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AGRONOMIC AND NITROGEN RECOVERY EFFICIENCY OF RICE UNDER TROPICAL CONDITIONS AS AFFECTED BY NITROGEN FERTILIZER AND LEGUME CROP ROTATION

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ABSTRACT

Nitrogen is one of the most limiting factors for crop growth and productivity. However excessive application can lead to low N efficiency, higher production costs and environmental pollution. Winged bean, bush bean and rice crop plants were grown in a greenhouse with different rates of N fertilizer to estimate nitrogen agronomic efficiency (NAE), nitrogen recovery efficiency (NRE) and N uptake of rice when tropical two vegetable legume plants were grown in rotation with rice crop. Bush bean and winged bean were grown with N fertilizer at rates of 0, 2, 4 and 6 g m^{-2} preceding rice planting while rice was grown with N fertilizer at rates of 0, 4, 8 and 12 g m^{-2}. Rice after winged bean grown with N at the rate of 4 g N m^{-2} achieved significantly higher NRE (30-33%) and NAE (24-27 g g^{-1}) during both years. This prevailing effect of rice after winged bean is likely associated with higher biomass and N uptake during both years. Data from two growing seasons showed that rice after winged bean at the rate of 4 g m^{-2} can produce higher biomass and N accumulation of rice along with superior NRE and NAE values, which indicated a positive response for rice production without deteriorating soil fertility.

Key words: Nitrogen efficiency, Nitrogen uptake, Legume residue.

INTRODUCTION

Rice (*Oryza sativa*) is one of the most important cereal crops, accounting for more than 40% of world food production (Amane, 2011). The intensive cultivation of high yielding varieties of rice requires better soil and nutrient management (Wei *et al*. 2006). However, injudicious rates of N fertilizer can lead to poor N efficiency; leaching loss and ammonia volatilization (Fageria and Baligar, 2005). The low nitrogen use efficiency (NUE) by rice crops leads not only to a heavy economic burden for growers but also to environmental pollution (Duan *et al*. 2007). This is obvious that poor NUE resulting higher production costs induce grower's poor net return (Wang *et al*. 2001). Thus, efficient N utilization must be ensured for sustainable crop production for the benefit of environment and economics (Delin *et al*. 2008; Stevens *et al*. 2005). Optimum use of N fertilizer is crucial step to improve NUE, while a positive relation between soil N supply and crop N demand are one of the basic factors to maximal N utilization. The loss of soil N is a continuous process through removal of plant, harvesting of grain and chemical processes in soil (Kirda *et al*. 2001). Soil N supply through biological nitrogen fixation (BNF) by associated microbial populations is the principal source of N for cereal crop production. The indigenous soil N supply in wetland rice may decline with intensive rice cultivation unless it is restored by BNF (Fageria *et al*. 2003). On the contrary green manure crops and leguminous cropping patterns can produce higher rice yield as compared to commonly practiced rice-wheat cropping pattern (Ali *et al*. 2012). Considering both environmental and economic perspectives, maintenance of available soil N resource and improvement of N output from plant sources are one of the desirable options to reduced use of chemical fertilizer in rice cropping system (Thuy *et al*. 2008). Introducing legume with upland rice based intercropping systems can improve soil physical properties and enhance residual soil N content (Jabbar *et al*. 2005). In addition, the use of effective legume crops may increase BNF inputs which can minimize soil N losses as well as improve soil N inputs. So the governing of endemic soil N and N_2 fixation through leguminous plant has the potential to improve soil N nutrition and NUE of crop plants (Yadvinder *et al*. 2005). In addition to fixing atmospheric N_2, well decomposed leguminous plant residues showed a significant role in maintaining NO_3. However excessive applications of N fertilizer in soil in turn have drawn much attention to the environmental impact of N fertilization practices (Cassman *et al*. 2002). Therefore, emphasis has been given to N fertilizer management practices to the maintenance of safe environment and sustainable agriculture. To achieve these goals, research priorities must consider for the improvement of both NUE and photosynthetic output for a given crop N accumulation.

In Malaysia, rice growers practicing double cropping systems with high yielding varieties of rice (Ho *et al*. 2008), which requires huge amounts of chemical fertilizers (Ali, 2009). Intensive rice production practices with excessive applications of chemical fertilizers poses a great threat to environment, as well as decreasing soil fertility. An environment safe crop production system is crucial to ensure a sustainable and healthy ecosystem (Khairuddin, 2002). Inclusion of legumes crops in rotation with rice crops can enhance fertility of soil N (Derksen *et al*. 2001), improve soil texture, water holding capacity (Russell *et al*. 2006), mineralizable C and N (Kumar and Goh, 2000; Goh *et al*. 2001), higher income, while minimizing production hazard and secure long-term credible as well to acquire agronomic and environmental favor (Delin *et al*. 2008). Soil amendment by addition of plant residues can influence the population of soil biota and their activity in the soil to transform soil nutrient (Yadvinder *et al*. 2005) for crop productivity (Kumar *et al*. 2001). Soil organic matter is a key indicator of soil quality, which provides plant nutrients upon mineralization and eventually improves soil structure and chemical properties of soil (Goh *et al*. 2001; Kumar *et al*. 2001).

Rice crop rotation with tropical grain or vegetable legumes are not often used in Malaysia, but rice growers practiced double crops annually or sometimes more than four crops in a two year period in rice producing areas (Khairuddin, 2002). For sustaining these practices excessive amounts of chemical fertilizers are endangering the ecosystem and degrading soil fertility. Thus rational application of fertilizer and use of crop residues are inevitable for the amendment of soil to improve quality and productivity under rice-based cropping systems in the tropics (Yadvinder *et al*. 2005). Bush bean and winged bean are traditional vegetables cultivated in marginal land but both crops can easily be fit in an upland rice crop rotation system. Currently growers are interested about the sustainability of natural resources and attention has been focused to fit legume crops in their existing cropping practices to enrich soil nutrient status for quality production. The use of tropical legumes such as winged bean or bush bean individually or in combination with chemical fertilizer N can offer favorable options to N supplement for rice production in Malaysia (Rahman *et al*. 2013). No systematic study has been carried out on the fate of N in vegetable legume crop and their effects on soil N contributions to the NUE of the following rice crop in Malaysia. The objectives of the study were to assess the addition of legume residues to nitrogen agronomic efficiency and nitrogen recovery efficiency and to clarify the effects of fertilizer N application to optimize biomass yield and N uptake of rice when tropical legumes are tested in the system.

MATERIALS AND METHODS

The experiments were tested in a greenhouse at the University of Malaya, Kuala Lumpur, Malaysia during 2010 and 2011. The details of soil properties, experimental pot, seeding time, methods of fertilizer application, and crop management practices were followed as described by Rahman *et al*. (2013). Bush bean and winged bean were grown with N fertilizer at rates of 0, 2, 4 and 6 g m^{-2} while rice was grown with N fertilizer at rates of 0, 4, 8 and 12 g m^{-2}. Nitrogen fertilizer was applied in the first cycle of the experiment in 2010 and no chemical fertilizers were applied in the second year crops to evaluate the consequence of legumes plants residue to the next rice crop performance. Additional 16 fallow pots were used to fulfill the requirement of rice after fallow crop rotation. Each crop along with their treatment schedule was tested in an individual experiment. Each treatment was replicated five times. Each experiment was laid out under completely randomized design. Bush bean, winged bean and corn were planted in early March of 2010 and 2011. All legume crops and corn were harvested at 70 days after emergence. Rice seedlings (14 d old) were transplanted during the 2nd week of July for both years. Rice was harvested during the second week of November in both years. Mean air temperature and humidity ranged from 25.5 to 33.5 ^{0}C and 70 to 85%, respectively. The crop rotation cycle, legume plant residue management practices and data collection procedure were as described elsewhere (Rahman *et al*. 2013). The plant samples were dried to a constant weight at 70^{0}C and dry weight was recorded from each pot. Nitrogen content in plants was determined by the Kjeldahl method (Chu *et al*. 2004). The following nitrogen agronomic efficiency (NAE) and nitrogen recovery efficiency (NRE) were determined for each treatment (Cassman *et al*. 2002; Lopez *et al*. 2001; Zuliang *et al*. 2012).

NAE (g g^{-1}) = (grain yield at Nx – grain yield at N0)/applied N at Nx, and

NRE (%) = [(N uptake at Nx – N uptake at N0)/applied at Nx] *100

Statistical analysis was conducted using SAS software (SAS, 2008) and treatment means were compared based on the Fishers Least Significant Difference (LSD) test at the 0.05 probability level.

RESULTS AND DISCUSSION

Biomass and nitrogen accumulation of rice rotation with legume crops: Biomass yield and N accumulation of rice was affected significantly by use of N fertilizer in each crop rotation. Rice after winged bean with 4, 8 or 12 g N m^{-2} recorded significantly higher biomass (1262-1290 g m^{-2} for 2010 and 1212-1254 g m^{-2} for 2011) during both years (Table 1). Biomass accumulation was lower in rice when it was rotated with bush bean and it was at par in rice after fallow with 8 and 12 g N m^{-2} rotation. Rice after fallow, grown without N fertilizer produced the lowest biomass (906-941 g m^{-2} yield (Table 1). The accumulated biomass following winged bean (169-197 g m-2) could probably be a positive impact of N from the above and below ground legume plant parts (Rahman *et al*. 2013).

Rice after winged bean grown with 4, 8 and 12 g N m^{-2} accumulated maximum N (13.4-13.9 g m^{-2} for 2010 and 12.5-12.9 g m^{-2} for 2011) compared with other crop rotations. Compared with rice after fallow, rice after bush bean grown with 8 and 12 g N m^{-2} accumulated appreciably higher N (11.0-11.6 g m^{-2} for 2010 and 10.7-10.9 g m^{-2} for 2011). The lowest N uptake (7.1-7.5 g m^{-2}) was recorded by rice after fallow when grown without N fertilizer (Table 2). The increased plant N in rice following rotation with winged bean could probably be attributed to the N contribution from the larger amount of above ground plant parts addition and the below ground plant residues in the legumes. Between two tested legume crops, winged bean supplied appreciably greater N over their residues at each season. The higher quantities of N uptake secured in winged bean afford from its larger supply of biomass yield (Rahman *et al*. 2013). The quality of residues in legume plants rotated with rice crops might be the reason for greater N uptake compared to rice after fallow systems. Despite poor below ground residues contributed by soybean and other pulses than cereals and other crops but their contribution was higher regarding soil microbes which enhanced nutrient status in rhizosphere for nutrient uptake (Raun and Johnson, 1999). Among crop rotations the highest N uptake was recorded by rice after winged bean followed by rice after bush bean and rice after fallow rotation. Soil microbial population increased rapidly when young and relatively fresh succulent green manure crop was added into the soil. After decomposition of plant residues through microbial breakdown, nutrients retained within the decomposed plant residues and soil microbes are released and made available to the following crop (Florian *et al*. 2008). In our study both legume crops were added into soil at pod formation stage. Apparently this could be slightly slow breakdown of legume residue resulting poor volatile loss of ammonia during rice after winged bean or rice rotated with bush bean growing cycle. While in rice after fallow rotation with fertilizer, a substantial amount of applied urea seemingly was lost by ammonia volatilization. This was possibly due to the fact that N was applied up to panicle initiation stage. Earlier studies have suggested that an appreciable amount of N can be lost by ammonia volatilization during plant sampling stage when top dressing of urea was not done (Diekmann *et al*. 1993).

Nitrogen recovery efficiency of rice: Nitrogen recovery efficiency (NRE) was influenced significantly by N fertilizer application in each crop rotation (Table 3). The highest NRE (32.5%) was obtained by rice after winged bean with 4 g N m^{-2}. In the present study NRE was relatively lower than those of other studies where N fertilizer was used during later part of crop growing period. During 2010, the year with the higher N uptake of rice, the value recorded for NRE was higher than that recorded during 2011 (Table 3). The higher values during 2010 could be due to higher N uptake, caused by both legumes residual effects along with N fertilizer. The NRE was appreciably higher in rice after both legumes than rice after fallow during both years. Regardless of N fertilizer rate the NRE values were 15-33% during 2010 and 13-30% during 2011 for rice after winged bean. The NRE values were 20-29% during 2010 and 20-28% during 2011 for rice after bush bean. In our study NRE values were lower compared with NRE values (42%) obtained in developed countries. The possible reason could be the difference in growing conditions whereby experiments in the present study were conducted under greenhouse conditions, while developed countries studies were conducted in on-station experiments (Raun and Johnson, 1999). The higher recoveries of N from legume rotations were possibly due to enrichment of soil-N. The availability of below-ground pool of legume N is an important source of supplying N for subsequent crops (Florian *et al*. 2008). When soil-N content increased, the amount of sequestered N contributed to higher NUE of the cropping system, and simultaneously sequestered N gained from applied N provided to higher NRE (Elcio *et al*. 2003). An average NUE of 31% was recorded for N based on-farm experiments in the major rice production regions of Asian countries. In contrast, NRE for rice in well-managed field experiments ranged from 50-80% (Florian *et al*. 2008). Therefore, emphasis has been given to improve NRE because N fertilizer is the main source of N and it losses from cereal-based cropping systems.

Nitrogen agronomic efficiency (NAE) was affected significantly by fertilizer N application in each crop rotation. The highest NAE (24 g g^{-1} to 27 g g^{-1}) was estimated from rice after winged bean with 4 g N m^{-2} for both years (Table 4). Rice after bush bean with 4 g N m^{-2} also showed similar trend although NAE was lower than rice after winged bean systems regardless of N fertilizer during both years (Table 4). The NAE trends were similar during both years. Rice after fallow also showed similar trend. Nitrogen agronomic efficiency of rice after winged bean systems indicated a positive response to rice production without deteriorating soil fertility. Therefore, AE has biological significance which contributed to grain yield supported by organic sources of N. The results proved that higher rate of N application decreased NAE. The highest and the lowest agronomical nitrogen use efficiencies were obtained in the 60 and 180 kg ha^{-1} N, respectively which showed that NAE reduced with increased N fertilizer rates (Shahzad *et al*. 2010). With this scenario of NRE, it is clear that the fertilizer response was very poor but N uptake differed significantly among fertilizer rates. In this regard, N efficiency decreasing with higher N rate and may be due to greater losses of N from the system (Huggins and Pan, 2003). Considering above fact it is clear that current fertilizer N management practices must be improved by addition of legume crops in cereal based cropping systems in Malaysia.

Table 1. Biomass accumulation of rice as affected by N fertilizer and legume residue

N fertilizer ($g\ m^{-2}$)		**Biomass yield ($g\ m^{-2}$)**					
		Rice after bush bean		**Rice after winged bean**		**Rice afterfallow**	
2010	**2011**	**2010**	**2010**	**2010**	**2011**	**2010**	**2011**
0	0	986.0 c	921.8 c	1154.7 b	1107.5 b	941.4 c	905.5 c
4	0	1058.6 b	993.5 b	1262.2 a	1211.7 a	1065.1 b	993.5 b
8	0	1074.9 ab	1074.9 a	1283.4 a	1244.3 a	1136.8 a	1042.3 a
12	0	1123.8 a	1084.0 a	1289.9 a	1254.1 a	1127.0 a	1058.6 a

Means followed by the same letters are not significantly different at the 5% level

Table 2. Nitrogen accumulation of rice as affected by N fertilizer and legume residue

N fertilizer ($g\ m^{-2}$)		**Nitrogen uptake ($g\ m^{-2}$)**					
		Rice after bush bean		**Rice after winged bean**		**Rice after fallow**	
2010	2011	2010	2011	2010	2011	2010	2011
0	0	9.4 d	8.5 c	12.1 b	11.3 b	7.5 c	7.1 d
4	0	10.4 c	9.5 b	13.4 a	12.5 a	8.5 b	7.9 c
8	0	11.0 b	10.7 a	13.7 a	12.8 a	9.5 a	8.4 b
12	0	11.6 a	10.9 a	13.9 a	12.9 a	9.7 a	8.7 a

Means followed by the same letters are not significantly different at the 5% level

Table 3. Nitrogen recovery efficiency of rice as affected by N fertilizer and legume residue.

N fertilizer ($g\ m^{-2}$)		**Nitrogen recovery efficiency (%)**					
		Rice after bush bean		**Rice after winged bean**		**Rice after fallow**	
2010	2011	2010	2011	2010	2011	2010	2011
0	0	0.0 c	0.0 d	0.0 d	0.0 d	0.0 c	0.0 d
4	0	28.8 a	27.5 a	32.5 a	30.0 a	25.5 a	20.0 a
8	0	29.5 a	23.8 b	20.0 b	18.8 b	25.0 a	16.3 b
12	0	19.6 b	20.0 c	15.0 c	13.3 c	18.3 b	13.3 c

Means followed by the same letters are not significantly different at the 5% level

Table 5. Nitrogen agronomic efficiency ($g\ g^{-1}$) of rice as affected by N fertilizer and legume residues

N fertilizer ($g\ m^{-2}$)		**Nitrogen agronomic efficiency ($g\ g^{-1}$)**					
		Rice after bush bean		**Rice after winged bean**		**Rice after fallow**	
2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
0	0	0.0 d	0.0 d	0.0 d	0.0 d	0.0	0.0 d
4	0	13.0 a	12.5 a	26.9 a	23.6 a	21.2 a	13.8 b
8	0	10.7 b	9.7 b	16.3 b	14.7 b	18.7 b	15.1 a
12	0	7.4 c	6.5 c	12.2 c	12.5 c	15.2 c	11.4 c

Means followed by the same letters are not significantly different at the 5% level.

Conclusions: Rice crop rotation with bush bean and winged bean were capable of producing consistently greater NRE than rice after fallow. Bush bean and winged bean residues incorporated into the soil supplied N to rice crop and produced benefits comparable with that of 4 to 8 g fertilizer N m^{-2}. The two year research findings suggest that both winged bean and bush bean are potential tropical vegetable legumes that can supplement N fertilizer for the following rice crop. Such kinds of tropical legumes those improve productivity of rice might be attractive to farmers who are generally resource-poor farmers. Thus, the combined application of bush bean and N fertilizer or winged bean grown without fertilizer can substitute for N fertilizer for the improvement of NUE rice crop.

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