Kasetsart J. (Nat. Sci.) 34 : 323 - 331 (2000)

Identification of Nutrients Limiting Rice Seedling Growth in Soils of Northeast Thailand under Water-Limiting and Non-Limiting Conditions

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ABSTRACT

Glasshouse nutrient omission trials are useful in identifying nutrient limitations for plant growth in a number of soils under the same environmental conditions. Soils of low fertility are commonly used for production of rainfed lowland rice (*Oryza sativa* L.), and the crop often encounters water stress. Nutrient requirements may be modified when standing water disappears from the field. Two experiments with rice seedlings were conducted in a glasshouse at Ubon Rice Research Center, Thailand, to identify the nutrients which limit rice growth in soils of Northeast Thailand, and to determine whether nutrient limitations are affected by water availability. In Experiment 1, rice was grown on two soils (Roi Et and Ubon series) under well-watered and water-limiting conditions, and 15 nutrient treatments were imposed. In Experiment 2, six soils from Northeast Thailand were examined using the same 15 nutrient treatments. The nutrients which clearly limited the growth of rice plants in soils of Northeast Thailand were nitrogen (N) and phosphorus (P). In some cases, potassium (K) and sulfur (S) also limited growth, and in one soil zinc (Zn) and boron (B) also limited growth. A shortage of N was the most important limitation for plant growth in all soils except one in which P was more important. The low supply of P decreased plant height and leaf area development during early growth; low N supply had a greater effect later during growth. The omission of P had a larger detrimental effect on growth when water supply was limited. In the Roi Et soil, the omission of S had a large effect on leaf area and total dry matter production only under water stress conditions, but this was not found in the other soils examined. These results from glasshouse studies showed that the nutrients limiting rice growth depend on soil type and water availability in soils of Northeast Thailand.

Key words : nitrogen, nutrient omission, *Oryza sativa* L., phosphorus, potassium

INTRODUCTION

The low productivity of rainfed lowland rice (*Oryza sativa* L.) in Northeast Thailand is linked to a general paucity of nutrients in the coarse-textured, acidic soils that prevail in the region. Dudal(1980)described problems associated with coarse-textured soils as low water-holding capacity, low cation exchange capacity and a deficiency in minor nutrients,including zinc (Zn), manganese (Mn), copper (Cu) and iron (Fe), normally bound to clay and organic matter. The utilization of applied nutrients, especially nitrogen (N), is low due to rapid leaching of nitrate in the coarse-textured soils. Under these conditions, rice yield responses to N and P fertilizer are often not

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high (Ragland and Bunpuckdee 1987).

In rainfed lowland rice in Northeast Thailand, water shortage is common as the amount of rainfall is only between 1000 and 1500 mm per annum(Keerati-Kasikorn, 1984). When the soils are no longer submerged or saturated, the reduced soils begin to oxidise, soil acidity increases, and the availability of plant nutrients, particularly phosphorus (P) decreases. Whether or not these changes decrease crop yield depend upon how rapidly the soil dries and the stage of plant growth when these changes occur. Several experiments have investigated the drought tolerance of rice in Northeast Thailand (Jearakongman *et al.*, 1995; Wonprasaid *et al.*, 1996). The results of these experiments showed that adapted rice cultivars were not only drought-tolerant, but also grew well under low fertility and low pH, the common features of soils in Northeast Thailand. In these soils, however, there is little information on which nutrients limit the growth of rice and how the nutrient availability is affected by water supply. Therefore, the aim of this study was to identify those nutrients that limit growth under well-watered and water-limiting conditions in a number of soils in Northeast Thailand. Soils were collected from different areas, and plants were grown in these soils under the same growing conditions.

MATERIALS AND METHODS

Two pot-experiments in glasshouse were conducted at the Ubon Rice Research Center, Ubon Ratchathani, Thailand.

1. Soils

Rice plants were grown on three soil series common in Northeast Thailand: Roi et (fine, loamy, kaolinitic, acid aric paleaquults) occupying 60% of paddy fields in the Ubon Ratchathani province, Ubon (coarse, loamy, siliceous, aquatic dystropepts) occupying 18% of Ubon paddy fields, and Phimai (vertic tropaquepts) occupying 1% paddy field of Northeast Thailand (Keerati-Kasikorn, 1984). Quantities of Roi et soils were collected from Ubon Rice Research Center (URRC), Sakon Nakhorn Rice Research Center (SKN), Surin Rice Experiment Station (SRN), Chum Phae Rice Experiment Station (CPA), Khon Kaen Rice Experiment Station (KKN) and Udon Rice and Temperate Cereal Experiment Station (UDN). Soil collected from another area at the Ubon Rice Research Center was classified as Ubon soil series, and the soil collected from Phimai Rice Experiment Station (PMI) as Phimai series.

Soil samples were collected from 0–20 cm depth at each site, and the samples were air-dried in a glasshouse. Rocks, clods and macro organic matter (e.g. undecomposed rice straw) were removed by sieving through a 2 cm screen.

The physical and chemical characters of these soils are shown in Table 1. All soils were acid, with pH (1:1 soil:water) varying from 4.42 (Roi Et soil URRC) to 6.12 (Phimai soil) indicative of the acid soils of Northeast Thailand. Likewise, all soils had extremely low organic matter (potassium dichromate method). Extractable P (Bray II method) varied from low (Roi Et soil at CPA and UDN) to moderate (Ubon soil URRC). Both the Roi et and Ubon soils had low cation-exchange capacity (CEC), in keeping with the low clay percentage in these soils. The exchangeable K level was low (Roi et soil SRN) to moderate (Roi et soil URRC).

2. Nutrient treatments

In each experiment, there were 15 nutrient treatments. These included four treatments aimed at establishing the response of rice to the application of all nutrients: 1. Control (no nutrient application), 2. Control+$Ca(OH)_2$, 3. All (N+P+K+Mg+S+Fe+Mn+Cu+Zn+B+Mo), 4. All+$Ca(OH)_2$. Each of the remaining treatments evaluated the omission of a single nutrient in turn: 5. All+$Ca(OH)_2$-N, 6. All+$Ca(OH)_2$-P, 7. All+$Ca(OH)_2$-K, 8. All+$Ca(OH)_2$-Mg, 9. All+$Ca(OH)_2$-S, 10. All+$Ca(OH)_2$-Fe, 11. All+$Ca(OH)_2$-Mn, 12. All+$Ca(OH)_2$-Cu, 13. All+$Ca(OH)_2$-Zn, 14. All+$Ca(OH)_2$-B, 15. All+$Ca(OH)_2$-Mo. The chemical forms and the rates of nutrients applied are shown in Table 2.

The effect of nutrient omission was determined by comparing the result of each treatment with that of Treatment 4. Treatments 2 and 4 were compared with Treatments 1 and 3, respectively, to examine the effect of liming to pH 6.0 with $Ca(OH)_2$.

3. Experiment 1

This omission pot experiment studied the growth of rice on two soils: Roi Et and Ubon soil series from URRC with the 15 nutrient treatments

Table 1 Physical and chemical properties of soils collected from eight sites in Northeast Thailand. The first two soils were used in Experiment 1. The remaining soils were used in Experiment 2.

Soil series	Site	pH (H_2O)	Organic matter (%)	Extractable P (mg kg^{-1})	Exch. K (mg kg^{-1})	CEC (cmol$_c$ kg^{-1})	Texture (%) Sand	Silt	Clay	Textural class
Roi Et	URRC	4.42	0.57	27	50.0	1.85	61	31	8	sandy loam
Ubon	URRC	4.68	0.97	74	25.0	1.53	77	18	5	loamy sand
Roi Et	SKN	5.45	1.81	25	14.8	-*	84	12	4	loamy sand
Roi Et	KKN	5.51	0.67	15	44.4	-*	74	14	12	sandy loam
Roi Et	CPA	5.40	0.36	10	44.4	-*	62	16	22	clay loam
Roi Et	UDN	6.04	1.20	10	33.3	-*	68	18	14	sandy loam
Roi Et	SRN	4.87	0.97	15	18.5	-*	72	22	6	sandy loam
Phimai	PMI	6.12	0.33	15	77.7	-*	58	14	28	silty clay loam

* No data available

Table 2 Salt forms and nutrient rates used in the nutrient omission pot trials.

Nutrient	Salt	Nutrient rate (kg/ha)
N	Urea	100
P	$NaH_2PO_4.H_2O$	30
K	KCl	80
Mg	$MgCl_2.6H_2O$	30
S	Na_2SO_4	25
Fe	$FeCl_2.4H_2O$	5
Mn	$MnCl_2.4H_2O$	5
Cu	$CuCl_2.2H_2O$	3
Zn	$ZnCl_2$	4
B	H_2BO_3	2
Mo	$(NH_4)_6Mo_7O_{24}.4H_2O$	0.4

detailed above. There were also two water supply treatments: well-watered and water-limited. In the well-watered treatment, the pots were maintained with 3 cm standing water after Week 2. In the water-limiting condition, after 2 weeks growing in well-watered condition, water was applied to field capacity for 2 weeks (week 1 and week 2), then in the third weeks of treatment (week 3), water was added to each pot with 70% *(for 4 days) and 50% *(for 3 days)(week 4) of water used by the plants in the well-watered treatment during week 1 and 2, to impose a moderate water stress. Water was then applied to field capacity during Week 4, and water stress again imposed over the subsequent weeks. In the subsequent 2 weeks, the well-watered condition was maintained and the plants were harvested. Treatments were laid out in a factorial design with four replications.

4. Experiment 2

The growth of rice was studied on six soils collected from SRN, SKN, KKN, CPA, and UDN (Roi-Et series) and PMI (Phimai series) in which 15 nutrient treatments were imposed as in Experiment 1. Rice was grown for 7 weeks under well-watered conditions with continuous standing water after Week 2. Treatments were arranged in a randomized complete block design with four replications.

5. Experimental procedures

Pots with 15.5 cm diameter were lined with two polyethylene bags to cover the drainage holes. Except for Treatments 1 and 3, finely-ground analytical grade $Ca(OH)_2$ was added to the soil for each pot and mixed thoroughly. Thereafter, except for N, nutrients were applied to the soil in solution. Nitrogen, as urea, was applied at the time that the flooded treatment was imposed in order to reduce the possibility of ammonium conversion to nitrate, and subsequent loss by denitrification in the waterlogged conditions.

Six uniform seeds of the rice cultivar, RD6, were sown at a depth of about 1 cm, and sufficient deionized water was added to bring soil moisture content of each pot up to field capacity, a condition maintained for 2 weeks after sowing. Seedlings were thinned to maintain 3 plants per pot. Thereafter, the two water treatments were imposed in Experiment 1 or standing water imposed in Experiment 2.

Leaf area was measured using a leaf area meter(LI-COR LI-3000A,1988) at the end of the growth period in Experiment 1, and in Weeks 4 and 6 in Experiment 2. Plant height was determined three times(at 2,4 and 6 weeks after sowing) in Experiment 2. Tiller number and total dry matter (TDM) of tops were determined at the end of each experiment. All results are expressed on a pot (3 plants) basis.

RESULTS

In both experiments, poor growth of rice was evident in all soils to which no nutrients had been added (Treatment 1). Growth was markedly increased in Treatment 3, in which all nutrients had been applied, but liming to pH 6.0 had no beneficial effect on plant growth (i.e. growth in Treatments 2 and 4 was no better than that in Treatments 1 and 3, respectively). Since all other nutrient treatments had received lime, Treatments 2 and 4 were used

* to obtain the 70% and 50% water used in well-watered condition, weigh the pots with soil and plant(B) before applying water, then after applied water weigh the pot(A) again. The amount of water applied(Y) is equal to : Y = A–B

70% of well-watered = 70(A–B) /100

50% of well-watered = 50(A–B)/100

for comparison of all other results.

1. Experiment 1

For both leaf area and TDM, there(Table 3) were significant main treatment effects of nutrient, water and soil type and also all interaction effects except for water by soil interaction. There was a significant detrimental effect with the omission of N, P, K or S, but the effect differed in the two soils and under the two water conditions.

In the Roi et soil under well watered conditions, there was a large reduction in leaf area when N or P was omitted (Figure 1a). Indeed, leaf area in these treatments was only 11 and 5 % of that in Treatment 4 (all nutrients added). The effects of N and P omission were similar under water-stress conditions. The effect of K and S omission had only a slight effect on leaf area under well watered conditions, but omission of S caused large reduction in leaf area under water-stress conditions. The effect of nutrient omission on TDM was similar to that on leaf area, but the effect was generally greater (Figure 1b). Omitting either N or P resulted in TDM similar to the nil nutrient (i.e. control) under both water conditions. Again, the omission of S had no effect under flooded conditions, but TDM was only 13 % of that of Treatment 4 under water-stress conditions.

Where all nutrients had been added (Treatment 4), there was a significant increase in leaf area and TDM of the plants grown in the Roi et and Ubon soils (Figure 1). However, nutrient omission had the lesser detrimental effect on growth in the Ubon soil. In this soil under well watered conditions, omission of N had a larger effect than omission of P. In contrast, omission of P had the larger effect under water-limiting conditions. Omission of either K or S decreased leaf area and TDM slightly under well watered conditions, but not under water-stress conditions.

2. Experiment 2

For most measurements made, there were significant effects of soil, nutrient treatments and

Table 3 Effects of nutrient managements, water regime and soil type on leaf area and dry matter of rice (6 weeks after sowing).

Soils	Leaf area (cm^2)		Dry Matter(g)	
	All	Control	All	Control
Roi-Et	79.6	56.4	17	1
Ubon	81.1	56.3	16	3
Nutrient(N)	**		**	
Water (W)	**		**	
Soil (S)	**		**	
N x W	**		**	
N x S	**		**	
W x S	ns		<1	
N x W x S CV	ns		**	
(%)	28.3		17.4	

ns = not significant * = significant at 5% level ** = significant at 1% level

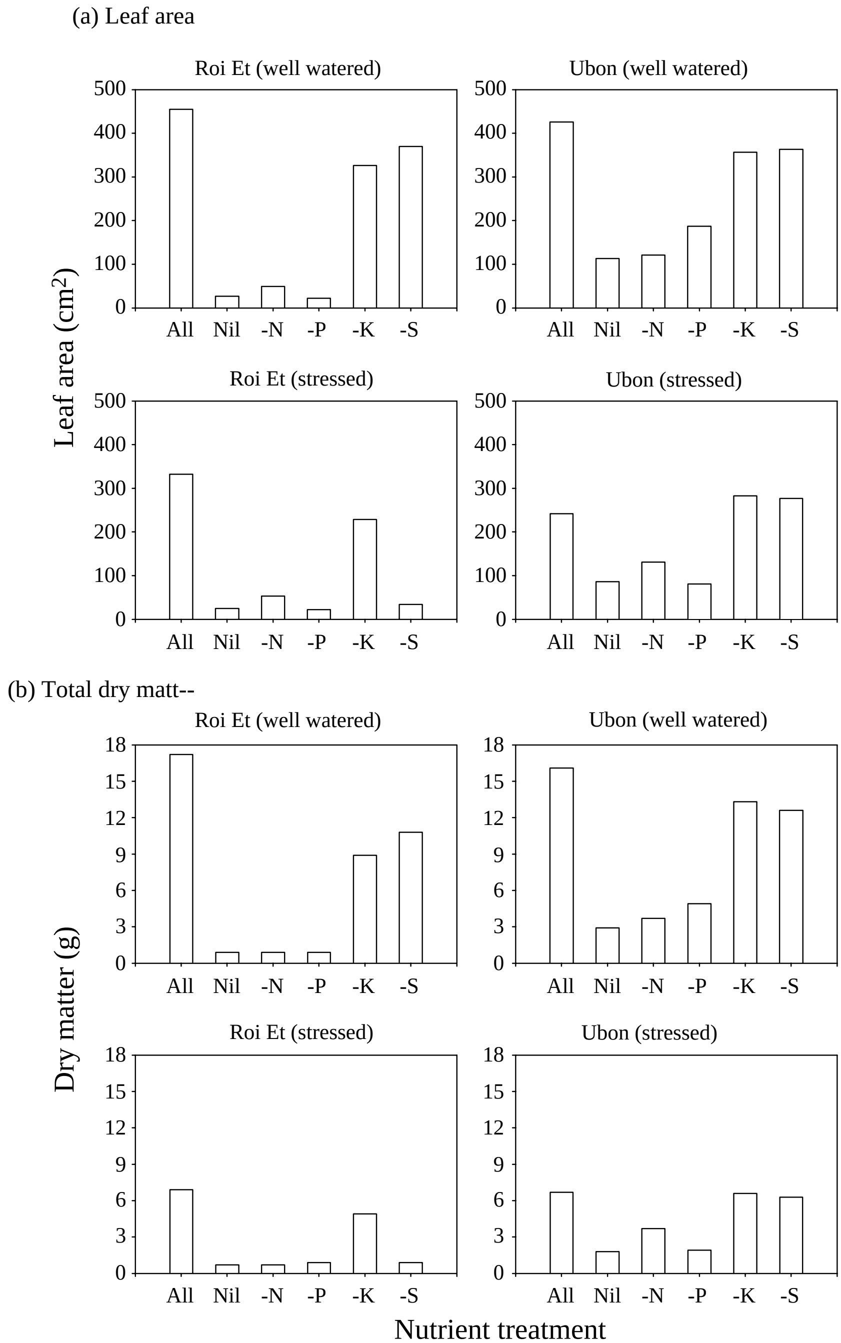

Figure 1 Response of rice seedlings (as measured by leaf area and total dry matter) to all nutrients applied(All) the omission of all nutrients(Nil), nitrogen(-N), phosphorus(-P), potassium(-K) and sulfur (-S). Rice seedlings were harvested after 6 weeks after sowing in two soils under well watered and water stress conditions (Experiment 1).

their interactions. There was a marked improvement in plant growth with the addition of all nutrients (Treatment 4) compared with Treatment 2 in which no nutrients had been applied (other than liming to pH 6) (Figure 2). Indeed, leaf area and TDM increased between 2- and 8-fold with the application of all nutrients. Omission of N had a similar detrimental effect to the omission of all nutrients in all soils. Omission of P, however, decreased plant performance only in the soils from PMI, KKN, CPA and UDN, whereas the effect was small and non-significant for soils from SRN and SKN. In the UDN soil, TDM with the omission of P was similar to that of nil nutrient addition. For PMI soil, omission of Zn and B also reduced dry matter production by about 30 %, and this reduction was significant.

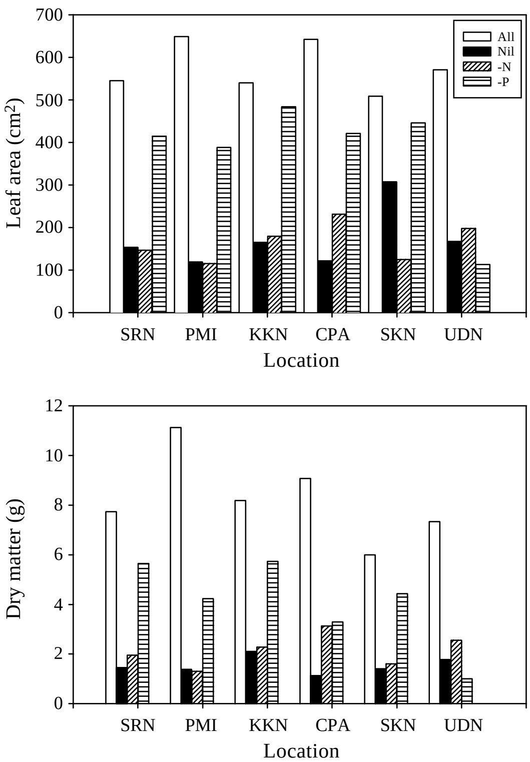

Figure 2 Response of rice seedlings as measured by leaf area and total dry matter to all nutrients applied(All), the omission of all nutrients(Nil) and of nitrogen(-N) and phosphorus(-P). Rice seedlings were harvested after 7 weeks on six soils from Surin(SRN), Phimai(PMI), Khon kaen(KKN), Chumphae(CPA), Sakon Nakhon(SKN) and Udorn Thani (UDN).

At 3 weeks after sowing, the mean effects of the omission of N, P and nil nutrient application across the six soils showed that plant height was most affected by P deficiency, but later N was most limiting (Table 4). A similar trend was found in leaf area. The results of nil nutrient addition indicate that at early stage omission of P alone and at later stages omission of N alone reduced plant growth to the same extent as no nutrient addition. At 6 weeks after sowing, the effect of nutrient omission on relative performance indicated as a percentage of the full nutrition addition was greater for height than for leaf area.

DISCUSSION

The experiments demonstrated that the largest nutritional limitation to rice growth in soils of Northeast Thailand was a shortage of N, and to a lesser extent P. The fact that omission of most other elements had little effect under well-watered conditions, and that plant growth in the N omission treatment was about the same as that of nil nutrient addition treatment, reflected the overall importance of N for growth of rice in these soils. Field experiments in rainfed lowland rice in Northeast Thailand often showed responses to fertiliser N application particularly when other elements were applied (Ragland and Bunpuckdee, 1987, Khunthasuvon *et al.*,1998). However, yield response varied in different locations, and was often small in the field experiments particularly when severe water stress developed (Ragland and Bunpuckdee, 1987).

Table 4 The effects of four nutrient treatments on plant height and leaf area of rice grown with standing water in Experiment 2. Data are the averages for the six soils which had been limed to pH 6.0.

Treatment	Plant height (cm)			Leaf area (cm^2)	
	24 das	31 das	38 das	28 das	50 das
Control	30.5 (84)	33.2 (72)	36.7 (62)	70 (33)	172 (30)
All	36.3 (100)	46.1 (100)	58.9 (100)	215 (100)	576 (100)
All-N	32.8 (90)	35.0 (76)	37.1 (63)	95 (44)	166 (29)
All-P	29.7 (82)	35.2 (76)	48.2 (82)	78 (37)	378 (66)
LSD (P=0.05)	4.54	6.53	8.63	79	226

das : days after sowing. Percentages relative to the All treatment are shown in brackets.

The results of the nutrient omission trials indicated general agreement in soil nutrient availability and rice plant's response to nutrient omission. For example, in Experiment 1 plants grown in the Roi Et soil responded more to nutrient omission. The Roi Et soils had lower organic matter and exchangeable P, although they were higher in exchangeable K. Similarly in Experiment 2, response to P omission was low in the soil from SKN where exchangeable P in the soil was the highest among the 6 soils tested. The largest response was obtained in the soil from UDN, which had the lowest exchangeable P.

The response to nutrient omission, particularly P differed under different water availability conditions. In the Ubon soil, the effect of P omission was more severe under water stress conditions. It is known that availability of some nutrients, such as P, decreases as standing water disappears from the paddy (Ragland *et al*., 1987), and this may have excerbated the response to P omission.

The result of leaf area response to P omission in Experiment 2 indicated that the plant response was more severe at earlier stages, and a similar result was also obtained in Experiment 1 (data not shown). This change in response with time may be related to growth of roots in the pot. Soil P may have become more available gradually with development of the root system. The result showed the high sensitivity in a seedling test, particularly for P, but this did not necessary mean that the yield in the field was limited by a shortage of P. Ragland and Bunpukdee (1987) showed rather small yield response to N application in Roi Et soils in Northeast Thailand, whereas in the present glasshouse experiments dry matter growth of seedlings in the N omission treatment was only 10 – 20 % of the full nutrient treatment. It was concluded that the use of seedlings in the nutrient omission trial in glasshouse is effective in identifying nutrients that limit plant growth, but the effect of nutrient omission on grain yield needs to be tested in the field.

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Received date : 13/06/00
Accepted date : 27/09/00