Nitrogen accumulation and recovery from Legumes and N Fertilizer in Rice-based cropping systems

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Abstract

This study was established in the long-term experimental plots of Kyoto University Farm at Takatsuki, Japan. Double cropping systems including rice (cv. Hinohikari)-fallow, rice-broad bean (*Vicia faba* L.), rice-hairy vetch (*Vicia villosa* Roth), and rice-naked barley (*Hordeum vulgare* Nudum) and ^{15}N-labeled fertilizers at rates 0, 40, 80 and 120 kg ha^{-1} were tested. The legumes broad bean and hairy vetch produced 3350 to 10820 kg aboveground biomass ha^{-1}, accumulated 131 to 352 kg N ha^{-1} of which 41 to 78 % was derived from N_2 fixation (% Ndfa). Legume residues significantly increased rice yield and recovery of ^{15}N-labeled fertilizer (% of N applied). Recoveries of ^{15}N-labeled fertilizer were 80, 76, 74 and 72 % in rice-broad bean, rice-hairy vetch, rice-naked barley and rice-fallow systems, respectively.. The greater performance of rice-broad bean systems was reflected in greater N fixation. The effects of combined application of unlabeled legumes and labeled fertilizer on N losses are lower than those obtained with a single application of labeled fertilizer N. Results show that legumes N can supply a substantial proportion of the N requirements of wetland rice.

Media summary

Legume incorporation into rice-based cropping systems contribute increased productivity and maintenance of soil fertility by virtue of their capacity to fix large amounts of atmospheric N.

Key Words

^{15}N-balance, Rice productivity, Soil fertility

Introduction

Rice N requirements are closely related to yield levels, which in turn are sensitive to climate, particularly solar radiation and supply of other nutrients and crop management practices (Kropff et al. 1993). These factors also affect the pattern and quantity of N supplied from indigenous soil resources. Fertilizer-N management strategies must therefore be responsive to potentially large variations in crop N requirements and soil N supply (Cassman et al. 1993). Nitrogen is the most important nutrient in rice systems, accounting for 67% of total fertilizer applications to rice worldwide (Vlek and Byrnes, 1986). Nitrogen uptake patterns in rice over the growing season depend on the availability of soil N and fertilizer N. When fertilizer N is applied preplant, fertilizer N uptake tends to be concentrated toward the beginning of the season, with soil N being the dominant N pool after the fertilizer N supply is depleted or immobilized (Bufogle et al. 1997). The relationship between fertilizer N uptake and total N uptake over the growing season depends on timing of the fertilizer N application (Guindo et al. 1994) and the amount of fertilizer N available (Bufogle et al. 1997). Enhanced N use efficiency for greater biomass production is essential in systems where N availability is often low and limiting for plant growth (Muchow et al. 1993) and development.

Because of intensification of cereal production, double cropping systems need additional amounts of nitrogenous fertilizer to maintain soil fertility. Inorganic N fertilizers are considered expensive by resource-poor Asian farmers. Leguminous crops are sources of N, and may also enhance soil fertility through their effects on soil physico-chemical properties. Legumes have the potential to increase the soil's N supplying capacity for succeeding crops. Thus, legume-based double cropping such as rice–legume represents a viable alternative for maintaining soil fertility while reducing production costs and protecting the environment by using less chemical fertilizer. Therefore, research was conducted to determine the effect of legume crops and ^{15}N labeled fertilizer on N accumulation, recovery and grain yield of wetland rice.

Materials and Methods

This study was developed in the long-term experimental plots of Kyoto University Farm at Takatsuki, Japan. Treatments were arranged in a split plot design, with double cropping system viz. rice-fallow; rice-broad bean (grain legume); rice-hairy vetch (legume as cover crop) and rice-naked barley (i.e. cereal after cereal) as main plot treatments and ^{15}N-labeled fertilizer as subplot treatments. ^{15}N-labeled fertilizers rates were 0, 40, 80 and 120 kg ha^{-1}. Treatments were replicated three times. No fertilizer was appliedto winter crops. The experiment was initiated on November, 2001 and continued until October 2002. Broad Bean (cv. Minpo), hairy vetch, naked barley (cv. Ichiban Boshi) and rice (cv. Hinohikari) were used. Naked barley was used as reference crop for estimation of biological nitrogen fixation (BNF). Micro-plots were established in each subplot and fertilized with ^{15}N-labeled ammonium sulphate [$(NH_4)_2SO_4$] at 3 atom % ^{15}N per treatment schedule. To prevent lateral movement of the labeled ^{15}N, wooden barriers surrounding the micro plots were inserted into the soil to a depth of approximately 20 cm. All data were recorded from labeled plant samples. The ^{15}N-labeled plants were analyzed for the concentration of N and atom percent of ^{15}N using a combustion continuous flow isotope ratio mass spectrometer. Plant tissue N concentration was also determined by Kjeldahl digestion. The proportion of N derived from ^{15}N-labeled fertilizer in the plant and soil and percent ^{15}N recovered by the plant and that remaining in soil were calculated with the following equation:

(atom % ^{15}N excess$_{plant}$) (N_{plant})

N recovery of ^{15}N-labeled fertilizer = -------------------------------- X ------------X 100

(atom % ^{15}N excess$_{fertilizer}$) ($N_{fertilizer}$)

Where atom % ^{15}N excess$_{plant}$ = atom % ^{15}N excess (over back ground levels) in the plant, atom % ^{15}N excess$_{fertilizer}$ = atom % ^{15}N excess in the labeled fertilizer N, N_{plant} = total plant N (kg ha^{-1}), and $N_{fertilizer}$ = fertilizer N applied (kg ha^{-1}).

Estimates of the proportion of plant N derived from N_2 fixation (% Ndfa) were calculated by the N difference procedure by comparing N accumulated in the legume with the nonlegume reference as follows:

100[(Legume N – Reference N)]

% Ndfa= ---

(Legume N)

Results and Discussion

Aboveground biomass yields of hairy vetch and broad bean were 3350 and 10820 kg ha^{-1}, with corresponding N accumulations of 131 to 352 kg ha^{-1}. Broad bean produced significantly higher biomass and N accumulation than hairy vetch. Legumes, however derived N from both soil and atmosphere (BNF). In this study, the plant N derived from N_2 fixation (% Ndfa) in broad bean and hairy vetch were 41 to 78 %. Contributions of BNF to the total above ground N accumulation ranged from 54 to 274 kg ha^{-1} (Table 1). The larger amounts of N_2 fixed in broad bean resulted from better growth and higher biomass accumulation. Contributions of BNF to the aboveground N accumulation ranged from 91 to 240 kg ha^{-1} in legumes (Ladha et al. 1996). Estimates of % Ndfa for other forage legumes and pigeonpea were with in the range of 44 to 95 % (Peoples and Herridge, 1990). In this study legumes play a positive role in the maintenance of soil N fertility, they must leave behind more N from N_2 fixation than the amount of soil N they remove (Table 1).

Table 1. The contributions of legume crops grown during winter season in Japan 2002.

Legume crops	Biomass kg ha^{-1}	N accumulation kg ha^{-1}	N fixed by legumes kg ha^{-1}	Soil N removal by legumes kg ha^{-1}	Plant Ndf N_2 fixation (%) ND method
Broad bean	10820	352	274	78	78
Hairy vetch	3350	131	54	77	41

Above ground total N accumulations were influenced by cropping system, N fertilizer, and their interaction. Regardless of N fertilizer levels, rice-broad bean systems recorded the highest N accumulation. Rice-hairy vetch systems with N 120 produced identical N accumulation. Rice-hairy vetch systems using N 40, 80 and rice-naked barley with N 120 and rice-fallow systems with N 120 produced identical and moderate N accumulation. The smallest quantities of N accumulation were obtained from the rice-fallow and rice-naked barley systems all without N (Table 2). In this study, the increased plant N following broad bean and hairy vetch incorporation indicates an increase in plant N accumulation.

The plant N recovery of ^{15}N-labeled fertilizer (% of N applied) values measured in this study were in the range of 41 to 56%. The highest plant N recovery from ^{15}N-labeled fertilizer was achieved in the rice-fallow systems. Rice-broad bean systems with N 40 and hairy vetch systems with N 80 and N 120 achieved moderate plant N recovery from ^{15}N-labeled fertilizer. Minimum plant N recoveries of ^{15}N-labeled fertilizer were obtained from the rice-naked barley and rice-hairy vetch systems with N 120 (Table 2). The rice recovered 65 to 94 % from applied ^{15}N-labeled fertilizer and legume residue incorporation. At the same labeled ^{15}N rate 65 to 78 % was recovered by rice-fallow systems. Rice-broad bean systems recovered the highest total N recovery (68 to 94 %). Recovery was poor when rice crop received both unlabeled legume residue and labeled fertilizer (> 40 kg ha^{-1}) regardless of legumes. In rice-fallow systems plant N recovery was higher from ^{15}N-labeled fertilizer while soil N recovery was poor compared to rice-broad bean and rice-hairy vetch systems (Table 2). A combined application of non labeled legume with 40 kg labeled N fertilizer resulted in significantly higher recoveries of N in the soil than that of labeled N fertilizer applied alone at the same N rates. Thus, based on total ^{15}N balances, N losses (N unaccounted for) from the soil-plant system in rice-fallow systems were appreciably higher than those in rice-broad bean and rice-hairy vetch systems. Therefore, recovery of ^{15}N-labeled fertilizer of rice-broad bean and rice-hairy vetch systems indicate a positive contribution of biological nitrogen fixation on rice production without deteriorating soil fertility.

Table 2. N accumulation, recovery determined by ^{15}N dilution method and grain yield of rice as affected by N fertilizer and cropping systems in Japan 2002.

Cropping systems	N fertilizer kg ha^{-1}	N accumulation kg ha^{-1}	Recovery of ^{15}N-labeled fertilizer (% of N applied)			Grain yield kg ha^{-1}
			Soil	Plant	Total	
Rice-broad bean	0	194	-	-	-	7280
	40	198	46	48	94	6920

	80	200	32	45	77	6880
	120	204	23	45	68	6910
Rice-hairy vetch	0	129	-	-	-	5230
	40	166	35	46	81	6600
	80	178	33	47	80	6880
	120	187	24	42	68	6500
Rice–naked barley	0	109	-	-	-	5420
	40	135	35	41	76	6180
	80	149	34	43	77	6520
	120	163	26	44	70	6530
Rice-fallow	0	92	-	-	-	4670
	40	123	22	43	65	5940
	80	144	20	54	74	6790
	120	176	22	56	78	7170
CS - LSD (0.01)		16				967
N - LSD (0.01)		11				630
CS X N–LSD (0.01)		22				1260

The recovery of ^{15}N-labeled fertilizer (% of N applied) from plant was greater in rice-fallow systems rather than incorporation of legumes over the growing season. Diekmann et al., (1993) found similar evidence when green manure was incorporated in rice. The substantial amount of N unaccounted for from labeled fertilizer is probably due to losses by ammonia volatilization, and denitrification from the flood water occurring during the first few days after fertilizer application as reported by Vlek and Byrnes (1986). The total recoveries of ^{15}N-labeled fertilizer found in the present study support the results of John et al. 1989; Diekmann et al. 1993). Incorporation of legumes in rice-broad bean and rice-hairy vetch systems compared with rice-naked barley and rice-fallow systems increased the soil N availability through an increase in net N mineralization and corresponding addition of fertilizer ^{15}N. The increase in fertilizer N uptake was associated with an increase in soil N uptake when broad bean or hairy vetch was incorporated (Table 2). Therefore the rate of fertilizer N application can be reduced when broad bean and hairy vetch are incorporated.

Grain yield of rice was affected significantly by cropping systems, N fertilizer and their interaction. Regardless of N fertilizer levels, rice-broad bean systems produced higher yield which was similar to rice-naked barley with N 80 and N 120, rice-hairy vetch with N 40, N 80 and N 120, and rice-fallow with N 120. Minimum yield was obtained by rice-fallow, rice-hairy vetch, and rice-naked barley systems without N. Rice-hairy vetch systems with N 40, N 80 and N 120 gave similar yields. Rice-naked barley systems with N 80 and N 120 showed similar yield. No appreciable difference was observed on rice-fallow systems with N 80 and N 120 (Table 2)

Conclusion

Legume residues incorporated into the soil supplied N to wetland rice and produced benefits comparable with that of 40 to 80 kg fertilizer N. Such winter legumes that improve annual productivity of rice might be attractive to farmers, who are generally resource-poor farmers, since the benefit of a steady increase in soil N and soil fertility is clear. Thus, legumes have the potential to substitute for or supplement chemical/inorganic fertilizer.

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