DOI : 10.5958/0974-0112.2016.00050.5

Indian J. Hort. 73(2), June 2016: 213-218

Influence of AM fungi and inorganic phosphorus on fruit and root characteristics, root colonization and soil phosphorus in okra-pea cropping system in Himalayan acid Alfisol

Anil Kumar*, **Anil K. Choudhary**** **and Vinod K. Suri**

Department of Soil Science, CSK Himachal Pradesh Agricultural University, Palampur 176062

ABSTRACT

In Himalayan acid Alfisol, the influence of arbuscular mycorrhizal fungi (AMF) on fruit and root characteristics in okra-pea cropping system was assessed at varying inorganic phosphorus and irrigation regimes (40 & 80% available water capacity). In okra, AMF inoculation significantly improved the fruit length, fruit girth and fruit weight besides enhancing rooting depth (13%), root volume (7%), root dry weight (7%) and root weight density (6%) over non-AMF treatments. In pea, AMF sharply increased the average pod weight (10%), rooting depth (9%), root volume (16%), root dry weight (13%) and root weight density (12%) over non-AMF counterparts. AMF enhanced mycorrhizal root colonization by 2 to 2.3-fold both in okra and pea besides significant improvement in available soil-P pool (21%). 'AMF + 75% soil-test based P dose (STB-P)' at both irrigation regimes remained statistically alike with generalized recommended nutrient-cum-irrigation dose (GRD) and 'AMF + 100% STB-P' with respect to fruit and root parameters in okra-pea system, thus, indicating an economy of about 25% applied-P through AMF inoculation in acid Alfisol. Hence, AMF had positive influence on fruiting and root characteristics, fertilizer-P economy and availability in Himalayan okra-pea production system.

Key words: Arbuscular mycorrhizal fungi, acid Alfisol, okra-pea cropping system, phosphorus.

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) and garden pea (*Pisum sativum* L.) are major vegetable crops in north-western (NW) Himalayas because of well-suited agro-climatic conditions (Choudhary *et al.*, 3); but, their productivity is quite low due to multiple nutrient deficiencies especially phosphorus under acid Alfisol (Suri *et al.*, 10). Erratic and ill-distributed rainfall pattern and poor irrigation infrastructure in NW Himalayas is another constraint for vegetable production (Choudhary *et al.*, 3). In acid Alfisol, fixation of applied-P as insoluble phosphates with soil Al and Fe ions leads to limited P availability (Suri *et al.*, 10). Thus, arbuscular mycorrhizal fungi (AMF) may prove as boon under acid soils to enhance both P availability and water use efficiency (Harrier and Watson, 5). Arbuscular mycorrhizal fungi expands the rhizospheric exploratory area of plant root system through their ramifying hyphae and help in acquisition of nutrients especially P and soil moisture. Thus, enhanced P supply and plant water relations in mycorrhizal plants may lead to better fruiting behavior and productivity in crops (Auge, 1). Currently, the information on influence of AMF on fruiting and root characteristics in vegetables like okra and pea at varied moisture regimes is lacking so as to make necessary recommendations to resource-poor hill farmers who cannot afford expensive P fertilizers. As such, the present investigation studied the influence of AMF on fruiting and root characteristics in okra-pea cropping system at varying inorganic-P and irrigation regimes, besides economizing fertilizer-P in Himalayan acid Alfisol.

MATERIALS AND METHODS

Field experimentation was conducted in okra (*Abelmoschus esculentus*)-pea (*Pisum sativum*) cropping system during 2009-11 at CSK Himachal Pradesh Agricultural University, Palampur (32º 6' N latitude, 76º3' E longitude, 1250 m above mean sea level) having wet-temperate climate and silty-clay loam soil. The rainfall received during *kharif* 2009 and 2010 was 1,274 and 2,076 mm, respectively, whereas *rabi* 2009-10 and 2010-11 received 240 and 362 mm rainfall, respectively. Initially, the experimental soil had medium phosphorus (available P 19 kg ha^{-1}), pH 5.1, organic carbon 7.1 g kg^{-1} soil and bulk density 1.23 Mg m^{-3}. The available-P was determined by 0.5 M $NaHCO_3$ at pH = 8.5 (Olsen *et al.*, 8). The experiment was replicated thrice in randomized block design having 14 treatments, *viz.*, 12 treatment combinations of two arbuscular mycorrhizal fungi (AMF) levels [0 & 12 kg ha^{-1}], three phosphorus levels [50, 75 & 100% of recommended P dose based on soil test] and

*Corresponding author's present address: GAD Veterinary and Animal Sciences Univ., Farm Science Centre, Tarn Taran 141004, Punjab; E-mail: anilkumarhpkv@gmail.com

**Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi 110012.

two irrigation regimes [40 & 80% of available water holding capacity (AWC)]; besides, one treatment with 'generalized recommended nutrient dose with generalized recommended irrigations (GRD)' as well as one treatment based on farmers' practice of plant nutrition and irrigation management (FP) in the region (Table 1). Recommended NPK dose in okra was supplied @ 75:50:55 kg ha^{-1}, whereas pea was supplied with recommended NPK @ 50:60:60 kg ha^{-1}.

Arbuscular mycorrhizal fungi used in present experimentation was *Glomus mosseae*. The AMF spore count was 29-31 per 10 g culture. The AMF inoculation of okra and pea seeds was performed by using the methodology of Suri *et al.* (10). 'Soil moisture regime approach', *i.e.* gravimetric method was adopted (Hillel, 6) for irrigation scheduling at pre-fixed moisture content (80 & 40% AWC). For this purpose, soil samples from 0-15 cm soil depth were collected regularly to work out relevant moisture content. The fresh okra fruits and green pea pods at each picking were weighed and summed up to get total fruit/pod yield. Fruit/pod length of ten randomly sampled fresh fruits/pods was measured at earmarked pickings (Tables 2 & 3). These representative fruits/pods from each plot were subjected to girth measurement (middle of fruit/pod). The root studies were carried out at the maximum flowering stage in both the crops. The root samples were taken by Core break method (Bohm, 2), to record maximum rooting depth or root length (cm). Root volume (cm^3) was determined by displacement method (Mishra and Ahmed, 7). Root weight density (g m^{-3}) was calculated as ratio between the weight of dry roots and the volume of soil (*i.e.* volume of sampling core) from which these were sampled (Mishra and Ahmed, 7). Mycorrhizal root colonization (%) was determined by the standard procedure suggested by Phillips and Hayman (9). Statistical analysis was carried out by the standard procedures suggested by Gomez and Gomez (4).

RESULTS AND DISCUSSION

At 2nd and 5th picking of okra fruits, the higher fruit length was registered under $V_{12}P_{100}I_{80}$, $V_{12}P_{100}I_{40}$ and GRD. At 8th picking, the maximum fruit length (11% each) was registered under $V_{12}P_{100}I_{80}$ and $V_{12}P_{100}I_{40}$ over GRD (Table 2). At 5th picking, highest fruit-girth was registered under $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{100}I_{40}$. At 8th picking, maximum and significant increase in above parameter was registered under $V_{12}P_{100}I_{80}$ and $V_{12}P_{100}I_{40}$. Similar trend was observed under irrigation at 40% available water capacity (AWC) in presence or absence of AMF at varying P. At 2nd picking, the highest fruit weight was registered under $V_{12}P_{100}I_{80}$ followed by $V_{12}P_{100}I_{40}$ and GRD. At 5th picking, heaviest fruit weight was registered under $V_{12}P_{100}I_{80}$ followed by $V_{12}P_{100}I_{40}$. At 8th picking, treatment effects with respect to (w.r.t.) okra fruit weight was found similar to that obtained during 5th picking. Overall, the okra fruit characteristics at 2nd and 5th pickings were marginally influenced by AMF inoculation, however, at 8th picking, AMF

Table 1. Details of treatments evaluated in okra-pea cropping system (2009-11).

Treatment No.	Details	Code
T_1	No AMF* + 100% NPK + irrigations as per need and soil moisture content (Generalized nutrient recommended dose and generalized irrigations)	$V_0$100%NPKI_{AR}(GRD)
T_2	No AMF + $N_{25\%}P_0K_0$ + irrigations now and then depending on water availability (Farmers' practice)	$V_0N_{25}P_0K_0I_{WA}$(FP)
T_3	No AMF + 50% P + 100% NK + irrigation at 40% AWC**	$V_0\ P_{50}I_{40}$
T_4	No AMF + 75% P + 100% NK + irrigation at 40% AWC	$V_0\ P_{75}I_{40}$
T_5	No AMF + 100% P + 100% NK + irrigation at 40% AWC	$V_0\ P_{100}I_{40}$
T_6	AMF @ 12 kg ha^{-1} + 50% P + 100% NK + irrigation at 40% AWC	$V_{12}\ P_{50}I_{40}$
T_7	AMF @ 12 kg ha^{-1} + 75% P + 100% NK + irrigation at 40% AWC	$V_{12}\ P_{75}I_{40}$
T_8	AMF @ 12 kg ha^{-1} + 100% P + 100% NK + irrigation at 40% AWC	$V_{12}\ P_{100}I_{40}$
T_9	No AMF + 50% P + 100% NK + irrigation at 80% AWC	$V_0\ P_{50}I_{80}$
T_{10}	No AMF + 75% P + 100% NK + irrigation at 80% AWC	$V_0\ P_{75}I_{80}$
T_{11}	No AMF + 100% P + 100% NK + irrigation at 80% AWC	$V_0\ P_{100}I_{80}$
T_{12}	AMF @ 12 kg ha^{-1} + 50% P + 100% NK + irrigation at 80% AWC	$V_{12}\ P_{50}I_{80}$
T_{13}	AMF @ 12 kg ha^{-1} + 75% P + 100% NK + irrigation at 80% AWC	$V_{12}\ P_{75}I_{80}$
T_{14}	AMF @ 12 kg ha^{-1} + 100% P + 100% NK + irrigation at 80% AWC	$V_{12}\ P_{100}I_{80}$

*AMF = Arbuscular mycorrhizal fungi (*Glomus mosseae*); **AWC = Available water holding capacity

Table 2. Effect of integrated application of AMF and inorganic phosphorus at varying irrigation regimes on okra fruit characteristics and productivity (mean data of two years).

Treatment	Fruit yield (q ha^{-1})	Fruit length (cm)			Fruit girth (cm)			Fruit weight (g)		
		2nd picking	5th picking	8th picking	2nd picking	5th picking	8th picking	2nd picking	5th picking	8th picking
T_1	76.6	14.9	15.0	13.3	4.2	4.3	3.8	11.1	10	10.1
T_2	36.9	12.7	12.4	10.9	4.0	4.1	3.4	8.7	8.9	8.2
T_3	63.2	13.6	13.4	12.8	4.2	4.2	3.7	9.5	9.6	8.9
T_4	68.1	14.0	14.1	13.0	4.2	4.3	3.7	10.3	10.2	9.4
T_5	73.4	14.7	14.9	13.2	4.2	4.3	3.8	10.9	11.2	9.7
T_6	70.8	13.9	13.5	14.2	4.2	4.2	4.1	10.4	10.5	10.4
T_7	74.7	14.7	14.9	14.6	4.2	4.2	4.2	10.7	11.5	11.1
T_8	77.6	14.8	15.0	14.7	4.2	4.3	4.3	11.2	11.4	11.3
T_9	62.7	13.1	13.0	12.7	4.1	4.1	3.4	9.3	9.7	8.9
T_{10}	68.1	14.5	14.0	13.2	4.2	4.2	3.9	10.4	10.4	9.2
T_{11}	72.5	14.8	14.9	13.2	4.2	4.2	3.9	10.8	11.3	9.8
T_{12}	71.0	14.2	14.0	13.9	4.2	4.2	4.2	10.3	10.4	10.2
T_{13}	76.3	14.8	14.8	14.6	4.2	4.3	4.2	11.0	11.2	11.0
T_{14}	77.4	14.8	14.9	14.8	4.2	4.3	4.3	11.4	11.6	11.3
LSD (P = 0.05)	4.68	0.99	0.66	0.69	NS	0.12	0.16	0.42	0.33	0.50

NS = Non-significant

Table 3. Effect of integrated application of AMF and inorganic phosphorus at varying irrigation regimes on pea pod characteristics and productivity (mean data of two years).

Treatment	Green pod yield (q ha^{-1})	Pod length (cm)		Pod girth (cm)		Pod weight (g)	
		1st picking	3rd picking	1st picking	3rd picking	1st picking	3rd picking
T_1	112.8	8.5	8.4	4.0	4.1	3.8	3.7
T_2	60.6	8.2	8.2	3.9	3.8	3.5	3.1
T_3	84.4	8.4	8.3	3.9	3.9	3.7	3.4
T_4	94.1	8.5	8.3	4.0	3.9	3.8	3.5
T_5	101.5	8.5	8.4	4.1	4.0	3.9	3.6
T_6	95.1	8.4	8.5	4.0	4.0	4.0	3.9
T_7	103.9	8.6	8.4	4.1	4.1	4.2	4.0
T_8	111.7	8.4	8.4	4.1	4.1	4.2	4.0
T_9	89.4	8.3	8.3	4.1	3.9	3.8	3.5
T_{10}	99.3	8.4	8.3	4.0	3.9	3.8	3.6
T_{11}	109.2	8.4	8.4	4.0	4.0	3.9	3.6
T_{12}	104.7	8.5	8.4	4.0	4.0	4.1	3.9
T_{13}	112.8	8.5	8.5	4.1	4.1	4.2	3.9
T_{14}	117.8	8.6	8.4	4.1	4.1	4.2	4.0
LSD (P = 0.05)	8.43	NS	NS	NS	NS	0.27	0.28

plants registered significantly higher values. As such, mycorrhizal plants maintained plant vigour for a longer period leading to better fruiting characteristics even at later fruiting stages owing to higher nutrient and water utilization through enhanced root exploratory area by AMF hyphae (Harrier and Watson, 5). Certain enzymes like phosphatase and organic acids secreted by AMF also play a vital role in converting insoluble-P into soluble-P form for plant use (Harrier and Watson, 5).

In pea, treatment effects on pod length and girth were non-significant. The highest pod weight was registered in $V_{12}P_{100}I_{80}$ followed by $V_{12}P_{75}I_{80}$ (Table 3). Similar trend was observed with irrigation scheduling at 40% AWC in presence or absence of AMF at varying P. At 3rd picking, treatment effect with respect to pea pod weight was found similar to that obtained during 5th picking. The AMF have ability to explore a large soil volume through mycelia enabling root system to efficiently absorb nutrients and water. This was consequently reflected as enhanced pod girth and weight (Harrier and Watson, 5).

Crop productivity data revealed that in okra, highest fruit yield was registered in $V_{12}P_{100}I_{40}$ followed by $V_{12}P_{100}I_{80}$ and GRD, all of which remained statistically alike. However, $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{50}I_{80}$ recorded significantly higher fruit yield by 7, 12 and 13% over their respective non-AMF counterparts. In pea, green pod yield was highest under $V_{12}P_{100}I_{80}$ followed by $V_{12}P_{75}I_{80}$ and GRD (Table 3). A similar trend was observed in treatments with irrigation at 40% AWC in presence and absence of AMF at varying P. Both in okra and pea 'AMF + 75% P at both irrigation regimes did not differ significantly over 'AMF + 100% P at both irrigation regimes' and GRD. It suggests an economy of about 25% soil test based P dose in okra-pea system in acid Alfisol. In acid Alfisol, soluble Fe, Al and Mn ions react with applied-P and produce insoluble-P complexes (Suri *et al.*, 10). The AMF help in utilizing greater amount of nutrients particularly P as a result of efficient solubilization and mobilization (Suri *et al.*, 10), thus, enhancing crop yields. Different treatments at same AMF levels and applied-P at both irrigation regimes behaved statistically alike during both crop seasons due to rains at regular interval. Hence, while discussing results, irrigation regime effects are omitted.

In okra, $V_{12}P_{100}I_{40}$ and $V_{12}P_{75}I_{40}$ exhibited significantly the higher maximum rooting depth (MRD) by 12% each over GRD (Table 4). $V_{12}P_{100}I_{40}$ and $V_{12}P_{100}I_{80}$ registered significantly higher root volume (8% each) over GRD. Likewise, root volume in $V_{12}P_{75}I_{40}$ and $V_{12}P_{75}I_{80}$ was respectively 6 and 4% higher, but non-significant over GRD. $V_{12}P_{100}I_{40}$ and $V_{12}P_{75}I_{40}$ registered non-significant respective increases of 4 and 2% in root dry weight (RDW) over GRD. $V_{12}P_{100}I_{40}$ and $V_{12}P_{75}I_{40}$ registered a non-significant increase of 4 and 2% in root weight density (RWD) over GRD. In pea, $V_{12}P_{100}I_{80}$ and $V_{12}P_{75}I_{80}$ gave significant respective increases of 9 and 6% in MRD over GRD (Table 4). MRD in $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{50}I_{80}$ was significantly higher by 11, 15 and 7% over their respective non-AMF counterparts. $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{50}I_{80}$ gave significant and higher root volume by 15, 20 and 13% over their respective non-AMF counterparts. Under $V_{12}P_{100}I_{80}$ and $V_{12}P_{75}I_{80}$, RDW

Table 4. Effect of integrated application of AMF and inorganic phosphorus at varying irrigation regimes on various root parameters of okra and pea crops (mean data of two years).

Treatment	Okra				Pea			
	Rooting depth (cm)	Root volume (cm^3)	Root dry wt. (g)	Root weight density ($g\ m^{-3}$)	Rooting depth (cm)	Root volume (cm^3)	Root dry wt. (g)	Root weight density ($g\ m^{-3}$)
T_1	23.7	15.7	5.4	4.8	16.3	19.5	1.2	1.1
T_2	14.9	11.0	3.1	2.8	8.6	12.9	0.8	0.7
T_3	20.4	14.5	4.7	4.2	13.4	14.5	1.0	0.9
T_4	22.1	15.4	4.9	4.4	14.5	16.0	1.1	1.0
T_5	23.1	16.0	5.1	4.6	15.6	17.9	1.1	1.0
T_6	23.3	15.8	5.2	4.7	14.4	18.1	1.2	1.0
T_7	26.5	16.7	5.5	4.9	16.3	19.7	1.3	1.2
T_8	26.6	16.9	5.6	5.0	16.8	20.3	1.3	1.2
T_9	21.2	14.6	4.6	4.2	14.0	16.3	1.1	1.0
T_{10}	22.5	15.3	4.9	4.4	15.0	17.6	1.2	1.1
T_{11}	23.6	15.9	5.1	4.6	16.0	18.8	1.3	1.1
T_{12}	23.5	15.6	5.2	4.6	15.0	18.4	1.2	1.1
T_{13}	25.5	16.4	5.5	4.9	17.3	21.1	1.3	1.2
T_{14}	26.2	16.9	5.5	5.0	17.8	21.7	1.4	1.2
LSD (P = 0.05)	0.20	1.15	0.50	0.45	0.31	0.95	0.05	0.05

was significantly higher by 17 and 8%, respectively over GRD. $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{50}I_{80}$ gave the significant respective increases of 8, 8 and 9% in RDW than their non-AMF counterparts. Respective magnitude of increases in RWD under $V_{12}P_{100}I_{40}$ and $V_{12}P_{75}I_{40}$ was to the tune of 9% each over GRD. The higher rooting length in okra and pea is attributable to increased number of higher order laterals in AMF imbedded treatments over non-AMF ones. Further, higher root volumes are again attributable to extension of root system into soil profile by way of development of higher order laterals through ramification of fungal hyphae associated with it (Suri and Choudhary, 11).

The AMF inoculation significantly improved the root colonization in okra from 7-29% (Fig. 1). Further, root colonization was high at low levels of applied-P while it decreased with increasing P. $V_{12}P_{100}I_{80}$, $V_{12}P_{75}I_{80}$ and $V_{12}P_{50}I_{80}$ gave significant increases of 1.9, 1.7 and 2.2-folds in above parameter over non-AMF counterparts. In pea, AMF showed higher root colonization at 50% P, while it decreased at higher applied-P (75 to 100%) at either of two irrigation regimes. Overall, AMF enhanced the extent of root colonization by 2 to 2.3-fold than non-AMF treatments. Under P deficient conditions, plant roots release large amount of sugars and amino acids which stimulate colonization (Suri *et al.*, 10). While under ample P supply (say 100 or 75% P), above secretions would be to a lesser extent, thereby, reducing AMF colonization. Similarly, higher P levels substantially decrease the acid phosphatase enzyme activity, leading to lesser root colonization at higher applied-P. In contrast, under P deficient conditions the sufficient secretion of acid phosphatase enzyme from roots leads to more root colonization (Suri *et al.*, 10).

In okra, AMF inoculation exhibited nominal increase in soil available-P over non-AMF plots and GRD (Fig. 2). Highest available-P build up was registered in $V_{12}P_{100}I_{40}$ followed by $V_{12}P_{75}I_{40}$ and $V_{12}P_{100}I_{80}$; all of which remained statistically alike with GRD. In pea, highest available-P was registered in $V_{12}P_{100}I_{40}$ followed by $V_{12}P_{100}I_{80}$ and $V_{12}P_{75}I_{80}$. Both in okra and pea, the available-P trends indicate that AMF with 75 or 100% P led to non-significant effects; probably due to lower efficiency of AMF at higher applied-P. Further, AMF helps in mobilization and solubilization of insoluble-P by releasing organic acids and phosphatase enzyme, which increased P availability in soil (Suri and Choudhary, 11). Various root parameters in okra indicated a positive and significant correlation with fruit yield (Table 5). The highest correlation coefficient was obtained with root dry weight and root weight density (r = 0.99**) followed by root volume (r = 0.98**). In pea, highest correlation coefficient was obtained with rooting depth (r = 0.98**) followed by root dry weight and root weight density (r = 0.97**). Thus, these root parameters contributed immensely towards crop productivity both in okra and pea (Table 3, 4).

Overall, AMF inoculation in okra led to significantly higher fruit length (12%) and fruit girth (11%) than non-AMF counterparts and GRD. On an average, okra fruit weight, root depth, root volume, root dry weight and root weight density significantly increased by 11, 13, 7, 7 and 6%, respectively over non-AMF counterparts. In pea, AMF sharply increased the average pod weight (10%), rooting depth (9%), root volume (16%), root dry weight (13%) and root weight density (12%) over non-AMF counterparts. Mycorrhizal root colonization was enhanced by 2 to 2.3-fold both in okra and pea by AMF inoculation. In summary, AMF greatly influenced the fruit and root characteristics and crop productivity, thus, it holds tremendous significance in fertilizer-P economy in

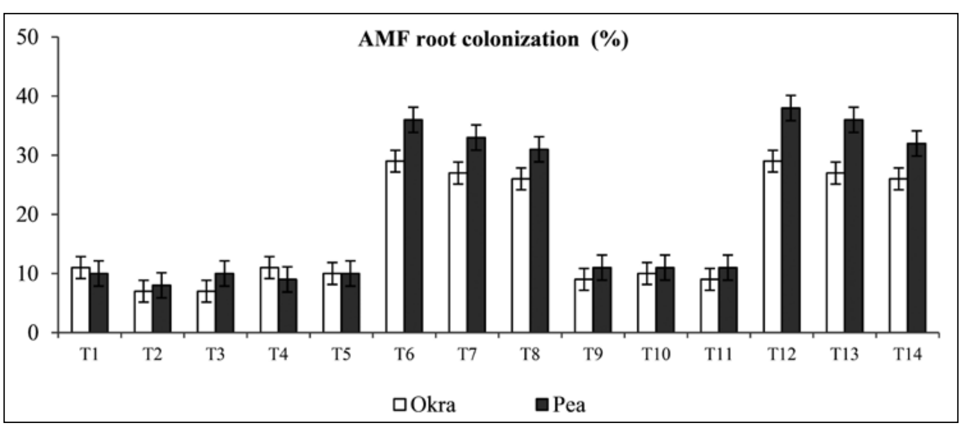

Fig. 1. Influence of integrated use of AM fungi and inorganic-P at varying irrigation regimes on mycorrhizal root colonization (%) in okra and pea (mean data of two years) [Bars represent LSD values at P = 0.05 to determine significance differences among treatment means].

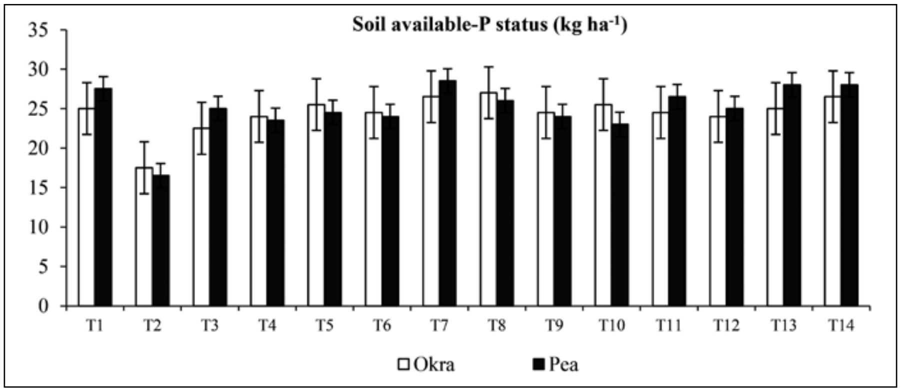

Fig. 2. Influence of integrated use of AM fungi and inorganic-P at varying irrigation regimes on available-P (g kg^{-1}) in soil at end of IInd year of experimentation. [Bars represent LSD values at P = 0.05 to determine significance differences among treatment means].

Table 5. Influence of AM fungi, inorganic phosphorus, and irrigation regimes on correlation coefficient between different root parameters and crop productivity in okra and pea.

Root parameter	Okra fruit yield	Pea green pod yield
Rooting depth	0.95**	0.98**
Root volume	0.98**	0.95**
Root dry weight	0.99**	0.97**
Root weight density	0.99**	0.97**

**Significant at 5% level of significance

Himalayan production systems, where resource poor Himalayan farmers ill-afford expensive P fertilizers.

ACKNOWLEDGEMENTS

Authors are thankful to Indian Council of Agricultural Research, New Delhi for financial assistance.

REFERENCES

1. Auge, R.M. 2006. Water relations, drought and VAM symbiosis. *Mycorrhiza*, **11**: 3-42.
2. Bohm, W. 1979. Methods of studying root systems. *Ecol. Studies: Anal. Synth.* **33**: 125-39.
3. Choudhary, A.K., Thakur, S.K. and Suri, V.K. 2013. Technology transfer model on integrated nutrient management technology for sustainable crop production in high value cash crops and vegetables in northwestern Himalayas. *Comm. Soil Sci. Plant Anal.* **44**: 1684-99.
4. Gomez, K.A. and Gomez, A.A. 1984. *Statistical Procedures for Agricultural Research*, Wiley-Interscience Publication, John Wiley and Sons Inc., New York, USA.
5. Harrier, L.A. and Watson, C.A. 2003. The role of AM fungi in sustainable cropping systems. *Adv. Agron.* **42**: 185-225.
6. Hillel, D. 1982. *Introduction to Soil Physics*, Department of Plant and Soil Science, University of Massachusetts, Amherst, Massachusetts, pp. 57-112.
7. Mishra, R.D. and Ahmed, M. 1987. *Manual on Irrigation Agronomy*, Oxford and IBH Publishing Company Pvt. Ltd., New Delhi, pp. 319-26.
8. Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954. *Estimation of Available Phosphorus in Soils by Extraction with Sodium Bicarbonate* (USDA Circular No. 939), U.S. Government Printing Office, Washington, D.C.
9. Phillips, J.M. and Hayman, D.S. 1970. Improved procedures for cleaning root and staining parasitic and VAM fungi for rapid assessment of infection. *Trans. British Mycol. Soc.* **55**: 58-61.
10. Suri, V.K., Choudhary, A.K., Chander, G. and Verma, T.S. 2011. Influence of vesicular arbuscular mycorrhizal fungi and applied phosphorus on root colonization in wheat and plant nutrient dynamics in a phosphorus-deficient acid Alfisol of western Himalayas. *Comm. Soil Sci. Plant Anal.* **42**: 1177-86.
11. Suri, V.K. and Choudhary, A.K. 2013. *Glycine-Glomus*-Phosphate solubilizing bacteria interactions lead to fertilizer phosphorus economy in soybean in a Himalayan acid Alfisol. *Comm. Soil Sci. Plant Anal.* **44**: 3020-29.

Received : July, 2015; Revised : April, 2016;
Accepted : May, 2016