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Nitrogen Fertilizer Response of Maize on Some Important Soils from DSSAT Software Prediction

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ABSTRACT

To lessen the environmental impact and cost of maize production, the efficient use of nitrogen fertilization is very important. Currently, the DSSAT software has been used to predict N fertilizer requirement of maize. However, the requirement of maize be to N fertilizer in some soils have been found to be lower than the amounts predicted by DSSAT. To use the predicted N fertilizer in some important maize soils of Thailand and Laos efficiently, field experiments were conducted on 4 representative sites. Two sites were on Lop Buri (Lb) and Pak Chong (Pc) soil series in Thailand, and the other two were on Saythong (St) and Bachieng (Bc) soil series in the Lao PDR. The results indicated that grain yields of maize grown on St and Bc soil series were increased with higher rates of N fertilizer while there was no response to nitrogen applications to maize grown on Lb and Pc series soils. These effects were attributed to N mineralization or nitrate release of the soils. From this study, the nitrate (NO_3^- -N) release of Pc and Lb soil series were higher than those of St and Bc soil series, especially at the first period of incubation study in the laboratory. In the case of St and Bc soil series, the nitrate release of Bc soil was higher than that released from St soil, thus, resulting in the response of maize at the lower rate of N fertilization on Bc soil series.

Key words: N response, N fertilizer prediction, maize, N mineralization, DSSAT

INTRODUCTION

Nitrogen is the most limiting essential nutrient for maize (*Zea mays* L.) production in the humid and sub humid tropics. It is the main driving force to produce large yields because nitrogen is vitally important and is required in large amounts. Efficient use of N in maize production requires the ability to adjust the quantity of nitrogen applied in relation to the variation in local soils. Standford (1966, 1973) presented convincing evidence that reasonable estimates of internal N requirements can be used to estimate the N fertilizer needs for maximum crop production. Viet (1965), however, concluded that the total N requirement of a crop cannot be accurately predicted. The University of Nebraska has developed an algorithm for estimating N fertilizer recommendations in maize for achieving a certain yield goal as a function of soil organic matter, subsoil nitrate content in spring, and N credits from previous crop, manure and irrigation (Hergert *et al*., 1997). Nitrogen management may be concerned to soil N mineralization potential and residual nitrate. Birch

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(1958) proposed that maximum nitrate production of dry soils occurred in well-defined wet-dry climates in the tropics at the start of the rain. Nitrogen fertilizer requirements depend on many factors, including yield goal, inorganic soil N, potential N mineralization and soil type (Schlegel and Havlin, 1995). There is an urgent need to improve the management of N in crop production, both in increasing efficiency of N utilization and reducing the nitrogen loss. Recently, many researchers used the Decision Support Systems for Agro-technology Transfer (DSSAT) software for nitrogen fertilizer prediction and Phosphorus Decision Support System (PDSS) for phosphorus and potassium recommendation. This technology was adapted and tested in some soils of the maize belt area of Thailand. Attanandana *et al*. (2004) found that maize yields with and without N fertilizer were not significantly different in some soil series. Thus, studies on site-specific nutrient management using DSSAT for N fertilizer prediction and PDSS for the phosphorus and potassium prediction were conducted. The objective of this study was to test the maize response to nitrogen fertilizer from DSSAT prediction with the optimum P and K fertilizations from PDSS. Moreover, the effect of wetting on nitrogen mineralization in soils that have undergone air drying was also investigated to understand the response of maize to nitrogen fertilizer in the 4 important soils of Thailand and Lao PDR.

MATERIALS AND METHODS

Field experiments study

Four experiments were conducted in the wet season 2005. Two sites in Thailand were located at maize farmers' fields in Praphuttabat district, Saraburi province, about 115 km North of Bangkok. Two representative soil series, namely, Lop Buri and Pak Chong, were selected because they were the common soils used for maize production in the maize belt area of Thailand. The distance between the two sites was about 8 km. The soils were classified as an isohyperthermic, Typic Haplusterts for Lb, and Rhodic Kandiustox for Pc soils. Before starting the study, soil samples were taken for chemical and texture analyses. The Lb soil series is black in color, with high clay content (600 g kg^{-1}), soil pH of 7.1 and 27 g kg^{-1} of organic matter content. The Pc soil series is reddish in color, with clay content of 350 g kg^{-1}, soil pH of 5.4 and 25 g kg^{-1} of organic matter content. The mean temperature and annual rainfall of this region during past 30 years (1968-1998) were 27.5 °C, and 1200 mm, respectively. The pattern of rainfall has been very erratic. The other two experiments were located in the Lao PDR. One of them was situated at Sendine village, Nasaytong district, 30 km North of Vientiane city, and the other one was located at the Agricultural Station, Bachieng district, about 24 km from central of Champasak province. The soils were Saythong (St) and Bachieng (Bc) soils which were corresponded to Ultisols and Oxisols, respectively. The characteristic of St soil series is gray in color, with clay content of 290 g kg^{-1}, soil pH of 5.2 and 22 g kg^{-1} of organic matter content. The Bc soil series is reddish, with clay content of 490 g kg^{-1}, soil pH of 4.7 and 43 g kg^{-1} of organic matter content. The mean temperature and annual rainfall of the two regions (Vientiane and Champasak) during past 15 years (1985-1999) were 26.5 °C, 1400 mm and 28 °C, 2000 mm, respectively. The characteristics of the selected soils are shown in Table 1.

Experimental design

The experiments were conducted with a randomized complete block designs (RCBD), with 5 treatments and 4 replications. The individual plot size was 6 × 5 m with plant spacing of 75 × 20 cm. Each plot consisted of 8 rows and the plant population was 200 plants per plot or 66,666 plants ha^{-1}. The hybrid maize varieties used were hybrid

'NK48' for Pc, St and Bc sites and hybrid 'CP989' for the Lb site.

Fertilizer treatments

Nitrogen fertilizer was applied at 5 different rates according to the simulation from the models and the soil series. The different N rates were used to develop a response curve based on the amount predicted by the DSSAT-CERES-Maize software (Version 4.0), which was predicted at 50, 82, 75, and 50 kg N ha^{-1} for Lb, Pc, St and Bc soils, respectively (Table 2). Phosphorus and potassium fertilizers were recommended by PDSS (Phosphorus Decision Support System) software.

Soil samples and plant data collection

At the end of September 2005, after maize harvesting, soil samples were taken from each plot at 0-20cm depth and analyzed for some selected chemical properties. Maize was harvested from 6 middle rows in 4.2 m × 4.5 m per plot. The grain weight was adjusted to 15 % moisture.

Data analysis

Maize yields of different treatments were statistically analyzed by SAS 8.1 program. The Sigma Plot program was used to fit a linear response plateau curves for the nitrogen study.

Soil nitrogen mineralization study

The nitrogen mineralization study was conducted to estimate the nitrate release during the growth stages of maize. This study was to test the wetting effect of air-dried soil on nitrogen mineralization (Birch, 1958). Soil samples were air-dried and crushed to pass a 2-mm sieve. Ten

Table 1 Characteristics of Lb, Pc, St and Bc soil series before experiments.

Soil properties	Soil series			
	Lop Buri (Lb)	Pak Chong (Pc)	Saythong (St)	Bachieng (Bc)
Texture	Clay	Clay loam	Clay loam	Clay
Sand (g kg^{-1})	220	290	380	290
Silt (g kg^{-1})	180	360	330	220
Clay (g kg^{-1})	600	350	290	490
pH (H_2O.1:1)	7.1	5.4	5.2	4.7
OM (g kg^{-1}) §	27	25	22	43
Total carbon (g kg^{-1}) ‡	16.4	14.9	12.8	25.3
Total N (g kg^{-1}) ‡	2.0	1.3	1.5	2.4
C/N	8.2	7.4	8.5	10.5
Extractable P(mg kg^{-1})$^{+}$	4	7	12.2	3.1
Extractable K(mg kg^{-1})$^{++}$	130	65	103	77

§ Walkley-Black. ‡ Combustion (Nelson and Sommers, 1986).
$^{+}$ Bray II. $^{++}$1 *M* Ammonium acetate, pH 7.

Table 2 Nitrogen, phosphorus and potassium fertilizer rates of the four experiments.

Treatment	Fertilizer rate (kg NPK ha^{-1})			
Soil series	Lb	Pc	St	Bc
N0- P-K	0- 44- 50	0- 44- 75	0- 32- 44	0- 44- 50
N1- P-K	32- 44- 50	44- 44- 75	38- 32- 44	25- 44- 50
N2- P-K	50- 44- 50	82- 44- 75	75- 32- 44	50- 44- 50
N3- P-K	100- 44- 50	125- 44- 75	113- 32- 44	75- 44- 50
N4- P-K	188- 44- 50	188- 44-75	188- 32- 44	150- 44- 50

grams of each air-dried soil was weighed into a 100 ml plastic bottle. The deionized water was added until the soil moisture increased to field capacity and the soils were then incubated at room temperature for 0, 3, 7, 14, 21, 28, 35 and 42 days. The incubated soils were weighed and deionized water was added until the soil moisture was restored to field capacity every two weeks and was maintained at this level throughout the entire period of study. After each specified incubation period the samples were extracted by Mehlich 1 method (1:5 soil: solution ratio), and nitrate was measured colorimetrically (Jackson, 1958).

RESULTS AND DISCUSSION

Maize grain yield response to N fertilizer rates

The grain yields of maize from the four soils were significantly increased with increasing rates of N fertilizer compared with the control treatment (N0), except for the Lb and Pc soils. However, the maximum grain yield of the four soils was lower than the yield predicted by DSSAT (7,000 kg ha^{-1}). In Lb soil series, there was no significantly response of maize yield to fertilizer N (Table 3, Figure 1). The DSSAT prediction was over-estimated the actual yield. In this particular case, the farmer rotated soybean with maize and applied poultry manure in the last wet and dry seasons. Cereal crops and non legume plants require less N when grow after legume (Lory *et al*., 1995). In the case of Pc soil series, the grain yield was not significantly increased with increase N fertilizer (7, 13, 27 and 22%, respectively) (Figure 2). Grain yield of St soil was greatly increased with higher N rates by 52, 128, 178, and 194 %. The yields of the two N treatments (N3 and N4) of this soil were obviously higher than the yields of maize in the other soils which received similar N treatments (Table 3). Effectiveness of N fertilizer use for maize in this soil was very high. The maize responded up to 115 kg N ha^{-1} which was 40 kg N higher than the DSSAT prediction for St soil (Figure 3). In this case, the N fertilizer requirement was under-estimated. The grain yield was slightly increased with increasing N fertilizer, with the increases of 33, 44, 56, and 81 %, respectively in the case of Bc soil. The response was obtained up to 45 kg N ha^{-1} which was very close to the DSSAT prediction of 50 kg ha^{-1}(Figure 4). Although Bc soil has relatively high soil OM compared to other soils, this soil was low in pH and high in dithionite and oxalate extractable aluminum content compared to the other soils (Table 4). The low pH and high Al contents in Bc soil inhibited maize growth. With Al toxic subsoil, maize root could not penetrate into the subsoil (Bushamuka and Zobel, 1998). The observation on maize growth and development during the course of experiment revealed that the plants were stunted and the roots were stunted, which was attributed to Al toxicity. Dobermann and Fairhurst (2000) described that an excess Al^{+3} concentration in the soil solution was caused by low soil pH (<5), and the most important symptom of Al toxicity is the inhibition of root growth.

Nitrogen mineralization

Nitrogen mineralization of Lb, Pc, Bc and St soils is presented in Figure 5. The effect of wetting on nitrogen mineralization in dry soils resulted in high nitrate release. We could see that the nitrate content was highest in Pc and Lb soils, resulted in no response to nitrogen fertilizer by maize in both soils. The NO_3^--N was greatly released so that the nitrate content was increased from 2.7 to17 mg kg^{-1} during 42 days of incubation period in Lb soil. The mineralization pattern process of Pc soil series was similar to that of Lb soil with the amount being increased from 12 to19 mg kg^{-1} during 0 to 42 days. These data suggested that rapid increase of N mineralization played an important role in providing plant N, and caused the over-estimation of N fertilizer prediction. On the other hand, soil nitrate in St soil slowly

Table 3 Grain yield of maize on Lb, Pc, St and Bc soil series under different N fertilizer management.

Treatment	Maize grain yield (kg ha^{-1})			
Soil series	Lb	Pc	St	Bc
N0	6,868 ab [1/]	5,185 a	2,539 d	2,931 b
N1	6,434 ab	5,542 a	3,855 c	3,903 ab
N2	6,916 a	5,841 a	5,806 b	4,246 ab
N3	6,440 ab	6,565 a	7,306 a	4,568 a
N4	5,491 b	6,328 a	7,470 a	5,314 a

1/ In a column, any two means followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test ($p \leq 0.05$).

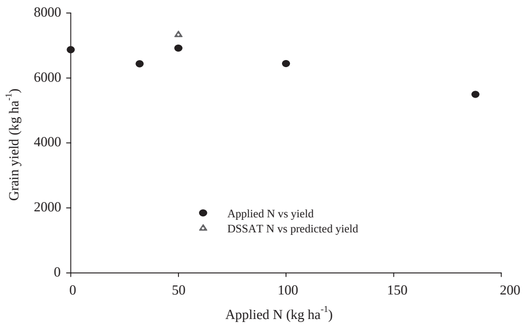

Figure 1 Maize yield response to N fertilizer of Lb soil.

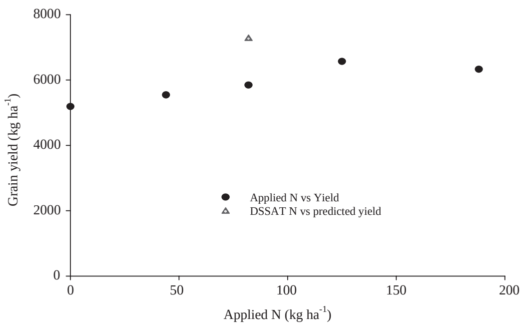

Figure 2 Maize yield response to N fertilizer of Pc soil.

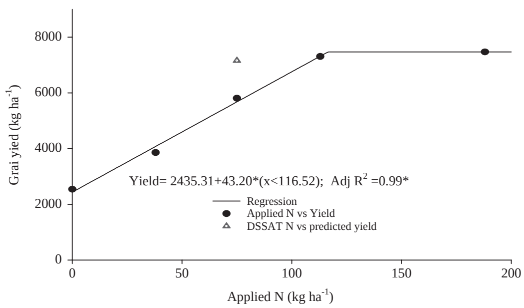

Figure 3 Maize yield response to N fertilizer of St soil.

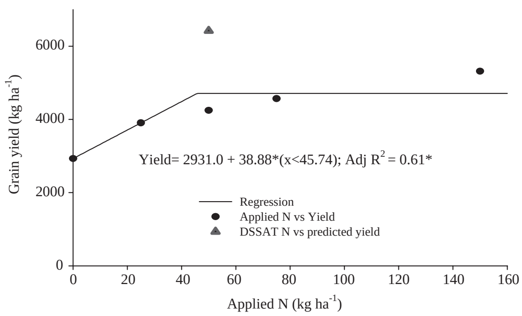

Figure 4 Maize yield response to N fertilizer of Bc soil.

Table 4 Al content of Lb, Pc, St and Bc soil series before maize planting.

Properties	Soil series			
	Lb	Pc	St	Bc
Extractable Al (g kg $^{-1}$)†	7.9	3.1	6.1	19.9
Extractable Al (g kg $^{-1}$)±	38.2	23.9	38.8	195.2

†Oxalate pH 3 in darkness (Loeppert and Inskeep, 1996).

±Citrate-bicarbonate-dithionite (Loeppert and Inskeep, 1996).

increased from 0.7 to 13.8 mg kg^{-1} during 0 to 42 days of incubation, probably because St soil was low in organic matter content. N mineralization pattern of Bc soil was similar to that of the St soil but there was higher nitrate released (1.4 to 16.8 mg kg^{-1}).

Soil analysis after maize harvest

The soil available nitrogen (ammonium and nitrate) after maize harvest is presented in Table 5. The results indicated that available N was very high in Lb and Pc soils while it was relatively lower in Bc and St soils, respectively. The soil available nitrogen data agreed with the results of nitrogen response of these soils. The higher available nitrogen of Lb and Pc soils agreed with no response of maize to nitrogen fertilizer in Lb and Pc soils. The relatively lower available nitrogen in St and Bc soils supported the high response to nitrogen fertilizer of maize in these two soils.

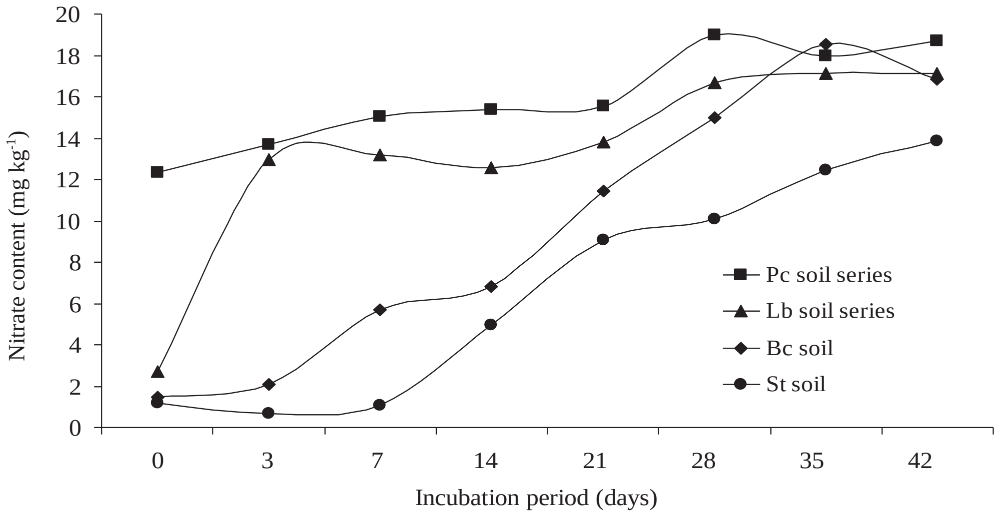

Figure 5 Nitrate release by Lb, Pc, St and Bc soils during 42 days of incubation.

Table 5 Nitrate and ammonium contents in the four soils after maize harvest.

Soil series	Tr.	NH_4^+-N	NO_3^--N	Available N	Soil series	Tr.	NH_4^+-N	NO_3^--N	Available N
		- - - - - - - - - mg kg^{-1} - - - - - - - - -					- - - - - - - - - mg kg^{-1} - - - - - - - - -		
Lb	N0	69.8	8.3	78.1	**St**	N0	32.9	0.56	33.5
	N1	86.1	9.9	96.0		N1	30.8	0.44	31.2
	N2	71.2	9.5	80.7		N2	33.7	0.44	34.2
	N3	71.8	10.9	82.7		N3	33.0	0.91	33.9
	N4	76.1	9.7	85.8		N4	35.5	0.19	35.6
Pc	N0	94.1	1.8	95.9	**Bc**	N0	70.5	3.9	74.4
	N1	98.9	2.4	101.3		N1	70.9	1.3	72.2
	N2	90.7	2.4	93.1		N2	69.1	1.7	70.8
	N3	91.4	2.2	93.6		N3	74.9	2.5	77.4
	N4	109.4	2.2	111.6		N4	78.2	2.6	80.8

CONCLUSIONS

The nitrogen response of maize grown on four soils was studied in Thailand and Laos. The maximum grain yields of most soils were lower than DSSAT's estimation. The maize did not respond to N fertilizer due to the rapid increase of N mineralization in Lb and Pc soils which had been utilized for maize growth. The released nitrate in these soils was taken up by maize and no response to any rates of N fertilizer. On the other hand, maize obviously responded to different rates of N fertilizer in St and Bc soils due to rather slow mineralization rate and thus, low mineralized nitrogen. The soil available nitrogen after harvest agreed with the results of nitrogen response of maize and nitrate release of these soils.

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