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ORIGINAL PAPER

Optimizing tillage schedule for maintaining activity of the arbuscular mycorrhizal fungal population in a rainfed upland rice (*Oryza sativa* L.) agro-ecosystem

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Abstract Rainfed uplands in India are predominantly mono-cropped with rice (*Oryza sativa* L.) in the wet season (June/July to September/October) and grown under aerobic soil conditions. The remaining fallow period (winter followed by summer) of about 8–9 months leads to natural crash in the population of native arbuscular mycorrhizal fungi (AMF) in the soil. Attempts have been made to minimize this population crash by reducing soil disturbance-induced deleterious effects on native AMF activity of improperly scheduled off-season tillage, an agronomic recommendation for weed and disease (soil-borne) management, practiced by the upland farmers. On-farm (farmers' field) evaluation of effects of all suitable off-season tillage schedule combinations on rice during wet seasons of 2004, 2005, and 2006 revealed that a maximum of two off-season tillage schedules with a minimum gap of 13 weeks between them minimized the population crash of native AMF with a concomitant increase in phosphorus (P) uptake and grain yield of upland rice (variety "Vandana").

Keywords Arbuscular-mycorrhiza · Phosphorus · Rice (*Oryza sativa* L.) · Soil disturbance-induced effect · Tillage

Introduction

Rainfed uplands are predominantly mono-cropped during the wet season (June/July to September/October). Rice (*Oryza sativa* L), the major crop of this ecosystem, is constrained by unfavorable environments mainly consisting of (1) unpredictable drought spells and (2) nutrient-poor, acidic soil conditions. The drought-prone acidic soils render upland rice inefficient in acquisition of phosphorus (P). Possibilities of increasing P acquisition efficiency of upland rice by enhancing native arbuscular mycorrhizal fungal (AMF) activity through manipulation of rice-based cropping systems in favor of AMF have been demonstrated (Maiti et al. 2006). Such enhancement, however, is subdued in this ecosystem by a crash in the natural AMF population during the fallow period (winter and summer; October/November to May/June) of about 8–9 months (Maiti et al. 1996). Such long fallow disorder in terms of reduced native AMF activity has been attributed to a decline in viable propagules of AMF (Thompson 1987). This problem is further aggravated by soil disturbance-induced deleterious effects on the natural AMF mycelial network (Jasper et al 1991; McGonigle and Millar 1993) in soil through off-season tillage, an agronomic recommendation for weed and disease (soil-borne) management practiced by upland rice farmers with un-judicious scheduling, whenever soil moisture is available (through post/pre-monsoon rainfall). Attempts have been made to minimize this soil disturbance-induced population crash of native AMF through judicious scheduling of off-season tillage. Previous evaluation of effects of all possible combinations of off-season tillage schedules during wet seasons of 2000, 2001, and 2002 revealed that a minimum gap of 10–13 weeks between two off-season tillage schedules minimized the population crash of native AMF (Maiti et al. 2008) with concomitant increases in P uptake and grain yield of upland rice (variety "Vandana"). This information has been further fine-tuned and validated through a farmers' participatory on-farm trial under farm field conditions conducted during the wet seasons of 2004,

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2005, and 2006, for recommendation as blanket practice for rainfed uplands.

Materials and methods

A farmers' participatory on-farm experiment on off-season tillage schedules was conducted during 2003–2004, 2004–2005, and 2005–2006 with upland rice grown during the wet seasons (June/July to September/October) in farmers' fields (mono-cropped, uplands) of the village Banadag (District: Hazaribag, State: Jharkhand, India). Four small and marginal farmers (land holding <1 ha) participated in the experiment, and the plots were adjacent, demarcated by very small alleys. The land situation of the experimental site was sloppy upland with acidic (pH 5.6 to 6.5), gray-colored, clay loam soil (Alfisols). The soils were poor in organic carbon (0.37–0.49%), moderate in available P (25.9–40.4 kg P_2O_5 kg/ha) and adequate in K (151–226 kg K_2O/ha) content.

The upland rice variety "Vandana", one of the improved, short-duration (90–95 days duration) varieties developed for rainfed uplands was used. Off-season tillage operations were initiated during the post-wet season of 2003. The previous crop (wet season 2003) was rice (cv. Vandana). The following off-season tillage schedules, laid out in a randomized block design, with four replications of minimum 250 m^2 fixed plots were evaluated: T_1=One initial tillage (IT; tillage immediately after crop harvest); T_2=One winter tillage (WT; 9–13 weeks after harvest); T_3=One summer tillage (ST; 17–26 weeks after harvest); T_4=One IT + one WT (T_1+T_2; IT + WT); T_5=One IT + one ST (T_1 + T_3; IT + ST); T_6=One IT + one WT + one ST (T_1 + T_2 + T_3; IT + WT + ST).

The two possible tillage combinations of WT + ST and "no off-season tillage" were not considered in the experiment because an earlier study (Maiti et al. 2008) showed that (1) WT + ST reduced native AMF activity in soil, (2) none of the combinations had any additional advantages on crop performance despite "no off-season tillage" supporting native AMF activity, and (3) farmers did not accept "no off-season tillage" for agronomic reasons. Land preparation prior to sowing of rice was common in all treatments.

All the off-season tillage schedules (initial tillage during October, winter tillage during December to January next year, and summer tillage during April to May) were performed whenever soil moisture was available through off-season rain received during the period as per Table 1. Tillage including land preparation was done by a bullock-drawn country plough up to a depth of 10–15 cm.

Rice was sown directly (dry seeding) in rows 20 cm apart. Fertilizer was applied at 40 (in two equal splits):30:20 kg N/P_2O_5/K_2O per hectare in the forms of urea, SSP, and MOP, respectively. The crop was harvested at maturity. Grain and straw yields were expressed on a dry weight basis after drying sub-samples at 70°C for 48 h. Plant samples (shoot, panicle, and root) were also taken at maturity, 90 days after emergence (DAE) for estimating respectively P content, panicle weight, and AM development [percent root length colonization (% RLC)] in roots.

The shoot/straw and grain samples were analyzed for P content by digesting the dried, ground samples in a tri-acid mixture (Jackson 1962) and estimating P in the digest colorimetrically (Murphy and Riley 1662). P content (% P in samples) was converted to P uptake (kilograms P_2O_5 per hectare) for the results.

Root samples were cut into pieces of about 1 cm length and fixed in FAA (formalin/acetic acid/70% alcohol, 5:5:90 ml; *v:v:v*) solution for 48 h. The fixed roots were cleared using KOH solution and stained by trypan blue following the

Table 1 Off-season tillage schedule of on-farm experiment site (village: Banadag) during 2003–2004, 2004–2005, and 2005–06

Sl.	Off-season tillage schedule	Operation/event	Dates of operations/rainfall (mm)/gap between tillage operations (days/weeks)		
			2003–2004	2004–2005	2005–2006
1	Initial tillage (IT)	Harvesting	14.10.03	12.10.04	7.10.05
		Rainfall (amount)[a]	9.10.03 (96.2 mm)	14.10.04 (72.5 mm)	18.09.05 (75.2 mm)
		Tillage	17.10.03	21.10.04	9.10.05
Gap between IT and WT			69 days (9+ weeks)	93 days (13+ weeks)	67 days (9+ weeks)
2	Winter tillage (WT)	Rainfall (amount)[a]	28.12.03 (12.5 mm)	18–19.01.05 (27.5 mm)	10–14.12.05 (145.0 mm)
		Tillage	29.12.03	23.01.05	17.12. 05
Gap between WT and ST			122 days (17+weeks)	99 days (14+ weeks)	123 days (17+weeks)
3	Summer tillage (ST)	Rainfall (amount)[a]	25.04.04 (31. mm)	2.05.05 (4.0 mm)	17–19.04.06 (11.8 mm)
	(Farmers' practice)	Tillage	28.05.04	3.05.05	20.04.06
Gap between IT and ST			191 days (27+ weeks)	192 days (27+ weeks)	190 days (27 weeks)
Gap between IT and sowing (next year)				8 months	

[a] Rainfall amount data of CRURRS (about 10 km from Banadag)

method of Kormanik et al (1980). The stained roots were observed under a stereo-zoom microscope (STEMI 2000C; Carl Zeiss) and percent RLC was assessed using a gridline-intersect method (Giovennetti and Mosse 1980).

The panicle weight and grain yield were estimated following the methods described by Yoshida et al. (1976).

Soil samples (0–20 cm) were collected twice, viz. prior to initial tillage (initial sample) and prior to rice sowing next year (final sample). Standard procedure of sampling was followed to collect soil samples from each plot. Five sub-samples from each plot were pooled, and final samples of 500 g were stored. Infective propagule (IP) population was monitored in the soil samples following the most probable number method of Powell (1980). The Mehlich 1 "P" was estimated colorimetrically using blue color ascorbic acid method.

Statistical procedure

The "Balanced ANOVA (BOAV)" procedure of "CROPSTAT 7.2" statistical package developed by International Rice Research Institute, Philippines, was used for statistical analysis of data.

Results

Native AMF population dynamics

The initial (October, 2003) native AMF population (IP) in the soils of the experimental site ranged between 19.4 and 20.8 IP/g soil (Fig. 1). The AMF population structure of the ecosystem under study was predominantly comprised of the genera *Glomus* and *Acaulospora* (Maiti et al. 1995). Under

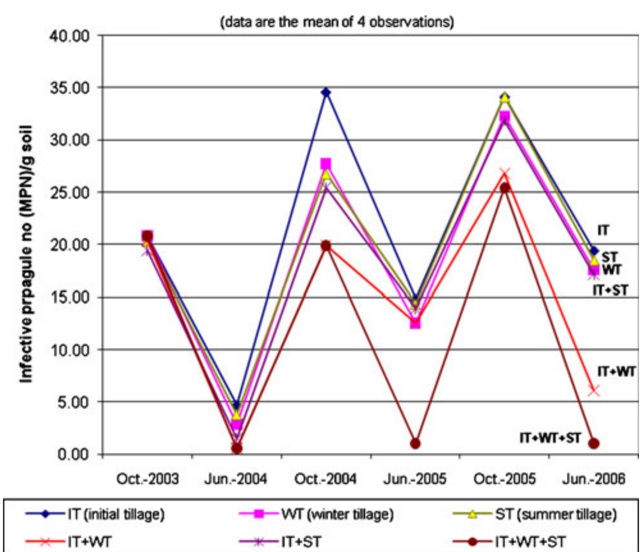

Fig. 1 Influence of off-season tillage schedule on population dynamics of native AMF as a function of time

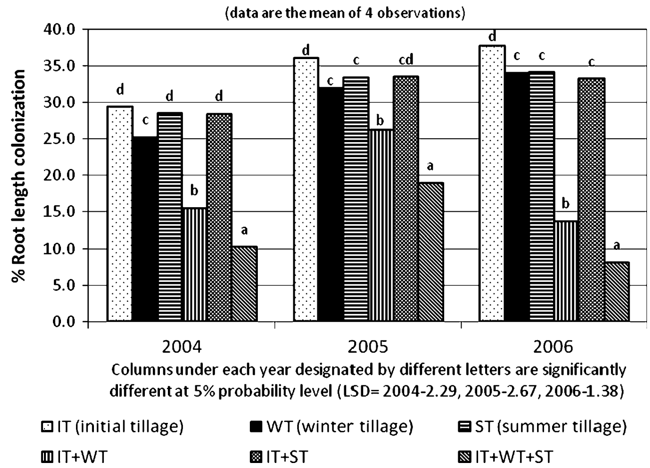

Fig. 2 Influence of off-season tillage schedule on colonization of upland rice (cv. Vandana) by native AMF

all off-season tillage schedules, a population crash (ranging between 43.1% and 97.3% decrease) was noticed during off-seasons (October to June next year) of 2003–2004, 2004–2005, and 2005–2006, having minimum variation (77.4–97.3% decrease; Pr>F=0.100) in the first off-season (October, 2003 to June, 2004) with least decline in single intervention (tillage) of IT (77.4%), ST (81.4%), and WT (86.3%) as compared with that of the double- and triple-intervention combinations of IT + ST (92.4%) and IT + WT/IT + WT + ST (97.3%). During the second off-season (October, 2004 to June 2005), however, single- and double-intervention combinations (IT + WT and IT + ST) resulted in lesser decline (37.0 to 45.3%; Pr>F=0.000) as compared with that of the triple-intervention combination of IT + WT + ST (94.9% decrease) with maximum soil disturbance. A similar trend was followed during the third off-season (October 2005 to June 2006). A natural population build-up was evident in both the seasons (wet seasons of 2004 and 2005) during the cropping season (July to September), supported by the higher root mass of the rice crop in soil as compared with fallow plot soil. Extents of population enhancement under the off-season tillage schedules in both the wet seasons were commensurate with initial population of June every year. The effects of the off-season tillage schedules became apparent from the second season (June 2005). The triple-intervention combination schedule (IT + ST + WT) and that of double combination of IT + WT were most destructive to the native AMF population with an order of least deleterious effects of IT>ST>WT=IT + ST by the third year (June 2006).

Native AMF colonization in rice

During all three wet seasons (2004, 2005, and 2006) under study, the triple-intervention combination off-season tillage schedule (IT + WT + ST) resulted in the significantly lowest

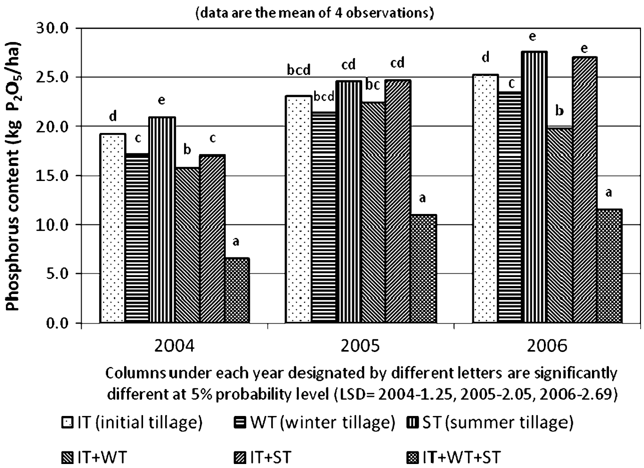

Fig. 3 Influence of off-season tillage schedule on P uptake of upland rice at maturity (cv. Vandana)

(Pr>F=0.000) percent root length colonization (Fig. 2). Consistently highest significant colonization was observed in IT followed by WT=ST>IT + WT>IT + ST in order across the years (wet seasons of 2004, 2005, and 2006).

Phosphorus uptake, panicle character, and grain yield of rice

P uptake of upland rice (Vandana) under least AMF colonization (8.2–19.0% RLC) in the IT + WT + ST schedule ranged between 6.6 and 11.5 kg P_2O_5/ha for a soil available P status of 25.9–40.4 kg P_2O_5/ha across the years (Fig. 3). Highest (Pr>F=0.000) P uptake was observed in plots with a single off-season tillage of ST (except in 2004) followed by that of IT>WT=IT + WT/ + ST in this order.

All the five off-season tillage schedules, individually or in double combination with lesser soil disturbances, led to significantly higher grain yield (Pr>F=0.000) of rice (Vandana) compared with the triple combination of IT + WT + ST schedule with highest soil disturbances (Table 2). However, significantly highest panicle weight and concomitant yield increase was observed in the off-season tillage schedule of ST followed by that of IT + ST/IT/WT>IT + WT>IT + WT + ST in this order.

Discussion

The single-tillage interventions (IT, WT, and ST) and the double-tillage intervention of IT + ST, during off-season, were least detrimental to the native AMF population. Single-tillage interventions imposed a minimum soil disturbance-induced effect on the native AMF mycelial network. Among these, IT, however, was slightly advantageous due to the longest period (about 8 months) of no soil disturbance. On the other hand, among the two double-tillage intervention schedules, IT + WT was more advantageous to the AMF population than that of IT + ST because of the differential gap between two tillage interventions of the schedules, i.e., IT to WT and IT to ST which were 9–13 weeks and 26–27 weeks, respectively, across the years (2003–2004, 2004–2005, and 2005–2006). The results revealed that an undisturbed (no tillage) period of 13 weeks was sufficient for maximum reduction of the soil disturbance-induced effect under rainfed uplands. In earlier studies (Maiti et al. 2008) of a similar ecosystem, an undisturbed period of 10–13 weeks was demonstrated to be supportive to the soil AMF population and was comparable to that of a “no off-season tillage” imposing no soil disturbance-induced effects. Similar findings were recorded by Fairchild and Miller (1988, 1990) who calculated the threshold of an undisturbed period (soil) to be 12 weeks.

No tillage intervention during the off-season was earlier found to be most advantageous in terms of maintaining a native AMF mycelial network (Evans and Millar 1990) and thereby it's normal activity in a rainfed upland ecosystem (Maiti et al. 2008). On the other hand, “no off-season tillage” is not recommended for the direct sown upland rice agro-eco system under study (for eco-friendly management of wet season weeds and soil-borne pests) and so, a minimum /optimum off-season tillage schedule was proposed making a compromise between zero and maximum off-season tillage schedules.

Table 2 Influence of off-season tillage schedule on panicle weight and grain yield of upland rice (cv. Vandana)

Off-season tillage schedules	Panicle weight (g)			Grain yield (t/ha)		
	2004	2005	2006	2004	2005	2006
IT	1.60 c	1.66 d	1.70 cd	1.57 c	2.04 c	2.13 c
WT	1.55 c	1.61 c	1.67 c	1.59 c	2.07 c	2.12 c
ST	1.62 c	1.68 d	1.75 d	1.87 d	2.17 d	2.36 d
IT + WT	1.30 b	1.56 b	1.34 b	1.08 b	1.11 b	1.90 b
IT + ST	1.59 c	1.66 d	1.72 cd	1.65 c	2.10 cd	2.29 d
IT + WT + ST	1.21 a	1.49 a	1.20 a	0.72 a	0.98 a	1.18 a
5% LSD	0.07	0.03	0.06	0.12	0.07	0.08

Data are the mean if four observations

Data under each column followed by different letters are significantly different at 5% probability level

The lesser soil disturbance-induced effects in plots with single off-season tillage schedule (IT, WT, and ST) and IT + ST led crop (rice) establishment (in late June/July) to begin with a comparatively higher native AMF population across the three seasons (2004, 2005, and 2006). Moreover, these four schedules induced a progressive increase over the years in the native AMF population during June in the fixed plots, indicating a gradual amplification of mycelial network establishments under less-disturbed soil conditions. The rate of population (native AMF) build-up during the cropping season was also higher in these plots, resulting in significantly higher colonization of rice at crop maturity (90 DAE) compared with that in the triple tillage intervention schedule (IT + WT + ST) across three seasons (wet seasons of 2004, 2005, and 2006).

A concomitant, significant, increase in P uptake by rice was observed with the increase in root colonization, mediated through the higher soil AMF population resulting from the different off-season tillage schedules. Such a significant increase of plant P uptake in the respective tillage schedules led to an improvement in panicle weight and grain yield. The single-intervention off-season tillage schedules (IT, ST, and WT) and the double-intervention schedule of IT + ST with least soil disturbance resulted in higher AMF colonization and consequent enhanced P uptake leading to greater panicle weight and a concomitant yield increase. Among the two double combinations of off-season tillage schedules, however, IT + ST, owing to soil disturbances with a longer gap of about 26 weeks between IT and ST, resulted in the highest yielding off-season tillage schedule across the years. The other double combination tested (IT + WT), on the other hand, was less advantageous in terms of population of native AMF, root colonization, and concomitant P uptake due to the shorter gap (9–13 weeks) between two interventions, across years, which significantly reduced grain yield.

The lesser the soil disturbances in plots, the higher was the AMF colonization leading to higher P uptake by the rice plants with a concomitant improvement in panicle weight and grain yield across the off-season tillage schedules and years. However, highest improvements (AMF colonization, P uptake, panicle weight, and grain yield) were observed, over 3 years, in ST and the double-intervention off-season tillage schedule of IT + ST which had a longer gap between two tillage operations. Whenever the gap was reduced to less than 13 weeks, AMF parameters, P uptake, and grain yield were reduced. This period (13 weeks) might have allowed re-establishment of a native AMF mycelial network during a subsequent flash of weed growth following tillage.

The two options of off-season tillage schedules (summer tillage alone and initial tillage after harvest + summer tillage) have been recommended to rice farmers for the studied rainfed, mono-cropped upland ecosystem in order to maintain optimum activities of native AMF.

References

Evans DG, Millar MH (1990) The role of external mycelia network in the effect of soil disturbance upon vesicular–arbuscular mycorrhizal colonization of maize. New Phytol 114:65–71

Fairchild GL, Miller MH (1988) Vesicular–arbuscular mycorrhizas and the soil disturbance induced reduction of nutrient absorption in maize. II. Development of the effect. New Phytol 110:75–84

Fairchild GL, Miller MH (1990) Vesicular–arbuscular mycorrhizas and the soil disturbance induced reduction of nutrient absorption in maize. III. Influence of P amendments to soil. New Phytol 114:641–650

Giovennetti M, Mosse B (1980) An evaluation of techniques for measuring vesicular–arbuscular mycorrhizal infection in roots. New Phytol 84:661–665

Jackson ML (1962) Soil chemical analysis, 1st edn. Asia Publ. House, New Delhi

Jasper DA, Abbot LK, Robson AD (1991) The effect of soil disturbance on vesicular arbuscular mycorrhizal fungi in soils from different vegetation type. New Phytol 118:471–476

Kormanik PP, Bryan WC, Schultz RC (1980) Procedures and equipment for staining large numbers of plant roots for endomycorrhizal assay. Can J Microbiol 26:536–538

Maiti D, Variar M, Saha J (1995) Colonization of upland rice by native VAM under rainfed mono-cropped ecosystem. In: Roy AK, Sinha KK (eds) Recent advances in phytopathological research. MD Publ. Ltd., New Delhi, pp 45–52

Maiti D, Variar M, Singh RK (1996) Perpetuation of native VAM fungi under mono-cropped, rainfed upland agro-ecosystem. Mycorrhiza News 8(1):7–9

Maiti D, Barnwal MK, Rana SK, Variar M, Singh RK (2006) Enhancing native arbuscular mycorrhizal association to improve phosphorus nutrition of rainfed upland rice (*Oryza sativa* L.) through cropping systems. Indian Phytopathol 59(4):432–438

Maiti D, Barnwal MK, Singh RK, Rana SK (2008) Approaches to utilize native arbuscular mycorrhizal association for improving P nutrition in upland rice under rainfed ecosystem. In: Tiwari M, Sati SC (eds) Mycorrhiza: diversity, ecology and application. Daya Publishing House, New Delhi, pp 193–199

McGonigle TP, Millar MH (1993) Mycorrhizal development and phosphorus absorption in maize under conventional and reduced tillage. Soil Sci Soc Am J 57:1002–1006

Murphy J, Riley JP (1662) A modified single solution method for determination of phosphorus in natural water. Anal Chim Acta 27:31–36

Powell CL (1980) Mycorrhizal infectivity of eroded soils. Soil Biol Biochem 12:247–250

Thompson JP (1987) Decline of vesicular–arbuscular mycorrhizae in long fallow disorder of field crops and its expression in phosphorus deficiency of sunflower. Aust J Agric Res 38:847–867

Yoshida S, Forno DA, Cock JH, Gomez KA (eds) (1976) Laboratory manual for physiological studies of rice, 3rd edn. The International Rice Research Institute, Philippines