Response of three popular varieties of wheat to arbuscular mycorrhizae grown in two common soil types of central India

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ABSTRACT : An experiment was conducted to study the response of three popular varieties of wheat, namely WH 147, Lok-1 and Kathiya, to ten arbuscular mycorrhizal (AM) fungi in two common soil types [alfisol (red) and vertisol (black)] of central India, under net-house conditions. The varieties recorded variable response in terms of growth and yield. Maximum yield was recorded in LOK-1, followed by WH 147 and Kathiya. AM inoculations significantly increased plant height, dry shoot weight, dry root weight and yield. The growth of different varieties was more vigorous in alfisol than vertisol. Maximum root:shoot ratio was recorded in Kathiya, which was significantly more than other two varieties. All the inoculants, except *Acaulospora mellea* and *A. scrobiculata* increased the root:shoot ratio. LOK-1 recorded maximum mycorrhizal dependency (MD), followed by Kathiya and WH 147. Plants grown in alfisol exhibited higher MD value than vertisol. Among different varieties, maximum phosphorus (P) uptake was recorded in Kathiya, followed by LOK-1 and WH 147. All AM inoculants significantly increased P uptake. Its higher value was recorded in plants grown in alfisol. Maximum root colonization index was recorded in WH 147, which varied from 32.4 to 47.3% in different AM treatments. Plants grown in alfisol recorded significantly higher colonization index. Thus, the results showed that AM fungi increased the growth, yield and P uptake of three popular varieties of wheat, which signifies that these can be utilized for inoculation of the crop under central Indian conditions.

Keywords: Arbuscular mycorrhizal fungi, central India, soil types and wheat cultivars.

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1. INTRODUCTION

Wheat is an important intercrop of agroforestry. It has given good results under agroforestry systems (Shukla *et al.,* 2012a). Historically, its four species, namely *Triticum aestivum*, *T. durum*, *T. dicoccum* and *T. sphaerococcum* were under cultivation. *T. sphaerococcum* has now practically gone out of cultivation because of its low productivity. In total production, *T. aestivum* contributes approximately 95%, followed by *T. durum* with 4% and *T. dicoccum* with 1%. India is surplus in wheat production but it is predicted that an annual rate increase of 4 to 5% in wheat production would be required in relation to the rate and nature of economic growth, population expansion and income elasticity (Goyal and Singh, 2002). In order to increase the production, the technologies utilizing indigenous microbes need to be explored (Minaxi *et al*., 2013).

Arbuscular mycorrhiza (AM) fungi are known to occur widely under various environmental conditions and are found associated with roots of most of the crops (Jha *et al*., 2012). By acquiring phosphate, micronutrients and water, they enhance the host nutritional status and thus their growth. In addition, AMF stimulate the production of growth substances and reduce stresses, diseases and pest attack (Shukla *et al*., 2014; Dehariya *et al*., 2015). For the appropriate use of these fungi, it is necessary to select the best fungi adapted to the specific environmental factors for crop productivity (Herrera-Peraza *et al*., 2011). Soil properties can influence the efficiency of AM inoculants (Carrenho *et al*., 2007; Gryndler *et al*., 2009; Shukla *et al*., 2013). According to Ramadhani *et al.* (2015), the effectiveness of AM inoculations can be different among species or even among varieties (cultivars) in a species. Varied response of different wheat varieties to AM inoculations have been reported by several workers (Hetrick *et al*., 1992; Behl *et al*., 2003; Singh *et al*., 2012). Therefore, an attempt was made to study the suitability of AM fungi for inoculation of the crop in central Indian soil types. In present study, three popular varieties of wheat among local farmers, namely WH 147 (bread wheat), Lok-1 (bread wheat) and Kathiya (macaroni wheat), were screened against ten AM fungi in two common soil types.

2. MATERIALS AND METHODS

The study was conducted at ICAR-Central Agroforestry Research Institute, Jhansi (25°27' N latitude, 78°35' E longitude and 271 m above mean sea level), which consisted of 11 treatments [10 AM species (*Acaulospora mellea*, *A. scrobiculata, Claroideoglomus etunicatum*, *Glomus aggregatum, G. arborense, G. cerebriforme, Rhizophagus diaphanus*, *R. fasciculatus, R. intraradices*, *Simiglomus hoi*) and a control], three wheat varieties [WH 147 (hexaploid), Lok-1 (hexaploid) and Kathiya (tetraploid)] and two soil types [red (alfisol) and black (vertisol) soils]. All treatments were replicated three times in completely randomized design (CRD). Thus, a total of 198 pots were employed in the study.

The soil substrates were passed through 2 mm sieves separately, moistened with water and filled in cotton bags, and autoclaved at 15 psi (121 ^{0}C for 30 minutes). After filling pots with autoclaved substrates, the mycorrhizal treatments were imposed and seeds of three wheat varieties were sown, as per treatments. The treated pots were transferred to the net-house and thinning was carried out 15 days after sowing, leaving one plant per pot. The pots were watered as and when required. The plants were harvested at maturity and observations on plant height, number of tillers plant^{-1}, dry shoot weight, dry root weight and yield plant^{-1} were recorded. Phosphorus (P) uptake plant^{-1} was estimated by vanado-molybdo phosphoric yellow color method (Jackson, 1973). Mycorrhizal dependency (MD) was calculated according to Plenchette *et al*. (1983). At the time of harvest, 1g fine roots from each plant were collected to estimate AM colonization index. Collected samples were cleared with 10% KOH and stained with acid fuchsin (0.01% in lactoglycerol) as reported by Kormanik *et al*. (1980) and the index was determined by gridline intersect method (Giovanneti and Mosse, 1980). The root: shoot ratio, which refers to the proportion of dry root weight to dry shoot weight, was also calculated.

All the data were subjected to three-way analysis of variance (ANOVA) for testing the effect of plant varieties, AM inoculations, soil types and interactions. Least significant difference (P<0.05) values were used to compare the treatment differences.

3. RESULTS AND DISCUSSION

Different wheat varieties recorded variable response in terms of growth and yield. Maximum plant height was recorded in WH 147, dry shoot weight in LOK-1 and dry root weight in Kathiya. Maximum yield was recorded in LOK-1, which was at par with WH 147. These values were significantly higher than the value recorded in Kathiya. AM inoculations significantly increased plant height, dry shoot weight, dry root weight and yield. Values of studied growth parameters (plant height, dry shoot weight and dry root weight) were significantly higher in plants grown in alfisol than in vertisol. However, soil types did not affect the yield (Table 1).

Maximum root: shoot ratio was recorded in Kathiya, which was significantly more than other two varieties. All the inoculants, except *A. mellea* and *A. scrobiculata* significantly increased the root: shoot ratio. The differences in its values in two soil types were found non-significant. Variety LOK-1 showed maximum dependency on inoculated fungi for dry matter production, followed by Kathiya and WH 147. MD of different wheat varieties on AM inoculants varied in a narrow range *i.e.* from 44.63-48.64%. MD in alfisol was significantly higher than MD in vertisol (Table 2). Among different varieties, maximum P uptake was recorded in Kathiya, which was at par with LOK-1. Its minimum value was recorded in WH 147. All AM inoculants significantly increased P uptake (Table 3). Its significantly higher value was recorded in plants grown in alfisol than vertisol. Maximum root colonization index was recorded in WH 147, which was at par with Lok-1 and significantly more than Kathiya. It varied from 32.37 to 47.31 in different AM treatments. Colonization index in alfisol was significantly higher than colonization index in vertisol (Table 4).

The results showed that studied wheat varieties exhibited variable growth, yield and P uptake patterns. This should be due to genetic variability. Variable response of different wheat cultivars to AM inoculations have been reported by several workers (Azcon and Ocampo, 1981; Vierheilig and Ocampo, 1991). Genetic variations for AM symbiosis have also been reported in many other crops also, like *Lycopersicon esculentum (*Bryla and Koide, 1998*)*, *Pisum sativum* (Rivera-Becerril *et al.*, 2002), *Phaseolus vulgaris* (Hacisalihoglu *et al*., 2005), *Trifolium repens* (Eason *et al.*, 2001), *Zea mays* (Ortas and Akpinar, 2011), etc.

As per our results, different AM inoculants increased plant height by 11-19%, shoot dry weight by 74-90%, root dry weight by 94-129% and yield by 88-106%, over control. Increase in growth and yield of AM inoculated plants can be attributed to increase in the soil volume explored for nutrient and water uptake by the mycorrhizal plants as compared to non-mycorrhizal ones. Better nutrient, especially P, which is evident from the results obtained in our study, generally leads to increase in plant biomass (Klironomos, 2003; Shukla *et al*., 2012b). Beneficial effects of AM inoculations on growth and productivity of wheat have been reported by various workers (Mohammad *et al*., 1995; Karagiannidis and Hadjisavva-Zinoviadi, 1998; Shukla *et al*., 2009; Abdel-Fattah and Asrar, 2012).

Further, the results obtained in present study suggested that plants grown in alfisol showed more dependency on inoculated fungi than in vertisol, which could be due to less fertility. According to Carrenho *et al*. (2007), low fertile soil limits plant development and increases their dependency on mycorrhizal association. Ortas and Akpinar (2006) have also suggested that the response of plants to AM inoculation is generally linked with soil fertility levels

Table 1. Effect of AM inoculations on growth and yield of three varieties of wheat in two soil types

AM species	Alfisol				Vertisol				Varietal means			Pooled
	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	mean
Plant height (cm)												
A. mellea	83.3	90.0	80.0	84.4	80.7	78.0	66.0	74.9	82.0	84.0	73.0	79.7
A. scrobiculata	81.7	85.3	68.0	78.3	82.0	68.0	82.0	77.3	81.3	76.7	75.0	77.8
C. etunicatum	81.3	88.7	61.3	76.4	83.3	78.0	78.0	79.8	82.3	82.3	69.7	78.1
G. aggregatum	84.0	85.0	72.0	80.3	86.0	72.7	72.7	77.1	85.0	78.3	72.3	78.7
G. arborense	87.7	81.3	78.0	82.3	80.7	75.3	70.7	75.6	84.2	78.3	74.3	78.9
G. cerebriforme	86.0	88.0	72.0	82.0	81.3	82.0	69.3	77.6	83.7	85.0	70.7	79.8
R. diaphanus	96.3	88.0	72.0	85.4	84.0	80.7	75.3	80.1	90.2	84.3	73.7	82.7
R. fasciculatus	82.7	86.7	74.0	80.4	78.0	80.0	69.3	75.8	80.3	82.3	71.7	78.1
R. intraradices	88.7	84.0	77.3	83.3	77.3	74.0	70.0	73.8	83.0	79.0	73.7	78.6
Sim. hoi	92.0	89.7	57.3	79.7	84.0	76.7	63.3	74.7	88.0	83.2	60.3	77.2
Un-inoculated	81.7	76.0	57.3	71.7	71.3	73.2	57.3	67.3	76.5	74.6	57.3	69.5
Mean	85.9	85.3	69.9	80.4	80.8	76.2	70.4	75.8				
Pooled mean	83.4	80.8	70.2									
Dry shoot weight (g)												
A. mellea	35.4	39.2	30.8	35.1	34.1	34.1	30.7	33.2	35.1	36.7	30.8	34.2
A. scrobiculata	34.2	35.5	34.0	34.6	36.6	36.7	33.0	35.4	35.4	36.1	33.5	35.0
C. etunicatum	36.0	33.2	29.2	32.8	31.6	32.0	30.8	31.5	33.8	32.6	30.0	32.1
G. aggregatum	34.0	37.2	29.8	33.7	34.2	37.3	31.4	34.3	34.1	37.2	30.6	34.0
G. arborense	34.3	35.6	33.3	34.4	32.6	32.0	29.2	31.3	33.5	33.8	31.3	32.8
G. cerebriforme	35.0	33.4	30.7	33.0	31.0	32.8	30.6	31.5	33.0	33.1	30.7	32.3
R. diaphanus	34.7	35.2	34.5	34.8	32.1	37.4	30.6	33.4	33.4	36.3	32.5	34.1
R. fasciculatus	36.3	36.7	33.0	35.3	35.1	33.4	31.5	33.3	35.7	35.1	32.3	34.4
R. intraradices	34.5	40.1	32.3	35.6	32.6	31.7	30.6	31.6	33.5	35.9	31.4	33.6
Sim. hoi	34.4	37.5	29.9	33.9	34.9	33.7	31.9	33.5	34.7	35.6	30.9	33.7
Un-inoculated	18.8	18.3	19.2	18.8	18.4	17.1	18.4	18.0	18.6	17.7	18.8	18.4
Mean	33.4	34.7	30.6	32.9	32.2	32.6	29.9	31.5				
Pooled mean	32.8	33.6	30.2									
Dry root weight (g)												
A. mellea	10.3	10.1	23.8	14.7	7.5	9.4	21.7	12.9	8.9	9.8	22.7	13.8
A. scrobiculata	8.9	8.7	24.2	13.9	7.9	8.8	22.9	13.2	8.4	8.7	23.5	13.6
C. etunicatum	9.7	8.3	25.5	14.5	9.5	8.4	27.5	15.1	9.6	8.4	26.5	14.8
G. aggregatum	8.11	9.5	22.4	13.3	9.2	12.3	22.8	14.8	8.6	10.9	22.6	14.1
G. arborense	10.0	13.1	29.0	17.4	9.8	10.6	24.2	14.9	9.9	11.8	26.6	16.1
G. cerebriforme	9.9	9.3	25.2	14.8	8.9	9.8	18.7	12.5	9.4	9.6	21.9	13.6
R. diaphanus	8.8	10.6	23.0	14.1	9.7	10.2	24.2	14.7	9.3	10.4	23.6	14.4
R. fasciculatus	8.6	12.8	28.2	16.5	9.4	9.0	23.0	13.8	9.0	10.9	25.6	15.2
R. intraradices	9.5	10.2	23.9	14.6	9.3	8.1	27.3	14.9	9.4	9.2	25.6	14.7
Sim. hoi	9.8	9.9	24.0	14.6	9.7	10.5	19.3	13.2	9.7	10.2	21.7	13.9
Un-inoculated	4.6	5.1	11.0	6.9	6.1	4.5	10.7	7.1	5.3	4.8	10.8	7.0
Mean	8.9	9.8	23.6	14.1	8.8	9.2	22.0	13.4				
Pooled mean	8.9	9.5	22.8									
Yield (g) plant^{-1}												
A. mellea	17.35	19.83	12.90	16.69	16.60	16.49	12.69	15.26	16.98	18.16	12.79	15.98
A. scrobiculata	16.88	17.35	14.81	16.34	16.58	17.45	14.74	16.26	16.73	17.40	14.28	16.30
C. etunicatum	15.10	16.04	14.75	15.30	14.56	17.64	13.97	15.39	14.83	16.84	13.86	15.34
G. aggregatum	17.76	17.97	11.32	15.35	14.69	18.38	14.87	15.98	16.23	19.51	13.10	15.67
G. arborense	16.58	17.10	13.55	15.74	17.23	20.33	13.97	17.18	15.90	17.88	13.76	16.46
G. cerebriforme	17.35	17.85	16.29	17.16	14.10	15.30	11.15	13.50	15.70	16.57	13.72	15.33
R. diaphanus	18.14	18.18	13.25	16.52	17.42	16.10	14.31	15.93	16.78	17.12	13.78	16.23
R. fasciculatus	17.10	15.26	13.33	15.23	16.96	15.18	12.57	14.90	17.03	15.22	12.95	15.01
R. intraradices	17.31	17.52	12.64	15.82	20.80	15.35	12.75	16.13	18.13	16.43	12.69	15.97
Sim. hoi	16.45	16.68	13.71	15.61	15.80	17.38	12.44	15.21	16.13	16.20	13.10	15.41
Un-inoculated	8.17	7.49	7.27	7.65	8.74	8.69	7.53	8.32	8.46	8.10	7.40	7.98
Mean	16.11	16.48	13.07	15.22	15.72	16.20	12.82	14.91				
Pooled mean	15.91	16.34	12.95									

	$LSD_{0.05}$			
	Plant height	Dry shoot weight	Dry root weight	Yield
Variety	1.3	0.8	0.6	0.73
AM inoculation	2.4	1.5	1.1	1.40
Soil types	1.0	0.6	0.5	NS
Variety × AM inoculation	4.2	2.6	1.9	NS
Variety × soil	1.8	NS	0.8	NS
AM inoculation × soil types	3.4	NS	1.6	NS
Variety × AM inoculation × soil types	5.9	NS	2.7	NS

Table 2. Effect of AM inoculations on root:shoot ratio and mycorrhizal dependency (%) of three varieties of wheat in two soil types

AM species	Alfisol				Vertisol				Varietal means			Pooled
	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	mean
Root: shoot ratio												
A. mellea	0.29	0.26	0.77	0.44	0.21	0.28	0.71	0.40	0.25	0.27	0.74	0.42
A. scrobiculata	0.26	0.25	0.72	0.41	0.22	0.24	0.70	0.38	0.24	0.24	0.71	0.40
C. etunicatum	0.25	0.30	0.67	0.41	0.30	0.28	0.79	0.46	0.28	0.29	0.73	0.43
G. aggregatum	0.27	0.25	0.88	0.47	0.30	0.26	0.89	0.49	0.29	0.26	0.89	0.48
G. arborense	0.24	0.26	0.75	0.41	0.27	0.33	0.73	0.44	0.25	0.29	0.74	0.43
G. cerebriforme	0.29	0.37	0.88	0.51	0.30	0.33	0.83	0.49	0.30	0.35	0.86	0.50
R. diaphanus	0.28	0.28	0.82	0.46	0.29	0.30	0.61	0.40	0.29	0.29	0.72	0.43
R. fasciculatus	0.24	0.35	0.86	0.48	0.27	0.27	0.73	0.42	0.25	0.31	0.80	0.45
R. intraradices	0.29	0.27	0.80	0.45	0.28	0.31	0.61	0.40	0.28	0.29	0.71	0.43
Sim. hoi	0.28	0.25	0.74	0.43	0.29	0.26	0.90	0.48	0.28	0.26	0.82	0.45
Un-inoculated	0.24	0.28	0.57	0.36	0.33	0.26	0.58	0.39	0.29	0.27	0.58	0.38
Mean	0.27	0.28	0.77	0.44	0.28	0.28	0.73	0.43				
Pooled mean	0.27	0.28	0.75									
Mycorrhizal dependency (%)												
A. mellea	48.69	52.34	44.69	48.57	42.10	50.10	44.17	45.45	45.39	51.21	44.43	4 7.01
A. scrobiculata	45.66	46.87	48.12	46.88	44.99	52.39	47.69	48.36	45.32	49.63	47.91	47.62
C. etunicatum	45.80	48.99	47.26	47.35	41.55	54.56	46.50	47.53	43.67	51.78	46.88	47.44
G. aggregatum	48.65	43.47	44.81	45.64	40.54	46.54	49.83	45.64	44.59	45.00	47.32	45.64
G. arborense	44.36	49.79	42.10	45.40	43.63	56.20	46.15	48.66	44.00	53.00	44.10	47.03
G. cerebriforme	47.00	51.70	51.64	50.11	42.20	48.98	45.37	45.52	44.60	50.34	48.51	47.81
R. diaphanus	47.63	45.31	46.11	46.35	38.73	49.20	40.80	42.91	43.18	47.25	43.46	44.63
R. fasciculatus	47.70	52.80	50.80	50.43	45.12	49.10	46.36	46.85	46.41	50.93	48.58	48.64
R. intraradices	46.91	50.73	43.92	47.18	45.16	50.78	43.03	46.32	46.03	50.75	43.47	46.75
Sim. hoi	46.63	53.37	46.29	48.76	41.65	45.23	49.53	45.47	44.14	49.30	47.91	47.12
Mean	46.90	49.54	46.57	47.67	42.57	50.30	45.94	46.27				
Pooled mean	44.73	49.92	46.26									

	$LSD_{0.05}$	
	Root:shoot ratio	Mycorrhizal dependency
Variety	0.02	1.21
AM inoculation	0.04	2.20
Soil types	NS	0.99
Variety × AM inoculation	0.07	3.82
Variety × soil	NS	1.71
AM inoculation × soil types	0.06	3.12
Variety × AM inoculation × soil types	0.10	5.40

Table 3. Effect of AM inoculations on phosphorus uptake (mg plant^{-1}) of three varieties of wheat in two soil types

AM species	Alfisol				Vertisol				Varietal means			Pooled
	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	mean
A. mellea	17.30	26.18	38.14	26.21	8.60	9.25	16.46	11.44	12.95	16.21	27.30	18.82
A. scrobiculata	12.38	17.83	45.88	25.36	10.93	10.08	21.66	14.23	11.66	13.95	33.77	19.79
C. etunicatum	16.08	47.17	23.78	29.01	12.21	13.12	14.62	13.31	14.14	30.15	19.20	21.16
G. aggregatum	25.33	34.78	28.64	29.59	12.34	11.54	14.31	12.73	18.84	23.16	21.48	21.16
G. arborense	15.37	46.84	44.49	35.57	12.80	17.43	16.36	15.53	14.10	32.14	30.42	25.55
G. cerebriforme	19.60	27.53	40.33	29.15	9.39	11.32	15.00	11.91	14.50	19.43	27.67	20.53
R. diaphanus	8.68	24.36	20.13	17.72	8.21	10.64	7.22	8.69	8.44	17.50	13.68	13.21
R. fasciculatus	16.44	47.15	54.99	39.53	10.92	13.15	17.80	13.96	13.68	30.15	36.40	26.74
R. intraradices	18.97	40.53	31.29	30.26	9.52	15.34	11.43	12.10	14.24	27.94	21.36	21.18
Sim. hoi	19.27	52.60	28.56	33.48	11.47	7.99	14.91	11.46	15.37	30.31	21.73	22.47
Un-inoculated	4.54	7.62	4.34	5.50	3.59	3.79	4.56	3.98	4.06	5.71	4.45	4.74
Mean	15.82	33.60	32.78	27.40	9.99	11.24	14.03	11.76				
Pooled mean	12.91	22.42	23.41									

	$LSD_{0.05}$
Variety	1.27
AM inoculation	2.44
Soil types	1.04
Variety × AM inoculation	4.22
Variety × soil	1.80
AM inoculation × soil types	3.45
Variety × AM inoculation × soil types	5.97

Table 4. Effect of AM inoculations on arcsine transformed value of root colonization index of three varieties of wheat in two soil types

AM species	Alfisol				Vertisol				Varietal means			Pooled
	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	Mean	WH 147	Lok-1	Kathiya	mean
A. mellea	38.14	40.45	31.97	36.85	36.41	32.65	21.61	30.22	37.28	36.55	26.79	33.54
A. scrobiculata	42.49	38.60	16.58	32.56	35.90	37.28	23.37	32.19	39.20	37.94	19.97	32.37
C. etunicatum	40.45	57.23	26.97	41.55	44.31	39.86	34.84	39.67	42.38	48.55	30.91	40.61
G. aggregatum	43.22	50.27	19.69	37.73	36.53	37.01	27.46	33.67	39.88	43.64	23.58	35.70
G. arborense	58.70	51.56	21.84	44.03	48.89	33.11	26.96	36.32	53.80	42.33	24.40	40.18
G. cerebriforme	45.04	56.15	38.76	46.65	46.17	47.68	27.59	40.48	45.61	51.91	33.18	43.56
R. diaphanus	48.05	42.36	33.28	41.23	41.61	33.74	33.93	36.43	44.83	38.10	33.60	38.83
R. fasciculatus	53.00	41.42	35.10	43.17	48.41	39.73	32.62	40.26	50.71	40.58	33.85	41.71
R. intraradices	56.50	49.64	33.00	46.38	48.91	56.81	39.00	48.24	52.71	53.23	36.00	47.31
Sim. hoi	46.80	38.25	35.38	40.14	55.30	40.39	40.11	45.26	51.05	39.32	37.74	42.70
Un-inoculated	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mean	42.95	42.36	26.60	37.30	40.22	36.21	27.95	34.79				
Pooled mean	41.58	39.28	27.27									

	$LSD_{0.05}$
AM inoculation	5.35
Variety	2.79
Soil types	2.28
AM inoculation × variety	9.27
AM inoculation × soil types	NS
Variety × soil	3.95
AM inoculation × variety × soil types	NS

and it is well known that P is the most influential element in mycorrhizal development and efficiency. In P-deficient soils, the yields of plant largely depend on their mycorrhizal status (Ortas, 2003; Herrera-Peraza *et al.,* 2011). P content of alfisol (olsen P: 4.0 – 5.6 kg ha^{-1}) is comparatively less than vertisol at the study site (olsen P: 7.6 – 23.4 kg ha^{-1}), which might explain the obtained results.

Thus, the results of present study showed that AM fungi increased the growth, yield and P uptake of three varieties of wheat. It signifies that these can be utilized for inoculation of the crop under central Indian conditions. As, the study was conducted under sterile soil conditions, the extrapolation of the results to the real field conditions should be done after their field testing. Looking to the good response of wheat to AM fungi obtained in above mentioned experiments, attempts are being made at the institute to integrate these with other bio-inoculants (*Azotobacter* and phosphate solubilizing bacteria) and chemical fertilizers.

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