PHOSPHORUS MANAGEMENT FOR RICE PRODUCTION ON ACID SULFATE SOILS IN ASIA : IMPHOS NETWORK IN FIVE COUNTRIES

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ABSTRACT

The acid sulphate soils represent a considerable land area in Asia (18-20 million hectares), mainly in Cambodia, China, Indonesia, Malaysia, Thailand, and Vietnam.

To design a strategy for sustainable crop production on acid sulphate soils(ASS), there is a need to test and experiment during several years of production technologies that will overcome the multiple constraints of these production environments. The World Phosphate Institute(IMPHOS) designed an experimental field research that is intended to improve our understanding and ability to convert these soils into productive ones. The project covers five countries (**China, Indonesia, Malaysia, Thailand, and Vietnam**) and is implemented by IMPHOS in collaboration with CIRAD France.

The effects of each phosphate rock(PR)are compared to the effect of water-soluble fertilizer (TSP, and in certain cases SSP or SP-36) and a control without P application. The rate of P application is 90 kg P_2O_5 per hectare per cropping season. Other nutrients (i.e. N and K_2O) are added at the rate recommended by extension.

The most appropriate rice cultivar for the local conditions was selected for the experimentation. The basic plot size was set large enough to allow later for split-plot treatments (with and without P) and measurement of the effects of residual and cumulative P applications.

As a first conclusion on field results, we may compare the calculated percentage of yield increase obtained when applying the P treatment (PR or soluble P fertilizer) giving the best result over the control. These results are in the attached table.

In the network experiments, the rice yield of control plots on actual ASS ranges from 1250 kg/ha (Belawang, Indonesia) to 5900 kg/ha (Sedu, Malaysia). On potential ASS, the highest yield on control plot is 4400 kg/ha (Jawa, Malaysia) and the lowest is 1660 kg/ha (Tabunganen, Indonesia).

The yield increases when applying 90 P_2O_5 are ranging from +3 to + 67 % over the control for actual ASS and from + 3 to +43 % for potential ASS. The lowest increase is the one with a control yield very high. In these cases, available P is not the most limiting factor for the growth and production of the crop. When considering the 21 experiments, even if the differences are not significant for every case, the maximum increase is given by soluble P for 9 trials. For the other cases, where the PR is giving the best results, the more soluble PR is inducing the highest increase for 4 cases. The 8 yield increases data remaining are resulting from the use of less soluble PR.

The results of soil incubation with the various PR and measure of available P after the incubations using ^{32}P method is useful to explain the P response of crops on the various soils studied. The results obtained by this method are showing that the fixation of P by these soils is very high indicating that it will be difficult to saturate the P fixing capacity of the soil in order to have more P available for crops.

INTRODUCTION

Since the green revolution was launched in the early 1960's, considerable progress has been made in agriculture development in Asian countries. For about four decades, agricultural production has been growing steadily. It averaged a 2.2% annual increase between 1983 and 1993, while population grew by 1.7% annually. The majority of Asian countries became self-sufficient in rice production, though they remain dependent on imports to meet their wheat and maize requirements. Imports of these two commodities account for 40 million tons in 1998.

Fertilizer (NPK) consumption raised from 2.2 million tons at the end of the 1970's to 53 million tons in 1996, a figure which represents about 50% of the world consumption. It remains true that this figure hides a wide variability of fertilizer use among Asian countries, from an average of 60 kg/ha of nutrients in Thailand, 74 kg/ha in India, to 100 kg/ha in Bangladesh. These application rates, some times below the average recommendations of research and extension services, are exacerbated by the nutrient imbalance in the mineral fertilizer. Indeed, the average NPK application ratio in Asia is currently 9:3:1, compared to the world average ratio of 2.5:1.25:1
This situation means that great efforts still need still to be made in Asia in order to promote intensive farming and crop diversification that will meet the requirements for food crops such as cereals other than rice, fruits, and animal products.

IMPHOS agronomic programs in Asia have been developed against this setting. They were designed :

- To increase production of irrigated crops and cropping sequences.
- To achieve the potential yields of rainfed crops, particularly those grown on upland acid soils.
- To promote a balanced mineral fertilization in order to achieve sustainable crop production.

To this end, several agronomic projects have been initiated by IMPHOS in Asia for more than 20 years among which are:

- **Phosphorus in tropical soils: assessing deficiency levels and phosphorus requirements.**

- **Comparative response of maize to fresh and residual phosphorus fertilizer in upland soils of Thailand.**

- **Balanced fertilization through phosphorus promotion at the farm level in Pakistan. This project was intended to create awareness among farmers of the benefits of an improved NP ratio in fertilizer use.**

- **Use of reactive phosphate rock for the rehabilitation of anthropic savannah in Indonesia. This project demonstrated an economical and effective means of rehabilitating abandoned lands.**

- **Phosphorus fertilization of food crops on upland soils in Indonesia, China and Vietnam.**

- **The use of rock phosphate as a source of P for sugarcane and fodder production on acid soil in China.**

- **Agronomic and economic evaluation of various phosphate rocks for direct application to acid soils, mainly Alfisols and Ultisols in several Asian countries including India, China, Indonesia, and Malaysia.**

- **Use of reactive phosphate rocks for improved crop production in acid sulfate soils in China, Indonesia, Malaysia, Thailand, and Vietnam.**
- **Effectiveness of reactive rock phosphate in the production of some important economic crops on the acid soils in south china.**
- **On- farm trials for increased and balanced use of fertilizers in India.**
- **Recapitalization of soil fertility of upland acid soils in the southeast Asia: a village level approach.**

The implementation of these IMPHOS projects was further strengthened by the convention of a number of regional seminars and workshops among which are the following international conferences :

- **Fertilizer management in rainfed agriculture in Southern Asia, New Delhi 1986.**
- **Phosphorus requirements for sustainable agriculture in Asia and Oceania, Los Banos 1989.**
- **Phosphate sources for acid soils in the humid tropics of Asia, Kuala Lumpur 1990.**
- **Nutrient management for Sustainable food production in Asia, Bali 1996.**
- **Plant Nutrient management for sustainable agricultural growth, Islamabad 1997.**

These international events were an opportunity to review current research works, many of which demonstrated again the prevailing soil deficiency of phosphorus and pointed out appropriate ways to ensure a wider dissemination of research findings.

In order to gain support to this important and constant endeavor, IMPHOS has been keen to develop a close cooperation with several national and international research and development agencies, including IRRI, IFDC, FAO, PPI, IBSRAM, ACIAR and CIRAD.

By joining efforts with these organizations, IMPHOS has been able, not only to contribute to the promotion of crop diversification through a better management of the extensive acid upland soils which cover an area of more than 500 million hectares in Asia but it has also been able to promote balanced fertilization practices, based on the management of plant nutrients for a productive and economically and environmentally sustainable agriculture.

Through this paper we will focus only on our network on acid sulfate soil.

PHOSPHORUS MANAGEMENT IN ACID SULFATE SOILS : IMPHOS NETWORK IN 5 COUNTRIES

Introduction

Acid sulfate soils (ASS) develop as result of drainage of parent materials that are rich in pyrite (FeS_2). This pyrite accumulates in waterlogged soils rich in both organic matter and dissolved sulfate from seawater flushing. When drainage brings oxygen into previously waterlogged soils, the pyrite is oxidized to sulfuric acid. When production of acid exceeds the neutralizing capacity of the parent material and the soil pH levels fall below 4, the acid-sulfate soils are formed. As such, approximately 1.8 million ha of acid sulfate soils occur in Vietnam, of which about 80% are under rice cultivation.

Useful recommendations are expected on the best profitable and agronomically effective applications of phosphate rock (PR). The project covers five countries (**China, Indonesia, Malaysia, Thailand, and Vietnam**) and is implemented by IMPHOS in collaboration with CIRAD France. To the extent possible, distinction was made between potential and actual acid-sulfate soils, and four objectives were set out to:

- improve rice yield on acid-sulfate soils through good fertilizer management.
- improve phosphorus nutrition of crops, especially flooded rice.
- monitor any durable changes in soil fertility and phosphorus status in particular.
- study the economics of fertilizer use on acid-sulfate soils.

In each country, soil samples were taken for analysis of the main soils parameters in order to select the appropriate experimental sites and to record the baseline soil conditions of the experimental site.

In each of the five countries, three types of IMPHOS phosphate rocks (PR) of different solubility as measured in commonly used reactants are tested with particle size of 100% passing through 100 mesh screen. One local Phosphate Rock (locally produced or locally available on the market for the farmers) is compared to the 3 IMPHOS PR.

The effects on irrigated rice yield and yield components of each phosphate rock are compared to the effect of water-soluble fertilizer (TSP, and in certain cases SSP or SP-36) and a control without P application. The rate of P application is 90 kg P_2O_5 per hectare per cropping season. Other nutrients (i.e. N and K_2O) are added at the rate recommended by extension.

The follow-up of the experiment was done by the measurement of variables such as yield components: number of plants / tillers / spicklets per m², weight of grains and vegetative parts per plot, weight of 1000 grains…

I. Soil conditions in the 5 countries of the network

Results of soil analyses carried out in CIRAD Montpellier on samples sent by partners (4 from China, 3 from Vietnam, 2 from Indonesia, Malaysia and Thailand) have been analysed, representing the 13 experimentation sites. Clay content ranges from 12.2 to 67.3 %, and sand content from 0.4 to 29.8 %.

The soils classification, according to texture, is Clay (6 samples), Silty clay (2), Clay loam (1), Silty Clay loam (2), Sandy clay loam (1) and Sandy loam(1). Total P is from 120 to 670 mg/kg and P available (Olsen) from 3 to 24 mg/kg. 10 mg/kg of available P Olsen is considered as a minimum for crop cultivation, thus these results are indicating that some soils have already enough P for growing a crop, i.e. Zhanjiang reclaimed (China), Tabunganen potential (Indonesia), Sedu and Jawa (Malaysia) soils.

The pH $_{H2O}$ ranges from 3.35 to 5.25. It should be noted that these pH have been measured on dry samples received in Montpellier. The potential acid sulfate soils should have a pH higher than the actual ASS, as the pyrite layer has not been oxidized yet. If the soil sampled contained pyrite, when drying, the pyrite can be oxidized and sulfuric acid produced, inducing a sharp decrease of pH. This can explain some differences in the pH measurement in Montpellier when compared with results obtained at field level on fresh soil.

As an example of actual ASS, the Belawang soil (Kalimantan, Indonesia) has a very low pH, high exchangeable aluminum level and a very high organic matter content. This soil is really representative of the actual acid sulfate soils and the farmers have nearly dropped the rice cultivation as the yield is very low. On the contrary, on the southern part of Kalimantan island, the soil of Tabunganen site allows a good level of rice production. This soil has been kept under water since the beginning of the cropping pattern many years ago. The tide effect is possible in this location, allowing flooding and drainage of the plots under cultivation.

II. Characteristics of the Rock Phosphates used in the field trials

The results of analysis carried out in CIRAD Montpellier on each Rock Phosphate, sent either by IMPHOS companies or by Network participants show that the P_2O_5 content of the PR analysed ranges from 30 to 35 %. The formic solubility of the PR after 1/2 hour and 2 hours has been measured as well as the solubility in neutral citrate and citric acid.

As a matter of classification, the solubility in formic acid has been chosen, as it is giving an idea of the reactivity of the PR added to acid soils.

With regard to the formic acid solubility after ½ hour, the classification of the samples tested is the following (the figure indicates the percent of total P_2O_5 dissolved and not the percent of PR dissolved): Gafsa (Tunisia, 57 %) > Ciamis (Indonesia, 56 %) > Djebel Onk (Algeria, 52 %) > Youssoufia brut (Morocco, 43 %) > Al Abiad 70/72 (Jordan, 42 %) > Al Abiad 65/67 (Jordan, 39 %) > Daoui (Morocco, 38 %) > Eschydia (Jordan, 38 %) > Senegal (24 %) > Christmas Island (24 %) > Kunyang (China, 20 %) > Togo (17 %) > Youssoufia calcinated (Morocco, 16 %) > Lao Cai (Vietnam, 11 %).

This classification, based on a single sample, is giving an indication concerning the reactivity of the PR. However, as we are implementing experimentation on very acidic soils, the reactivity of the PR may not be the only characteristic explaining the positive influence of applied PR on rice growth.

III. Conclusion on first results of field trials

As a first conclusion on field results, we may compare the calculated percentage of yield increase obtained when applying the P treatment (PR or soluble P fertilizer) giving the best result over the control. These results are in table enclosed (table 1).
In the network experiments, the rice yield of control plots on actual ASS ranges from 1250 kg/ha (Belawang, Indonesia) to 5900 kg/ha (Sedu, Malaysia). On potential ASS, the highest yield on control plot is 4400 kg/ha (Jawa, Malaysia) and the lowest is 1660 kg/ha (Tabunganen, Indonesia).

Table 1 : Maximum increase of yield over the control (%) for each site. The yield is given in kg/ha.

Country	Location	Season	Actual ASS		Potential ASS	
			Control Yield	% increase / Control	Control Yield	% increase / Control
China	Zhanjiang	1999	3000	+ 67 %	4850	+ 3 %
China	Hainan	1998	3200	+ 25 %	2800	+ 43 %
China	Hainan	1999	1760	+ 35 %	1700	+ 35 %
Indonesia	Belawang (-lime)	1998	1250	+ 18 %	1660	+ 8 %
Indonesia	Belawang (+lime)	1998	1400	+ 24 %	1920	+ 15 %
Indonesia	Tabunganen (-lime)	1999			1670	+ 35 %
Indonesia	Tabunganen (+lime)	1999			2030	+ 6 %
Malaysia	Sedu	1998	5900	+ 3 %	4400	+ 8 %
Thailand	Ban Na	1999	3225	+ 18 %		
Vietnam	Binh Mi	1999			2850	+ 18 %
Vietnam	Kien An	1999	5020	+ 11 %		
Vietnam	Kenh Dong	1999-1	3250	+ 20 %		
Vietnam	Kenh Dong	1999-2	2180	+ 32 %		

The yield increases when applying 90 P_2O_5 are ranging from +3 to + 67 % over the control for actual ASS and from + 3 to +43 % for potential ASS (table1) .

The lowest increase are observed in the experiments where the control yield is very high. In these cases, available P is not the most limiting factor for the growth and production of the crop. When considering the 21 experiments, even if the differences are not significant for every case, the maximum increase is given by soluble P for 9 trials. For the other cases, where the PR is giving the best results, the more soluble PR is inducing the highest increase for 4 cases. The 8 yield increases data remaining are resulting from the use of low or medium soluble PR.

The first results of plot splitting in Indonesia, on potential ASS, indicate that there is no significant difference between the cumulative (180 P_2O_5) and the residual (90 P_2O_5) effects. But the yield increases are very low, even in the potential ASS. In Malaysia, the rice receiving 180 P_2O_5 is giving a better yield than the one with 90 P_2O_5 applied one cropping season before. It will be important to continue the follow-up of each plot to see if the total P level of the soil will increase without an increase of available P (i.e. P fixation by the soil).

IV. Preliminary laboratory data

The CIRAD laboratory experiments on the kinetics of isotopic exchanges of soil P show considerable P fixation by soil. Kinetic studies performed one month after incubation of soil with various rock phosphates show the following :

- The soils tested from the five countries have a very high fixing capacity for P.
- The percentage of P remaining in the soil water solution after 1 minute of phosphate contact with soil (considered to be readily available to plants) varies from 1.5% to 5.4%.
- When some RP's are added to the soil (at the rate of 50 mg of P/kg of soil, corresponding to nearly 340 kg P_2O_5/ha), the fixing capacity decreased after 1 month of RP contact with soil. Small differences were observed in the magnitudes of the decrease in P fixing capacity as a result of the added RP.

If we strictly extrapolate these data to the field experiments, we should assume entire first crop uptake and/or soil fixation of the P added (90 kg P_2O_5/ha). However, acid sulfate soils are heterogeneous at the field level. This implies a need to assess the P fixing capacity of the soil by splitting the experimental plots into two subplots, one receiving the same P fertilization as the first rice cropping (90 kg P_2O_5/ha) while the second receives no P. This will enable to determine the residual effect, if any, of the P added in the first cultivation.

V. Conclusion

It is necessary to continue following up the yield components in order to understand on which component the differences in P nutrition have a significant influence. Some control plots are giving a very high rice yield, indicating that P is not the main limiting factors for the growth of rice crop in these experimental site. In specific conditions where an edaphic factor, other than plant available P, is limiting the rice yield, it is possible, within the framework of the experimental design to measure the influence of P nutrition. However the available P content of these soils should decrease regularly in the control plots by crop exportations. When the plant available soil P becomes lower than the threshold level, the yield should decrease. The follow-up of the direct and residual effects of P application on yield will provide information with regard to that.

The results of soil incubation with the various PR and measure of available P after these incubations using ^{32}P method will be useful to explain the P response of crops on the various soils studied. The first results obtained by this method are showing that the fixation of P by these soils is very high indicating that it will be difficult to saturate the P fixing capacity of the soil in order to have more P available for crops.

The splitting design for studying the effect of P application of cumulative vs residual doses on crop production is important to monitor for a longer time. This will provide information on periodicity for P application, depending on the product to be used, the crop to be grown and the expected rice yield.

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