*Indian Journal of Agricultural Sciences* **85** (8): 1030–7, August 2015/Article

# Influence of AM–fungi and applied phosphorus on growth indices, production efficiency, phosphorus–use efficiency and fruit–succulence in okra (*Abelmoschus esculentus*)–pea (*Pisum sativum*) cropping system in an acid Alfisol

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Received: 21 February 2015; Accepted: 18 March 2015

## ABSTRACT

The current experiment was conducted at Palampur, India during 2009–11 in okra (*Abelmoschus esculentus* L.)–pea (*Pisum sativum* L.) cropping system in RBD replicated thrice with 14 treatments comprising arbuscular mycorrhizal fungi (AMF), applied–P (50, 75 and 100% recommended P dose) and irrigation regimes (40 and 80% available water holding capacity). At active growth period (50–100 DAS), AMF imbedded treatments exhibited 7 and 20% higher absolute growth rate (AGR) in okra and pea over non–AMF counterparts, while relative growth rate (RGR) both in okra and pea was not affected significantly by AMF application. Net assimilation rate (NAR) and crop growth rate (CGR) in okra were higher by 17 and 3%, respectively with AMF inoculation, though, effect on pea was inconspicuous. At both irrigation regimes, 'AMF + 75% soil–test based P dose' registered statistically similar okra fruit and pea pod yields as that obtained under '100% soil–test based P dose', thus, indicating an economy of about 25% soil–test based P dose. AMF inoculated plants also showed nominally higher succulence level (moisture) in okra fruits and pea pods at their picking stages compared to their non–AMF counterparts, again demonstrating a positive impact of AMF on quantitative vegetable freshness and plant water relations as well. AMF significantly enhanced the various indices of P-use efficiency in both crops. The increase in partial factor productivity (PFP), crop recovery efficiency (CRE) and % recovery (PR) of applied–P in okra under AMF inoculation was 9, 36 and 20%, respectively over non–AMF counterparts. In pea, AMF inoculation exhibited respective increase of 12, 61 and 27% in PFP, CRE and PR of applied–P over non–AMF counterparts. Production and monetary efficiencies in okra–pea cropping system were also enhanced by AMF inoculation. Overall, utilization of AMF in okra–pea cropping system indicated an economy of about 25% in soil–test based applied–P dose besides improved plant growth. AMF also revealed a tremendous potential in enhancing P- use efficiency, which otherwise is very low in acid Alfisol. Further, AMF inoculation may lead to improved fruit succulence to fetch better prices in market.

**Key words:** Acid Alfisol, Arbuscular mycorrhizal fungi, Okra-pea cropping system, Partial factor productivity, Phosphorus-use efficiency, Production efficiency

North–western Himalayas have favourable climatic conditions for cultivation of various vegetable crops especially okra (*Abelmoschus esculentus* L.) and garden pea (*Pisum sativum* L.) in wet–temperate mid–hills, fetching high premium prices to hill farmers. But, yield potential of above crops is low due to various soil constraints specifically acidic soils, low water retentivity, erratic and uneven distributed rainfalls, etc. (Kumar *et al.* 2014). In acid soils, much of applied P react with Fe and Al ions, thereby, getting precipitated/fixed as Fe and Al hydroxyl phosphates and becoming unavailable for plant use (Kumar *et al.* 2014). Moreover, due to large mean weight diameter, soils of above region possess low water retentivity. Erratic and ill–distributed rainfall patterns particularly in *rabi* season, further affect yield potential (Paul *et al.* 2011). Resource poor farmers of above region are unable to apply recommended P doses due to higher cost (Suri *et al.* 2013), thus, further hindering crop production. In above scenario, utilization of arbuscular mycorrhizal fungi (AMF) may prove as a valuable input in enhancing P- and water-use efficiency. The AMF carry–out its functions by expanding surface area of plant root system by 10 to 1000 folds into the soil through their ramifying hyphae, thereby, enhancing rhizospheric exploratory area for harnessing soil P, other essential nutrients and soil moisture (Harrier and Watson 2003). The AMF also mineralizes organic–P and solublize inorganic–P in

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acid soils by secreting organic acids (oxalic and malic acids) and enzymes, such as chitinase, peroxidase, cellulase, protease, phosphatase etc. (Chen *et al.* 2007). AMF also enhance acquisition of other nutrient elements from the soil such as nitrogen (N), potassium (K), calcium (Ca), copper (Cu), zinc (Zn), which are otherwise low in acid soils (Kumar *et al.* 2014). Therefore, keeping in view the potential of AMF in enhancing phosphorus and water use efficiencies as well as crop productivity, current investigation was designed to study the influence of AMF on crop growth indices, fruit–succulence, P–use efficiencies vis–a–vis production and monetary efficiencies in okra–pea cropping system in Himalayan acid Alfisol.

## MATERIALS AND METHODS

The current field experiment was conducted in fixed–plots for two consecutive years (2009–11) in okra–pea cropping system in a randomized block design replicated thrice at CSK Himachal Pradesh Agricultural University, Palampur (32º 6’ N, 76º3’ E; 1250 m above mean sea level) in a medium–P (19 kg/ha) acid Alfisol. The experiment comprised of 14 treatments, viz. 2 AM–fungi levels [0 and 12 kg/ha], 3 phosphorus levels [50, 75 and 100% of recommended P–dose based on soil–test], and 2 irrigation regimes [40 and 80% of available water holding capacity (AWC) of field soil]; one treatment with ‘generalized recommended nutrient dose with generalized recommended irrigations (GRD) and one treatment based on farmers’ practice of plant nutrition and irrigation management (FP) in the region (Table 1). The experimental site represents wet–temperate climate, besides having silty–clay loam soil texture. Soil pH (5.1), organic carbon (7.1 g/kg soil), available N (190 kg/ha), available $K_2O$ (105 kg/ha) and soil bulk density (1.23 $Mg/m^3$) were also worked out before experimentation (Prasad *et al.* 2006). N, P and K were supplied through urea (46% N), single super phosphate (16% $P_2O_5$) and muriate of potash (60% $K_2O$), respectively. The various inputs including FYM were applied as per treatment plan in different plots (Table 1).

Inoculation of okra and pea seeds with AMF culture (*Glomus mosseae*; spore count 29–31/10 g culture) was done by preparing soil slurry using AMF culture @ 12 kg/ha followed by dipping of seeds into it for half an hour for seed pelleting. Inoculated seeds were then dried in shade and subsequently sown in the field.

For the purpose of irrigation scheduling, gravimetric–method (soil moisture regime approach) was followed, which involved determination of soil moisture content and accordingly irrigation (5 cm) at pre–fixed moisture content. In present field experiments, irrigations were scheduled at 80 and 40% of available water capacity (AWC). The 80% AWC involved irrigation at 23.8% soil moisture content, whereas, it was applied at 21.6% soil moisture content in case of 40% AWC [Available water capacity or range (11%) was obtained by deducting moisture content pertaining to permanent wilting point (26%) from field capacity (15%) moisture content]. For this purpose, soil samples were collected regularly from 0–15 cm field depth and dried in oven at 105ºC for 24 hours. The relevant moisture contents were worked out using fresh and oven-dry soil weights.

In order to assess the plant growth indices in okra and pea crops, the periodical plant height, dry matter accumulation and leaf area measurements were done at 50 and 100 days after sowing (DAS) of both the crops

Table 1 Details of treatments evaluated in okra–pea cropping system in current field experimentation

| Treatment | Treatment details | Treatment code |
|---|---|---|
| $T_1$ | 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) |
| $T_2$ | No AMF*+100% NPK + Irrigations as per need and soil moisture content *(Generalized nutrient recommended dose and generalized irrigations)* | $V_0$100%NPK $I_{AR}$(GRD) |
| $T_3$ | No AMF + 50% P + 100% NK + Irrigation at 40% of AWC** | $V_0\ P_{50\%}\ I_{40\%}$ |
| $T_4$ | No AMF + 75% P + 100% NK + Irrigation at 40% of AWC | $V_0\ P_{75\%}\ I_{40\%}$ |
| $T_5$ | No AMF + 100% P + 100% NK + Irrigation at 40% of AWC | $V_0\ P_{100\%}\ I_{40\%}$ |
| $T_6$ | AMF @ 12 kg $ha^{-1}$ + 50% P + 100% NK + Irrigation at 40% of AWC | $V_{12}\ P_{50\%}\ I_{40\%}$ |
| $T_7$ | AMF @ 12 kg $ha^{-1}$ + 75% P + 100% NK + Irrigation at 40% of AWC | $V_{12}\ P_{75\%}\ I_{40\%}$ |
| $T_8$ | AMF @ 12 kg $ha^{-1}$ + 100% P + 100% NK + Irrigation at 40% of AWC | $V_{12}\ P_{100\%}\ I_{40\%}$ |
| $T_9$ | No AMF + 50% P + 100% NK + Irrigation at 80% of AWC | $V_0\ P_{50\%}\ I_{80\%}$ |
| $T_{10}$ | No AMF + 75% P + 100% NK + Irrigation at 80% of AWC | $V_0\ P_{75\%}\ I_{80\%}$ |
| $T_{11}$ | No AMF + 100% P + 100% NK + Irrigation at 80% of AWC | $V_0\ P_{100\%}\ I_{80\%}$ |
| $T_{12}$ | AMF @ 12 kg $ha^{-1}$ + 50% P + 100% NK + Irrigation at 80% of AWC | $V_{12}\ P_{50\%}\ I_{80\%}$ |
| $T_{13}$ | AMF @ 12 kg $ha^{-1}$ + 75% P + 100% NK + Irrigation at 80% of AWC | $V_{12}\ P_{75\%}\ I_{80\%}$ |
| $T_{14}$ | AMF @ 12 kg $ha^{-1}$ + 100% P + 100% NK + Irrigation at 80% of AWC | $V_{12}\ P_{100\%}\ I_{80\%}$ |

*AMF– Arbuscular mycorrhizal fungi; **Available water holding capacity (AWC), In okra, FYM application @ 2.5 t/ha on fresh weight i.e. 1.6 t/ha on dry weight basis was applied in 13 treatments, viz. $T_2$ to $T_{14}$; whereas, in $T_1$ FYM was applied @ 10 t/ha on fresh weight basis, i.e. 6.4 t/ha on dry weight basis. In pea, FYM application @ 5 t/ha on fresh weight i.e. 3.1 t/ha on dry weight basis, was applied in 13 treatments, viz. $T_2$ to $T_{14}$; whereas, in $T_1$ FYM was applied @ 20 t/ha on fresh weight basis, i.e. 12.6 t/ha on dry weight basis. Recommended NPK dose for okra @ 75:50:55 kg/ha. Whereas, recommended NPK dose for pea @ 50:60:60 kg/ha.

following standard procedures. Absolute growth rate (AGR) is the total gain in height by a plant within a specific time interval, which is calculated by the formula given by Dube (2011).

$$\text{AGR (cm/day)} = \frac{H_2 – H_1}{t_2 – t_1}$$

where, $H_1$ and $H_2$ are plant height at $t_1$ and $t_2$ times, respectively. In the present study, plant growth observations were taken at 50 ($t_1$) and 100 DAS ($t_2$) both in okra and pea crops.

The Relative growth rate (RGR*)* is determined using the formula given by Fisher (1921):

$$\text{RGR (g/g/day)} = \frac{\text{Log}_e\, W_2 - \text{Log}_e\, W_1}{t_2 - t_1}$$

where, $W_1$ , Weight of dry matter at sampling time ($t_1$); $W_2$, weight of dry matter at sampling time ($t_2$).

Net assimilation ratio (NAR) represents the efficiency of production and is calculated by the formula given by Vernon and Allison (1963) as follow:

$$\text{NAR (g/cm}^2\text{/day)} = \frac{(W_2 - W_1)\ (\text{Log}_e\, L_2 - \text{Log}_e\, L_1)}{(t_2 - t_1)\ (L_2 - L_1)}$$

where, $L_1$, Leaf area at time $t_1$; $L_2$ , leaf area at time $t_2$.

The Crop growth rate (CGR) is the efficiency of the complete crop over a specific area. It is estimated with following formula:

$$\text{CGR (g/plant/day)} = \frac{W_2 - W_1}{t_2 - t_1}$$

where, $W_1$, weight of dry matter at sampling time ($t_1$); $W_2$, weight of dry matter at sampling time ($t_2$); $L_1$, leaf area at time $t_1$; $L_2$, leaf area at time $t_2$.

The fresh okra fruits and green pea pods at each picking were weighed and summed up to get total fruit/pod yield. Yields are expressed in term of t/ha. For the estimation of moisture content (succulence level) in freshly harvested okra fruits/pea pods at each picking and stover just after last fruit/pod picking operation in respective crops; the aforesaid samples collected from all the field plots were weighed for fresh weight, then air–dried followed by oven–drying at 60 ± 2ºC. Subsequently, their dry weights were recorded to obtain moisture value to assess the plant succulence both in fruits/pod and plant biomass at harvest (stover).

The different efficiencies of applied phosphorus were calculated as per the formulae given by Dobermann (2005). As there was no absolute control treatment in the experiment, the farmers' practice ($V_0N_{25\%}P_0K_0I_{WA}$) was utilized to calculate different P- use efficiencies, as no P was applied in this treatment (Table 1). Thus, following methodology suggested by Dobermann (2005) was used to calculate different efficiencies of applied P in the current study:

$$\text{PFPp} = \frac{\text{Yp}}{\text{Fp}}$$

$$\text{CREp} = \frac{\text{Up} - \text{Uo}}{\text{Fp}}$$

$$\text{PEp} = \frac{\text{Yp} - \text{Yo}}{\text{Up} - \text{Uo}}$$

where, Fp – Amount of fertilizer P applied (kg/ha), Yp–crop yields with applied P (kg/ha), Yo–crop yield (kg/ha) in a control treatment with no P, Up–total plant P uptake by crop (kg/ha) in treatment receiving P, Uo–total plant P uptake by crop (kg/ha) in a control treatment with no P, PFPp–partial factor productivity of applied P, CREp–crop recovery efficiency of applied P, PEp–physiological efficiency of applied P.

The % P recovery (PR) in different treatments was calculated as per the formula given by Syers (2008) as under:

$$\text{\% P recovery (PR)} = \frac{\text{P removal by the crop}}{\text{P applied in the crop}} \times 100$$

The system productivity of okra and pea crops under okra–pea cropping system was computed by estimating pea–equivalent–yield (PEY) by the formula suggested by Ahlawat and Sharma (1993):

$$\text{PEY} = \frac{\text{Yield of okra crop (t/ha)} \times \text{Economic value of okra crop (INR/t)}}{\text{Price of pea (INR/t)}}$$

The system productivity was calculated by adding the PEY of both the crops (Ahlawat and Sharma 1993). Production efficiency (PE) of okra–pea cropping system (kg/ha/day) was computed using following expression:

$$\text{PE} = \frac{\text{Total economic yield of okra–pea cropping system as PEY (kg/ha)}}{365}$$

System profitability in terms of monetary efficiency (ME) (INR/ha/day) was calculated using following formula:

$$\text{ME} = \frac{\text{Total net returns of a okra–pea cropping system (INR/ha)}}{365}$$

The data generated on various parameters was statistically analyzed using *F*–test. Least significance difference (CD) values at *P*=0.05 were used to determine the significant differences between treatment means.

## RESULTS AND DISCUSSION

### *Crop growth studies*

In okra, the highest increase in absolute growth rate (AGR) was found in $V_0$100%NPK $I_{AR}$ (GRD) i.e. general recommended nutrients and irrigation practice, although it remained statistically alike to $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{40\%}$ (Table 2). However, AMF imbedded treatments viz. $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ exerted significant increase in AGR by 5 and 9%, respectively over their non–AMF counterparts at same P and irrigation levels. AMF with irrigation at 40% AWC in $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ did not exhibit any influence on AGR over $V_0P_{100\%}I_{40\%}$, $V_0P_{75\%}I_{40\%}$ and $V_0P_{50\%}I_{40\%}$. In

Table 2 Effect of integrated application of AM fungi, applied P and irrigation regimes on different growth parameters in okra– pea cropping system (pooled data of 2 years)

| Treatment | | AGR(cm/day) | | RGR(g/g/day) | | NAR(g/cm/day) | | CGR(g/plant/day) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Okra | Pea | Okra | Pea | Okra | Pea | Okra | Pea |
| $T_1$ | $V_0N_{25\%}P_0K_0I_{WA}$ (FP) | 0.73 | 0.58 | 0.025 | 0.013 | 3.894 | 0.052 | 0.304 | 0.028 |
| $T_2$ | $V_0$100%NPK $I_{AR}$(GRD) | 1.04 | 0.60 | 0.021 | 0.008 | 6.121 | 0.095 | 0.479 | 0.044 |
| $T_3$ | $V_0\ P_{50\%}\ I_{40\%}$ | 0.91 | 0.69 | 0.022 | 0.007 | 5.543 | 0.045 | 0.452 | 0.032 |
| $T_4$ | $V_0\ P_{75\%}\ I_{40\%}$ | 0.94 | 0.64 | 0.022 | 0.008 | 5.796 | 0.060 | 0.466 | 0.037 |
| $T_5$ | $V_0\ P_{100\%}\ I_{40\%}$ | 0.96 | 0.69 | 0.021 | 0.008 | 6.211 | 0.067 | 0.477 | 0.040 |
| $T_6$ | $V_{12}\ P_{50\%}\ I_{40\%}$ | 0.94 | 0.73 | 0.022 | 0.008 | 6.450 | 0.058 | 0.461 | 0.037 |
| $T_7$ | $V_{12}\ P_{75\%}\ I_{40\%}$ | 0.96 | 0.71 | 0.022 | 0.008 | 7.166 | 0.073 | 0.488 | 0.040 |
| $T_8$ | $V_{12}\ P_{100\%}\ I_{40\%}$ | 0.99 | 0.73 | 0.021 | 0.008 | 6.957 | 0.073 | 0.486 | 0.041 |
| $T_9$ | $V_0\ P_{50\%}\ I_{80\%}$ | 0.89 | 0.69 | 0.021 | 0.008 | 5.906 | 0.093 | 0.442 | 0.040 |
| $T_{10}$ | $V_0\ P_{75\%}\ I_{80\%}$ | 0.94 | 0.66 | 0.021 | 0.008 | 6.076 | 0.083 | 0.459 | 0.041 |
| $T_{11}$ | $V_0\ P_{100\%}\ I_{80\%}$ | 0.96 | 0.66 | 0.022 | 0.008 | 6.640 | 0.099 | 0.478 | 0.045 |
| $T_{12}$ | $V_{12}\ P_{50\%}\ I_{80\%}$ | 0.97 | 0.71 | 0.021 | 0.009 | 6.060 | 0.129 | 0.452 | 0.045 |
| $T_{13}$ | $V_{12}\ P_{75\%}\ I_{80\%}$ | 0.99 | 0.76 | 0.022 | 0.009 | 7.182 | 0.120 | 0.492 | 0.048 |
| $T_{14}$ | $V_{12}\ P_{100\%}\ I_{80\%}$ | 0.99 | 0.71 | 0.021 | 0.009 | 6.899 | 0.121 | 0.488 | 0.049 |
| SEm± | | 0.013 | 0.020 | 0.0005 | 0.001 | 0.214 | 0.024 | 0.009 | 0.006 |
| CD (P=0.05) | | 0.036 | 0.058 | 0.001 | NS | 0.626 | NS | 0.026 | NS |

AGR (absolute growth rate); RGR (relative growth rate); NAR (net assimilation rate); CGR (crop growth rate)

pea, AMF inoculation gave higher AGR at either of the two irrigation regimes. The treatments $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ exhibited significant respective increase of 18, 27 and 18% in AGR over GRD. Absolute growth rate using AMF at 100 and 75% P dose was statistically similar probably due to lower efficiency of AMF at higher applied–P (Harrier and Watson 2003). Dube (2011) has also shown higher AGR with phosphate solubilizing bacteria and AMF. In okra, treatment effects on relative growth rate (RGR) were non–significant except farmers' practice. Similarly in pea, treatment differences for RGR were non–significant amongst various treatments (except farmers' practice).

In okra, the highest values of net assimilation rate (NAR) were registered in $V_{12}P_{75\%}I_{80\%}$ followed by $V_{12}P_{75\%}I_{40\%}$. Likewise, $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ exhibited 12, 24 and 16% higher NAR over their non–AMF counterparts. In pea, integrated use of AMF, applied–P and irrigation regimes led to non–significant influence on NAR (Table 2). In okra, higher crop growth rate (CGR) values were observed in $V_{12}P_{75\%}I_{80\%}$ followed by $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{80\%}$, all of which remained statistically at par with GRD; though, AMF inoculation exhibited a nominal (*but non–significant*) increase in CGR over non–AMF treatments (Table 2). The treatments $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ enhanced CGR marginally by 2, 7 and 2%, respectively over their non–AMF counterparts. Similarly, CGR in $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ increased by 2, 5 and 2%, respectively over their non–AMF counterparts. In pea, different treatments behaved statistically alike for CGR; though, AMF inoculation exhibited a numerically higher CGR values over their non–AMF counterparts (Table 2). The enhanced AGR, NAR and CGR with AMF inoculation is attributable to capability of AMF to solublize insoluble/fixed phosphate through release of certain organic acids and enzymes, in turn, making them available for plant use (Kumar *et al.* 2014). AMF explores larger soil volume through its mycelial growth, again, resulting in higher nutrient utilization (Suri *et al.* 2013). The AMF also leads to efficient absorption and assimilation of soil moisture, thus, regulating stomatal openings and enhanced dry matter production (Bethlenfalvay *et al.* 1988). All growth indices (AGR, RGR, NAR and CGR) under $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ did not differ significantly over $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$, respectively. As such, effects due to irrigation regimes were observed statistically non–significant. Hence, while discussing results, effects due to irrigation regimes are omitted. During both the years under study, different treatments behaved statistically similar at both the irrigation regimes (40 and 80% AWC) w.r.t. to all above growth indices owing to rains at regular interval during study.

### *Crop productivity*

Pooled data on okra fruit yield revealed that highest yield was found in $V_{12}P_{100\%}I_{40\%}$ followed by $V_{12}P_{100\%}I_{80\%}$ and GRD, all of which behaved statistically similar (Fig 1). Fruit yield in $V_{12}P_{100\%}I_{80\%}$ did not differ significantly over $V_0P_{100\%}I_{80\%}$ probably due to lower efficiency of AMF at higher applied–P (Harrier and Watson 2003). $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ gave significantly higher fruit yield by 7, 12 and 13%, respectively over their non–AMF counterparts. Similarly, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ exhibited 10 and 12% higher yield over non–AMF counterparts. Differences in fruit yield between '$V_{12}P_{100\%}I_{40\%}$ and $V_0P_{100\%}I_{40\%}$' were non–significant again, probably due to lower efficiency of AMF at higher applied–P. Green pod yield in pea was the highest at $V_{12}P_{100\%}I_{80\%}$

Table 3 Effect of integrated application of AM–fungi, applied P and irrigation regimes on different P efficiencies in okra–pea cropping system (pooled data of 2 years)

| | Treatment | PFPp(kg yield/kg P) | | CREp(kg yield/kg P) | | PEp(kg yield/kg P) | | % P recovery | |
|---|---|---|---|---|---|---|---|---|---|
| | | Okra | Pea | Okra | Pea | Okra | Pea | Okra | Pea |
| $T_1$ | $V_0N_{25\%}P_0K_0I_{WA}$ (FP) | | | | | | | | |
| $T_2$ | $V_0$100%NPK $I_{AR}$(GRD) | 139.3 | 188.1 | 0.20 | 0.23 | 357.7 | 383.4 | 32.5 | 40.8 |
| $T_3$ | $V_0\ P_{50\%}\ I_{40\%}$ | 225.9 | 281.4 | 0.30 | 0.21 | 318.0 | 372.5 | 53.8 | 57.5 |
| $T_4$ | $V_0\ P_{75\%}\ I_{40\%}$ | 166.2 | 209.0 | 0.25 | 0.19 | 306.8 | 394.9 | 41.4 | 43.1 |
| $T_5$ | $V_0\ P_{100\%}\ I_{40\%}$ | 133.4 | 169.2 | 0.20 | 0.18 | 324.5 | 382.4 | 32.8 | 36.0 |
| $T_6$ | $V_{12}\ P_{50\%}\ I_{40\%}$ | 252.7 | 317.1 | 0.41 | 0.38 | 294.3 | 305.2 | 65.7 | 74.1 |
| $T_7$ | $V_{12}\ P_{75\%}\ I_{40\%}$ | 182.1 | 231.0 | 0.33 | 0.31 | 282.3 | 306.1 | 49.2 | 55.7 |
| $T_8$ | $V_{12}\ P_{100\%}\ I_{40\%}$ | 141.1 | 186.3 | 0.25 | 0.26 | 295.3 | 322.7 | 37.4 | 44.6 |
| $T_9$ | $V_0\ P_{50\%}\ I_{80\%}$ | 224.0 | 297.9 | 0.34 | 0.26 | 269.6 | 375.5 | 58.6 | 61.9 |
| $T_{10}$ | $V_0\ P_{75\%}\ I_{80\%}$ | 166.0 | 220.6 | 0.22 | 0.22 | 345.1 | 385.2 | 38.8 | 46.5 |
| $T_{11}$ | $V_0\ P_{100\%}\ I_{80\%}$ | 131.9 | 182.0 | 0.19 | 0.20 | 335.8 | 403.1 | 31.7 | 38.3 |
| $T_{12}$ | $V_{12}\ P_{50\%}\ I_{80\%}$ | 253.4 | 349.1 | 0.44 | 0.45 | 279.7 | 330.0 | 67.7 | 80.9 |
| $T_{13}$ | $V_{12}\ P_{75\%}\ I_{80\%}$ | 186.1 | 250.7 | 0.34 | 0.35 | 283.1 | 328.9 | 50.5 | 59.5 |
| $T_{14}$ | $V_{12}\ P_{100\%}\ I_{80\%}$ | 140.7 | 196.4 | 0.26 | 0.29 | 285.8 | 329.8 | 38.1 | 47.1 |
| SEm± | | 2.68 | 4.92 | 0.014 | 0.007 | 13.45 | 12.89 | 1.34 | 0.68 |
| CD (P=0.05) | | 7.87 | 14.4 | 0.042 | 0.020 | 39.5 | 37.8 | 3.95 | 2.02 |

PFPp (partial factor productivity of applied–P); CREp (crop recovery efficiency of applied–P); PEp (physiological efficiency of applied–P)

followed by $V_{12}P_{75\%}I_{80\%}$ and GRD, all of which remained statistically at par. The differences between $V_{12}P_{100\%}I_{40\%}$ and GRD were also found non–significant. The AMF imbedded treatments, viz. $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ exhibited significantly higher green pod yield over their non–AMF counterparts. The same trend was observed in treatments irrigated at 40% AWC in the presence and absence of AMF at varying applied–P (Fig 1). It is also found that yields of both okra and pea under AMF + 75% soil–test based P–dose did not differ significantly than AMF + 100% soil–test based P–dose and GRD as well. These results suggest an economy of about 25% soil–test based P dose in okra–pea cropping system in Himalayan acid Alfisol. As AMF enhance ability of plants to utilize greater amount of nutrients, particularly P as a result of efficient solubilization and mobilization through AMF (Kumar *et al.* 2014), which finally resulted in improved productivity of okra and pea in the current study. Further, AMF enhanced growth parameters of okra and pea (Table 2), which consequently resulted in higher productivity of both the crops (Fig 1). The different treatments behaved statistically similar at both the irrigation regimes (40 and 80% AWC) in both seasons due to rains at regular interval. Hence, while discussing results, effects due to irrigation regimes are omitted. The farmers' practice was the trailing treatment as a matter of fact that farmers of wet–temperate NW Himalayas apply only one–fourth of recommended N dose and sub–optimal FYM doses (Choudhary *et al.* 2013). Thus, AMF application could be a boon under such conditions to enhance the crop productivity.

### *Agronomic indices of P use efficiency*

Agronomic indices of P-use efficiency (PUE) provide accurate assessment of P utilization (Dobermann 2005). Overall, there was an impressive increase in P-use efficiency in AMF imbedded treatments (Table 3), though, the response was comparatively lower at higher applied–P probably due to lower efficiency of AMF at higher P (Harrier and Watson 2003). However, in pursuance of the law of diminishing returns, PUE decreased as the P levels increased both in AMF inoculated and non–inoculated counterparts with every additional increment of P.

### *Partial factor productivity of applied–P*

In okra, AMF at varying P levels at either of irrigation regime led to higher partial factor productivity (PFPp) of applied–P (Table 3). $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$ gave significantly higher PFPp to the tune of 13, 12 and 7%, respectively over their non–AMF counterparts, viz. $V_0P_{50\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{100\%}I_{80\%}$. Similarly, $PFP_p$ in $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ enhanced respectively by 7, 10 and 6% over non–AMF counterparts. In pea, PFPp followed the same trend as obtained for okra with higher values under AMF imbedded treatments. PFPp was significantly enhanced by 17, 14 and 8% in $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$ over their non–AMF counterparts. $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ showed potential increases of 13, 11 and 10% in PFPp over $V_0P_{50\%}I_{40\%}$, $V_0P_{75\%}I_{40\%}$ and $V_0P_{100\%}I_{40\%}$, respectively.

### *Crop recovery efficiency of applied–P*

The crop recovery efficiency of applied P (CREp) followed the similar pattern as obtained under PFPp in both okra and pea. In okra, $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$ led to significant increases of 29, 54 and 36%

in CREp, respectively over $V_0P_{50\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{100\%}I_{80\%}$ (Table 3). Likewise, $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ led to enhancement in CREp by 37, 32 and 25%, respectively over non–AMF counterparts, viz. $V_0P_{50\%}I_{40\%}$, $V_0P_{75\%}I_{40\%}$ and $V_0P_{100\%}I_{40\%}$. In pea, AMF imbedded treatments, viz. $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$ gave significantly higher CREp by 73, 59 and 45%, respectively over their non–AMF counterparts. Similarly, $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ enhanced CREp by 81, 63 and 44% over non–AMF counterparts.

*Physiological efficiency of applied–P*

The physiological efficiency of applied–P (PEp) was registered higher in treatments receiving no AMF inoculation (Table 3). In okra, $V_0P_{75\%}I_{80\%}$ and $V_0P_{100\%}I_{80\%}$ registered 22 and 17% higher PEp over $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$, respectively. Whereas in pea, PEp was higher by 14, 17 and 22% in $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ over $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$. Similar magnitude of increases in PEp both in okra and pea were also registered in treatments irrigated at 40% AWC in the presence or absence of AMF at varying applied–P.

*Per cent phosphorus recovery*

The % P recovery (PR) in okra increased significantly to the extent of 16, 30 and 20% in $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$, respectively over non–AMF counterparts, viz. $V_0P_{50\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{100\%}I_{80\%}$ (Table 3). PR increased by 22, 19 and 14% in $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$, respectively over non–AMF counterparts. In pea, AMF imbedded treatments, viz. $V_{12}P_{50\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{80\%}$ exhibited significantly higher %P recovery to the tune of 31, 28 and 23%, respectively over their non–AMF counterparts (Table 3). Similarly, PR in $V_{12}P_{50\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{100\%}I_{40\%}$ was higher by 29, 29 and 24% over their non–AMF counterparts. During both years of study, irrespective of AMF and P levels, treatments having irrigation either at 80 or 40% AWC at varying P levels with or without AMF registered almost similar PR values owing to rains at regular interval during study. The general trend of 'agronomic indices of P use efficiency' may be explained following law of diminishing returns. However, higher PUE in case of AMF imbedded treatments with varying applied–P is obviously the outcome of higher okra and pea productivity; as the AMF inoculated plants have ability to utilize greater amount of P as a result of efficient solubilization and mobilization of P by AMF (Suri *et al.* 2013). Further, AMF release certain organic acids and enzymes which have the ability to solublize organic– and inorganic–P and other insoluble nutrients into soil solution for plant use (Suri *et al.* 2013).

*Fruit and plant succulence (moisture content)*

In okra crop, none of the treatments influenced fruit moisture content significantly (Fig 2). This could be attributed to the reason that there was sufficient soil moisture during *kharif* season owing to well distributed monsoons when okra fruit pickings were done thus, non–significant impact of imposed treatments. However, all AMF imbedded treatments showed relatively higher moisture level in fruits as compared to non–AMF counterparts. The moisture level ranged from 88.7 to 88.8% with AMF, whereas it ranged 87.9–88.2% under non–AMF ones, indicating, nominal higher moisture status in AMF plants (Fig 2). As regard to okra biomass (stover) harvested just after last fruit picking, AMF inoculated treatments showed significantly higher moisture status in plants, which is attributable to the reason that there was monsoon seizing by the end of September during both years, which led to moisture stress at latter plant growth stages, thus, different treatments especially AMF significantly influenced the water relations in the mycorrhizal plants. The treatments $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ registered nominal increases of 1, 2 and 2% in moisture value, respectively over their non–AMF counterparts at same P and irrigation levels, viz. $V_0P_{100\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{50\%}I_{80\%}$ (Fig 2). Similarly, above parameter increased by 2% each in case of $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ over their non–AMF fungi counterparts, viz. $V_0P_{100\%}I_{40\%}$, $V_0P_{75\%}I_{40\%}$ and $V_0P_{50\%}I_{40\%}$, respectively (Fig 2).

In case of pea green pods, $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ showed marginally higher (1–2%) moisture content over their respective non–AMF counterparts, viz. $V_0P_{100\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{50\%}I_{80\%}$ (Fig 3). Similar nominal increases in moisture content were also found in

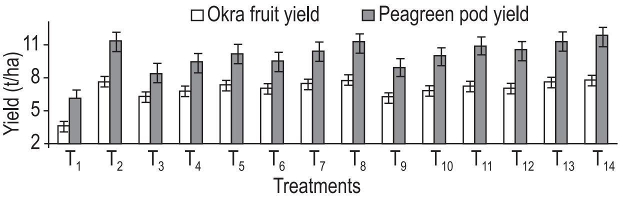

Fig 1 Effect of integrated application of AM–fungi, applied P and irrigation regimes on productivity (t/ha) of okra and pea (pooled data of two years). (Bars represent CD values at P=0.05 to *determine the significance differences among treatment means*)

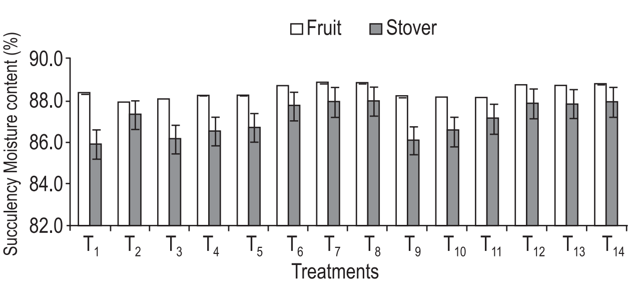

Fig 2 Effect of integrated application of AM–fungi, applied P and irrigation regimes on okra fruit succulence (moisture content) and stover moisture content (pooled data of two years). (*Bars represent CD values at P=0.05 to determine the significance differences among treatment means*)

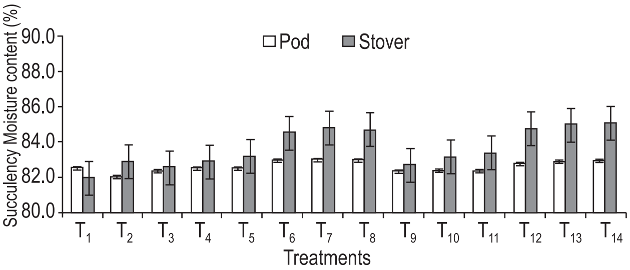

Fig 3 Effect of integrated application of AM–fungi, applied P and irrigation regimes on pea green pod succulence (moisture content) and Stover moisture content (pooled data of two years). (*Bars represent CD values at P=0.05 to determine the significance differences among treatment means*)

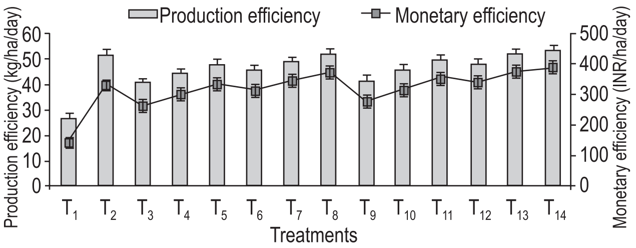

Fig 4 Effect of integrated application of AM–fungi, applied P and irrigation regimes on production efficiency (kg ha$^{-1}$ day$^{-1}$) and monetary efficiency (INR ha$^{-1}$ day$^{-1}$) of okra–pea cropping system (pooled data of two years). (*Bars represent CD values at P=0.05 to determine the significance differences among treatment means*)

treatments having irrigation at 40% AWC in the presence or absence of AMF at varying applied–P. As regards pea biomass (stover) harvested just after last pod picking, AMF imbedded treatments, viz. $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ registered higher moisture content to the tune of 2, 2 and 3%, respectively over their non–AMF counterparts (Fig 3). Similarly, above parameter in $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ was higher by 2% each over their non–AMF counterparts. Since, pea is grown in *rabi* season in the region facing more moisture stress, thus, AMF significantly influenced the water relations in the mycorrhizal pea plants (pods and biomass) in current study (Fig 4). Overall, AMF imbedded treatments at varying applied–P at either of irrigation regimes registered substantial increase in plant water relations over their non–AMF counterparts at same P and irrigation regimes. Enhanced okra fruit/pea pod succulence through AMF inoculation indicates that it helps in maintaining more freshness in vegetable produce adding value to fetch better prices in the market besides better quality produce as well. The results clearly revealed that different treatments exhibited a marked effect on fruit/pod succulence and plant moisture content (maintained higher moisture level) in okra–pea cropping system, indicating the ability of mycorrhizal plants to retain more moisture as compared to non–mycorrhizal plants at moisture stress which helps to maintain plant succulence and induce drought tolerance in plants (Auge 2006). This implies that mycorrhizal plants are able to induce drought tolerance to some extent in case of moisture stress (Yadav *et al.* 2015).The probable reason for high plant water status is that the mycorrhizal plants are able to maintain higher tissue water content, which might impart a greater drought resistance power to plants (Tisdall 1991); as well as improved physiological, morphological and phenological characteristics of mycorrhizal plants (Auge 2006, Harrier and Watson 2003).

*Production and monetary efficiency*

The highest magnitude of production efficiency was registered in $V_{12}P_{100\%}I_{80\%}$ followed by $V_{12}P_{100\%}I_{40\%}$ and GRD, all of which remained statistically similar (Fig 5). AMF imbedded treatments, viz. $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ gave significant higher values by 6, 13 and 14%, respectively in respect of above parameter over their non–AMF counterparts at same levels of applied–P and irrigation regimes, viz. $V_0P_{100\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{50\%}I_{80\%}$. Similarly, production efficiency of okra–pea cropping system was enhanced by 8, 11 and 13% in $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{750\%}I_{40\%}$, respectively over their non–AMF counterparts owing to better crop yields governed by higher nutrient and water acquisition by mycorrhizal plants (Harrier and Watson 2003, Auge 2006, Suri *et al.* 2013). Production efficiency in AMF + 75% P dose did not differ significantly than AMF + 100% P dose at either of irrigation regime (40 and 80% AWC) and GRD as well, thus, suggesting an economy of about 25% soil–test based P dose in okra–pea cropping system.

The highest monetary efficiency of okra–pea system was obtained in $V_{12}P_{100\%}I_{80\%}$ followed by $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{100\%}I_{40\%}$ with respective increases of 18, 14 and 13% over GRD (Fig 4). Likewise, $V_{12}P_{100\%}I_{80\%}$, $V_{12}P_{75\%}I_{80\%}$ and $V_{12}P_{50\%}I_{80\%}$ led to higher monetary efficiency by 10, 19 and 23%, respectively over $V_0P_{100\%}I_{80\%}$, $V_0P_{75\%}I_{80\%}$ and $V_0P_{50\%}I_{80\%}$. $V_{12}P_{100\%}I_{40\%}$, $V_{12}P_{75\%}I_{40\%}$ and $V_{12}P_{50\%}I_{40\%}$ exhibited significant increases of 11, 15 and 19% in above parameter over their non–AMF counterparts. Again, statistically similar monetary efficiency was registered under $V_{12}P_{100\%}I_{80\%}$ and $V_{12}P_{75\%}I_{80\%}$, which indicates an economy of about 25% soil–test based P dose by the AMF application in acid Alfisol. Better crop yields owing to higher nutrient and water acquisition by mycorrhizal plants may be the possible reason for enhanced monetary efficiency in current study (Harrier and Watson 2003, Auge 2006, Suri *et al.* 2013). On the other hand, irrigation regime of 80% AWC at varying applied–P in the presence or absence of AMF exhibited significantly higher 'production and monetary efficiencies' over irrigation at 40% AWC (Fig 4). It is attributable to fact that irrigation at 80% AWC involved more irrigations (especially in rabi season) which maintained sufficient soil moisture for harnessing higher crop yields and net returns resulting in comparatively higher production and monetary efficiencies over 40% AWC (Choudhary *et al.* 2013). Moreover, roots intercept more nutrients under moist conditions than a dry one, because root growth is more extensive under wet soil condition, this in turn, led to more productivity and enhanced production and monetary efficiencies in current study.

Based on the findings of this study, it could be concluded that AMF inoculation led to enhanced plant growth which got reflected in higher growth indices in mycorrhizal plants over their non–AMF counterparts. AMF significantly enhanced the partial factor productivity (9%), crop recovery efficiency (36%) and % recovery of applied–P (20%)' of okra, whereas in pea, above indices increased by 12, 61 and 27% with AMF inoculation. Production and monetary efficiencies were also improved by the AMF inoculation. Mycorrhizal plants retained more succulence (moisture) in okra fruits/pea pods, indicating a vital role of AMF in plant water relations. AMF inoculation at either of these irrigation regimes suggested an economy of about 25% soil–test based P dose in okra–pea cropping system in Himalayan acid Alfisol.

## ACKNOWLEDGEMENTS

Authors are thankful to Indian Council of Agricultural Research, New Delhi and CSK Himachal Pradesh Agricultural University, Palampur for providing financial assistance for undertaking this study.

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