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# Pigeonpea Productivity and Soil Health as Influenced by Phosphorus Levels and AM Fungi under Different Planting Methods

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

A field experiment was conducted at ARS, Bheemarayarnagudi, Karnataka to study the effect of phosphorus graded levels and inoculation of arbuscular mycorrhizal (AM) fungi under different establishment techniques in pigeonpea during *kharif* season of three years (2010-13) in Upper Krishna Project command area of Karnataka. The treatment consists of phosphorus graded levels (0, 12.5, 25, 37.5 and 50kg $ha^{-1}$) with inoculation VAM fungi under two establishment techniques (Transplanted and dibbled) with randomized block design. Three-year pooled data indicated that, Application of 50 kg P + VAM under transplanting technique recorded significantly higher pigeonpea

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yield (1510 kg ha$^{-1}$) and it was on par with application 37.5 kg P + VAM under transplanting method over rest of the treatment. The economics and nutrient uptake also noticed similar trend. It proved that pigeonpea could be successfully transplanted in the UKP command area of Karnataka by applying 37.5 kg of phosphorus ha$^{-1}$ in conjunction with VAM fungus inoculation. This boosted crop productivity, nutrient availability, and net returns.

*Keywords: Phosphorus; VAM fungi; transplanting; pigeonpea.*

## 1. INTRODUCTION

Pigeonpea (*Cajanus cajan* (L.) Millsp.) is one of the major grain legume (pulse) crops of the tropics and subtropics, endowed with several unique characteristics. It finds an important place in the cropping system adopted by small farmers in most of the developing countries. Globally pigeonpea ranks sixth in area and production in comparison to other grain legumes such as beans, peas and chickpea [1]. Pigeon pea is the second most important pulse crop in India after chickpea in terms of area and production. It is cultivated over an area of 4.43 million hectares, with production accounting for 4.25 million tonnes, and an average productivity of 937 kg ha$^{-1}$ [2]. It is largely grown in the northern parts of the state especially in Kalaburgi, which is called “Pulse bowl of Karnataka”. In this district, it occupies an area of 3.5 lakh ha and production of 1.37 lakh tonnes, but productivity is 359 kg ha$^{-1}$ which is very low compared to the state average productivity of 458 kg ha$^{-1}$ [3]. Abiotic stresses associated to soil fertility and moisture content, particularly in the early stages of crop growth, are mostly responsible for the crop's low productivity (<1 t/ha).

The primary constraint to increased pigeonpea productivity in the subtropics of India is soil moisture-related limitation, which is made worse by the crop's experience with climate aberrations that are unfavorable to its growth and development [4,5]. The yield of pigeonpea is greatly influenced by a number of factors such as agronomic, pathogenic, entomological, genetic and their interaction with environment. Among the different agronomic practices, inadequate and imbalanced nutrient application is one of the important factors, which is limiting the yield [4,6].

As pigeonpea is a legume crop, can meet its nitrogen demand through biological nitrogen fixation. However, the supply of phosphorus becomes crucial for yield maximization. Phosphorus is an important mineral element for grain legumes as it helps in root development, participates in synthesis of phosphates and phosphor-proteins and takes part in energy fixing and releasing process in plants. Significant response of pigeon pea to phosphate nutrition [5]. In tropical and subtropical locations, phosphorus is typically the most limiting nutrient for the growth of leguminous crops [7]. Using Arbuscular Mycorrhizal fungi and plant growth-promoting rhizo-bacteria, often known as bio-fertilizers, can increase the efficiency of phosphorus consumption [8].

In dry farming areas of Northern Karnataka, where the rainfall is not only scanty but also erratic, soil moisture becomes the most limiting factor in production of pigeonpea. To ensure timely sowing due to late onset of monsoon and late release of water to the canal in Upper Krishna Project (UKP) command area of Karnataka, transplanting of pigeonpea seedlings is one of the climate resilient practices to overcome delayed sowing. This technique involves raising seedlings in the polythene bags in the nursery for a period of one month and then transplanting those seedlings in the main field, immediately after soil wetting rains [9]. There is hardly any work done on the use of VAM in pigeonpea in this region. The technique of raising the pigeonpea seedlings in poly bags and transplanting is catching up in northern Karnataka region, due to manifold benefits. Use of AM fungi under transplanted condition (in poly bags containing germination media) would be advantageous over applying directly to the field under dibbled condition. Keeping all these aspects in view, the present investigation carried out to known effect of planting methods and phosphorus levels with AM fungi in northeastern dry zone of Karnataka.

## 2. MATERIALS AND METHODS

A field experiment was conducted at the College of Agriculture Farm, Bheemarayanagudi, University Agricultural Sciences, Raichur, Karnataka, during the *kharif* season of three years (2010-11 to 2012-13) to evaluate the performance of transplanted pigeonpea (Var. TS-3R) as influenced by mycorrhizal application at varied phosphorus levels. The treatment consisted of 5 phosphorus levels (0, 12.5, 25, 37.5, and 50 Kg $P_2O_5$/ha) with and without Arbuscular mycorrhizal fungi (AM) and two planting methods (transplanted and dibbling) replicated three times. The station comes under the North-Eastern dry zone of Karnataka, located between 16°43'N and 76°51'E longitude at an elevation of 411.75 meters above MSL, characterized by a dry climate with an average annual rainfall of 774.1 mm, and it lies in the heart of the UKP, a prestigious and largest irrigation command of the country with a projected irrigation potentiality of 10 lakh ha. The soil of the experimental site was medium black soil with soil pH 7.32, EC 0.18dS/m organic carbon 0.17%, available nitrogen 214 kg/ha, available phosphorus 31.5 kg/ha and available potassium is 352 kg/ha.

Two to three bold and healthy seeds of pigeonpea were sown during May in all the years in polythene bags having ¾th of soil, vermicompost and the AM fungus *Glomus fasciculatum* was inoculated at 10 g per polythene bag. Polythene bags were watered regularly. After one month, the seedlings were transplanted in the main field, and seeds were also sown on the day of transplanting by dibbling two to three seeds up to 4 to 5 cm deep in the rows at a 90 x 60 cm spacing. The recommended dose of nitrogen and phosphorus (25: 50 kg NP kg/ha) as per the treatments was applied as basal dose at the time of sowing in the form of urea and SSP. weed growth suppressed by three hand weeding operations to keep the plots free from weeds during the cropping period. To control spotted pod borer (*Maruca vitrata* (G)), Pod borer and Pod fly, Curacron (2 ml/l) – one spray, Acephate (2 ml/l) – one spray, were sprayed during flowering to grain filling stage.

Soil samples were collected from 0-30 cm depth before sowing and after harvest of the crop from each treatment in all the three replications. The collected samples were air-dried and processed in the laboratory. The soil samples were analyzed for available nitrogen, phosphorus and potassium content. Available soil nitrogen was estimated by alkaline permanganate method [10]. Available phosphorus was determined by Olsen's method [11] using spectrophotometer. Available potassium was extracted with neutral normal ammonium acetate and the content was estimated by flame photometer [11]. Nitrogen, phosphorus and potassium contents in plant samples of pigeonpea at harvest were estimated by modified micro-kjeldhal method, Vanado-molybdate yellow colour method and flame photometer method, respectively [11]. Nutrient uptake was calculated by using the following formula.

Uptake (kg/ha) =

$$\frac{\text{Nutrient concentration (\%) x Biomass (kg/ha)}}{100}$$

The analysis and interpretation of data was done using the Fisher's method of analysis of variance technique [12]. The level of significance used in "F" and "t" test was p=0.05. Critical difference values were calculated whenever the "F" was significant.

## 3. RESULTS AND DISCUSSION

### 3.1 Pigeonpea Yield and Growth Performance

The production of economic yield of a crop is an outcome of interaction among the crop, soil, environmental factors and the agronomic manipulations [6]. The agronomic practices can modify its surrounding environment (microclimate) to a certain extent and thereby help the crop exploit the available resources more efficiently and achieve higher production [13]. Thus, maximum yields are obtained when optimum conditions are provided for a crop, which, in precise terms, is the object of optimum plant nutrition and a better method of establishment for increasing the productivity and production of the food legumes [14,1].

Applying 50 kg $P_2O_5$/ha inoculating with AM fungi and transplanting of pigeonpea produced significantly higher seed yield (1510 kg/ha) compared to the other treatments (Table 1). However, it is on par to application of 37.5 $P_2O_5$/ha and inoculating with AM fungi and transplanting method (1478 kg/ha). The dibbling method of pigeon pea without phosphorus and the AM fungi showed significantly lower seed yield (785 kg/ha). Crop being photosensitive, proper time of planting is critical; planting early in the season with the onset of monsoon is more paying as it ensures adequate soil moisture throughout life cycle and accumulate required growing degree days (GDD) besides escaping from pod borer [15,16]. The early-planted crop's yield advantage was mostly attributable to higher growth, yield characteristics, and physiological traits. Climate and temperature during the periods of growth, development, and maturity also supported it.

Higher growth and yield features were the result of better utilization of moisture, nutrients, and light interception [17].

The seed yield per plant is governed by yield components like number of pods per plant, 100 seed weight and seed weight per plant. Application of 50 kg $P_2O_5$/ha inoculating with AM fungi and transplanting method recorded significantly higher seed yield per plant, 100 seed weight and seed weight per plant (83.00 g, 11.30g and 210 pods per plant, respectively) as over other treatments and it was on par transplanting of pigeonpea with application of 37.5kg $P_2O_5$/ha inoculating AM fungi (81.83g, 11.14 g and 207 pods per plant, respectively) (Table 1). Conspicuously higher yields obtained with application of 50 kg $P_2O_5$/ha inoculating AM fungi under transplanting technique may be attributed to satisfactory improvement in plant height (158.90cm) and number of branches per plant (17.57) which might have facilitated the crop to undergo increased photosynthetic activity which in turn might helped the crop to accumulate significantly higher dry matter production (113 g/plant) at harvest as compared with rest of the treatments and it was on par with application of 37.5 kg $P_2O_5$/ha inoculating AM fungi under transplanting technique (156.93cm and 17.37, respectively). All these parameters might have more crops to give significantly higher yield over dibbling method and application of phosphorus at lower graded levels (Table 1). Transplanting is a novel and clever agronomic technique that has recently gained popularity in the Northeastern dry zone [18], the Eastern Gangetic plains of India [4], and the Northeastern transition zone [19]. It is intended to overcome yield reduction caused by late sowing. Phosphorus plays a pivotal role in the higher yield, by stimulation of root development, energy transformation and metabolic processes in the plants, which turn, resulted in greater translocation of photosynthates towards the sink development [20]. Use of Arbuscular Mycorrhiza along with graded levels of phosphorus under transplanting technique enhanced growth and yield of pigeonpea [1].

## 3.2 Root Length and Diameter

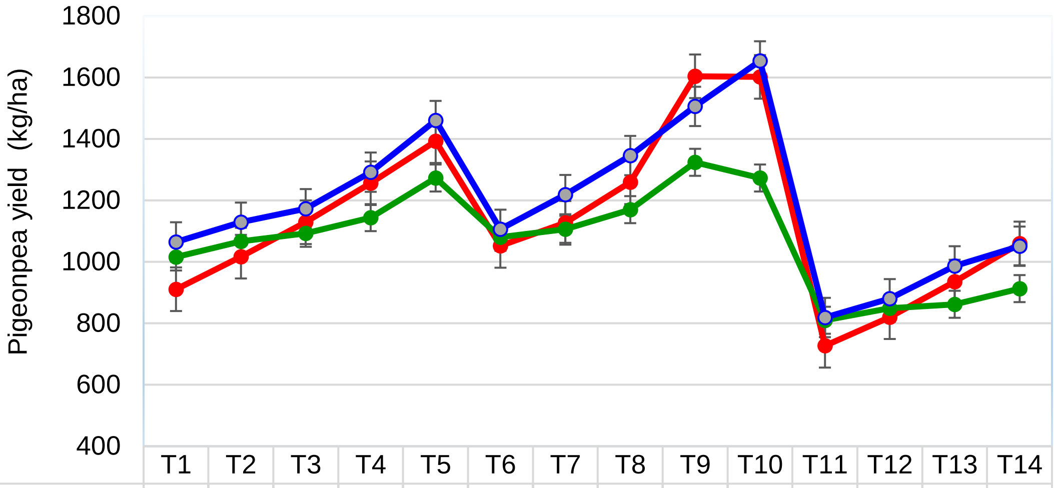
Mycorrhiza inoculated seedlings recorded comparatively higher root length (26 cm) and diameter (0.92 cm) over the non-mycorrhized seedlings (22 and 0.89 cm respectively), which may be due to optimum supply of phosphorus to the seedlings in the juvenile stage of growth compared to the seedlings grown without mycorrhizal inoculation (Fig. 2). Use of Arbuscular Mycorrhiza increases the production of growth promoters, increases tolerance to diseases by plant and improves the synergistic interaction with Beneficial N-fixer and P-solubilizes microorganism in chickpea [21]. This is achieved by increasing plant P absorption—a crucial step for biological nitrogen fixation by utilizing VAM. Additionally, mycorrhiza strengthens the plant's resilience to various diseases caused by soil, enhances its water intake, making it more drought-tolerant, and protects it from weed species like striga. Furthermore, mycorrhizal fungi produce glomalin, a glycoprotein that binds soil particles and improves soil structure and additionally, by binding heavy metals, it increases plants' tolerance to their detrimental effects [22]. Arbuscular Mycorrhizal Fungi (AMF) play important roles in agroecosystems, including the involvement of the extra radical mycelium in providing soil aggregation [23].

## 3.3 Nutrient Uptake (kg ha$^{-1}$)

Nutrient uptake of pigeonpea differed significantly due to graded phosphorus levels and mycorrhizal inoculation. Higher uptake of nitrogen, phosphorus and potassium (116.33 kg ha$^{-1}$) was noticed with application of 50 kg P + AM fungi under transplanting technique and which was on par with 37.50 kg P + AM fungi with Transplanting method (115.33 kg ha$^{-1}$) over other treatments (Table 2). A significantly higher uptake of nitrogen, phosphorus, and potassium was recorded in transplanted conditions when compared to the dibbled method. It was mainly due to the strong and deep root system of pigeonpea transplanted rather than the dibbled method. Such plants had robust, well-developed root systems, and it's because mycorrhizal treatment enhanced the amount of available N, P, and K in the rhizosphere, as well as its solubility. The results agree with a study that shows an increase in mycorrhizal colonization with fertilization by N or P in nutrient limited soils, varying with species, with incidences of *Glomus spp*. increasing in relatively fertile soils [24]. Similarly, VAM fungal inoculation promotes rhizosphere colonization, leads to in higher nutrient uptake and improves BNF, crop growth, and yields in legume-based cropping systems [22].

**Table 1. Effect of phosphorus levels with AM fungi inoculation and planting methods on growth parameters, yield parameters and economics of pigeonpea (pooled over 3 year's data)**

| Treatment Details | Plant height (cm) | No of branches per plant | Dry weight (g/plant) | No of pods per plant | Seed weight (g/plant) | 100 Seed wt. (g) | Pigeonpea yield (kg/ha) | Gross returns (Rs./ha) | Cost of cultivation (Rs./ha) | Net returns (Rs./ha) | B:C ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Transplanted with 0 kg $P_2O_5$/ha | 132.07 | 14.97 | 141.30 | 169.57 | 67.03 | 9.13 | 997 | 38569 | 16818 | 21751 | 2.30 |
| Transplanted with 12.5 kg $P_2O_5$/ha | 137.57 | 15.17 | 148.10 | 177.77 | 70.27 | 9.57 | 1071 | 41473 | 17548 | 23925 | 2.38 |
| Transplanted with 25 kg $P_2O_5$/ha | 138.87 | 15.60 | 149.77 | 179.70 | 71.03 | 9.67 | 1132 | 43896 | 18230 | 25666 | 2.43 |
| Transplanted with 37.5 kg $P_2O_5$/ha | 147.07 | 16.43 | 160.10 | 192.10 | 75.93 | 10.34 | 1231 | 47744 | 19087 | 28657 | 2.54 |
| Transplanted with 50 kg $P_2O_5$/ha | 150.67 | 16.87 | 164.97 | 197.53 | 78.10 | 10.63 | 1375 | 53333 | 20112 | 33221 | 2.71 |
| Transplanted with 0 kg $P_2O_5$/ha + VAM | 140.03 | 15.77 | 151.23 | 181.30 | 71.73 | 9.77 | 1079 | 41860 | 17554 | 24306 | 2.40 |
| Transplanted with 12.5 kg $P_2O_5$/ha +VAM | 142.23 | 15.93 | 154.00 | 184.77 | 73.03 | 9.94 | 1151 | 44584 | 18234 | 26350 | 2.47 |
| Transplanted with 25 kg $P_2O_5$/ha + VAM | 149.97 | 16.70 | 163.77 | 196.50 | 77.67 | 10.55 | 1258 | 48764 | 19131 | 29632 | 2.59 |
| Transplanted with 37.50 kg $P_2O_5$/ha + VAM | 156.93 | 17.37 | 172.53 | 207.03 | 81.83 | 11.14 | 1478 | 57478 | 20708 | 36770 | 2.87 |
| Transplanted with 50 kg $P_2O_5$/ha + VAM | 158.90 | 17.57 | 175.00 | 210.00 | 83.00 | 11.30 | 1510 | 58545 | 21096 | 37449 | 2.88 |
| Dibbling 0 kg $P_2O_5$/ha | 109.70 | 12.77 | 113.00 | 135.57 | 53.60 | 7.30 | 785 | 30398 | 12004 | 18395 | 2.56 |
| Dibbling 0 kg $P_2O_5$/ha + VAM | 114.70 | 13.20 | 118.53 | 142.23 | 56.23 | 7.66 | 850 | 32926 | 12608 | 20318 | 2.65 |
| Dibbling 50 kg $P_2O_5$/ha | 115.77 | 13.03 | 120.67 | 144.77 | 57.23 | 7.79 | 928 | 35984 | 14044 | 21941 | 2.61 |
| Dibbling 50 kg $P_2O_5$/ha + VAM | 119.00 | 13.70 | 124.80 | 150.67 | 59.63 | 8.12 | 1008 | 39144 | 14750 | 24394 | 2.72 |
| SEM ± | 5.89 | 0.55 | 7.40 | 8.34 | 3.51 | 0.47 | 47 | 2131 | - | 2131 | 0.11 |
| CD(0.05) | 17.11 | 1.59 | 21.49 | 24.23 | 10.18 | 1.37 | 134 | 6193 | - | 6193 | 0.28 |




| | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 | T11 | T12 | T13 | T14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2010-11 | 911 | 1017 | 1129 | 1256 | 1393 | 1052 | 1127 | 1259 | 1604 | 1602 | 727 | 820 | 936 | 1060 |
| 2011-12 | 1016 | 1067 | 1093 | 1144 | 1273 | 1080 | 1106 | 1170 | 1324 | 1273 | 810 | 849 | 862 | 913 |
| 2012-13 | 1065 | 1129 | 1173 | 1292 | 1460 | 1106 | 1219 | 1346 | 1506 | 1654 | 819 | 880 | 987 | 1051 |

**Fig. 1. Pigeonpea yield (kg/ha) as influenced by planting methods and phosphorus levels with AM fungi inoculation from 2010-11 to 2012-13**

*Symbol indicates standard error bars at 5%)*

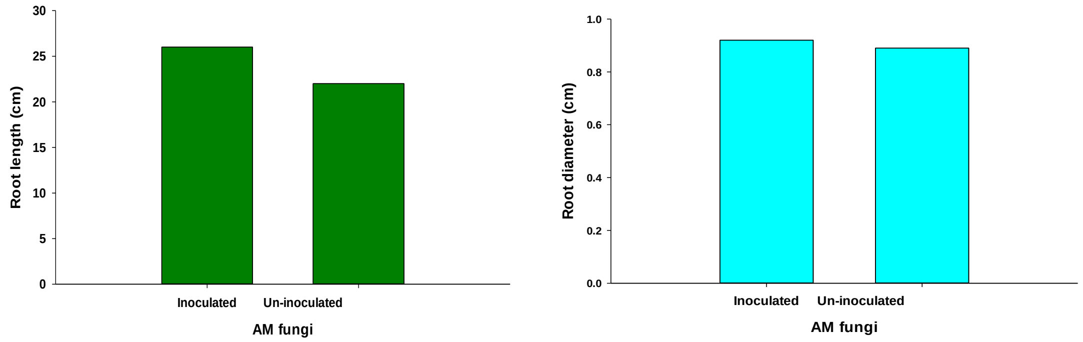



**Fig. 2. Root length and diameter (cm) of pigeonpea seedlings at the time of transplanting as influenced by mycorrhizal inoculation**

### 3.4 Available Nutrients after the Harvest of Crop

Significantly higher availability of nitrogen (198kg ha$^{-1}$) was registered with application of 50 kg P + VAM under transplanting method which was on par with all other treatments except without 0 kg P- Dibbling) (170kg ha$^{-1}$) and 0 kg P + AM with dibbling method (172kg ha$^{-1}$) as compared to other treatments (Table. 2). Significantly higher availability of phosphorus (60 kg ha$^{-1}$) was noticed in 50 kg P with dibbling method compared to rest of the treatments. It might be due to the higher amount of phosphorus applied and lower amount of phosphorus uptake by the crop due to week root system, P- fixation and absence of mycorrhiza in soil. Availability of potassium did not differ significantly due to graded levels of phosphorus application.

Higher availability of nitrogen and phosphorus was registered in transplanted pigeonpea when compared to dibbled one. This was because, in transplanted conditions crops have produced better root system, a greater number of root nodules per plant and higher number of root hairs as observed during harvest [19]. It helped to leave more residual nitrogen in soil after crop harvest, which was the product of biological nitrogen fixation [22,21].

**Table 2. Total uptake of nutrients and Available nutrients (kg/ha) in soil after harvest of pigeon pea as influenced by phosphorus levels with AM fungi inoculation and planting methods (Pooled over 3 year)**

| Details | Nutrients Uptake (kg/ha) | | | Available nutrients (kg/ha) | | |
|---|---|---|---|---|---|---|
| | Nitrogen | Phosphorus | Potash | Nitrogen | Phosphorus | Potash |
| Transplanted with 0 kg $P_2O_5$/ha | 114 | 27 | 32 | 186 | 33 | 380 |
| Transplanted with 12.5 kg $P_2O_5$/ha | 116 | 28 | 33 | 187 | 37 | 376 |
| Transplanted with 25 kg $P_2O_5$/ha | 117 | 31 | 34 | 189 | 48 | 376 |
| Transplanted with 37.5 kg $P_2O_5$/ha | 120 | 34 | 38 | 193 | 51 | 377 |
| Transplanted with 50 kg $P_2O_5$/ha | 122 | 39 | 39 | 197 | 53 | 375 |
| Transplanted with 0 kg $P_2O_5$/ha + VAM | 117 | 36 | 33 | 186 | 30 | 376 |
| Transplanted with 12.5 kg $P_2O_5$/ha +VAM | 121 | 42 | 34 | 188 | 36 | 376 |
| Transplanted with 25 kg $P_2O_5$/ha + VAM | 125 | 46 | 37 | 190 | 46 | 375 |
| Transplanted with 37.50 kg $P_2O_5$/ha + VAM | 128 | 51 | 42 | 195 | 38 | 374 |
| Transplanted with 50 kg $P_2O_5$/ha + VAM | 129 | 53 | 43 | 198 | 40 | 373 |
| Dibbling 0 kg $P_2O_5$/ha | 103 | 26 | 29 | 170 | 36 | 383 |
| Dibbling 0 kg $P_2O_5$/ha + VAM | 104 | 36 | 32 | 172 | 39 | 382 |
| Dibbling 50 kg $P_2O_5$/ha | 108 | 37 | 36 | 189 | 60 | 380 |
| Dibbling 50 kg $P_2O_5$/ha + VAM | 110 | 47 | 38 | 192 | 41 | 378 |
| SEM ± | 3.3 | 1.3 | 1.2 | 5.44 | 1.29 | 6.15 |
| CD(0.05) | 9.4 | 3.7 | 3.4 | 15.81 | 3.74 | NS |

### 3.5 Economics

Application of 50 kg P + AM fungi under transplanting technique has recorded the higher Gross returns (Rs.58, 545 $ha^{-1}$) and net returns (Rs. 37,449 $ha^{-1}$) over the rest of the treatment. However, it was on par with the application of 37.5 kg P + AM fungi under transplanting method. This is mainly due to high seed yield being produced. The higher cost of cultivation recorded in with application of 50 kg P + AM fungi under transplanting method (Rs. 21, 096 $ha^{-1}$) as compared to other treatments. This clearly indicates that the cost of cultivation in transplanted pigeonpea was higher than in dibbing, which was due to extra cost incurred on raising seedlings, polythene bags, nursery maintenance and more labour requirement for transplanting. Transplanted pigeonpea has recorded comparatively higher gross returns compared to dibbling (Table. 1), it was due to higher seed yield over the dibbled method. Similar results were analyzed by Priyanka et al. (2013) [25] in transplanted and dibbled establishment techniques in pigeonpea. Application of 50 kg P + AM fungi under transplanting method recorded significantly higher B:C (2.88) as compared to other treatments, and it was on par with application of 50 kg P + AM fungi under transplanting method (2.87). This is mainly due to transplanted pigeonpea has given significantly higher net returns under same set of management compared to dibbling, which was because of significantly higher seed yield and cost saved on phosphorus supply. Similarly higher remunerative returns were observed in transplanted pigeonpea over dibbled method by Yadahalli et.al [16], Jayaraja et al [17] and Priyanka et al. [25].

## 4. CONCLUSION

From the results of this agronomic investigation, it may conclude that the application of 37.5 kg phosphorus $ha^{-1}$ with mycorrhizal inoculation was found to be beneficial for pigeonpea because of higher seed yield and net returns. Which will save phosphorus to the tune of 12.5 kg $ha^{-1}$. Among the different methods of crop establishment transplanting was found to be better because of higher seed yield and net returns. This method is very well suited to Upper Krishna Project command area of Karnataka due of late onset of monsoon and late release of canal water.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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