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Response of Various Mycorrhizal Inoculants on Rice Growth, Productivity and Nutrient Uptake

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Abstract

Mycorrhizal inoculant is one of the options to increase the nutrient availability in soil which ultimately increases the crop yield. The effect of various mycorrhizal inoculants on plant growth and nutrient status in *Kharif* rice was studied at 'C' block farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, West Bengal, India. The soil was was typical Gangetic Alluvium with sandy loam in texture with medium water holding capacity. The experiment comprises of nine treatments replicated thrice in RBD during 2016 and 2017. The crop having treated with RhizoMyco @ 250 g ha^{-1} at 15 DAT significantly increased plant height, dry matter accumulation (DMA), leaf area index (LAI), crop growth rate (CGR), yield attributes and yield than others. The range of increase was 0.72% to 27.17% in grain yield under mycorrhizal inoculants treatments over untreated control in this experiment. Grain yield was maximum (3.51 t ha^{-1}) in the treatment applied with RhizoMyco @ 250 g ha^{-1} at 15 DAT which was statistically superior over other treatments except T_5. Nutrient availability in soil and uptake of N, P and K was also found higher in RhizoMyco application. A positive correlation prevailed in between different growth and yield parameter of rice with available N, P, K in soil and uptake of different nutrients by plant. This study suggests growing transplanted rice with application of RhizoMyco @ 250 g ha^{-1} at 15 DAT for better growth, higher productivity and higher nutrient uptake.

Keywords: Transplanted rice, mycorrhizal inoculants, yield, nutrient

1. Introduction

Rice is the staple food of India. India has highest area but second largest producer next to China (FAS-USDA, 2017). Rice is grown in an area of 43.79 mha annually with a production of 113 mt, which contributes 39.6% of the total food grain production of the country during 2017-18 (Anonymous, 2018). Rice cultivation results in more fertility decline and crops responding to wider NPK ratios over time. Integrated nutrient management has shown considerable improvement in rice yields by minimizing nutrient losses to the environment and managing the nutrient supply, which resulted in high nutrient use efficiency (Kumar and Yadav, 2008). In West Bengal, rice productivity is even much lower than Punjab (Anonymous, 2018). Unbalanced nutrient management along with deficiency of different macro and micronutrient in soil is one of the major reasons behind this low yield of rice (Pal et al., 2008). The cost

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of chemical fertilizers has gone higher and their availability may be limited at some places. This opens up a possibility to explore available bio-fertilizers which can partly substitute inorganic fertilizers. Biofertilizer along with different inoculants may play a vital role to overcome these problems and maximize food production (Alori et al., 2017). The use of mycorrhizal biofertilizer helps to improve higher branching of plant roots and the mycorrhizal hyphae grow from roots to soil enabling the plant roots to contact with wider area of soil surface, hence increasing the absorbing area for water and nutrients of the plant root system (Lehmann et al., 2014). The application of inoculants is seen as being very attractive since it would substantially reduce the use of chemical fertilizers and pesticides, and there are now an increasing number of inoculants being commercialized for various crops (Berg, 2009). Microorganisms play an important role in agricultural systems, particularly plant growth promoting microorganisms by supplying or facilitating availability of different kind of nutrient for maintaining soil health and sustainable agriculture development (Kennedy and Islam, 2001). Mycorrhizal fungi can absorb, accumulate and transport large quantity of phosphate within their hyphae and release to plant cells in root tissue (Barman et al., 2016). Mycorrhizas are the structures resulting from the symbiosis between these fungi and plant roots, and are directly involved in plant mineral nutrition. The symbiotic root-fungal association increases the uptake of less mobile nutrients (Ortas et al., 2001), essentially phosphorus (P) but also of micronutrients like zinc (Zn) and copper (Cu), the symbiosis has also been reported as influencing water uptake. Mycorrhiza can also benefit plants by stimulating the production of growth regulating substances, increasing photosynthesis, improving osmotic adjustment under drought and salinity stresses and increasing resistance to pests and soil borne diseases (Al-Karaki, 2006). These benefits are mainly attributed to improved phosphorous nutrition (Plenchette et al., 2005). Thus the present investigation was conducted to find out the response of different mycorrhizal inoculants on growth, yield and nutrient characteristic of rice under West Bengal condition

2. Materials and Methods

2.1. Experimental site

The field experiments were conducted during the *Kharif* (rainy) season (July to October) of 2016 and 2017 at the Kalyani C block Farm of Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal, India. The location is situated at 23°59'14'' N latitude, 88°27'16''E longitude and at an altitude of 9.75 m above the mean sea level. The experimental soil was typical Gangetic Alluvium with sandy loam in texture (56.84% sand, 23.83% silt and 19.73% clay). The initial properties of the soil collected at the beginning of the field experiment were 0.57% organic C, 162.35 mg kg^{-1} available N, 28.76 mg kg^{-1} available P_2O_5, 225.24 mg kg^{-1} available K_2O and soil pH 6.86. The climate is classified as subtropical humid, characterized by hot summer, hot-humid rainy and mild winter. The temperature and relative humidity (maximum and minimum RH) during the crop growing period of both the years did not deviate much more. The maximum temperature ranged from 27.0 °C to 36.0 °C; while, the minimum temperature varied from 21.6 °C to 28.8 °C during the cropping season (July to October). The average RH during the cropping season varied from 65.1% to 98.4%. During the experiment the area receives 20 mm more rainfall at the second season 2017 (851.9 mm) than 2016 (832.8 mm) (Figure 1).

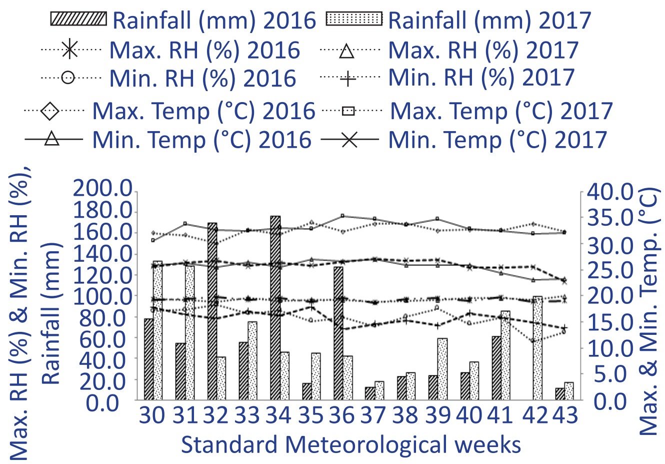

Figure 1: Weather condition of the experimental area during the two cropping system

2.2. Experimental design and treatments

The experiment was laid out in randomized complete block design with nine treatments: T_1 = Seed treatment with jumpstart 2.0 @ 1.33 ml kg^{-1} seed, T_2 = Soil application with Bolt gr. @10 kg ha^{-1} at 15 DAT, T_3 = Soil application with Myc100 @250 g ha^{-1} at 15 DAT, T_4 = Soil application with RhizoMyco @ 250 g ha^{-1} at 15 DAT, T_5 = Soil application with RhizoMyx @ 250 g ha^{-1} at 15 DAT, T_6 = Soil application with Ratchet @ 300 g ha^{-1} at 30 DAT, T_7 = Soil application with Ratchet @ 300 g ha^{-1} at 30 DAT and 60 DAT, T_8 = Soil application of PSB @ 1 kg PSB q^{-1} compost and T_9 = Untreated control. Each treatment was replicated thrice in 5×3 m^2 plots. The experiment was conducted in two successive years in the same layout.

2.3. Crop management practices

Rice (IET-4786) seedlings at 21 days were transplanted on 4th week of July during both the year at 20×20 cm^2. The recommended fertilizer dose was 80:60:40 kg ha^{-1} N, P_2O_5 and K_2O, respectively, applied in the form of urea, single super phosphate and muriate of potash. Organic manure as compost @ 1.5 t ha^{-1} was applied at final land preparation. Quarter amount of the remaining nitrogen (excluding N from neem cake), and full dose of P_2O_5 and K_2O were applied as basal before transplanting in the form of urea, SSP and MOP, respectively. The remaining portion of N was scheduled as ½ N at maximum tillering and $^1/_4$ N at panicle initiation stages, respectively. In addition to rainfall, the crop received three irrigations at maximum tillering (37 DAT), grain formation (70 DAT) and grain filling (85 DAT) stages in 2016 and three irrigations at panicle initiation (50 DAT), flowering (57 DAT) and grain filling (85 DAT) stages in 2017 for maintaining the field under saturated condition from planting to 25 days after flowering (DAF). Normal plant protection measures were taken for rice to keep the disease and insect damage beyond economic threshold level. All the mycorrhizal inoculants were applied in soil except jumpstart 2.0 which was used as seed treatment material during nursery bed preparation. PSB was applied with compost at final land preparation.

2.4. Observations recorded

All the biometric observations on growth stages of plant, yield components, grain and straw yield were measured following standard methods. For available nutrient status analysis of collected soil samples before the experiment and at harvest, alkaline permanganate method (Subbiah and Asija, 1956) for nitrogen, UV-VIS spectrophotometer (Olsen et al., 1954) for phosphorus and Flame photometer (Brown and Warncke, 1988) for potassium were used. For plant analysis micro-Kjeldahl method was used for plant nitrogen content. Tri-acid (HNO_3: H_2SO_4: $HClO_4$= 0:1:4) (Jackson, 1973) was used for determination of P_2O_5 and K_2O with the help of spectrophotometer and flame photometer, respectively.

2.5. Statistical analysis

The data were statistically analyzed by standard analysis of variance technique for randomized complete block design as suggested by Gomez and Gomez (1984), and the treatments means were compared based on the least significant difference (LSD) at 0.05 level of probability. Thus, pooled data of two years have been presented. The Excel software (version 2007, Microsoft Inc., WA, USA) and Sigma plot 12.5 version was used to draw graphs and figures.

3. Results and Discussion

3.1. Growth attributes

Different mycorrhizal inoculants had a significant effect on plant height, dry matter accumulation (DMA), crop growth rate (CGR) and leaf area index (LAI) of transplanted rice. The percent increase in plant height variation ranges from 2.35 to 16.88 than control treatment at harvest. Maximum plant height was recorded in T_4 i.e. RhizoMyco @ 250 g ha^{-1} in all date of observation except at 30 DAT where T_3 i.e. Myc100 @250 g ha^{-1} was found to record highest plant height. There were no significant differences among T_3, T_4, T_5 and T_8 in recording plant height at all date of observation but their results were significantly superior over rest of the treatments (Table 1). DMA increased gradually and steadily as the crop progressed towards its maturity, and the highest DMA was recorded at harvest. Highest DMA was in RhizoMyco @ 250 g ha^{-1} which was significantly higher than all treatments in all date of observation. There was 21.41% higher DMA accumulation in T_4 *i.e.* RhizoMyco @ 250 g ha^{-1} than control at harvest. The next best treatment was T_5 i.e. RhizoMyx @ 250 g ha^{-1} (791.78 g m^{-2}) which was found to produced statistically at par result with T_3 i.e. Myc100 @250 g ha^{-1} and T_8 i.e. PSB @ 1 kg PSB q^{-1} compost. There was a 5.96% to 21.41% higher DMA in all mycorrhizal treated plot than untreated control. Lowest DMA was in untreated control (679.30 g m^{-2}) which was significantly lower that all treatments. The CGR of transplanted rice vary significantly during 61-90 DAT. CGR was generally higher at the early stage in most of the treatments which was gradually deceasing with the advancement of crop growth and was lowest in between 91 DAT- at harvest (Table 2). Among the different treatments highest CGR was noticed at the early stage in T_7 = Ratchet @ 300 g ha^{-1} at 30 DAT and 60 DAT (7.13 g m^{-2} day^{-1}), in between 61-90 DAT it was in T_4 i.e.

Table 1: Effect of different mycorrhizal inoculants on plant height and dry matter accumulation in transplanted rice (pooled data)

No.	Treatment	Plant height (cm) at different DAT				Dry matter (g m^{-2}) at different DAT			
		30	60	90	At Harvest	30	60	90	At Harvest
T_1	Jumpstart 2.0 @ 1.33 ml kg^{-1} seed	31.98	72.05	95.62	100.97	322.05	519.32	683.62	719.76
T_2	Bolt gr. @10 kg ha^{-1} at 15 DAT	31.62	73.73	102.70	104.35	330.10	537.60	697.67	736.74
T_3	Myc100 @250 g ha^{-1} at 15 DAT	33.12	76.29	106.19	107.22	345.60	551.45	753.31	781.96
T_4	RhizoMyco @ 250 g ha^{-1} at 15 DAT	32.92	77.47	110.74	112.20	364.10	566.32	795.16	824.76
T_5	RhizoMyx @ 250 g ha^{-1} at 15 DAT	32.25	74.85	107.62	109.31	353.41	555.92	761.36	791.78
T_6	Ratchet @ 300 g ha^{-1} at 30	31.85	72.48	97.45	98.26	317.96	527.78	715.98	744.96
T_7	Ratchet @ 300 g ha^{-1} at 30 DAT & 60 DAT	30.30	73.73	99.56	100.94	325.53	539.42	727.00	753.94
T_8	PSB @ 1 kg PSB q^{-1} compost	32.13	76.14	105.62	106.79	349.03	550.49	754.10	778.26
T_9	Untreated control	29.18	70.31	95.01	96.00	283.41	487.54	650.56	679.30
	SEm±	0.60	1.09	1.01	1.14	4.23	4.12	4.33	4.26
	LSD (p=0.05)	1.72	3.14	2.92	3.29	12.18	11.86	12.47	12.27

Table 2: Effect of different mycorrhizal inoculants on crop growth rate and leaf area index in transplanted rice (pooled data)

No.	Treatment	CGR (g m^{-2} day^{-1})			LAI		
		30-60 DAT	61-90 DAT	91 DAT - at harvest	30 DAT	60 DAT	90 DAT
T_1	Jumpstart 2.0 @ 1.33 ml kg^{-1} seed	6.58	5.48	3.01	2.63	4.36	3.82
T_2	Bolt gr. @10 kg ha^{-1} at 15 DAT	6.92	5.34	3.26	2.68	4.38	3.87
T_3	Myc100 @250 g ha^{-1} at 15 DAT	6.86	6.73	2.39	2.78	4.61	4.03
T_4	RhizoMyco @ 250 g ha^{-1} at 15 DAT	6.74	7.63	2.47	2.81	4.70	4.05
T_5	RhizoMyx @ 250 g ha^{-1} at 15 DAT	6.75	6.85	2.53	2.79	4.64	4.02
T_6	Ratchet @ 300 g ha^{-1} at 30	6.99	6.27	2.41	2.57	4.54	3.80
T_7	Ratchet @ 300 g ha^{-1} at 30 DAT & 60 DAT	7.13	6.25	2.25	2.59	4.56	3.81
T_8	PSB @ 1 kg PSB q^{-1} compost	6.72	6.79	2.01	2.81	4.67	3.98
T_9	Untreated control	6.80	5.43	2.40	2.51	4.33	3.68
	SEm±	0.21	0.19	0.42	0.05	0.05	0.05
	LSD (p=0.05)	NS	0.56	NS	0.13	0.14	0.14

RhizoMyco @ 250 g ha^{-1} (7.63 g m^{-2} day^{-1}) and T_2=Bolt gr. @10 kg ha^{-1} (3.26 g m^{-2} day^{-1}) was in 91 DAT-at harvest, respectively. In between 61-90 DAT lowest CGR was in untreated control which was significantly lower than all treatments except T_1 = Seed treatment with jumpstart 2.0 @ 1.33 ml kg^{-1} seed. LAI also varied significantly due to different mycorrhizal inoculants. LAI was generally lower at the early stage which was gradually increasing up to 60 DAT and gets lower down with the advancement of crop growth. Maximum LAI was in T_4 though it was statistically at par with T_3, T_5 and T_8. Lowest LAI was in control and the result had no significant difference with only T_1 during entire date of observation. Application of mycorrhizal strains may increases the nutrient availability and better uptake of those nutrients by plant in the treated plot than control and as a result plant may grow and accumulate more than untreated which is reflected in the different growth attributes in those treatments (Sharma et al., 1988).

3.2. Yield components

The yield components, like number of tiller m^{-2}, number of panicles m^{-2}, filled grains $panicle^{-1}$ varied significantly among the different treatments. Application of RhizoMyco @ 250 g ha^{-1} was found to record highest all these parameter (325.09, 417.98, 155.15 number of tiller m^{-2}, number of panicles m^{-2}, filled grains $panicle^{-1}$, respectively) among all the treatment. The treatments performed in the order RhizoMyx > PSB> Myc 100 in number of tiller m^{-2}, number of panicles m^{-2} and filled grains $panicle^{-1}$. There was 29.33%, 15.25% and 19.67% higher number of tiller m^{-2}, number of panicles m^{-2} and filled grains $panicle^{-1}$, respectively in T_4 *i.e.* RhizoMyco @ 250 g ha^{-1} than control treatment. It was found that over the control plot there was an increase from 2.90%-29.33%, 2.58%-15.25% and 3.20%-19.67% in terms of number of tiller m^{-2}, number of panicles m^{-2} and filled grains $panicle^{-1}$, respectively among the different mycorrhizal inoculants treatments. This is the conformity of the result as obtained by various mycorrhizal applications on plant growth and yield characteristics (Hajiboland et al., 2009; Vinayak and Bagyaraj, 1990)

3.3. Crop productivity

Different mycorrhizal inoculants showed significant variation in grain and straw yield of rice which is presented in Table 3. Highest grain yield was found when the plant was treated with RhizoMyco @ 250 g ha^{-1} at 15 DAT (3.51 t ha^{-1}) which was 27.17% higher over untreated control and this treatment was significantly higher over all other treatments in terms of producing grain yield except T_5. Application of RhizoMyx @ 250 g ha^{-1} at 15 DAT (T_5) produced next best result in terms of grain and straw yield. There was 0.72% to 27.17% variation in higher grain yield production over untreated control in different mycorrhizal inoculants application among the different treatment. Straw yield production also varied among the different treatment where maximum was in T_4 and least in T_9. Harvest index of rice did not varied significantly among the different mycorrhizal treatment. High DMA and LAI at vegetative stage enhanced tillering that caused further increase in DMA during the reproductive period leading to greater spikelet formation, better grain development and higher crop productivity [Ghosh et al., 2013, Gupta et al., 2007, Ghodake et al., 2008]. Besides this application of mycorrhizal inoculants in flooded transplanted rice may increases colonization of roots which was most likely developed after transplantation and throughout the experiment due to submergence (Purakayastha and Chhonkar, 2001; Hajiboland et al., 2009) and this may increases nutrient uptake by plant and ultimately crop yield. Grain yield also showed very strong and positive relations with dry matter accumulation (r^2 = 0.869**), LAI (0.777*) and no. of tiller m^{-2} (0.942**) under the study. Grain yield also showed positive correlation with available soil N, P_2O_5 and K_2O. There was a very high positive correlation among different nutrient uptake (N, P & K) with grain and straw yield also (Table 5). Similar positive correlation

Table 3: Effect of different mycorrhizal inoculants on yield attributes and yields in transplanted rice (pooled data)

No.	No. of Tillers m^{-2}	No. of Panicles m^{-2}	Filled grains $Panicle^{-1}$	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Harvest index (%)
T_1	258.65	372.05	133.80	2.90	4.34	40.05
T_2	266.77	386.31	137.46	2.97	4.30	40.81
T_3	308.96	400.34	145.21	3.29	4.56	41.91
T_4	325.09	417.98	155.15	3.51	4.77	42.38
T_5	314.35	407.10	149.93	3.37	4.67	41.93
T_6	272.47	376.70	136.63	2.76	4.09	40.24
T_7	277.99	384.60	138.57	2.86	4.16	40.69
T_8	308.47	402.17	147.31	3.29	4.56	41.95
T_9	251.37	362.68	129.65	2.78	4.30	39.24
SEm±	4.51	3.88	1.93	0.04	0.05	0.44
LSD (*p*=0.05)	12.99	11.17	5.57	0.14	0.15	1.26

also observed by Seeilia and Bagyaraj, 1992.

3.4. *Nutrient status in soil and plant uptake*

Available soil N did not vary significantly among the different treatments at harvest though highest and lowest availability was recorded in T_4 and T_2 respectively. There was much variation in soil P_2O_5 and K_2O due to different mycorrhizal treatment. Highest availability was in T_4 which was statistically similar with T_5 for both the nutrient (Table 4). Lowest availability was in T_1 followed by T_8. Gazey et al. (2006) reported that the mycorrhizal benefit was independent of the plant available phosphorus in the soil. Uptake of different nutrient by grain and shoot varied significantly (Figure 2 and 3) among the different treatments. N, P and K uptake by grain was maximum when the crop was treated with RhizoMyco @ 250 g ha^{-1} at 15 DAT (T_4) (37.74 kg ha^{-1}, 6.27 kg ha^{-1} and 6.70 kg ha^{-1} N, P and K, respectively) whereas lowest was in untreated control. Nutrient uptake by shoot also followed the similar trend. Application of Ratchet or seed treatment with Jumpstart 2.0 showed not much variation in terms of N, P

Table 4: Effect of different mycorrhizal inoculants on soil nutrient status in transplanted rice at harvest (pooled data)

No.	Available N (mg kg^{-1} soil)	Available P_2O_5 (mg kg^{-1} soil)	Available K_2O (mg kg^{-1} soil)
T_1	152.35	17.74	163.52
T_2	148.53	21.76	181.57
T_3	154.80	23.84	194.13
T_4	155.48	27.10	200.13
T_5	155.12	25.04	200.53
T_6	155.25	20.88	176.12
T_7	154.60	17.86	170.25
T_8	151.08	18.55	169.82
T_9	152.40	24.72	191.63
SEm±	2.81	0.80	4.15
LSD (*p*=0.05)	8.09	2.32	11.97

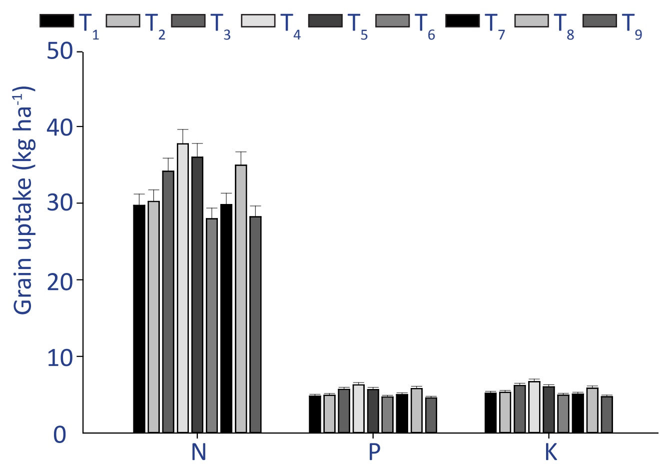

Figure 2: Response of various mycorrhizal inoculants on nutrient uptake by grain of rice

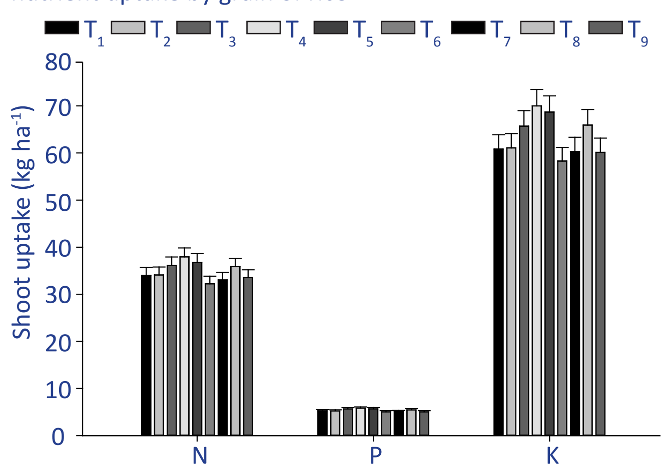

Figure 3: Response of various mycorrhizal inoculants on nutrient uptake by shoot of rice

and K uptake by both grain and shoot with control treatment. Application of PSB with compost in T_8 resulted in much higher P uptake (5.80 kg ha^{-1}) in grain than other treatments. Uptake of different nutrient depends upon nutrient concentration in plant part and their corresponding yields. Higher plant uptake may reduce the soil availability whereas higher yield increases total uptake. Seeilia and Bagyaraj (1992) reported that selected species of mycorrhizal fungi can survive under flooded conditions and can colonize rice roots to increase the uptake of P and plant growth. Mycorrhizal plants have increased uptake of P from poorly soluble P sources through either direct or indirect mechanisms deriving from the effects of mycorrhizal fungal on rhizosphere properties including changes in soil pH (Li and Christie, 2001) and root exudates patterns (Laheurte et al., 1990). Inoculation of Mycorrhiza can improve significantly P uptake per unit root length due to the enhancement of the total root surface by hyphal growth (Smith and Read, 1996). Application of mycorrhizal inoculants in different crops may increases K uptake due to the reason as like P and these kind of results in different crops previously reported by (Bagayoko et al., 2000; Mohammad et al., 2003).

Table 5: Correlation matrix among different parameter of transplanted rice due to mycorrhizal inoculants

Parameter	Dry matter (X_1)	LAI (X_2)	No. of tiller (X_3)	Grain yield (X_4)	Straw Yield (X_5)	Available N (X_6)	Available P_2O_5 (X_7)	Available K_2O (X_8)	N uptake (X_9)	P uptake (X_{10})	K uptake (X_{11})
X_1	1	.956**	.968**	.869**	.716*	.493	.328	.402	.885**	.925**	.896**
X_2		1	.938**	.777*	.616	.557	.244	.331	.805**	.858**	.780*
X_3			1	.942**	.834**	.452	.436	.520	.951**	.966**	.936**
X_4				1	.960**	.254	.511	.571	.995**	.976**	.976**
X_5					1	.201	.593	.627	.953**	.904**	.916**
X_6						1	.340	.387	.287	.319	.330
X_7							1	.973**	.487	.436	.520
X_8								1	.549	.488	.563
X_9									1	.981**	.965**
X_{10}										1	.972**
X_{11}											1

**: Correlation is significant at the 0.01 level (2-tailed); *: Correlation is significant at the 0.05 level (2-tailed).

4. Conclusion

Application of RhizoMyco @ 250 g ha^{-1} at 15 DAT may be the recommended for better growth and yield parameter for productivity of transplanted rice. Despite higher uptake of nutrient supporting higher yields, the phosphorus content in soil (27.10 mg kg^{-1} of soil) improved significantly.

5. Acknowledgement

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