The Balanced Nutritional method and Fertilizer use in Paddy rice in Bolivia

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bstract

Rice has been cultivated in Colonial San Juan, Bolivia, without the use of fertilizers for more than 40 years. However, yields have gradually declined and farmers have now begun to utilize fertilizers. An effective strategy might be to apply fertilizer according to the nutrient content of the soil and the nutritional requirements of the crop. To investigate this theory, we used the 'balanced nutritional' method to calculate the required amounts of fertilizer. The target yield for the rice grains was set at 8 t/ha and five experimental plots were created: a control, which received no fertilizers; G8, which received the required amount of fertilizer for a yield of 8 t/ha; G10, which received the required amount of fertilizer for 10 t/ha; G12, which received the required amount of fertilizer for 12 t/ha; and GA, which received the average amount of fertilizer applied by the farmers. The resulting yields were 7.5 (control), 8.6 (G8), 8.4 (G10), 8.8 (G12) and 8.7 (GA) t/ha. The yield obtained in plot G8 was similar to the target (8 t/ha) and excess fertilizer increased vegetative growth only. Therefore, the balanced nutritional method was effective in determining the appropriate quantity of fertilizer for rice plants. In addition, we compared the performance of three types of nitrogenous fertilizer (urea, ammonium sulfate and ammonium nitrate) on growth and yield. Urea had the highest nitrogen efficiency and should therefore be the fertilizer of choice for the cultivation of paddy rice in developing countries.

Media Summary

The 'balanced nutritional' method was shown to be effective in determining the amount of fertilizer necessary for high-yield and low-cost rice production in developing countries.

Keywords

Yield components, low-cost, oxidized layer, reduced layer, $NH_{4,}$ NO_3, SO_4

Introduction

For more than 40 years, rice has been cultivated without the use of fertilizers in Colonial San Juan, Bolivia, by farmers that emigrated from Japan. Because of this long period of cultivation, rice yield has gradually decreased and farmers have found that the application of chemical fertilizers is effective in increasing yields. Currently, farmers tend to apply fertilizers uniformly and in quantities that exceed the amounts required. It might, however, be more efficient to chemically analyze the soil and to apply fertilizer depending on both the nutrients that are available from the soil and those that are required by rice plants. We therefore experimentally tested the 'balanced nutritional' method (Gracia 1996; Zennow 1998b, 1998c) for determining the appropriate amounts of fertilizer to produce the highest yield at the lowest cost of fertilizer. The effects of different types of nitrogenous fertilizer on the growth and yield of rice were also investigated.

Methods

Experiment 1: Determination of adequate amounts of fertilizer

Seeds of Indica cultivar Epagri 109 from Brazil were sown in a seedbed on 2 October 2002. Thirteen days after the emergence of the seedlings, they were transplanted into an experimental paddy field in Colonial

San Juan. The field was located at 17?15' south latitude and 63?50' west longitude, at a height of 277m above sea level. The seedlings were planted with a distance of 30 cm between rows and 15 cm between individual plants.

The silky clay soil contained nitrogen (N), phosphorus (P) and potassium (K) at levels of 172.7, 78.5 and 165.3 kg/ha, respectively (Abd?n and Kobayashi 2002, Abd?n et al. 2003). The N, P and K requirements of Indica rice for a yield of 1 t/ha are 25.0, 4.8 and 22.0, respectively (Gracia 1996, Zennow 1998b). The target yield was set at 8 t/ha and five experimental plots were created, as follows: control, without fertilizer; G8, which received the necessary quantity of fertilizer for a yield of 8 t/ha; G10, which received the necessary amount of fertilizer for a yield of 10 t/ha; G12, which received the necessary amount of fertilizer for a yield of 12t/ha; and GA, which received the average amount of fertilizer currently applied by the farmers in Colonial San Juan. The quantities of N, P and K that were necessary to satisfy the requirements of the rice plants in each experimental plot and the average amounts of fertilizers applied by the farmers are shown in **Table 1**.

Urea, potassium chloride (KCl) and diammonium phosphate (DAP) were used as fertilizers. The required amounts of urea and KCl were calculated on the basis of 50% efficiency. Urea was applied in three stages: 10% of the total was applied before transplantation, 40% was applied at the maximum tiller number stage and 50% was applied at the panicle formation stage. Similarly, 70 % of the KCl was applied before transplantation and 30% at the panicle formation stage. DAP was used uniformly by the farmers and was applied basally.

The plants were harvested on 18 February 2003 and rice grains, leaves and stems were dried and weighed separately. The yield components were measured using standard methods. Four replications of this experiment were carried out.

Experiment 2: Effects of different nitrogenous fertilizers

This experiment was carried out in 1/2000 a Wagner pots containing 15 kg of dry soil (20 cm depth) from the paddy field described in experiment 1. Epagri 109 seeds were sown on 11 October 2002. After the emergence of the seedlings, five plants were selected for each pot and were grown under irrigated conditions until harvest. Three different nitrogenous fertilizers were tested: urea, ammonium sulfate (SA) and ammonium nitrate (NA). The amounts required for a yield of 8t/ha were calculated on the basis of the capacity of the pots (1/20000ha) (Table 1), and the fertilizers were applied using the method described in experiment 1. And as the control, an experimental plot without nitrogenous fertilizer was created. The plants were harvested on 19 February 2003 and the rice grains, leaves and stems were dried and weighed separately. The yield components were measured using standard methods. Three replications of this experiment were carried out.

Results and Discussion

Experiment 1: Determination of adequate amounts of fertilizer

Plant height and the number of stems per plant differed significantly between the experimental plots, in the following order: control < G8 < G10 < G12. The values for the GA were similar to those of G8 and the control. The dry weight of the leaves and stems also differed significantly between the experimental plots, in the order: control < G8 < G10 < G12. The value for the GA was between that for G8 and G12. The number of panicles/m^2 and the number of grains/panicle were significantly lowest in the control. Although the number of panicles/m^2 and the number of grains/panicle were higher in G10 and G12, respectively, and the number of grains/panicle was lower in G10, there were no clear differences among G8, G10, G12 and GA. By contrast, the percentage of ripened grains differed significantly between the experimental plots, in the order: G12 ≦ G10 < G8 < control. The value for GA was between that of G8 and G10. The thousand-grain weight was significantly the lower in G12 than in the other plots, but there was no clear pattern of difference in this parameter. The dry-matter yield of rice grains was lowest in the control, but no clear differences were found among the other experimental plots (Table 2; Figure 1).

It is clear from these results that excess fertilizer (above the required amount for a yield of 8t/ha) had an effect on promoting vegetative growth rather than yield: the yield obtained in plot G8 (8.5t/ha) was similar to the target yield (8 t/ha). Therefore, the balanced nutritional method was successful in determining the amount of fertilizer required.

Experiment 2: Effect of different nitrogenous fertilizers

The dry-matter weights of the leaves and stems differed significantly between experimental treatments, in the order: control ≦ SA < NA < urea. Almost all of the yield components were significantly higher in the urea treatment (that is, number of panicles/pot, number of grains/panicle and thousand-grain weight). Comparing the SA and NA, the number of grains/panicle and the thousand-grain weight were higher in the NA, whereas the percentage of ripened grain was slightly higher in the SA; the number of panicles/pot was similar in the both plots. In the control, the number of panicles/pot was similar to both the SA and NA treatment, the percentage of ripened grain was the highest of all the experimental treatments, and the number of grains/panicle and the thousand-grain weight were the lowest. The dry weights of rice grains differed significantly between the treatments in the order: SA ≦ control < NA < urea (Table 2, Figure 2).

These results showed that urea was superior to the other nitrogenous fertilizers tested for growing paddy rice under irrigated conditions. This is a consequence of chemical differences between the fertilizers, $(NH_4)_2CO_2$, $(NH_4)_2SO_4$ and NH_4NO_3: NH_4, NO_3 and SO_4 undergo different reactions in the oxidized and reduced layers of an irrigated paddy field (Arroz Irrigado 2002; Zennow 1998b). To briefly summarize, most NH_4 penetrates the oxidized layer and is assimilated effectively by the rice in reduced layer. However, a portion is oxidized to NO_3 before penetrating the oxidized layer; NO_3 is easily reduced to gaseous N_2 in reduced layer and escapes into the air. This phenomenon occurs in all three types of fertilizer used in the experiment. However, it occurs in the largest quantity in NH_4NO_3, in which one-half of the total nitrogen content is in the form of NO_3. Furthermore, the SO_4 of $(NH_4)_2SO_4$ penetrates the oxidized layer and is converted to hydrogen sulfide (H_2S) in reduced layer. H_2S prevents respiration in the roots of rice plants and notably reduces the absorption of nutrients, especially during the later stages of growth. This leads to reduced numbers of grains/panicle, reduced thousand-grain weights and reduced yields. Urea should be the fertilizer of choice for the cultivation of paddy rice.

Table 1. Nutrient and fertilizer requirements.

Experiment 1

Plots	N (kg/ ha)	P (kg/ ha)	K (kg/ ha)
Control	-	-	-
G8	27.3	-	10.7
G10	77.3	-	54.7
G12	127.3	-	98.7
GA	50.5	5.0	12.5

Experiment 2

Plots	g/ pot
Control	-
Urea	0.59
Ammonium sulfate(SA)	1.30
Ammonium nitrate(NA)	0.78

Table 2. Yield components of rice.

	Experimental plots	Panicle no / m^2	No. of grains per panicle	%of ripend grain	Thousand-grain wt. (g)
Experiment 1	Control	328.4 $^{a)}$	89.9 $^{a)}$	85.1 $^{c)}$	33.1 $^{b)}$
	G8	345.3 $^{b)}$	101.2 $^{b)}$	83.7 $^{b)}$	32.5 $^{b)}$
	G10	351.4 $^{b)}$	97.6 $^{b)}$	80.7 $^{a)}$	34.2 $^{b)}$
	G12	344.9 $^{b)}$	104.6 $^{b)}$	79.2 $^{a)}$	31.5 $^{a)}$
	GA	344.3 $^{b)}$	101.6 $^{b)}$	81.3 $^{a)}$	32.1 $^{b)}$
Experiment 2	Control	23.5 $^{a)}$	110.5 $^{a)}$	77.8 $^{c)}$	24.7 $^{a)}$
	Urea	26.5 $^{b)}$	127.1 $^{b)}$	72.1 $^{b)}$	28.8 $^{c)}$
	SA	23.5 $^{a)}$	119.7 $^{a)}$	69.7 $^{a)}$	27.7 $^{b)}$
	NA	23.0 $^{a)}$	125.2 $^{b)}$	67.7 $^{a)}$	28.2 $^{c)}$

Means with different superscripts differ significantly ($p<0.05$). 2) In Exp. 2; No. of Panicle/pot.

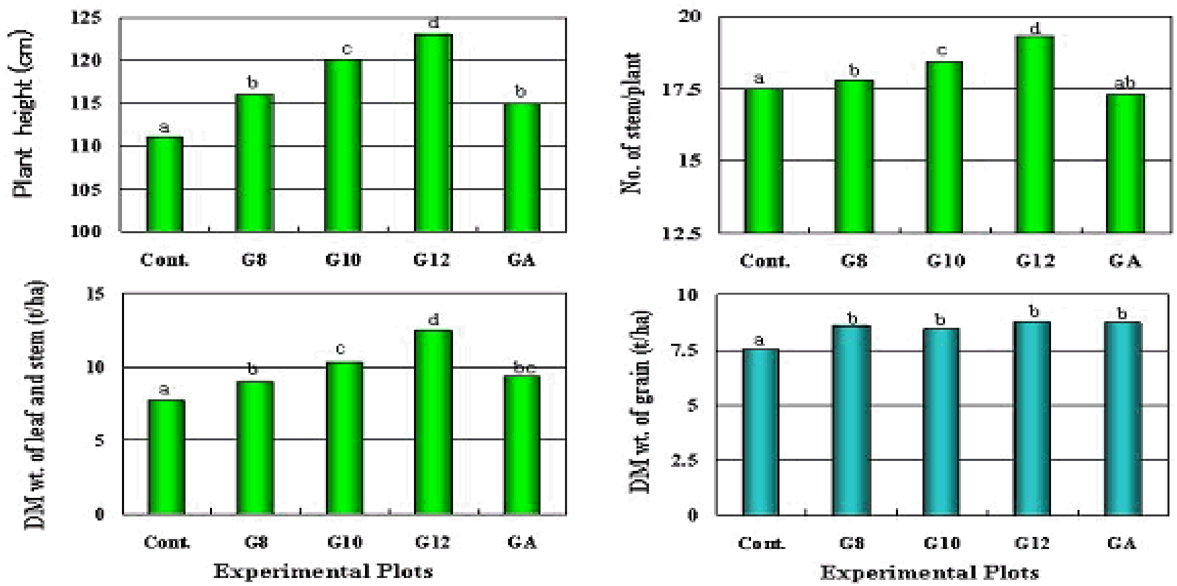

Figure 1. Growth and yield of rice produced using different amounts of fertilizer.

Cont., control; DM, dry matter. Means with different superscripts differ significantly (p<0.05).

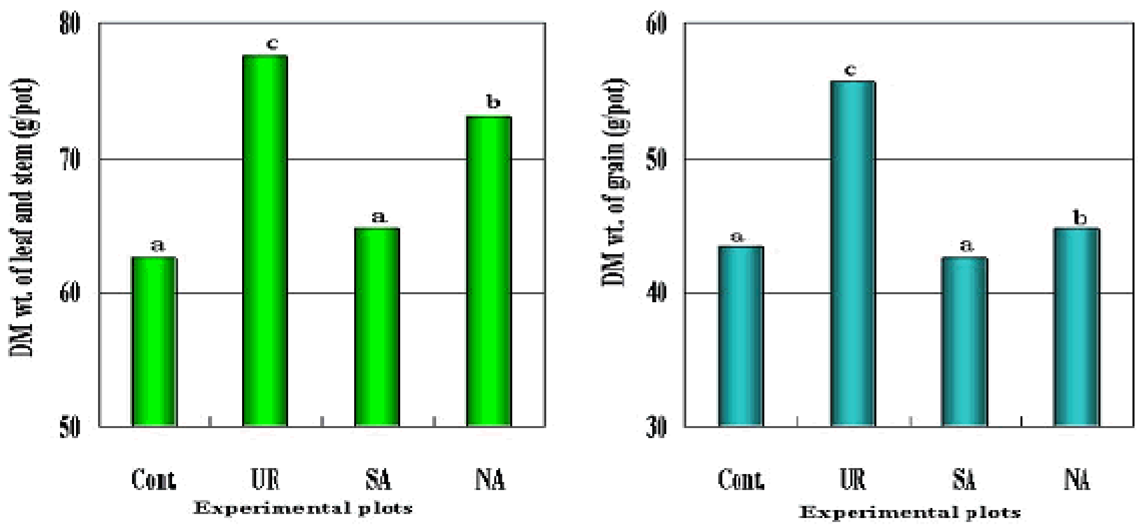

Figure 2. Growth and yield of rice produced using different types of nitrogenous fertilizer.

Cont., control; DM, dry matter. Means with different superscripts differ significantly (p<0.05).

Conclusion

Farmers in Colonial San Juan commonly apply fertilizers to their fields, often in quantities that exceed those required by rice plants. We have shown that the balanced nutritional method is useful in determining the appropriate amount of fertilizer to be applied in order to produce the maximum rice yield with the minimum cost of fertilizers. In addition, our study confirms that urea is the best source of nitrogen for the cultivation of rice under irrigated conditions in this area of Bolivia.

Acknowledgments

This work was supported by Japan International Cooperation Agency. We are grateful to Dr. Kozo Toshimitsu and Dr. Takeo Sasaki of Centro Tecnol?gico Agropecuario en BOLIVIA for their useful suggestions.

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