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Use of *Azolla* as biofertilizer to enhance crop yield in a rice–wheat cropping system under mild climate

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Abstract

A field study was conducted to observe the effect of *Azolla* on rice yield, N uptake and its residual effect on subsequent wheat crop. *Azolla* developed into a thick mat due to the mild temperature prevailing during the rice season. *Azolla* was grown as intercrop with rice in field conditions and was used as cover, and also as incorporated treatment alone and in combination with a low dose of urea. As compared to unfertilized control, increase in rice grain yield was 28% for *Azolla* cover, 53% for *Azolla* incorporated and 71% for *Azolla* incorporated +30 kg N/ha treatment. The grain yield of wheat, grown after rice harvest and without any fertilizer application, was significantly higher for *Azolla* than control and chemical-N treatments. The results of this field study indicated that *Azolla* can successfully be used for increasing crop yield in a rice–wheat cropping system.

Introduction

Rice and wheat are the most important staple food crops in the world. The yields of rice and wheat in South Asia have been steadily declining; thus serious efforts are needed to increase the yield of these crops (IRRI, 1992). Because of the high prices of chemical fertilizers, the farmers of developing countries can barely afford to use expensive chemical fertilizers, and thus cannot achieve optimum yield. *Azolla* has been used for centuries as a biofertilizer in rice (Lumpkin and Plucknett, 1982), and is still considered a potential nitrogen biofertilizer in a rice-based cropping system (Peoples *et al.*, 1995). The usefulness of *Azolla* for increasing rice yield has been reported in various countries (Watanabe, 1987; Kumarasinghe and Eskew, 1993). However, little information is available on its use in a rice–wheat cropping system; therefore the present study was carried out

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to investigate the usefulness of *Azolla* for enhancing the grain yield of these important crops.

Materials and methods

The field experiment was carried out at Swat, located in the rice-growing northern valley of Pakistan, having a maximum temperature of 35°C during the rice season (Choudhry, 1978). The study was conducted in 3 m × 5 m plots, arranged in a randomized complete block design. The soil was flooded for a few days before rice transplanting, and rice (var. JP-5) was transplanted at three seedlings/hill with 20 × 20 cm hill spacing. A mixed culture of six strains of *Azolla*, *viz. A. pinnata* (local), *A. filiculoides, A. caroliniana, A. microphylla, A. pinnata var. pinnata and Rong Ping* (hybrid) was inoculated in *Azolla* nursery, and farmyard manure was applied at 0.5 kg/m^2 to encourage its multiplication. Twenty-five days after rice transplanting (DAT) a mixed inoculum of above-described six *Azolla* strains was inoculated at 200 g (f.w)/m^2, into *Azolla* experimental plots (Table 1), and 5 g P_2O_5/m^2 (superphosphate) was also applied to all plots to supply phosphorus to rice, and enhance *Azolla* growth. For prevention of insect attack to *Azolla* and rice, Furadan granules (at 60 mg carbofuran/m^2) were broadcast 25 DAT to all plots. Urea at 30 kg N/ha was applied 38 DAT to nitrogen alone and N+*Azolla* treatment plots.

After *Azolla* inoculation it was allowed to grow without mixing into soil for *Azolla* cover treatments; while for *Azolla*-incorporated treatments nearly half of the *Azolla* mat was incorporated manually into the soil and the remainder was left to grow again until the next incorporation. Two such incorporations, i.e. 60 and 73 DAT, were made during the period of rice growth. Rice plants were harvested at maturity and then dried at 70°C for dry weight and total N analysis.

Table 1. Effect of *Azolla* and urea on dry-matter yield of rice, cv. JP-5

Treatment	Straw (kg/ha)	Grain (kg/ha)	Straw+grain (kg/ha)
T1. Control	5542^{c}	3917^{d}	9458^{c}
	0	*0*	*0*
T2. *Azolla* cover	6000^{bc}	5000^{c}	11000^{bc}
	8	*28*	*16*
T3. *Azolla* incorporated	7188^{abc}	6000^{ab}	13188^{ab}
	30	*53*	*39*
T4. 30 kg N/ha	7375^{ab}	6125^{ab}	13500^{ab}
	33	*56*	*43*
T5. *Azolla* cover+30 kg N/ha	6250^{bc}	5625^{bc}	11583^{bc}
	13	*44*	*22*
T6. *Azolla* incorporated +30 kg N/ha	8108^{a}	6683^{a}	14792^{a}
	46	*71*	*56*

Means followed by the same letter are not statistically different at 5% p. Figures in italics show percentage increase over control.

After harvesting rice, the soil was ploughed to mix the left-over *Azolla* and rice stubble into the soil. To investigate the residual effect of *Azolla*, wheat (var. Khyber 87) was sown without applying any fertilizer.

Results and discussion

Azolla developed into a thick mat in the nursery and experimental plots, which may be due to the mild temperature (20–35°C) prevailing during the rice growth period; as for most of the *Azolla* species, a temperature around 25°C is considered to be optimum for its growth and nitrogen fixation (Lumpkin and Plucknett, 1982).

As compared to unfertilized control the increase in rice grain yield was 28% for *Azolla* cover, 53% for *Azolla* incorporated and 71% for *Azolla* incorporated +30 kg N/ha (Table 1). Similarly an increase in rice yield due to *Azolla* cover and/or incorporation was also reported by Watanabe (1987) and Kulasooriya *et al.* (1994), while the use of *Azolla* along with chemical-N fertilizer was found to be better than chemical fertilizer for rice yield by Yanni *et al.* (1994). As compared to control, the total nitrogen accumulated in rice plants (straw+grain) was 71% while in rice grain it was 82% higher, for *Azolla* incorporated +30 kg N/ha (Table 2). An improvement in N uptake and fertilizer-N use efficiency in the presence of *Azolla* was also reported from different countries (Kumarasinghe and Eskew, 1993).

The application of *Azolla* not only increased rice yield, but its residual effect on wheat straw and grain yield was significantly higher as compared to control for *Azolla* treatments (Table 3). As compared to unfertilized control the increase in wheat straw yield was 106% for *Azolla* cover, 108% for *Azolla* cover+30 kg N/ha and 143% for *Azolla* incorporated +30 kg N/ha (Table 3). Similarly, the wheat grain yield was 70% and 93% higher for *Azolla* incorporated (T3) and

Table 2. Effect of *Azolla* and urea on nitrogen uptake in rice, cv. JP-5

Treatment	Straw (kg/ha)	Grain (kg/ha)	Straw+grain (kg/ha)
T1. Control	26.44^{c}	35.61^{c}	62.05^{d}
	0	*0*	*0*
T2. *Azolla* cover	30.80^{bc}	46.65^{b}	77.46^{cd}
	16	*31*	*25*
T3. *Azolla* incorporated	37.01^{ab}	55.49^{ab}	92.50^{abc}
	40	*56*	*49*
T4. 30 kg N/ha	42.14^{a}	55.89^{ab}	98.04^{ab}
	59	*57*	*58*
T5. *Azolla* cover+30 kg N/ha	33.23^{abc}	54.37^{b}	87.60^{bc}
	26	*53*	*41*
T6. *Azolla* incorporated +30 kg N/ha	41.39^{a}	64.88^{a}	106.27^{a}
	57	*82*	*71*

Means followed by the same letter are not statistically different at 5% *p*. Figures in italics show percentage increase over control.

Table 3. Residual effect of *Azolla* and urea on dry-matter yield of wheat, cv. Khyber-87

Treatment (given to rice)	Straw (kg/ha)	Grain (kg/ha)	Straw+grain (kg/ha)
T1. Control	2273[d]	1740[c]	4013[d]
	0	*0*	*0*
T2. *Azolla* cover	4690[b]	2640[b]	7330[b]
	106	*52*	*83*
T3. *Azolla* incorporated	2817[c]	2960[b]	5777[c]
	24	*70*	*44*
T4. 30 kg N/ha	2933[c]	2750[b]	5683[c]
	29	*58*	*42*
T5. *Azolla* cover+30 kg N/ha	4723[b]	2990[b]	7713[b]
	108	*72*	*92*
T6. *Azolla* incorporated +30 kg N/ha	5517[a]	3363[a]	8880[a]
	143	*93*	*121*

Means followed by the same letter are not statistically different at 5% *p*. Figures in italics and smaller font show percentage increase over control.

Azolla incorporated + N treatments (T6) respectively (Table 3). The wheat biomass (straw+grain) was maximum for *Azolla* incorporated + 30 kg N/ha (T6) followed by *Azolla* cover treatments, i.e. T2 and T5 (Table 3). Kolhe and Mitra (1987) have also reported a better residual effect of *Azolla* on the subsequent wheat crop, while a higher residual effect of *Azolla* and *Sesbania* than urea was observed on the following rice crop by Watanabe and Ventura (1992). The combined effect of conserved soil N during the rice season due to nitrogen fixation by *Azolla* and mineralization of unused *Azolla* during wheat growth, might have led to a higher residual effect for *Azolla* than control or chemical-N application, as a similar residual effect is expected for a leguminous crop on the subsequent crop (Peoples *et al.*, 1995).

The field study indicated that *Azolla* alone and/or in combination with a low dose of chemical-N can be used quite successfully to increase grain yield in a rice-wheat cropping system under mild climate conditions.

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