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Effects of Nitrogen and Copper Fertilization on Rice Yield and Fertilizer Nitrogen Efficiency: A ^{15}N Tracer Study

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A greenhouse experiment was conducted at University Putra Malaysia to evaluate the effects of nitrogen (N) and copper (Cu) fertilizations on rice yield and fertilizer N efficiency using ^{15}N tracer technique. Four rates of N (0, 60, 120 and 180 kg N ha^{-1} and three rates of Cu (0, 5 and 10 kg Cu ha^{-1}) were used in this study. Nitrogen was applied as ^{15}N tracer technique. Four rates of N (0, 60, 120 and 180 kg N ha^{-1}) and three rates of Cu (0, 5 and 10 kg Cu ha^{-1}) were used in this study. Nitrogen was applied as ^{15}N labelled urea. Grain yield increased significantly due to N fertilization up to 120 kg N ha^{-1}. Regression analysis indicated that grain yield response due to N fertilization that was quadratic in nature. Estimated N rate for maximum yield was 158 kg N ha^{-1}. Copper application did not increase grain yield although the soil was deficient in Cu. The ^{15}N atom excess percentage in both grain and straw, and fertilizer N uptake by rice plant increased gradually with increasing N rates. Recovery (%) of fertilizer N was around 40% irrespective of N and Cu rates. The non-significant effect of Cu might be due to higher Cu adsorption in the soil. Plant analysis results indicated that Cu content in the straw was below the critical deficiency level of 6 mg kg^{-1}. These findings indicate that higher rate of Cu fertilizer (above 10 kg Cu ha^{-1}) may be useful in this soil to increase rice yield and fertilizer N efficiency if Cu is applied as basal. Alternately, Cu may be applied as foliar spray on standing crop to avoid Cu adsorption in the soil. Further, research is needed to find out the optimum Cu rate and method of application for this soil.

Key words: Nitrogen, Copper, Rice, ^{15}N Tracer technique.

Introduction

Nitrogen (N) is a primary essential macro nutrient element for all plants including rice. Nitrogen requirement of rice is high (Sahrawat 2000; Choudhury *et al* 2001). Rice plant removes about 16 kg N for the production of 1 tonne rough rice including straw (De Datta 1981). Most of the rice soils of Asia are deficient in Nitrogen. So, fertilizer N application is essential to meet the crop's demand. Copper (Cu) is an essential micro nutrient element for all crops including rice. Rice crop removes about 8 g Cu for the production of 1 tonne rough rice including straw (De Datta 1981). In wetland rice soils, the availability of water soluble Cu decrease in yield (Ambak and Tadano 1991). This problem can be solved by applying proper amount of Cu fertilizer in Cu deficient soils.

The largest rice growing area of Malaysia is located in the Muda irrigation scheme, Kedah that covers an area of about 95,000 ha. Recent investigations showed that there is a tendency of yield decline in many sites of this area due to Cu deficiency (Samy *et al* 1992a). Investigations showed that soils of some locations of this Irrigation Scheme are deficient in Cu (Choudhury and Khanif 2000a). Farmers are applying a single fertilizer dose of $N_{80}P_{30}K_{20}$ (80 kg N ha^{-1}, 30 kg P_2O_5 ha^{-1} and 20 kg K_2O ha^{-1}) in rice fields throughout the irrigation scheme (Samy *et al* 1992b). Indiscriminate application of fertilizers throughout the irrigation scheme caused low yield in many locations due to Cu deficiency. In addition, this N dose (80 kg N ha^{-1}) is not optimum in many locations. It is necessary to determine the appropriate doses of N and Cu fertilizers to increase rice yield and fertilizer N efficiency. The ^{15}N tracer technique is used as the precise method to estimate fertilizer N efficiency (Cao *et al* 1984; Choudhury and Khanif 2001). With this view in mind, the present study was undertaken to evaluate the effects of N and Cu fertilization on rice yield and fertilizer N efficiency using ^{15}N tracer technique.

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Materials and Methods

A greenhouse experiment was conducted at University Putra Malaysia to evaluate the effects of N and Cu fertilization on rice yield and fertilizer N efficiency. The study was conducted in two soils (Idris and Tebengau series). In this paper, the findings on one soil (Tebengau series) are discussed. The taxonomy of the soil is Typic endoaquent, very fine clayey, mixed, isohyperthermic, pallid (Paramananthan 1998). The soil was collected from rice growing areas under the Muda irrigation scheme, Kedah, about 500 km north of Kuala Lumpur, Malayasia, soil samples were collected from 0 - 15 cm depth. These soil samples were air dried, ground and sieved through 2 - mm sieve. Soil was analysed for organic matter, pH, cation exchange capacity (CEC), total N and available Cu. Organic matter was analysed by potassium dichromate and sulphuric acid (H_2SO_4) digestion method (Walkley and Black 1934). Soil pH was measured by glass electrode (Peech 1965). Total N was determined by sulphuric-salicylic acid digestion method (Bremner and Mulvaney 1982). Cation exchange capacity was determined by ammonium acetate extraction method (Schollenberger and Simon 1945). Available Cu was analysed by 0.05N HCl extraction method (Ponnamperuma *et al* 1981). The soil had a pH of 4.1 with CEC 26.36 cmol kg^{-1}. It contained 5.07% organic matter, 0.18% total N and 0.06 mg kg^{-1} available Cu.

Four N rates (0, 60, 120 and 180 kg N ha^{-1}) and three Cu rates (0, 5 and 10 kg Cu ha^{-1}) were used in the experiment. The experiment was laid out in randomised complete block design with four replications. The soil used for the study was collected from the plough layer of the field and was filled into plastic pots of 15 - liter capacity to 10 cm below the brim of the container. The height and diameter of the pots were 29 cm and 28 cm, respectively. The soil was flooded and preincubated for three weeks to stabilize the physico-chemical properties before seed sowing. Sprouted rice seeds of variety MR 185 were sown. The number of seeds needed per pot was calculated on the basis of surface area of the pot and a sowing rate of 40 kg ha^{-1}. Ten sprouted seeds were equally spaced in the puddle soil of each pot.

Phosphorus (30 kg P_2O_5 ha^{-1} and K (20 kg K_2O ha^{-1}) fertilizers as triple superphosphate (TSP) and muriate of potash (MOP), respectively, were applied as basal dressings to all pots. The N in the form of 15N - labelled urea (8.378% atom excess was applied according to treatments (0, 60, 120 and 180 kg N ha^{-1}). Nitrogen was applied in three splits (1/2 as basal + 1/4 at active tillering stage + 1/4 at panicle initiation stage). Copper was applied as copper sulphate ($CuSO_4.5H_2O$) according to treatments (0, 5 and 10 kg Cu ha^{-1}). Copper application was done all as basal. Nitrogen and copper were applied in solution form. The amount of fertilizers was calculated on the basis of soil surface area of each pot. Rice crop was harvested at maturity. Grain and straw weights (gram per pot) were recorded. Grain and straw yields were calculated as t ha^{-1} considering the surface area of each pot. About 10 g of representative grain and straw samples were ground to pass through a 1 mm sieve and were kept in plastic containers for chemical analyses. Total N of the plant tissue was analysed by H_2SO_4 digestion followed by steam distillation

Table 1
Effects of N and Cu on grain and straw yields of rice

N rate kg ha^{-1}	Cu rate (kg ha^{-1}) 0	5	10	Mean
	Grain yield (t ha^{-1})			
0	2.12	2.14	2.36	2.21 c
60	3.70	3.94	3.91	3.85 b
120	5.36	4.68	5.16	5.07 a
180	5.03	5.16	4.83	5.01 a
Mean	4.05	3.98	4.07	
	Straw yield (t ha^{-1})			
0	2.89	2.81	3.10	2.93 c
60	4.73	5.52	5.08	5.11 b
120	6.66	6.65	6.62	6.64 a
180	6.92	7.11	6.93	6.99 a
Mean	5.30	5.52	5.43	

Effect of Cu was not significant on either grain or straw yield.
Means followed by different letters for a parameter in a column are significantly different at 5% level by Duncan's Multiple Range Test (DMRT).

method (Bremner and Mulvaney 1982), and subsequently the ^{15}N content of the plant samples was analysed by using emission spectrometry (Hauck 1982). Total N uptake by grain and straw were calculated from yield and N content data. The fertilizer uptake and recovery percentage of added N by rice plant were calculated following 1N HCl extraction method (Yoshida *et al* 1976). Total Cu uptake by grain and straw was calculated from yield and Cu content data.

The data were analysed for of variance (ANOVA) and the means were compared using Duncan's multiple range test (DMRT) where the F - test was significant. Regression analysis was also done using four replicated values where F-test was significant. All the analyses were done following statistical analysis system (SAS Institute Inc. 1987). Nitrogen level for maximum yield was calculated from the equation $Y = a + bx - cx^2$ (Gomez and Gomez 1984) as follows:

$N_y = (b/2c)$, where N_y = N rate (kg ha^{-1}) for maximum yield.

Results and Discussion

Grain and straw yields. Grain yield ranged from 2.12 to 5.36 t ha^{-1} while straw yield ranged from 2.81 to 7.11t ha^{-1} (Table 1). Effect of N on both grain and yields was significant, whereas, the effect of Cu was not significant on either of the parameters. Grain and straw yields increased significantly due to N fertilization up to 120 kg N ha^{-1}. Regression analysis indicated that grain and straw yield responses to N

Table 2
Effects of N and Cu on N contents in grain and straw, and total N uptake by rice plant

N rate kg ha^{-1}	Cu rate (kg ha^{-1}) 0	5	10	Mean
	Grain yield (t ha^{-1})			
0	0.80	0.86	0.88	0.85 c
60	0.95	0.83	0.88	0.89 c
120	1.10	1.06	1.08	1.08 b
180	1.21	1.20	1.19	1.20 a
Mean	1.02	0.99	1.01	
	N content (%) in straw			
0	0.43	0.34	0.39	0.39
60	0.41	0.37	0.40	0.39
120	0.37	0.38	0.42	0.39
180	0.40	0.48	0.47	0.45
Mean	0.40	0.39	0.42	
	Total N uptake (kg ha^{-1}) by whole rice plant (grain + straw)			
0	29.43	27.96	32.81	30.07
60	54.49	50.99	54.44	53.31 c
120	83.08	74.95	80.35	79.46 b
180	93.51	95.60	89.94	93.02 a
Mean	65.13	62.38	64.39	

Effect of N was not significant on N content in straw. Effect of Cu was not significant on any of the three parameters.
Means followed by different letters for a parameter in a column significantly different at 5% level by DMRT

Table 3
Effects of N and Cu on ^{15}N atom excess percentage in grain and straw

N rate kg ha^{-1}	Cu rate (kg ha^{-1}) 0	5	10	Mean
	^{15}N atom excess percentage in grain			
60	3.741	3.643	3.520	3.635 c
120	5.205	5.433	5.350	5.329 b
180	6.255	6.088	6.205	6.183 a
Mean	5.067	5.055	5.025	
	^{15}N atom excess percentage in grain			
60	4.144	3.768	3.670	3.861 c
120	5.233	5.550	5.147	5.310 b
180	6.149	6.184	6.177	6.170 a
Mean	5.175	5.167	4.998	

Effect of Cu on ^{15}N atom excess (%) in either grain or straw was not significant. Means followed by different letters in a column for a parameter are significantly different at 5% level by DMRT.

Table 4
Effects of N and Cu on N uptake and recovery by rice plant

N rate kg ha^{-1}	Cu rate (kg ha^{-1}) 0	5	10	Mean
	Fertilizer N uptake (kg ha^{-1}) by whole plant (grain + straw)			
60	25.44	22.46	23.25	23.72 c
120	51.74	48.73	50.73	50.40 b
180	69.24	69.71	66.95	68.63 a
Mean	48.81	46.97	46.98	
	Fertilizer N recovery (%) by rice plant			
60	42.40	37.44	38.75	39.53
120	43.12	40.61	42.28	42.00
180	38.47	38.73	37.20	38.13
Mean	41.33	38.93	39.41	

Effect of N was not significant on fertilizer N recovery percentage. Effect of Cu was not significant on either fertilizer N uptake or recovery percentage.
Means followed by different letters in a column are significantly different at 5% level by DMRT.

rates that were quadratic in nature (Table 6). The increase in grain and straw yields due to N fertilization was expected as the soil was deficient in N. It is in agreement with previous findings (Shah *et al* 1996; Choudhury *et al* 1997). The estimated N rate (calculated from the regression equation) for maximum yield was 158 kg N ha^{-1}. Farmers are applying single N rate (80 kg N ha^{-1}) throughout the Muda Irrigation Scheme (Samy *et al* 1992b). The present study indicated that this level is not optimum for all soils. In Tebengau series, application of higher N rate (158 kg N ha^{-1}) may be useful to get maximum yield. This should be verified by field experiments before recommendation. Copper application did not increase grain and straw yields although the soil was deficient in Cu. The non-significant effect of Cu was attributed to higher Cu adsorption in this soil (Choudhury and Khanif 2000b). Plant analysis indicated that the Cu content in the straw was below the critical deficiency level of 6 mg kg^{-1} (Yoshida *et al* 1976). This indicates that application of 5 or 10 kg Cu ha^{-1} was not sufficient to increase grain yield in this soil. Higher rates of Cu over these rates might be useful to increase grain yield significantly. Further, research is needed to get optimum Cu rate for this soil.

Nitrogen content and uptake. Nitrogen content in grain ranged from 0.80 to 1.21%, while N content in straw ranged

Table 5
Effects of N and Cu on Cu contents in grain and straw, and total Cu uptake by rice plant

N rate kg ha^{-1}	Cu rate (kg ha^{-1}) 0	5	10	Mean
Cu content (mg kg^{-1}) in grain				
0	2.76	3.25	3.53	3.18 d
60	3.20	3.67	4.13	3.67 c
120	4.46	4.59	4.78	4.61 b
180	4.61	5.31	5.28	5.07 a
Mean	3.76 C	4.21 B	4.43 A	
Cu content (mg kg^{-1}) in straw				
0	3.28	4.21	5.38	4.29 c
60	3.79	4.73	5.94	4.82 b
120	4.91	5.44	6.84	5.40 a
180	5.30	5.43	6.58	5.44 a
Mean	4.32 C	4.95 B	5.69 A	
Total Cu uptake (g ha^{-1}) by whole rice plant (grain + straw)				
0	15.24	18.71	25.12	19.69 c
60	29.79	40.93	46.38	39.03 b
120	56.16	57.92	63.27	59.12 a
180	59.71	65.43	63.55	62.90 a
Mean	40.23 C	45.75 B	49.58 A	

Means followed by different small letters for a parameter in a column, and different capital letters in a row are significantly different at 5% level by DMRT.

from 0.34 to 0.48% (Table 2). Nitrogen content (%) in grain increased significantly due to N fertilization up to 180 kg N ha^{-1}, whereas, Cu effect was not significant. There was no significant effect of N or Cu on N content in straw. Total N uptake by whole plant (grain and straw) ranged from 27.96 to 95.60 kg ha^{-1} (Table 2). Total N uptake increased significantly due to N fertilization up to 180 kg N ha^{-1}, whereas, the effect of Cu was not significant. The increase in total N uptake by whole plant (grain and straw) due to N fertilization was attributed to the increases in grain and straw yields due to N fertilization as well as due to the increase N content in grain and total N uptake increased linearly with increasing N rates (Table 6).

The ^{15}N atom excess. The ^{15}N atom excess (%) in grain ranged from 3.520 to 6.255 while the ^{15}N atom excess (%) in straw ranged from 3.670 to 6.184 (Table 3). The ^{15}N atom excess (%) in grain and straw increased significantly at higher N rates, whereas, Cu effect was not significant. Regression analysis indicated that the ^{15}N atom excess (%) in both grain and straw increased linearly with increasing N rates (Table 6). The increase in ^{15}N atom excess in grain and straw with increasing N rates indicates that fertilizer contributed more amounts in total N uptake at higher N rates.

Table 6
Regression equations and R^2 values relating N rate with different parameters

Parameter	Regression equation	R^2 value
Grain yield	$y = 2.18 + 0.037167 x - 0.000118x^2$	0.9537**
Straw yield	$y = 2.9275 + 0.04525 x - 0.000125x^2$	0.9716**
N content in grain	$y = 0.819 + 0.0021 x$	0.9503**
Total N uptake	$y = 31.715 + 0.3583 x$	0.9849**
^{15}N atom excess in grain	$y = 2.501 + 0.0212x$	0.965**
^{15}N atom excess in straw	$y = 2.8047 + 0.0192x$	0.9788**
Fertilizer N uptake	$y = 2.6733 + 0.3743x$	0.9883**
Cu content in grain	$y = 3.141 + 0.011x$	0.9805**
Cu content in straw	$y = 4.383 + 0.0067x$	0.9129**
Total Cu uptake	$y = 22.727 + 0.2495x$	0.9372**

** = significant at 1% level of probability

Table 7
Regression equations and R^2 values relating Cu rates with Cu content in grain and straw, and total Cu uptake by rice plant

Parameter	Regression equation	R^2 value
Cu content in grain	$y = 3.7983 + 0.067x$	0.9622**
Cu content in straw	$y = 4.3017 + 0.137x$	0.9979**
Total Cu uptake	$y = 40.512 + 0.935x$	0.9892**

** =Significant at 1% level of probability.

Fertilizer N uptake and recovery. Fertilizer N uptake by whole plant (grain and straw) ranged from 22.46 to 69.71 kg ha^{-1} (Table 4) Fertilizer N uptake increased significantly at higher N rates, whereas, Cu effect was not significant. Regression analysis indicated that fertilizer N uptake increased linearly with increasing N rates (Table 6). The increase in fertilizer N uptake by whole plant with increasing N rates was attributed to higher ^{15}N atom excess at higher N rates (Table 3) as well as due to higher total N uptake at higher N rates (Table 2). The increase in fertilizer N uptake at higher N rates is in agreement with previous findings (Guindo *et al* 1994b; Panda *et al* 1995). Fertilizer N recovery percentage (quantified by ^{15}N atom excess) by rice plant is presented in Table 4. Fertilizer N recovery ranged from 37.20 to 43.12%. Effects of N and Cu were not significant on fertilizer N recovery. In general, the recovery of fertilizer N by rice plant was around 40.00%. It is in agreement with previous findings (Craswell and Vlek 1979; Guindo *et al* 1994a). Copper application did not increase fertilizer N recovery by rice plant significantly. This was due to the non-significant response of rice crop to add Cu. The available Cu content in the soil was below the critical deficiency level of 0.1mg kg^{-1} (Ponnamperuma *et al* 1981), and it was expected that Cu application might increase rice yield and thereby, increase fertilizer N uptake. But due to higher adsorption of Cu was not significant. Higher doses of Cu (above 10 kg Cu ha^{-1}) might be useful to increase grain yield and N uptake. Further, research using various levels of Cu is needed to draw the inference.

Copper content and uptake. Copper content in grain ranged from 2.76 to 5.31 mg kg^{-1} while Cu content in straw ranged from 3.28 to 5.94 mg kg^{-1} (Table 5). Copper content in grain and straw increased significantly due to both N and Cu fertilization enhanced plant growth. This might contribute in increase in Cu content of both grain and straw due to higher Cu absorption capacity of the rice plants. Although Cu content in straw increased significantly due to Cu fertilization, it was below the critical deficiency level of 6 mg kg^{-1} (Yoshida *et al* 1976). This indicates that the applied Cu rates were not enough in this soil to meet the demand of the rice plants. As a consequence, grain yield did not increase due to Cu fertilization . A follow - up laboratory experiment indicated that Cu adsorption capacity of this soil was high (Choudhury and Khanif 2000b). Maximum Cu adsorption capacity (calculated from the Langmuir equation) in this soil was 833 mg kg^{-1} (Choudhury and Khanif 2000b). So, higher rate of Cu (more than 10 kg Cu ha^{-1}) is needed to get response in this soil if Cu is applied as basal. Alternately, Cu may be applied as foliar spray on standing crop to avoid Cu adsorption in the soil. Copper uptake by whole rice plant (grain + straw) ranged from 15.24 to 65.43 g ha^{-1} (Table 5). Copper uptake by rice plant increased significantly due to both N and Cu fertilization. This was attributed to the increases in Cu content in grain and straw, due to N and Cu fertilization. Regression analysis indicated that copper content in grain and straw due to Cu fertilization is in agreement with some other findings (Ambak and Tadano 1991; Choudhury and Khanif 2002).

Conclusion

The present study indicates that application of 80 kg N ha^{-1} is not enough for all soil of the Muda Irrigation Scheme. In Tebengau series, application of higher N rate (158 kg N ha^{-1}) instead of the present farmers' practice (80 kg N ha^{-1}) may be useful to get maximum yield. This should be verified by field experiments before giving recommendation. Copper application did not increase grain yield and fertilizer N efficiency significantly although the soil was deficient in Cu. This was attributed to higher Cu adsorption in this soil. It indicates that application of 5 or 10 kg Cu ha^{-1} was not enough to increase grain yield and fertilizer N efficiency in this soil. Higher rates of Cu over these doses may increase grain yield and fertilizer N efficiency if Cu is applied as basal. Alternately, Cu may be applied as foliar spray on standing crop to avoid Cu adsorption in the soil. Further, research is needed to find out optimum Cu rate and method of application for this soil.

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