IMPROVEMENT AND FERTILIZATION OF ACID SULFATE SOILS IN THAILAND

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Abstract

This paper reviews research on improvement and fertilization of acid sulfate soils in Thailand carried out by two major institutions of the Ministry of Agriculture and Cooperatives (MAC), the Department of Agriculture (DA) and the Land Development Department (LDD) and only one of the institutions in the Government University Bureau (GUB), Kasetsart University (KU). Subjects investigated separately by the three organizations are reviewed and discussed under three categories of land suitability classes for paddy P II a, P III a and P IV a, recognized by Thai soil scientists. The results of the cooperative project on "Rice Yield Improvement in Acid Sulfate Soils" by the working committee organized within the MAC is presented and discussed separately.

Introduction

Acid sulfate soils are one of the major problem soils of Thailand. These soils occupy approximately 1.5 million hectares (Pons and Kevie, 1969). Approximately 0.6 million hectares of the Southern Central Plain are covered with the soils while the remaining 900,000 hectares are scattered along the South-East Coast and the Peninsula Thailand (Kevie and Yenmanas, 1972) physiographic regions identified (Moormann and Rojanasoonthon, 1968).

Low to very low rice yield in the soils ranging from 500 to 1,500 kg/ha has been always reported (Fukui, 1969; Komes, 1973 a and b). Investigations on the problems and improvement of some acid sulfate soils have been indirectly carried out by the Department of Agriculture (DA) and Kasetsart University (KU) during 1943–1959 when the university was affiliated to the Ministry of Agriculture and Cooperatives (MAC) as well as the Rice Department (RD) which split from the DA in 1954 at Bangkhen Rice Experiment Station (BRES), Bangkok, and Rangsit Rice Experiment Station (RRES), Pathum Thani and in pot experiments for soils collected from farmer's field nearby. More direct and extensive interest in the improvement of these soils in the Central Plain, the rice bowl of the country, stems from intensive pedologic and pedogenic investigations under the FAO Aid to the Land Development Department (LDD) during 1963–1972, resulting in two classical soil survey reports (Pons and Kevie, 1969; Kevie and Yenmanas, 1972). Classification and extent of 12 important acid sulfate soil series are presented in Table 1 and some important edaphological characteristics of the surface horizon of 4 representative acid sulfate soils are illustrated in Table 2.

Investigations on the improvement and fertilization of acid sulfate soils in Thailand before 1978 were independently carried out by two departments of the MAC, the DA and the LDD. The DA, reaffiliated to the RD in 1973, concentrated most of the research in the RRES mentioned earlier and Klong Luang Rice Experiment Station (KRES), Pathum Thani, transferred to the RD since 1960. The research activities at the BRES have decreased since 1973 owing to planting area reduction. The soils of the BRES, KRES and RRES are presently recognized as Bang Khen (Bn), Rs and Rs respectively. The Bn and Rs series are grouped into class P II a and P III a respectively. The edaphologic properties of these soils are shown in Table 3. The LDD emphasized more applied research than the DA in farmer's field of class P IV a and some P III a areas and in their two Land Development Centers (LDC) at Thanyaburi (TLDC), Pathum Thani and at Ongkarak (OLDC), Nakorn Nayok inaugurated in 1974. The KU had cooperated effectively

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Table 1 Classification and extent of acid sulfate soils in the Central Plain

Soil series	Area (ha)	Index %	Remarks
Class P II a			
1. Maha Phot, Ma	62,664	8.1	Soils well suited
2. Ayutthaya, Ay	78,205	10.1	to paddy due to
3. Ay/Ma Complex	7,474	1.0	slight acidity
4. Sena, Se	147,814	19.0	problem, pH 4.7–6.0
5. Chachoeng SaO, Co	141,642	18.2	
Class total	474,179	61.0	
Class P II a/P III a			
6. Se/Rs complex	13,062	1.7	
Class P III a			
7. Rangsit, Rs	180,222	23.2	Soils moderately
8. Rs-h**	168	–	suited to paddy
9. Thanyaburi, Tan	26,518	3.4	due to strong
			acidity problem
Class total	206,909	26.6	
Class P IV a			
10. Rs-a***	51,240	6.6	Soils poorly suited
11. Ongkharak, Ok	12,323	1.6	to paddy due to
12. Cha-am, Cm	8,811	1.1	severe acidity
			problem, pH 3.5–4.1
Class total	83,690	10.8	
Total	777,840	100	

* Modified from Kevie and Yenmanas (1972)

** Rangsit high phase

*** Rangsit very acid phase series

Table 2 Some edaphologic properties of the A horizon of representative acid sulfate soils*

Properties	Ma			Se			Rs			Ok		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
pH (1:1) H_2O	5.18	4.50	4.73	4.90	4.02	4.44	5.00	3.68	4.39	4.65	4.30	4.49
1:1 KCl	4.17	3.55	3.77	450	3.66	3.92	4.30	3.46	3.79	4.00	3.50	3.79
O.M (%)	3.24	2.95	3.09	4.72	1.24	2.76	9.03	1.40	4.50	4.62	1.67	2.83
Bray II-P	8.2	2.3	5.8	14.3	2.6	9.8	20.8	3.53	9.27	10.6	3.6	7.5
Exch. (meq/100g)												
Ca	11.4	2.4	7.4	38.0	10.5	23.4	11.6	0.9	4.6	6.5	5.1	5.9
Mg	7.3	4.2	6.0	8.0	2.4	5.3	5.0	1.6	3.2	5.9	4.3	5.0
K	0.27	0.20	0.22	1.0	0.29	0.56	0.69	0.17	0.41	0.85	0.40	0.67
Na	0.9	0.6	0.79	4.1	0.64	1.32	1.59	0.40	0.95	2.35	0.50	1.23
CEC (meq/100g)	38.8	20.1	29.2	36.7	22.1	30.2	39.3	22.2	30.4	29.3	24.9	27.2
Extr. acidity (meq/100g)	33.4	18.7	24.4	27.4	15.2	21.4	46.2	20.7	33.9	30.2	19.0	23.0

* Modified from leaflets compiled by Land Development Department.

Table 3 Some edaphologic properties of the Apg horizon of the soil of the three rice Experiment Stations of Agriculture (modified from Motomura *et al.*, 1979)

Properties	BRES	KRES	RRES
pH (1:2.5) H_2O	5.3	4.2	4.0
KCl	4.3	3.5	3.4
O.M (%)	2.49	2.52	4.05
Total N (%)	0.13	0.13	0.18
Avail. N (ppm)	56.9	12.3	19.8
Total P (ppm)	231	196	201
Bray II-P (ppm)	4.5	7.5	5.1
Exch. (meq/100g)			
Ca	11.7	8.22	8.34
Mg	16.8	3.79	7.46
K	9.1	1.84	3.38
Na	1.1	0.37	0.64
CEC (meq/100g)	32.8	19.39	28.01
Exch. acidity (meq/100g)	n.d.*	10.1	22.9
Clay (%)	67.5	51.8	69.8
Free Fe_2O_3 (%)	1.42	1.44	1.83
Eas. red. MnO_2 ppm	57	44	91

* not determined

during 1943–1959 with the DA mentioned above for B.S. theses of the College of Agriculture students at BRES and some at RRES, as well as for pot experiments. After that more intensive investigations mostly in laboratory and greenhouse for students' M.S. degree and by the Department of Soil Science staffs, very spotty however, owing to financial and facility constraints have been carried out.

In 1978 the MAC designated a working committee for the project on "the Rice Yield Improvement in Acid Sulfate Soils" (RYIASS) with many scientists of the DA and some of the LDD and other institutions concerned in the MAC (Working Committee of RYIASS, 1980). The project covers many aspects of rice yield improvement by marl, rock phosphate and other fertilizer trials in KRES, recently established PRES (Prachin Buri Rice Experiment Station), TLDC and OLDC and in farmer's fields.

Since the incorporation of the areas studied by the DA and LDD in land class P II a and P III a and P III a and P IV a respectively, discoveries of the DA and LDD and of KU are reviewed and discussed separately for each class along with a part for the cooperative project of the MAC.

Table 4 **Influence of marl, superphosphate (SP), rock phosphate (RP) and ammonium sulfate on average rice yield (ton/ha) at BRES during 1951–1957 (Komes, 1958)**

P rate	SP rate (kg P_2O_5/ha)					RP rate (kg P_2O_5/ha)				
kg/ha	0	25	75	125	Ave.	0	25	75	125	Ave.
a. Without marl										
0	1.79	2.34	2.34	2.74	2.30	1.79	2.25	2.25	2.54	2.21
20	2.44	2.40	2.48	2.77	2.52	2.44	2.60	2.41	2.46	2.48
55	2.20	2.62	2.67	2.58	2.52	2.20	2.55	1.53	2.76	2.51
90	2.38	2.69	2.44	2.77	2.57	2.38	2.72	2.57	2.73	2.60
Ave	2.20	2.51	2.48	2.70	2.48	2.20	2.53	2.44	2.62	2.45
b. With 1.25 ton CaO/ha of marl										
0	1.92	2.26	2.50	2.56	2.31	1.92	2.21	2.35	2.50	2.24
20	1.89	2.59	2.59	2.62	2.42	1.89	1.92	2.34	2.64	2.20
55	1.96	2.55	2.75	2.78	2.51	1.96	2.15	2.49	2.69	2.32
90	1.94	2.56	2.60	2.79	2.47	1.94	2.35	2.39	2.63	2.33
Ave	1.93	2.49	2.61	2.69	2.43	1.93	2.15	2.39	2.62	2.27
c. With 2.50 ton CaO/ha of marl										
0	2.02	2.28	2.47	2.53	2.32	2.02	2.13	2.46	2.60	2.30
20	2.03	2.42	2.70	2.74	2.47	2.03	2.38	2.41	2.64	2.36
55	2.26	2.51	2.59	2.81	2.54	2.26	2.41	2.40	2.65	2.43
90	2.09	2.38	2.68	2.69	2.46	2.09	2.07	2.47	2.71	2.34
Ave	2.10	2.40	2.61	2.69	2.45	2.10	2.25	2.44	2.65	2.36
c. Regardless of marl rate										
0	1.91	2.29	2.44	2.61	2.31	1.91	2.20	2.35	2.55	2.25
20	2.12	2.47	2.59	2.71	2.47	2.12	2.30	2.39	2.58	2.35
55	2.14	2.56	2.67	2.72	2.52	2.14	2.37	2.47	2.70	2.42
90	2.14	2.54	2.57	2.75	2.50	2.14	2.38	2.48	2.69	2.42
Ave	2.08	2.47	2.57	2.70	2.45	2.08	2.31	2.42	2.63	2.36

Improvement and fertilization of class P II a soils

Improvement and fertilization of the P II a soils can be adopted from the general recommendations of the DA after a long history of soil fertility investigations.

Several years before 1935, according to Montrakun (1964), some experiments on fertilizer trials had been made on an exploratory basis but were inconclusive owing to the lack of statistical design and interpretation.

Jugsujinda and Suwanwaong (1970) reported that during 1949–1951 there were many preliminary studies on the effect of kinds of fertilizers at the BRES to investigate their role in rice yield improvement. Those were done mostly by the senior agronomy students of KU as B.S. theses. The results of the studies brought about the same general conclusion that N and P only are the rice limiting nutrients. Studies on different sources of N have shown that NH_4-N and urea-N are much more effective than NO_3-N and the mixed N, P fertilizers were not different from the compound forms. Some results have been reported by Suwanwaong and Jugsujinda (1969). Liming was also tested in the Bn series (Suthdhani, 1957; Komes, 1958) with only limited positive results. In the Bn series at BRES fertilization only was needed (Table 4).

After simple fertilizer trial scheme in all experiment stations throughout the country during 1958–1964, following the technique recommended by the International Rice Commission (IRC) Working Party under the United Nations Development Program for Soil Fertility (UNDP/SF), research projects were summarized and mimeographed in Thai by Suwanwaong *et al.* (1965). From the results of these trials followed by the Large Pilot Demonstration (LPD) throughout the country during 1964–66, generalized recommendation for the most economic return fertilization for transplanted rice was 75 kg/ha of 16-20-0 regardless of either soil types or location (Jugsujinda and Suwanwaong, 1970). The UNDP/SF program was renewed for another five years, also in the farmer's field based on soil series instead of texture as in Phase I. The outcome of the project was the second fertilization recommendation for the improved hybrid rice varieties (RD varieties), i.e., 75 kg/ha of ammophos (16-20-0) as basal application and additional 15 kg N/ha of either urea or NH_4-N, as top dressing dose at the PI stage. This recommendation has been proved satisfactory also for the P II a class soils.

Improvement and fertilization of class P III a soils

The DA emphasized the improvement of this soil class with rock phosphate (RP) and N without liming after long successive investigations at the 2 stations of RRES and KRES. Suwanwaong (1960 a) tested sources and rate of P fertilizers at PRES as compared with the P II at BRES (Table 5). It could be concluded from the experiment that (1) the rice plant responded to all P sources up to 37.5 kg P_2O_5/ha at BRES but not always at RRES; (2) all of the RP sources were slightly better than the superphosphate (SP) and hyperphosphate (HP) at BRES but the RPs and HP were better than SP at RRES. Pure positive effects and interaction of $(NH_4)_2\ SO_4$ and SP were also investigated at the RRES and reported (Suwanwaong, 1960 b) (Table 6).

Table 5 Effect of sources and rates of P fertilizers on rice yield (ton/ha) in two acid sulfate soils (modified from Suwanwaong, 1960)

P rates kg P_2O_5/ha	Sources					
	SP	HP	X-mas RP	Fla R	Pat P	BMP
BRES (1955–56)						
Check	1.13	1.13	1.13	1.13	1.13	1.13
0	1.18	1.18	1.18	1.18	1.18	1.18
37.5	2.04	2.06	2.09	2.13	2.93	2.16
75.0	2.04	2.01	2.22	2.03	2.29	2.27
Ave	1.60	1.60	1.66	1.62	1.88	1.68
RRES (1955–56)						
Check	1.12	1.12	1.12	1.12	1.12	1.12
0	1.71	1.71	1.71	1.71	1.71	1.71
37.5	1.71	1.74	1.81	1.86	1.78	2.06
75.0	1.54	1.71	1.76	1.66	1.52	1.89
Ave	1.52	1.57	1.60	1.59	1.53	1.70

Note : All plots received 37.5 kg N basal application as $(NH_4)_2 SO_4$ except check.

SP = **Ordinary superphosphate (20% P_2O_5)**

HP = **Hyperphosphate (27% P_2O_5)**

X mas RP = Christmas island rock phosphate (30% P_2O_5)

Fla RP = Florida pebble rock phosphate (30% P_2O_5)

Pat P = **Patalung phosphate (Thai phosphate)(8% P_2O_5)**

BMP = Bone meal phosphate (30% P_2O_5)

Table 6 Effect of N and P on average yield of rice (ton/ha) in two acid sulfate soils (modified from Suwanwaong, 1960 b)

N rates kg/ha	P_2O_5 rates (kg/ha)			
	0	37.5	75.0	150.0
BRES (average yield of 3 crop years, 1952–55)				
0	1.50	–	–	–
37.5	–	2.79	2.99	3.10
75.0	–	3.16	3.26	3.38
150.0	–	3.41	3.60	3.69
RRES (average yield of 1953–54 crop years)				
0	2.14	–	–	–
37.5	–	2.59	2.72	2.90
75.0	–	2.77	2.97	3.04
150.0	–	2.89	3.12	3.27

Note :
1. $(NH_4)_2SO_4$ was used as N-source
2. Ordinary superphosphate served as P source
3. Five standard varieties recommended for each experiment station were used and averaged.

After the discovery of Ongkarak (OK) clay soil in Nakorn Nayok and provinces nearby including Pathum Thani (Pendleton, 1959; Pendleton and Montrakun, 1960), improvement of the soils with P sources was somewhat promoted. Suwanwaong and Saisoong (1964) compared the effect of SP and BS (basic slag) in the RRES and BRES and reported a clear positive response to the P sources especially in the RRES (Table 7). Jugsujinda *et al.* (1968) reported the effect of sources and rates of high and low analysis P carriers at the RRES and BRES during the 1966–67 trials (Table 8). No difference among P sources and between the two rates was discovered. During 1966–1974, the transitional period of the late Phase II and Phase III UNDP/SF programs, 134 research reports carried out by staffs of the Rice Fertilization Research Branch (RFRB), Rice Division (RD), DA were summarized into 75 abstracts (RFRB, 1978). Among these reports, 21 reports considered various aspects of the P effects on the acid soils including acid sulfate soils. Some of the results were published (Jugsujinda *et al.*, 1971; Jugsujinda and Suwanwaong, 1972) and are summarized partly in Table 9. The Table shows a similarity of the effects of RP (N, Fla.) and TSP (triple superphosphate) both in the main and residual effects. Jugsujinda *et al.* (1971) were also able to predict paddy yield increase with the 6 RP sources from their relative citrate solubility with reference to total P by this regression equation for the KRES:

$$\Delta Y = -1868\text{-}179.8X + 1804X^{1/2},\ R^2 = 0.92$$

where ΔY = yield increase in kg/ha

X = citrate soluble P in % of total

Table 7 **Comparative effect of superphosphate (SP) and basic slag (BS) on rice yield in two acid sulfate soils (Suwanwaong and Saikoong, 1964)**

P_2O_5 rates kg/ha	BRES			RRES		
	Yield	Response		Yield	Response	
	ton/ha	ton/ha	%		ton/ha	%
Check	2.26	0	0	1.12	0	0
0	2.85	0.30	11.5	1.17	0.06	5.1
25 (SP)	3.37	0.81	31.8	1.62	0.51	45.4
50 (SP)	3.52	0.96	37.5	1.59	0.47	42.1
75 (SP)	3.24	0.68	26.6	1.55	0.43	38.8
Ave (SP) 1)	3.38	–	–	1.59	–	–
SP response 2)		0.53	18.6	–	0.42	35.9
25 (BS)	3.20	0.64	24.9	1.63	0.52	46.3
50 (BS)	3.47	0.91	35.7	1.74	0.62	55.4
75 (BS)	3.40	0.84	32.8	1.78	0.67	59.8
Ave (BS) 1)	3.36			1.72	–	–
BS response 2)		0.51	17.9	–	0.55	46.7

Note : All plots, except check, received basal application of 38 kg/ha of N and K_2O as $(NH_4)_2SO_4$ and KCl respectively

1) Average of the 3 SP and BS applied

2) This response = Ave – 0 for the ton/ha

$$\text{and} = \frac{(\text{Ave} - 0)}{0} \times 100 \text{ for the } \%$$

One year later, after investigating P sources at RRES, Jugsujinda and Suwanwaong (1972) reported a linear relationship between rice yield and citrate soluble P by this equation:

$$Y = 1407 + 107.71\,X \quad (r = 0.828^*,\ n = 7)$$

where ΔY = predicted grain yield (kg/ha)

X = citrate soluble P (% P_2O_5)

After releasing the RD 1 variety in 1969, investigations on N requirement were also carried out throughout the country including the two DA experiment stations. Suwanwaong and Jugsujinda (1969) compared average response to N of RD varieties at KRES and selected the native ones at BRES (Table 10) and hybrid varieties at RRES (Puh and Suthdhani, 1972) (Table 11).

From these findings, the DA recommended the farmers in the Rangsit area to apply 625 kg/ha of commercial Thai RP (25 – 30% total P_2O_5 and 3 – 5% available P_2O_5) and 15 kg N/ha as basal fertilizer with additional 15 kg/ha at P.I. top dressing for the RD varieties (personal communication).

Table 8 **Influence of sources and rates of high and low analysis phosphate fertilizers on rice yield (ton/ha) in two acid sulfate soils (modified from Jugsujinda *et al.*, 1968)**

P sources	Rate kg/ha of P_2O_5	BRES			RRES		
		1966	1967	Ave	1966	1967	Ave
Check	0	1.5	2.4	2.0	0.7	1.5	1.1
AP	18.75	2.0	2.9	2.4	0.7	1.7	1.2
DAP	18.75	2.2	2.7	2.4	0.5	1.6	1.1
SP	18.75	2.1	3.3	2.7	0.7	1.6	1.1
TSP(P)	18.75	2.2	2.7	2.4	0.5	1.7	1.1
TSP(G)	18.75	2.1	2.5	2.3	0.5	1.7	1.1
AP	37.50	2.3	3.0	2.7	0.6	1.6	1.1
DAP	37.50	2.4	2.8	2.6	0.6	1.7	1.2
SP	37.50	2.4	2.4	2.4	0.5	1.6	1.1
TSP(P)	37.50	2.2	2.4	2.3	0.5	1.7	1.1
TSP(G)	37.50	2.3	2.7	2.5	0.6	1.7	1.2
Average		2.2	2.7	2.4	0.6	1.6	1.1

Note: 1. AP = ammonium phosphate (16-20-0)

2. DAP = diammonium phosphate (18-46-0)

3. SP = ordinary superphosphate (0-20-0)

4. TSP(P) = powdered triple superphosphate (0-46-0)

5. TSP(G) = granulated TSP (0-46-0)

6. **All treatments except check received basal applications of 37.5 kg/ha of N and** K_2O from $(NH_4)_2SO_4$ and/or the compound fertilizer and KC1.

Table 9 Effect of rates and selected sources of phosphates in grain yield (ton/ha) of RDI rice in acid sulfate soils in Thailand

Sources	Rates (kg total P_2O_5/ha)					Average
	0	25	50	100	200	
BRES[1]						
a. **Main effect, wet season, 1969**						
TSP	3.4	5.2	5.5	5.5	5.8	5.1
R P(NF)	3.4	4.4	4.4	5.1	5.1	4.5
Average	3.4	4.8	5.0	5.3	5.4	4.8
b. **Residual effect, dry season, 1969**						
TSP	3.7	3.9	4.4	4.3	4.7	4.2
RP(NF)	3.7	4.0	4.1	3.7	4.2	3.9
Average	3.7	4.0	4.2	4.0	4.4	4.1
KRES[1]						
a. **Main effect, wet season, 1969**						
TSP	2.7	5.5	5.9	6.2	5.9	5.2
RP(NF)	2.7	5.0	5.2	5.9	5.6	4.9
Average	2.7	5.2	5.6	6.0	5.8	5.0
b. **Residual effect, dry season, 1969**						
TSP	1.2	2.4	2.9	4.6	4.7	3.2
RP(NF)	1.2	2.5	2.4	3.5	4.5	2.8
Average	1.2	2.4	2.6	4.0	4.6	3.0
RRES[2]						
a. **Main effect, wet season, 1970**						
TSP	0.8	1.9	2.5	2.9	2.4	2.1
RP(NF)	0.8	2.0	2.8	2.4	3.0	2.2
Average	0.8	2.0	2.7	2.6	2.7	2.2
b. **Residual effect, wet season, 1971**						
TSP	1.6	1.9	1.7	2.8	3.0	2.2
RP(NF)	1.6	2.0	1.7	2.6	3.0	2.2
Average	1.6	2.0	1.7	2.7	3.0	2.2

[1] modified from Jugsujinda *et al.*, (1971)

[2] modified from Jugsujinda and Suwanwaong (1972)

Table 10 Effect of N on rice yield (ton/ha) of two acid sulfate soils (modified from Suwanwaong and Jugsujinda, 1969)

Rate of N	BRES (1962-64)		KRES (1968)			
kg/ha	Wet[1]	Index (%)	Wet	Dry	Ave.[2]	Index (%)
Check	2.0	100	0.2	0[4]	0	0
0	2.6	107	1.5	1.2	1.3	100
18.75	3.1	125	1.8	1.9	1.9	144
37.50	3.1	127	1.8	2.5	2.1	162
56.25	3.3	133	2.4	2.9	2.7	203
75.00	3.3	133	2.5	3.2	2.9	220
112.50	3.1	128	3.0	3.0	3.0	229
150.00	3.0	121	[5]	–	–	–
Average	3.0	–	2.2[3]	2.5[3]	2.3[3]	–

Note: 1. All plots, except check, received basal application of 37.5 kg/ha of P_2O_5 and K_2O.

[1] Average yield of 5 standard varieties (photosensitive, *indica* type)
[2] Average yield of 3 non photosensitive varieties.
[3] Average yield of all 6 N rates except check.
[4] No panicle bearing tillers developed.
[5] No experiment at 150 kg N/ha.

Table 11 Influence of N and spacing on yield (t/ha) of C_4-63 at RRES (1969-71) (modified from Puh and Suthdhani, 1972)

Variety	N rate	Spacing (cm^2)			N
	kg/ha	25 x 25	25 x 18	25 x 12	mean
C_4-63	60	2.9	3.1	3.2	3.1
	100	3.5	3.5	3.4	3.4
	140	3.6	3.8	3.8	3.7
	S mean	3.3	3.5	3.5	3.4
RD 1	60	3.6	3.4	3.7	3.6
	100	4.5	4.6	4.6	4.6
	140	5.0	5.3	5.4	5.2
	S mean	4.4	4.4	4.6	4.5

Note: 1. All plots received basal application of 60 kg P_2O_5/ha and 50 kg K_2O/ha as superphosphate and KC1 respectively;

2. Half of N as $(NH_4)_2SO_4$ basal application and another half 25 days before flowering.

The LDD has recommended marl for improving the acid sulfate soils 2–4 weeks prior to basal fertilization with ammophos at transplanting, since the establishment of the TLDC in 1965. Charoenchamratcheep (1980) reviewed all the studies done by the Soil and Water Conservation Division (SWC), LDD since the commencement of the LDD in 1963. Four-year marl and ammophos trials in representative acid sulfate soils recently proposed (Maneewan *et al.*, 1981) have been modified and presented in Table 12. This Table shows clearly that liming in the class P III a soils may not be economically feasible. Positive effect of ammophos is significantly higher than that of marl.

Table 12 Influence of marl and ammophos on five-year average[1/] yield of rice (ton/ha) in the acid sulfate soils of Thailand (modified from Maneewan *et al.*, 1981)

Fertilizer	Marl rate (ton/ha)				F effect	Response
(kg AP/ha)	0	3.125	6.25	to pH 7	(ton/ha)	%
a. Ma series, P II a representative, farmer's field Prachin Buri						
Check	1.41	1.45	1.51	1.47	1.40	0
156.25	1.74	1.82	1.80	1.78	1.79	27.5
M effect, ton/ha	1.58	1.64	1.66	1.62		
Response %	0	3.8	5.1	2.5		
b. Rs series, P III a representative, TLDC, Pathum Thani						
Check	0.47	0.47	0.48	0.58	0.50	0
156.25	0.63	0.70	0.68	0.73	0.69	38.0
M effect ton/ha	0.55	0.58	0.58	0.66		
Response %	0	5.5	5.5	20		
c. Re-a series, PIV a representative, OLDC, Nakorn Nayok						
Check	0.05	0.26	0.06	0.19	0.14	0
156.25	0.31	0.83	0.83	1.03	0.75	436
M effect ton/ha	0.18	0.54	0.44	0.61		
Response %	0	200	144	239		

Note: All of the ammophos (AP) plots received additional 62.5 kg/ha of $(NH_4)_2SO_4$ (21% N) at PI stage, and RD7 rice was used in all places.
[1/] All yields are the average of 1976–79 result.

While the DA and LDD emphasized applied research for appropriate rice yield improvement technology, for P III a soils, KU gathered more basic information despite financial and facility constraints after joining the GUB. Klaewwigam (1963), as a RD research trainee, studied the effect of marl at the RRES for his B.S. thesis. He showed that 3.75 ton/ha of marl was adequate but 75 kg N/ha was still not sufficient for the rice plant (Table 13). There was no further interest in liming trial from the DA after this discovery. Im-Erb (1979) reinvestigated the effect of limes on the kinetics of chemical factors that might influence the behavior of RD 1 rice in 4 acid sulfate soils under ample supply of N, P and K, in pot experiments for her M.S. thesis. She used 4 acid sulfate soils, Se and Ma for P II a, Rs for P III a and Rs-a for P IV a classes. Four lime sources, flue dust, marl, arc furnace slag, blast furnace slag to increase the pH of each soil to 5.5 were also used for her first experiment. She reported many interesting findings: (1) the rice plant response to lime sources differed and was positively correlated with their CCE, (2) response to lime among the soils, as expected followed the order P II a (21%) < P III a (27%) < P IV a (35%); (3) liming depressed water soluble Al by increasing the solution pH with this relationship, during the first 3 weeks after submergence (WAS): Al (ppm) = 4.65–0.1056 pH (r = −0.67** n = 80); (4) dry matter of the plant at maturity was negatively correlated with Al concentration (ppm) within the first 3 WAS and Fe in the 7–9 WAS as presented in Table 14; and (5) the plant responded more to the residual lime than the first crop.

Table 13 Effect of marl and fertilizer on grain yield of rice (ton/ha) at PRES (modified from Klaewwigam, 1963)

$N - P_2O_5 - K_2O$	Marl rate (ton/ha)				F mean	Response
kg/ha	0	1.875	3.75	7.5	ton/ha	%
0-0-0	1.37	1.79	1.87	1.71	1.68	0
37.5-37.5-0	2.49	3.03	3.48	3.28	3.07	82.7
75.0-37.5-0	2.88	3.59	4.18	3.17	3.46	106.0
M mean	2.25	2.80	3.18	2.72	–	–
Response %	0	20.9	41.3	20.9	–	–

Table 14 Influence of soluble Al and Fe on dry matter (DM) production at maturity in 4 acid sulfate soils of Thailand (Im-Erb, 1979)

Weeks submerged	Y (g/pot)	X (ppm)	r	Regression
0	D.M.	Al	- 0.72**	Y = 280.26 - 1.22 X
1	D.M.	Al	- 0.73**	Y = 180.39 - 1.81 X
2	D.M.	Al	- 0.69**	Y = 179.12 - 1.83 X
3	D.M.	Al	- 0.69**	Y = 179.49 - 2.39 X
0–3	D.M.	Al	- 0.73**	Y = 180.23 - 0.45 X
7	D.M.	Fe	- 0.65**	Y = 183.72 - 0.08 X
9	D.M.	Fe	- 0.60**	Y = 178.08 - 0.06 X

Since many experiments showed that soils in the P III a class responded to fertilizer more than to lime (Maneewan *et al.*, 1981) N P K factorial experiment with RD variety should be re-investigated. The author had a very good chance to investigate basic facts about rice and two P III a class soils and the other two non problem soils of the Central Plain, as coordinator and consultant of the ATT-DANIDA (Asian Institute of Technology, Thailand and Danish International Development Agency, Denmark), joint project entitled "Paddy Fertilization Based on Chemical Composition of the Plant" during 1977–78. The joint research project was approved after the discovery by Sriyong (1976) that the system of cereal fertilization based on chemical composition of the plant developed in Denmark by Nielsen and Nielsen (1976 a, b and c) could be applied to the paddy in Thailand. Three advanced studies were carried out at KRES intensively enough to become M.Sc. theses of three AIT students (Sriyong, 1976; Patipanawattana 1977; Anupotemontri, 1977). Study sites of this project were KRES, RRES, CRES (Chainat RES) and SRES (Suphanburi RES). The project was carried out intensively in these 4 experiment stations. Development of models for diagnosis and therapy and yield prognosis were the aims of this master project. Two N P K factorial analyses in systematic design experiments of both high fertility levels = 0,50 and 100 kg/ha of N, P_2O_5 and K_2O and low fertility levels = 0,25 and 50 kg/ha of N,P_2O_5 and K_2O with 27 treatment combinations of each experiment in each RES were carried out in the wet season of 1977 and the dry season of 1978. Within each treatment combination, the subplot of 5 x 6m^2 was split into two (2 of 5 x 3m^2) for basal and basal + top dressing fertilization. The total plots in each RES were 108. At KRES and RRES all of the basal + top dressing plots with high fertility were top dressed 3 weeks after transplanting of 21-day-old RD 7 rice seedlings with 50 kg/ha of P_2O_5 and 25 kg P_2O_5/ha for the high and the low fertility basal + top dressing plots respectively. Samples for dry matter and chemical composition determination from the second guard row were collected each week up to 8 weeks after transplanting and at maturity arbitrarily (not too big and not too small). Part of the investigation at KRES was a KU M.S. thesis (Jatupote, 1979) under the author's guidance. All of the results with emphasis on modeling for the diagnosis and therapy and yield prognosis procedures are described by Nielsen *et al.* (1979). Application of the models for yield prediction in acid sulfate soils was also presented (Jatupote *et al.* 1979). The models proposed for the acid sulfate soils are presented in Fig. 1, 2, 3. The information collected in the master project was also simplified and compiled in 3 papers (Prabuddham, 1981 a and b; Prabuddham and Nielsen, 1981). Some of the results are summarized in Tables 15, 16 and 17. It should be pointed out that analysis of variance of dry matter, contents and uptake of N,P and K indicated that only N can influence all the parameters studied, while P statistically influences only P contents in both grain and straw and P uptake in straw and in the whole top parts of the plant.

Improvement and fertilization of class P IV a soils

KU played some important role in basic research on the edaphological approach of this soil class. Sinanwongsa (1965) tried to reclaim the Ok soil series by liming, for her B.S. thesis (pot experiments). She tested the effectiveness of 5 limes and 5 rates = 0, 12.5, 18.75, 25 and 31.25 ton/ha using Nang Mol S4 a standard photosensitive rice variety as indicator crop. All pots received basal application equivalent to 156.25–156.25–62.5 kg/ha of N, P_2O_5 and K_2O respectively, after 20 days of liming and flooding of the soil. She found that slaked lime was more effective than ground $CaCO_3$ and 12.5 ton/ha of the lime was the best. Patiyut (1968) tested the ameliorative effect of MnO_2 comparing Mn supplying materials such as $MnSO_4$ and $MnCl_2$ under liming and ample supply of N P K for her B.S. thesis under the author's guidance. She found that MnO_2 was superior to $MnSO_4$ and $MnCl_2$. Problems and amelioration of Ok soil series were first intensively investigated by Attanandana (1971). She shipped tons of the soils to IRRI and carried out a classical experiment aiming at improving the soil by these four important practices, with and without performance; (1) leaching the soil to remove soluble acid salts; (2) liming with 7 ton/ha of $CaCO_3$ to minimize toxic effects of Al and other metallic elements; (3) presubmergence to

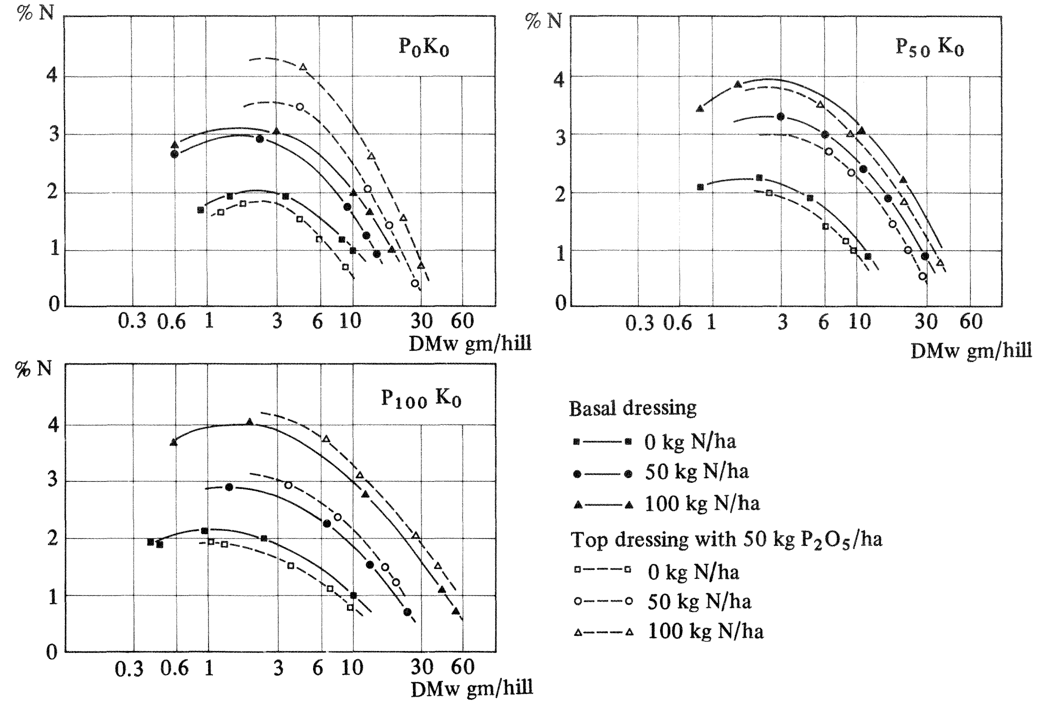
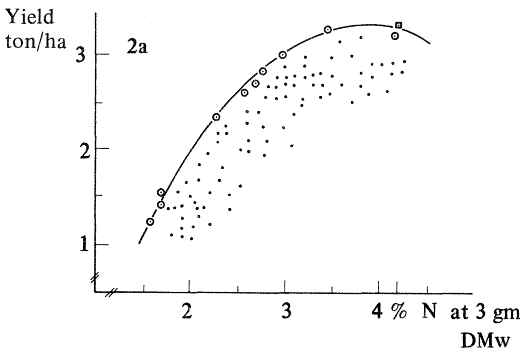
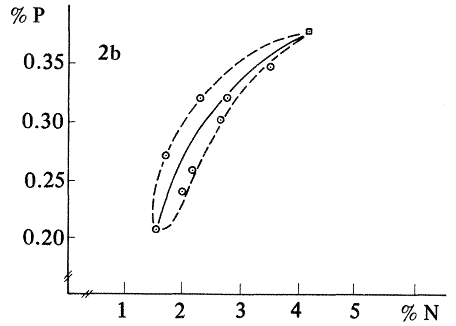
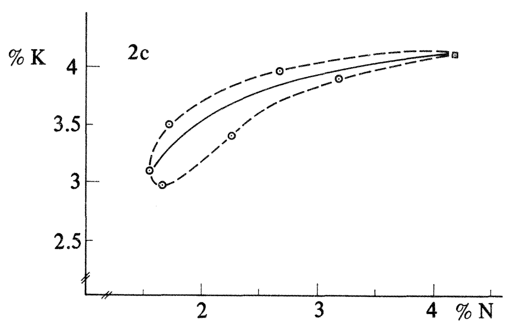


Fig. 1 N concentration as function of dry matter weight per hill.



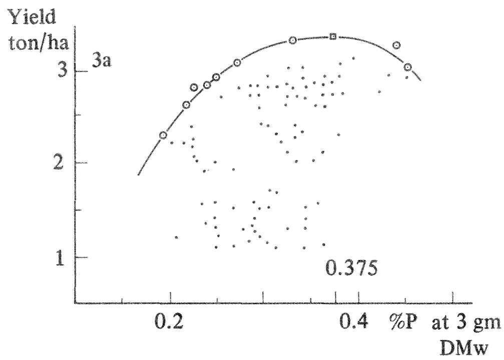


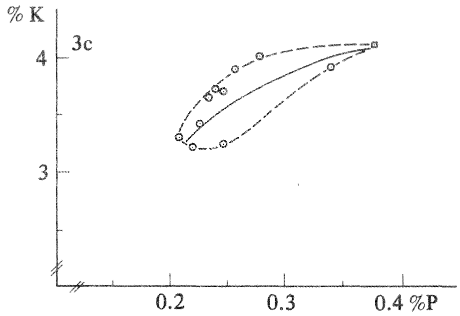


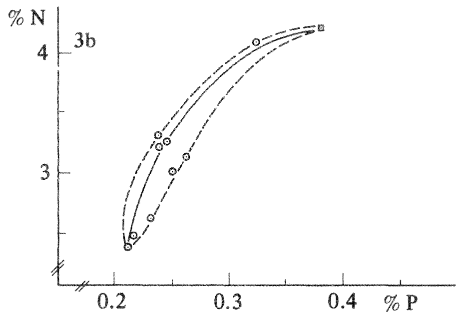
□ Absolute optimal concentration

Fig. 2 Diagnosis model.

2a. Pure effect of N on grain yield
2b. Relative optimal conc of F to pure N
2c. Relative optimal conc of K to pure N







⊡ Absolute optimal concentration

Fig. 3 Diagnosis model.

3a. Pure effect of P on grain yield
3b. Relative optimal conc of M to pure P
3c. Relative optimal conc of K to pure P

Table 15 Some important statistics of dry matter production (g/hill) of RD7 rice influenced by the most probable NPK rates (n=27 combinations) and their influence on grain yield at KRES (modified from Prabuddham, 1981 a)

WAT	Some statistical parameters						
	Max.	Min.	X	CV(%)	r	a	b
a. Wet season, 1977							
2 (X_1)	2.4	0.4	1.2	44	0.69**	0.98	1.10
3 (X_2)	9.2	0.9	4.2	75	0.65**	1.58	0.17
4 (X_3)	16.0	1.6	6.2	73	0.55**	1.67	0.10
5 (X_4)	36	4.0	13.0	69	0.63**	1.55	0.06
6 (X_5)	41	5.0	15.0	73	0.62**	1.58	0.05
7 (X_6)	46	6.0	18.0	67	0.62**	1.51	0.04
8 (X_7)	46	5.0	20.0	64	0.69**	1.41	0.04
Yield[1/] (X_8)	4.8	1.1	3.0	43	0.93**	0.52	0.59
Yield (Y)	3.3	1.1	2.3	36	–	–	–
b. Dry season, 1978[2/]							
2 (X_1)	1.8	0.6	1.0	31	0.81**	1.09	2.22
4 (X_2)	5.7	1.2	3.0	47	0.58**	2.27	0.35
6 (X_3)	10	3.0	7.0	38	0.69**	1.75	0.24
8 (X_4)	21	5.0	12.0	39	0.84**	1.49	0.15
10 (X_5)	44	7.0	21.0	48	0.79**	1.91	0.07
Yield (X_6)	3.5	1.6	2.5	22	0.85**	0.19	0.21
Yield (Y)	5.0	2.0	3.3	26	–	–	–

Note: [1/] Calculated yield from sampling yield (g/hill x 0.16)
[2/] 6 ton $(CaOH)_2$/ha was applied 3 weeks before transplanting, the others remain the same as the 1st crop.

Table 16 Some important statistics of the contents (%) and uptake (mg/hill) of N and P of RD 7 rice influenced by most probable NPK rates (n=27 combinations) and their influence on grain yield at KRES (modified from Prabuddham, 1981 b)

WAT	Some statistical parameters						
	Max	Min	X	CV(%)	=	a	b
a. Wet season, 1977							
(a) N content (%)							
2 (X_1)	4.1	1.8	2.9	29	0.75**	0.14	0.74
3 (X_2)	4.1	1.7	2.7	27	0.83**	−0.23	0.94
4 (X_3)	3.3	1.7	2.5	22	0.80**	−0.69	1.20
5 (X_4)	3.5	1.5	2.2	25	0.54**	0.46	0.83
6 (X_5)	2.2	0.8	1.2	32	0.52**	0.97	1.11
8 (X_6)	1.1	0.4	0.7	25	−0.29NS	–	–
(b) N uptake (mg N/hill)							
2 (X_1)	89	10	40	63	0.55**	1.57	0.02
3 (X_2)	340	15	134	89	0.63**	1.72	4.34
4 (X_3)	350	30	159	78	0.63**	1.64	4.17
(c) P content (%)							
2 (X_1)	0.34	0.08	0.20	40	0.29NS	–	–
3 (X_2)	0.37	0.14	0.26	27	0.21NS	–	–
4 (X_3)	0.39	0.22	0.31	17	−0.12NS	–	–
5 (X_4)	0.37	0.22	0.30	16	−0.07NS	–	–
6 (X_5)	0.36	0.11	0.20	30	−0.27NS	–	–
8 (X_6)	0.23	0.12	0.18	19	−0.54**	−3.68	−33.2
(d) P uptake (mg P/hill)							
2 (X_1)	6.60	0.55	2.60	76	0.51**	1.75	0.21
3 (X_2)	32.4	1.3	12.3	89	0.57**	1.77	0.04
4 (X_3)	51.0	3.8	19.8	81	0.49**	1.79	0.03
b. Dry season, 1978							
(a) N content (%)							
2 (X_1)	3.2	2.0	2.5	15	0.73**	−0.89	1.70
4 (X_2)	2.7	1.8	2.2	11	0.04NS	–	–
(b) N uptake (mg N/hill)							
2 (X_1)	51.8	12.8	25.5	42	0.63**	2.60	0.05
4 (X_2)	128	18	68	47	0.54**	2.34	0.01
(c) P content (%)							
2 (X_1)	0.41	0.11	0.23	39	0.66**	1.83	6.42
4 (X_2)	0.38	0.13	0.24	32	0.46*	2.08	5.11
6 (X_3)	0.38	0.11	0.25	34	0.57**	1.88	5.73
8 (X_4)	0.30	0.11	0.23	29	0.51**	1.76	6.71
(d) P uptake (mg P/hill)							
2 (X_1)	6.97	0.77	2.47	67	0.64**	2.49	0.33
4 (X_2)	16.2	1.7	7.7	62	0.61**	2.48	0.11

Table 17 **Influence of N and P on dry matter, contents and uptake of NPK at maturity of RD7 rice at KRES, wet season 1977**

	N level (kg N/ha)			P level (kg P/ha)		
	N_0	N_{50}	N_{100}	P_0	$P_{21.8}$	$P_{43.7}$
Dry matter (ton/ha[1])						
Grain	1.46^c	3.16^b	4.48^a	3.13^k	3.04^k	2.93^k
Straw	1.83^c	3.61^b	5.05^a	3.63^k	3.47^k	3.40^k
Total top	3.29^c	6.77^b	9.43^a	6.76^k	6.51^k	6.33^k
NPK contents (%)						
a. Grain						
N	1.0^a	0.9^a	1.0^a	1.0^k	1.0^k	1.0^k
P	0.29^a	0.29^a	0.29^a	0.25^l	0.30^k	0.32^k
K	0.34^a	0.40^a	0.41^a	0.36^k	0.39^l	0.41^k
b. Straw						
N	0.41^a	0.32^b	0.33^b	0.37^k	0.36^{kl}	0.34^l
P	0.11^a	0.12^a	0.08^b	0.08^m	0.10^l	0.13^k
K	2.0^a	2.2^a	2.1^a	2.2^k	2.1^k	2.0^k
NPK uptake (kg/ha)[2]						
a. Grain						
N	14.1^c	29.5^b	45.4^a	30.2^k	30.0^k	28.9^k
P	4.2^c	9.3^b	12.9^a	7.7^k	9.2^k	9.5^k
K	5.1^c	12.6^b	18.4^a	11.4^k	12.5^k	12.3^k
b. Straw						
N	7.6^c	11.6^b	17.2^a	11.5^k	12.7^k	12.2^k
P	2.0^b	4.1^a	4.3^a	2.6^l	3.4^{kl}	4.4^k
K	37.0^c	79.5^b	105.6^a	84.5^k	70.2^k	67.4^k
c. Total top						
N	21.7^c	41.1^b	62.6^a	41.7^k	42.6^k	40.8^k
P	6.3^c	13.4^b	17.2^a	10.3^l	12.7^{kl}	13.8^k
K	45.9^c	92.2^b	123.8^a	95.7^k	86.4^k	79.7^k

1) Calculated from :

$$\text{Dry matter (kg/ha)} = \frac{\text{dry matter (g/hill) x 160,000 (hill/ha)}}{\text{1000 (g/kg)}}$$

2) The N P K uptake was also calculated as in [1].
Same letter in the same line indicates no significant difference ($\alpha = 0.05$)

Table 18 Influence of soil amelioration on grain yield (g/pot) of RD1 and relative response and some important factors controlling grain yield on OK soil series (modified from Attanandana, 1971)

Treatment	Grain yield g/pot Y	Grain yield Response %	pH at planting X_1	Panicle number X_2	Straw g/pot X_3	Sterility % X_4
Le + Li	49	36.1	5.94	27	146	33
Le + MnO_2	48	33.3	5.23	25	144	28
Le + Li + MnO_2	47	30.6	5.86	26	155	33
Li + MnO_2	47	30.6	5.38	25	146	32
Li + Ps	45	25.0	5.61	25	136	35
Le + Li + Ps + MnO_2	45	25.0	4.76	25	144	29
Le + Li + Ps	44	22.2	4.63	27	137	34
Li	43	19.4	5.48	26	132	37
Le	43	19.4	5.00	27	129	28
Le + Ps	41	13.9	4.10	27	129	32
Li + Ps + MnO_2	40	11.1	5.49	26	146	38
Ps + MnO_2	39	8.3	4.62	27	138	38
Le + Ps + MnO_2	38	5.6	4.62	25	139	35
Ps	38	5.6	4.88	26	133	35
MnO_2	37	2.8	4.32	26	132	38
Control	36	0	4.27	27	135	41
r			0.71**	0.25^{NS}	0.49^{NS}	-0.68**
a			16.51	–	–	17.0
b			5.19	–	–	0.75

Note: Le = leaching; Li = Lime; Ps = presubmergence

– All plots received 75 ppm each of N, P and K in 12 kg soil/pot.

avoid peak concentration of toxin for 4 WAS and (4) addition of 0.5% MnO_2 to retard excessive soil reduction. She used RD1 rice planted at the same time in 12 kg soil/pot with ample supply of N P K (75 ppm each of N,P and K). Various chemical reactions for possible adverse factors were also investigated. Grain yield and response to the amelioration techniques and some important factors controlling the yield are retabulated and summarized in Table 18. From this Table one can see that (1) liming + presubmergence of this Ok soil series may be the most practical amelioration technique for farmer; (2) pH at transplanting was positively correlated ($r = 0.71^{**}$, $n = 16$) with grain yield and (3) sterility (% no/no) was negatively correlated ($r = -0.68^{**}$) with the plant yield. Sterility of the grain, undoubtedly reflects rhizospheric environment of the acid sulfate soil negatively influenced by the soil pH. These discoveries promoted Im-Erb (1979) to reinvestigate the effect of liming, as has been already discussed in the P III a soils. It should be mentioned also here that the P IV a, Rs-a soil responds very well to lime if plant nutrients are not limited (35% in the first crop and 61% in the residual effect). Im-Erb (1979) also compared the efficiency of Thai RP, FMP and TSP at 100 ppm total P_2O_5 level in the absence and presence of flue dust in her third experiment in Rs-a soil (Table 19). One can see from the Table that: (1) liming slightly depressed grain yield; (2) FMP was the best and Thai RP (TRP) was the worst of the three P sources regardless of liming; (3) interaction was observed clearly for the TRP by negative effect of lime, and (4) without lime TRP contributed 64% efficiency with reference to TSP. Therefore, if available P_2O_5 basis is used, TRP could be more effective than TSP. More or less at the same time as Im-Erb (1979), Pongpayack (1979) carried out a field trial at farmer's field near OLDC (P IV - a) to test the effect of limes and fertilizers on RD1 rice plant. Table 20 shows the calculated grain yield from total dry matter in the experiment and straw/grain ratio of P residual experiment.

Table 19 Effect of flue dust (0.3%) and P sources (100 ppm total P) on grain yield (g/pot) of RD1 rice in Rs-a series (Im-Erb, 1979)

Lime	P sources			Lime effect
	TRP	FMP	TSP	
Lime	20.8	68.4	65.6	51.6
% of TSP	31.7	104.3	100	–
No lime	40.2	71.2	62.2	57.9
% of TSP	64.2	113.7	100	–
P effect	30.5	69.8	64.1	–

Note: 1. TRP = Thai rock phosphate (36.6% total P_2O_5)

2. EMP = Fused magnesium phosphate (20% avail P_2O_5)

3. TSP = Triple superphosphate (45% avail P_2O_5)

4. TRP was applied on the basis of total P, while the other P source on the basis of available P.

Table 20 Influence of limes and fertilizers on grain yield of RD1 rice in Rs-a (Pongpayack, 1979)

Fertilizer kg/ha		Liming materials				Mean fertilizer effect	
		Slaked lime		Marl			
N	P_2O_5	kg/ha	Response %	kg/ha	Response %	kg/ha	Response %
First crop							
0	0	700	0	362	0	531	0
56.25	70.3[1/]	2,881	312	2,606	620	2,744	417
112.5	140.6[2/]	2,994	328	2,800	673	2,897	446
56.25	70.3[3/]	988	41	619	71	804	51
Lime effect		1,891	–	1,597		1,769	
Second crop							
a. **Residual effect of limes**							
0	0	870	0	865	0	868	0
56.25	70.3	2,994	244	2,872	232	2,933	238
112.5	140.6	3,463	298	3,419	295	3,441	296
56.25	70.3	1,551	78	1,439	66	1,495	72
Lime effect		2,220	–	2,149	–	2,184	
b. **Repeated application of limes**							
0	0	923	0	903	0	913	0
56.25	70.3	3,090	235	2,950	227	3,020	231
112.5	140.6	3,592	289	3,426	279	3,509	284
56.25	70.3	1,641	78	1,471	63	1,556	70
Lime effect		2,312	–	2,188	–	2,250	–

1/ and 2/ 16-20-0 compound fertilizer was used at the rate of 351.6 and 703.1 kg/ha respectively;

3/ Mixed fertilizer: urea (46% N) and Thai rock phosphate (37% total P_2O_5 basis) was used for 1/ and 3/ comparison.

Table 21 Correlation coefficient and regression analysis of grain yield of RD 1 and some yield components (X_n) in Rs-a soil (n = 16) (Pongpayack, 1979)

Yield components X_n	r	Linear regression
Tiller no/hill, 10 WAT, X_1	0.9911**	$Y = -93.79 + 24.64 X_1$
1,000 grain weight, X_2	0.9798**	$Y = -3{,}680 + 1{,}560.2 X_2$
Good grain no/panicle, X_3	0.9736**	$Y = -410.61 + 11.51 X_3$
Straw weight, X_4	0.9457**	$Y = 75.18 + 0.63 X_4$
Panicle no/hill, X_5	0.9228**	$Y = -173.0 + 53.03 X_5$
% unfilled grain (wt/wt), X_6	- 0.7771**	$Y = 775.34 - 50.27 X_6$

This table clearly shows that: (1) Rs-a is very deficient in N and P; (2)urea RP efficiency was depressed by limes in the 1st crop but it was recovered in the 2nd crop. However, if the calculation was based on citrate solubility, the TRP efficiency surpassed that of ammophos especially in the 2nd crop. These fertilizers and lime played a large role in the growth and yield components of the crop as illustrated in Table 21. Another investigation carried out by our former graduate student (pot trial) also provides much valuable information as illustrated in Tables 22 and 23 (Paditaporn, 1980). Table 22 also shows the efficiency of the TRP regardless of marl or even in the presence of it. Bray II-P values of the residual TRP could be used to predict the rice yield in Rs-a and other P IV a soils, probably (Table 23).

The results of these three M.S. theses strengthen the DA recommendation mentioned in the former part. Very recently Attanandana *et al.* (1981) have investigated the chemical characteristics and fertility status of acid sulfate soils with emphasis on the problems and improvement of the Rs-a series which has low total and extractable contents of Si and P and low exchangeable K and extractable Fe, Mn and Cu but high exchangeable Al, Na and Mg as well as quite high jarosite and pyrite contents in the surface horizon as compared with P I, P II a and P III a representatives. Pot experiment on rate of N, P and K with and without lime of this Rs-a soil showed distinctly lower dry matter content than in the good rice producing soils. In the absence of P, high content of Fe and Mn in the plant was observed. With complete fertilizer, high levels of S, Al and Na but low contents of P, Mg and Si in the plant were the common phenomena. This discovery undoubtedly will be very valuable for future investigations on yield potential.

Progress of the rice yield improvement in Acid Sulfate Soils Project

Since the designation of a working committee for the RYIASS in 1978, recommendation of the DA and LDD has been tested both in the experiment stations and farmer's field aiming at the most economical and practical package of technology for the farmers. The 1978–1979 report (253 pages) has been released (Working Committee RYIASS, 1980). Some of the technical results

Table 22 Influence of marl and Thai rock phosphate on grain yield of RD7 rice in Rs-a (modified from Paditaporn, 1979)

Rock phosphate rate	No marl		Marl		Rock phosphate effect	
g/pot	Yield g/pot	Response %	Yield g/pot	Response %	Yield g/pot	Response %
Fist crop						
0	1.4	0	0.9	0	1.2	0
3,205	23.3	1,564	34.6	3,744	29.0	2,317
6,410	49.5	3,436	44.5	4,789	47.0	3,817
9,615	58.9	4,107	46.6	5,078	52.8	4,300
Lime effect	33.3	–	31.6	–	32.5	–
Second crop (residual phosphate)						
0	1.4	0	1.8	0	1.6	0
3.205	10.6	657	10.3	472	10.4	550
6.410	19.0	1,257	11.1	517	15.0	838
9.615	29.4	2,000	20.0	1,011	24.7	1,444
Lime effect	15.1	–	10.6	–	12.9	–

Marl was applied to raise soil pH to 6.0

Table 23 Correlation coefficient and regression analysis of grain yield Y_1 and Bray II-P and some yield components of RD7 rice in Rs-a (Paditaporn, 1979)

Independent variable		Regression
Bray II-P (ppm), X_1	0.88**	$Y = 0.78 + 0.7219 X_1$
Panicle/hill, X_2	0.99**	$Y = 1.64 + 0.59 X_2$
Good grain/panicle, X_3	0.82*	$Y = 26.01 + 1.52 X_3$

Table 24 Effect of liming and fertilization on rice yield (ton/ha) at Experiment Stations (modified from Charoenchamratcheep *et al.*, 1981)

Treatment	Rs (TLDC)[1)]		Rs-a (OLDC)[1)]		Rs (KRES)[1)]		Rs (PRES)[1)]	
	Yield	Res %	Yield	Res %	Yield	Res %	Yield	Res %
CK	3.6	0	0.3	0	1.6	0	1.8(3)	0
AS	3.7	3	0.4	33	–	–	–	–
AP	4.4	22	2.9	867	3.1	94	2.1	17
AP+L_1	5.1(3)	42	3.2	967	3.5(2)	119	1.9	6
AP+L_2	4.5	25	4.3(2)	1,333	3.6(3)	125	2.5(2)	39
AP+L_3	4.6	28	3.8	1,167	3.8(1)	138	2.7(1)	50
AS+R_1	4.1	14	3.7	1,133	3.2	100	2.2	22
AS+R_2	3.5	–3	3.7	1,133	3.0	88	2.1	17
AS+R_3	4.0	11	3.4	1,033	3.0	88	2.2	22
AS+R_2+L_1	5.5(3)	53	4.4(3)	1,367	–	–	–	–
AS+R_2+L_2	5.7(1)	58	4.8(1)	1,500	3.6	125	2.5	39
AS+R_2+L_3	4.7	31	3.9	1,200	–	–	–	–

Note: PRES = Prachin Buri Rice Experiment Station

Res = Response to the CK plot (%)

Figure in parenthesis = rank of net profit

1) RD7 rice variety was used

AS = ammonium sulfate (20% N) = 150 kg/ha

AP = ammonium phosphate (16–20–0) = 187.5 kg/ha

L_1, L_2, L_3 = marl 6.25, 12.5 and 18.75 ton/ha

R_1, R_2, R_3 = Thai rock phosphate 0.625, 1.25 and 1.875 ton/ha

CK = check

have also been presented recently (Charoenchamratcheep *et al.*, 1981) and rearranged and tabulated in Tables 24 and 25. Variation in actual yield among locations within Rs soil series in Table 24 is undoubtedly due to many environmental factors controlling growth and yield of rice, within the series as indicated in Table 2, besides water and pest management problems dictating the yield variation. Tremendous increase after AP application as compared with AS application in Rs-a soils at OLDC and P.P and may be N.S. indicates serious P deficiency in the soil series (Tables 24 and 25). Detailed variation of fixed and variable cost of each treatment in the locations studied has been reported (Charoenchamratcheep *et al.,* 1980). Evaluation of variable cost seems to be unfair for the RP treatment as compared with the marl one because: (1) there was no subsidy at all for the RP in contrast to marl (mining and personnel); (2) transportation cost within the farmer's field by the farmer was omitted, marl should be paid 10 times more than RP; (3) sieving and/or grinding cost for marl during this trial was also omitted and (4) residual effect of RP was omitted but not that of marl. If mining and grinding the RP were offered by LDD in the same manner as for the marl, net return from the RP treatment might be high.

Flooding and drought, besides the acidity problems, control the management practices of the farmer. Flooding of the major part of the acid sulfate soils forces the farmers to utilize tall and leafy photoperiod sensitive *indica* varieties that have poor N receptivity and, therefore, low yield.

It could be concluded partly at this stage that the class II a soils need no lime nor RP but they need ammophos or other mixed or single N P fertilizer having no NO_3. The P III a soils might need only N and RP, while for the P IV a soils liming is essential. However, more economic investigations on these two classes are needed.

Table 25 Effect of liming and fertilization on rice yield (ton/ha) at farmer's field (modified from Charoenchamratcheep *et al.,* 1981)

Treatment	Rs-a(N.S)		Rs-A(P.P.)		Ma (B.S.)		Ay (B.P.)	
	Yield	Res.%	Yield	Res.%	Yield	Res.%	Yield	Res.%
CK	2.4	0	1.6	0	3.3	0	4.1	
L_2	2.7(3)	12	–	–	–	–	–	–
AS	–	–	1.8	12	4.3	30	5.1	24
AP	3.6(2)	50	3.0(3)	88	4.1	24	4.7	15
$AS+R_1$	–	–	2.6	62	4.5	36	4.8	17
$AS+R_2$	3.5	46	3.0	88	4.6	39	4.8	17
$AP+L_1$	–	–	3.3(1)	106	4.5	36	5.1	24
$AP+L_2$	4.0(1)	67	3.2(2)	100	4.5	36	5.0	22

Note: N.S = Nong Sua, Pathum Thani (RD7)
P.P = Pak Phli, Nakorn Nayok, (Kan Mali)
B.S = Ban Sang, Prachin Buri, (Hah Ruang)
B.P = Bang Pa-in, Ayutthaya, (RD7)

Other abbreviations are the same as in table 24.

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Discussion

Imai, H. (Japan): 1) You mentioned that Patalung phosphorus fertilizer was easily dissolved and increased phosphorus concentration in the soil solution. May I have more precisions in this regard? 2) You mentioned that the application of 37.5 kg P_2O_5 of Patalung fertilizer resulted in maximum yield of rice. However when you increased the content in phosphorus of the fertilizer, yield tended to decrease. Could you explain why? 3) I have observed that when 100 mg/g P soil was added to Klang Luang soil which is a typical acid sulfate soil, phosphorus adsorption increased steeply due to the formation of an aluminum-phosphorus complex by precipitation. I agree with you that rock phosphate application is highly recommendable because the phosphorus added to the soil is easily dissolved, resulting in the promotion of phosphorus precipitation.

Answer: 1) Patalung P is a Thai rock phosphate which was discovered in the Patalung province in the southern part of Thailand. It is released gradually depending on the size of the particles and the second crop usually shows a better response to that fertilizer. 2) The difference recorded is probably not statistically significant. 3) Thank you very much for your explanation.