH 4.0, 4.5, 5.0, 5.5, and 6.0 were incubated in cores under submerged condition. At the periods of ½, 1, 2, 4, and 8 months, Eh, pH and ion profiles were run like the processes in Experiment IV. In addition, kinetic of Eh at the depth of 0.5 cm, 3 cm, and 5 cm from zero time to 2 months were also established.

The supplementary in this experiment is the study of phosphorus fractionation (after Chang and Jackson, 1957).

The results of this experiment will be presented in the next report.

EXPERIMENT VI. Diffusion of ^{59}Fe and ^{54}Mn in a Severely Acid Sulfate Soil Incubated in Cores under Submerged Condition.

Rangsit soil was mixed with $^{59}FeCl_3$ and $^{54}MnCl_2$ to yield the activities of .05 μci/g soil for ^{59}Fe and .02 μci/g soil of ^{54}Mn. The soil with tagged Fe and Mn being put in the bottom of the core was 3 cm thick. The non-taggerd counterpart soil being put on the top of the former was 5 cm thick. The whole soil then was submerged. At the periods of three days and ½, 1, 2, 4, 6 months the soil was sectioned horizontally into 16 layers with the thickness of 5mm each. The soil was then extracted by water and followed by 2M NH_4OAc at pH 4. The extracts were run for the activities of ^{59}Fe and ^{54}Mn by the Auto-γ counter. When the activites were as low as background levels, the extracts were then run for the soil Fe and Mn by the ICAP. The results of this experiment will be included in the next report.

SUPPLEMENTARY EXPERIMENT Mineralization of ^{14}C-tagged Organic Matter under Different Eh in the Suspension of a Severely Acid Sulfate Soil.

In the suspensions of Rangsit Soil, Eh were lowered to the most reduced for 2 months; then the Eh in each flask was adjusted to 600, 400, 200, and 0 mV and maintained at the specific level throughout the experiment. After the Eh was stable for two weeks, ^{14}C-tagged ground maize of 150 mg was put in each flask. NaOH was used to catch $^{14}CO_2$ and the activity was defected by the Liquid Scintillation Counter.

The results show that at the extreme low and high Eh, the rates of mineralization were lower as compared to at the intermediate Eh.

Annual Progress Report

on

Redox Chemistry of Acid Sulfate Soils Project(Thai Soils)

by

Jirapong Prasittikhet

This part of the Redox Chemistry of Acid Sulfate Soils Project was initiated since 1983 utilizing the microcosm system in the Laboratory of Wetland Soils and Sediments to investigate the relationship of both redox potential(Eh) or acidity(pH) on nutrient uptake, added labelled nitrogen uptake, and growth performance of two rice varieties that was identified as sensitive and non-sensitive to acid sulfate soils conditions in the farmer's fields of Thailand.

The main approach of this research is to dertermine both eaech individual effect of the two major physico-chemical parameters, pH and Eh, or the combined effect of these two parameters in governing the transformation of soil constituents that affects growth production and uptake of minerals of the representative rice varities. At least the major soil chemical constituents to be investigated will be iron, manganese, aluminum, calcium, magnesium, potassium, sodium, zinc, molybdenum, and sulfate. Therefore three major categorized experimental system were set up under the laboratory conditions seeking to investigate the interrelation among plant and soil under selected range of controlled conditions of redox potential and acidity considered to be the most suitable range existed in the acid sulfate soils under natural conditions.

Five common rice topsoils of the Central Plain of Thailand were collected for this study. Two of these soils, Bangkok and Ratchaburi series, are non acid sulfate soils having no significant limiting factor for rice production; the other three soils, Mahaphot, Rangsit, and Rangsit very acid series, are acid sulfate soils having an acidity conditions as a limiting factor for rice production.

The first experiment was the two rice varieties planted to five sampled soils with preincubation under controlled acidity at pH 3.5, 4.0, 4.5, 5.0, and 5.5 respectively. These acidity ranges are believed to be the critical potential range in releasing a large or even an excess amount of any harmful element enough to accumulate in soil solution at the concentration far beyond the optimum level and reach to the point that can cause toxic effects on growth and nutrient uptake of plant. Redox potential was not controlled but was monitored throughout the whole experimental period. At the end of the experiment the shoots and roots of rice plant werw harvested, washed, and dried separately in a forced draft oven. Growth of rice was estimated as gaining in dry weight at the end of the experiment(Final dry weight-Initial dry weight). First portion of divided plant materials were subjected to analytical extraction technique by distilled nitric acid digestion and to elemental analysis of plant extracts by an inductively coupled argon plasma emission spectrometor. Anion analysis of plant extracts were obtained by an ion chromatography. The second portion of plant materials were analysed for total nitrogen content using the microKjeldahl digestion procedure of which the plant extracts were processed for further analysis of nitrogen isotope ratio by the mass spectrometer. Samples of soil suspension were determined for

nutrient fractions such as water soluble, exchangeable, and reducible and also brought to be analysed for total nitrogen and nitrogen isotope ratio utlizing the same procedure as that processed on the plant materials.

The second experiment was accomplished by utilizing the same controlled microcosm system when the two rice varieties were grown onto five sampled soil suspensions with preincubation of controlled redox potential at oxidized conditions(Eh= +500mV), moderately reduced conditions(Eh= +250mV), reduced conditions(Eh= +50mV), and highly reduced conditions(Eh= -100mV) respectively. Analytical technique of plant and soil samples was the same as that described in the first experiment.

The third experiment dealt with study of rice performance upon soil suspension incubated at interested combinations of controlled redox potential and acidity conditions. Sensitive and non-sensitive to acid sulfate soils rice varieties were planted to five sampled soils under nine combinations of controlled redox potential and acidity conditions obtaining from cross-combinations of three redox potentials, +500mV, +250mV, and +50mV with three acidity conditions, pH 3.5, pH 4.5, and pH 5.5 respectively. Analytical technique of plant and soil materials was completed by the same procedure as that described in the first experiment.

Therefore, the research for this kind of investigation has been successfully conducted so far for 19 sets of selected microcosm system. Each set required about 6-7 weeks for soil preincubation, experimental period of rice growing, and processing of soil and plant analysis. To date, even though all plant and soil materials has not been completely manipulated there are certain portions of

experimental data that has already been submitted for statistical analysis and for interpretation of the results obtained through the SAS computer program of Louisiana State University.

In general, results indicated that growth production of the rice plant was affected by both redox potential(Eh) and acidity(pH). Rice weights tended to increase with an increase in pH conditions as averaged over all eH conditions. Redox potential at moderately reduced conditions (Eh= +250mV) tended to promote somewhat better growth production than that resulted in oxidized conditions or other reduced conditions as averaged over all acidity conditions studied here. However there was some evidence that at certain Eh conditions growth of the rice plant at pH 5.5 was lower than that at pH 4.5 in some acid sulfate soil series. This might apparently due to the relationship which existed between redox potential and acidity. These results will be truely confirmed if the final of statistical analysis of the experimental data is obtained. Among the notorious metals such as iron, manganese, and aluminum etc., it has been observed that iron transformation was governed by both redox potential and acidity while manganese transformation was primarily affected by redox potential and aluminum transformation was solely controlled by acidity. Aluminum was the most largely responsible for irregular or poor growth production of the rice plant at low pH conditions.

Plant performance as sensitive and non-sensitive to acid sulfate soils was somewhat illustrated by a difference of their ability of mineral uptake. It seemed that non-sensitive variety had more phosphorus concentration but less iron and/or aluminum than that concentration appeared in the sensitive plant. It should be

clearly stated that this result was not consistently observed in plant sample grown on all of five sampled soils introduced into investigation at this time.

In the near future, plan are made to continue analysing elemental composition and nitrogen isotope ratio of plant and soil extracts so that all of the results will be statistically subjected to multiple regression or stepwise regression-correlation to provide more meaningful interpretation on the interrelation among soils and plants under both controlled redox potential or acidity conditions of the acid sulfate soils. Finally, effort would be devoted in implementing the publication of research results before the end of this year.

Annual Progress Report
on
Redox Chemistry of Acid Sulfate Soils of Thailand
by
P. A. Moore, Jr.

The objectives of this research were; 1) to characterize the relationships between trace metal availability in acid sulfate soils with physico-chemical parameters such as oxidation-reduction processes, pH and salinity, 2) to determine the extent of trace metal uptake by rice (Oryza sativa) and associated growth patterns found with these soils, and 3) to determine which agricultural practices minimize the detrimental impact acid sulfate soils have on rice production. In order to fulfill these objectives, three experiments were conducted on acid sulfate soils from Thailand during the last two years.

The first experiment was a field study conducted on acid sulfate soils in the Central Plains Region of Thailand. In this study, 134 sites comprising a wide range of acidity conditions were sampled from farmers' fields and research stations from May until October in 1984. Trace metal availability in these soils was assessed by analytical extraction techniques and uptake by rice. Approximately 80 different rice varieties were sampled in this study. Each site was sampled when the rice crop was at the panicle initiation stage of growth (about one to two months after flooding). Soil pH, Eh, and salinity were measured by electrochemical methods. Trace metal analysis was conducted utilizing an inductively coupled argon plasma emission

spectrometer. Anion analysis was accomplished by ion chromatography.

The second experiment was a growth chamber study utilizing 50 soils collected from the previous study and the R.D. 23 rice variety. In this study, changes in redox potential and pH were monitored on a weekly basis throughout the growing season. Trace metal availability was determined by analytical extraction techniques at the time of transplanting and at harvest. Dry matter production and metal uptake by the plants was also evaluated.

The third experiment was a micronutrient fertility trial of acid sulfate soils. In this study, dry matter production and rice yields were determined under greenhouse conditions from five acid sulfate soils (Bangkok, Sena, Rangsit, Rangsit very acid phase and Rangsit very acid phase plus lime) amended with micronutrients. Micronutrients investigated in this study were boron, copper, iron, manganese, molybdinum, silica, and zinc.

Redox potential and pH measurements taken in the field and growth chamber experiments indicated that goethite (FeOOH) was the solid phase of iron controlling the oxidation-reduction process in these soils. In order to test this hypothesis, theoretical redox potentials were calculated from pH and iron activity data utilizing the Nernst equation for the reduction of goethite. The predicted Eh values found from this technique were highly correlated ($R=.91$, $p<.001$) with observed values, indicating that goethite is the dominate electron acceptor in flooded acid sulfate soils.

Iron was also found to play an important role in governing the availability of trace metals in these soils. Water soluble iron was found to be highly correlated with water soluble As, B, Cd, Cr, Mn, Mo, Ni and Pb. This relationship is thought to be due to the release of occluded and coprecipitated metals from oxidizied iron compounds such as goethite following flooding.

Although extremely low pH's and elevated levels of water soluble and exchangeable iron and manganese were found in many soils, mortality of rice was found only in soils with high levels of aluminum. Critical toxicity values for water soluble aluminum in the field and growth chamber experiments were 63 and 130 ppm, respectively. The large difference in the critical values found under field and growth chamber conditions was probably due to inadequate phosphorus levels in the field. Water soluble and exchangeable aluminum were inversely related to pH, with large quantities measured below pH 4.4. Dry matter production and soil pH were found to be negatively correlated ($R=-.58$, $p<.001$) in the growth chamber study.

In the micronutrient fertility trial, a response to Si was observed in the Rangsit very acid phase soil that was limed. Since this soil had the highest levels of water soluble iron, it was hypothesized the addition of Si improved the oxidizing power of the roots, causing decreased iron uptake. This hypothesis will be tested when the trace metal analysis of the leaves has been completed.