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Quantifying the Effects of Phosphate Solubilising Fungi and Phosphorus Chemical Fertilizer on Phosphorous Economy and Productivity of Rainfed Castor on Alfisols

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Abstract

A three year (*kharif* 2011-12, 2012-13 and 2013-14) field study was conducted to understand the effect of seed treatment with biophos biofertilizer at different phosphorus levels on phosphorus economy, growth and productivity of rainfed castor, at Regional Agricultural Research Station, Palem, Professor Jayashankar Telangana State Agricultural University, India. The experiment had eight treatments including control, seed treatment with biophos (30 g inoculant per 50 g seed), 20, 40 and 60 P_2O_5 ha^{-1} with and without biophos, replicated thrice in a randomized block design. The seed yield was relatively low during 2011 and higher in 2012 and 2013. It increased linearly from no phosphorus application upto 40 kg P_2O_5 ha^{-1} afterwhich it declined. Biophos was very effective at lower or medium phosphorus dose than at higher P dose. The pooled data indicated that supply of 20 kg P_2O_5 ha^{-1} besides biophos seed treatment with higher seed yield (1439 kg ha^{-1}) has significantly outyielded 60 kg P_2O_5 ha^{-1} (1254 kg ha^{-1}) and control (1098 kg ha^{-1}), but, at par with other phosphorus doses. However, gross returns (INR 46,555 ha^{-1}), net returns (INR 26,071 ha^{-1}) and B:C ratio (2.26) were greater due to integrated application of 20 kg P_2O_5 ha^{-1} and seed treatment with biophos@30g inoculant 50 g^{-1} seed only. Besides, this helped in saving of 20 kg P_2O_5 ha^{-1} against the recommended dose of 40 P_2O_5 ha^{-1}.

Keywords: Biophos, castor, economics, phosphorous, seed yield

1. Introduction

Castor is a well known non-edible oilseed crop primarily grown in India, China, Brazil, U.S.A. and Mozambique. Though, it is indigenous Eastern Africa, the south-eastern Mediterranean basin and India, but, it is grown across tropical, subtropical, temperate and Mediteranean regions of the world (Koutroubas et al., 1999; Barreto et al., 2010; Kumar et al., 2015). Castor seed and other parts of the plant have umerous applications in Agriculture, industry, health and ornamnental fields (Ramanjaneyulu et al., 2017), thus, it plays an important role in Indian Agricultural economy through foreign exchange earnings of 864.99 million USD (Department of Commerce, 2019). The castor crop is mainly cultivated under rainfed conditions in South India (Ramanjaneyulu et al., 2013) where the seasonal and annual rainfall doesnot exceed 500 mm and 750 mm, respectively, often leading to moisture stress at critical stages like flowering and capsule development.

Modern Agriculture depends heavily on chemical fertilizers for nourishing the crops in order to achieve maximum productivity. Indian soils in general and castor growing areas in particular are low in nitrogen, low to medium in phosphorous to medium to high in potash. A nutrient dose of 80-40-30 kg N, P_2O_5, K_2O ha^{-1} is advocated for hybrid castor under rainfed conditions. Of this, half dose of nitrogen, a full dose of phosphorus and potash have to be applied as basal and the remaining half N dose has to be applied in three equal splits at 30, 60 and 90 days after sowing (DAS) (Ramanjaneyulu et al., 2021). However, majority of the castor growers are applying complex fertilizers like diammonium phosphate (DAP) or 28-28-0 or 17-17-17 or 19-19-19 or 14-35-14 for top dressing nitrogen resulting in inadvertent application and build up of phosphorus. Though phosphorus (P) is one of the 17 essential nutrients required for plant growth and development, energy transfer, photosynthesis, transformation of sugars and starches, nutrient movement within the plant and transfer of genetic characters from one generation to the other, it's excess in the soil reduces the capacity of plant to absorb micronutrients leading to deficiency of zinc and iron, pollution of water bodies which inturn reduces the water quality and threaten the aquatic life. Further, phosphate toxicity suppress the FGF23-klotho system and cause damage to tissues leading to hyperphosphataemia in human beings (Shawkat, 2011).

Plants can utilize P in soluble form only, hence, small amount of applied P is being absorbed by plants, as approximately 50% (Rajput et al., 2014) to 75-90% (Sharma et al., 2013) of it is converted into insoluble form and fixed in soils by it's reaction with other elements such as iron, aluminium, calcium, magnesium and manganese leading to precipitation (Dean, 1949; Kanwar and Grewal, 1990) in the soil reaching medium to high status in the soil. In otherwords, it can be considered as insoluble phosphate pollution which leads to eutrophication of proximate water bodies and soil degradation. Farmers have been adding phosphatic fertilizers indiscriminately regardless of its status, soil type, pH, insolubility in soil and utilization by the plant, leading to increase in cost of production besides accumulation in the soil. On the otherhand, India is importing 90% of the phosphates either as raw material or finished fertilizers (Department of Fertilizers, 2020) to meet the requirement in Agriculture. It is causing loss of foreign exchange and chemicalization of Agricultural fields. Therefore, there is an urgent need to explore the possibilities to utilize efficiently the P accumulated in soil.

In general, the P solubility and mobility in soils and accessibility to the plants is influenced by various soil physical, chemical and biological characteristics (Schmitt et al., 2017). Therefore, it is a major challenge to improve the P availability to plants (Owen et al., 2015) and its use efficiency. Among several approaches suggested viz., efficient methods of application, incorporation of organic or green manures, addition of sulphur, humic acid and introduction of liquid fertilizers (Holloway et al., 2001; Giovannini et al., 2013; Rahman et al., 2014), use of phosphate solubilizing biofertilizers or bio-inoculants (Chen et al., 2006) was found easy, effective, ecologically and economically sound approach (Kalayu, 2019). They contain microbes which help in promoting the growth of plants and trees by increasing the supply of essential nutrients to the plants. Many bacteria (*Pseudomonas, Bacillus, Rhizobium*), fungi (*Penicillium, Aspergillus*), actinomycetes and arbuscular mycorrhiza can be used for this purpose (Chen et al., 2006; Thakur et al., 2014; Hajjam and Cherkaouli, 2017). The organic acids and phosphorus-hydrolyzing enzymes such as phosphatases and phytases produced by these microbial strains decrease the soil pH which helps in solubilization of the insoluble phosphates, thereby increasing P availability to the plants. Several researchers reported positive results across various crops and diversified climatic zones with considerable improvement in growth, yield traits, early maturity, biomass production, P content in plants, higher yield by 15-20%, avoidance of phytopathogens, saving of P and relaisation of higher farm income due to seed treatment with phosphate solubilizing micro-organicms especially *Pseudomonas, Bacillus and Rhizobium* (Arangarsaran et al., 1999; Sundara et al., 2002; Ramanjaneyulu et al., 2007; Afzal and Bano, 2008; Ahmed and Shahab, 2011; Walpola and Yoon, 2012; Mathukia et al., 2014; Kumar Naik et al., 2020). However, research on phosphorus solubiling fingi for efficient utilization of insoluble or fixed soil phosphsours is meager. Biophos, a biofertilizer prepared by using a phosphate solubilizing fungus *Chaetomium globosum*. This fungi can tolerate high soil temperature in tropical and sub tropical regions and releases phosphatases, phytase and organic acids when applied through seed treatment. These substances solubilize and mobilize the insoluble and immobile native phosphorus and make it available to the plants (Tarafdar and Gharu, 2006).

The research studies on impact of conjuctive use of phosphorus chemical fertilizer and biophos biofertilizer are scarce in castor ecosystem. Hence, the present study was undertaken to ascertain the role of biophos at varying P levels, in economising the P application and enhancing the productivity of castor crop under rainfed conditions on Alfisols.

2. Materials and Methods

2.1. Site characterization

A field experiment was conducted during *kharif* season of 2011-12, 2012-13 and 2013-14 at Regional Agricultural Research Station, Professor Jayashankar Telangana State Agricultural University, Palem, Telangana state, India. The experimental site was low in nitrogen (224 kg ha^{-1}), medium in phosphorus (35.2 kg ha^{-1}) and high in potash (402 kg ha^{-1}). There were eight treatments *viz*., T_1: Control (No phosphorus and no biophos), T_2: Seed treatment with biophos @ 30 g inoculant per 50 g seed, T_3: 20 kg P_2O_5 ha^{-1}, T_4: 20 kg P_2O_5 ha^{-1} +T_2, T_5: 40 kg P_2O_5 ha^{-1}, T_6: 40 kg P_2O_5 ha^{-1}+T_2, T_7: 60 kg P_2O_5 ha^{-1} and T_8: 60 kg P_2O_5 ha^{-1}+T_2. The experiment was laid out in a randomized block design with three replications.

2.2. Rainfall

The castor crop was grown rainfed in all the years of expeeimentation. An amount of 364.6 mm rainfall in 32 rainy days, 531.6 mm in 36 days and 841.0 mm in 46 days was received during the crop growing season in 2011-12, 2012-13 and 2013-14, respectively.

2.3. Seed treatment, spacing, fertilizer application and plant protection

The castor hybrid PCH-111 was used in the experimentation. In case of T_1, T_3, T_5 and T_7 treatments, seeds were treated with a fungicide Carbendazim (3 g kg^{-1}) alone. On the otherhand, in case of T_2, T_4, T_6 and T_8, first, jaggery solution (250 ml ha^{-1} seed) followed by black coloured biophos powder (3 kg ha^{-1}) were sprinkled on the castor seeds and both were mixed gently without rupturing the seed coat. Later, these seeds were treated with Carbendazim (3g kg^{-1}) followed by air-dried in shade.

The treated castor seeds @ 5 kg ha^{-1} were sown at a spacing of 90×60 cm^2 on 12-07-2011, 15-07-2012 and 11-07-2013, on a well pulverized soil. An amount of 40 kg N and 30 kg K_2O ha^{-1} through urea and muriate of potash were applied as basal.

Further, another 40 kg N through urea was applied in three equal splits at 30, 60 and 90 DAS. In general, 40 kg P_2O_5 ha^{-1} is recommended for hybrid castor unde rainfed conditions. However, in this trial, the treatment wise phosphorus dose (20 or 40 or 60 kg) was applied through single super phosphate (SSP) as basal. The castor semilooper (*Achaea Janata)* and tobacco caterpiller (*Spodoptera litura)* were controlled by erecting bird perches and also spraying Novoluron 10% EC @ 1 ml l^{-1} during all the three years of experimentation. The dreaded disease *Botryotinia* gray rot (*Botrytis ricini*) was controlled by spraying Carbendazim @ 1 g l^{-1} during 2013-14 only as the incidence was meager in 2011-12 and 2012-13.

A gross plot size of 5.4mx6.0m (6 rowsx10 plants)and a net plot size of 3.6×4.8 m^2 (4 rows×8 plants) were maintained. The crop was kept weed-free by spraying a pre-emergence herbicide Pendimethalin @ 1.0 kg a.i ha^{-1} followed by two times intercultivation and one hand weeding in the intra row. Five healthy seedlings with consistent growth were selected from net plot of each treatment to record anicilliary characters. A total of three pickings were done during November, December and January every year. Seed yield from all the three pickings was pooled for arriving at the final seed yield and the same was expressed as kg ha^{-1}. The phosphorus use efficiency (PUE) was computed by dividing the castor seed yield with the P applied. The significance of the treatment effect was determined using the f-test and the least significant differences were calculated at the 5% probability level to determine the significance of the difference among treatments (Panse and Sukhatme, 1985).

3. Results and Discussion

3.1. Changes in growth and yield traits of castor due to P application

As furnished in the Table 1, the plant population was similar in all the treatments under test. The plant height was significant during 2011-12 only during which, the castor plants grew significantly taller when fertilized with 40 kg P_2O_5 ha^{-1} alone over control, but, was on par with that of seed treatment with biophos alone, 20 or 60 kg P_2O_5 ha^{-1} with or without seed treatment with biophos. Significantly more no. of branches plant^{-1} were observed due to application of 20 kg P_2O_5 ha^{-1} besides seed treatment with biophos which declined with higher levels of phosphorus application with or withour biophos, either in 2011-12 or on pooled data basis. No. of branches plant^{-1} observed with control was significantly inferior (Table 1). Similarly, the treatments failed to exert any significant influence on no. of nodes plant^{-1} (Table 2). Though no. of total spikes did not vary significantly due to various treatments during 2011-12 and 2013-14, application of 40 kg P_2O_5 ha^{-1} and 20 kg P_2O_5 ha^{-1}+biophos resulted in significantly greater no. of total spikes plant^{-1} over other treatments barring 20 kg P_2O_5 ha^{-1} No. of effective spikes plant^{-1} was significantly affected by various treatments during 2011-12 and 2012-13 only during which supply of 40 kg P_2O_5 ha^{-1} to castor resulted in significantly more no. of effective spikes plant^{-1} (Table 2). Similalry, total spike length was significantly influenced by the different treatments during 2011-12 and 2012-13 during which significantly longer spikes and effective spike length were observed with the application of 40 kg P_2O_5 ha^{-1} alone or in integration with biophos. All the tested treatments recorded a similar 100 seed weight irrespective of dry or wet year.

3.2. Changes in seed yield and PUE of castor due to P application

The differential yield during three years could be due to variation in rainfall pattern. The yield levels were comparatively lower during the first year (2011-12) due to deficit rainfall by 35.5% which has created a dry spell like situation during 13th September to 3rd October and from 17th October onwards, which inturn badly affected the crop growth and seed filling.

Table 1: Effect of Biophos on plant population, plant height and no. of branches plant^{-1} of castor (*kharif* 2011, 2012 and 2013)

Treatments	Plant population (ha^{-1})				Plant height (cm)				No. of branches plant^{-1}			
	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled
T_1	15638	16564	18313	16838	59.3	41.8	58.1	53.1	2.3	2.6	2.8	2.6
T_2	16667	16872	18004	17181	84.0	49.5	59.1	64.2	2.9	3.3	3.2	3.1
T_3	16049	17284	18209	17181	77.0	43.0	61.0	60.3	3.1	3.9	3.1	3.4
T_4	15844	16255	17695	16598	77.0	45.8	53.9	58.9	4.1	4.7	3.8	4.2
T_5	16461	16461	18004	16975	87.7	40.7	50.3	59.6	3.2	3.6	2.9	3.2
T_6	16255	16975	17489	16907	74.7	47.6	54.4	58.9	3.2	3.5	2.7	3.1
T_7	17181	17284	18004	17490	80.7	42.5	46.9	56.7	2.9	3.2	3.0	3.0
T_8	16667	17387	17798	17284	66.7	45.5	56.1	56.1	2.9	3.0	3.9	3.2
SEm±	319	353	436	209	6.8	2.5	4.9	3.2	0.3	0.4	0.5	0.2
CD (p=0.05)	NS	NS	NS	NS	20.5	NS	NS	NS	0.9	NS	NS	0.7

T_1: Control (No phosphorus and no biophos), T_2: Seed treatment with biophos @ 30 g inoculant per 50 g seed, T_3: 20 kg P_2O_5 ha^{-1}, T_4: 20 kg P_2O_5 ha^{-1}+T_2, T_5: 40 kg P_2O_5 ha^{-1}, T_6: 40 kg P_2O_5 ha^{-1}+T_2, T_7: 60 kg P_2O_5 ha^{-1} and T_8: 60 kg P_2O_5 ha^{-1}+T_2

Table 2: Effect of biophos on no. of nodes plant^{-1}, total spike and effective spike plant^{-1} of castor (*kharif* 2011, 2012 and 2013)

Treatments	No. of nodes plant^{-1}				Total spike plant^{-1}				Effective spike plant^{-1}			
	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled
T_1	10.1	12.0	11.7	11.3	2.9	3.7	3.5	3.4	1.5	3.2	2.2	2.3
T_2	11.4	12.1	11.3	11.6	3.3	4.8	3.9	4.0	2.0	4.2	2.3	2.8
T_3	11.3	11.9	11.4	11.5	3.9	5.3	3.8	4.3	2.9	4.7	2.5	3.4
T_4	11.1	11.6	12.3	11.7	4.2	6.5	3.9	4.9	3.1	5.8	2.9	3.9
T_5	10.6	10.7	12.4	11.2	4.5	6.7	3.9	5.0	4.3	5.8	2.6	4.2
T_6	11.3	12.3	11.1	11.6	4.8	5.0	4.0	4.6	4.3	4.4	2.5	3.7
T_7	11.0	11.2	11.1	11.1	4.6	4.3	3.7	4.2	4.1	3.5	2.4	3.4
T_8	10.9	11.9	11.9	11.6	4.2	4.8	3.8	4.3	3.6	3.9	2.8	3.4
SEm±	0.4	0.4	0.4	0.2	0.6	0.5	0.5	0.3	0.3	0.4	0.3	0.2
CD (p=0.05)	NS	NS	NS	NS	NS	1.4	NS	0.8	1.0	1.3	NS	NS

T_1: Control (No phosphorus and no biophos), T_2: Seed treatment with biophos @ 30 g inoculant per 50 g seed, T_3: 20 kg P_2O_5 ha^{-1}, T_4: 20 kg P_2O_5 ha^{-1}+T_2, T_5: 40 kg P_2O_5 ha^{-1}, T_6: 40 kg P_2O_5 ha^{-1}+T_2, T_7: 60 kg P_2O_5 ha^{-1} and T_8: 60 kg P_2O_5 ha^{-1}+T_2

On the otherhand, the yield was higher during second year due to receipt of normal rainfall which has created congenial atmosphere for better crop performance. Conversely, during third year, the rainfall was excess by 48.8% which promoted good crop growth. However, the yields were not higher as expected due to incidence of *Botryotinia gray* rot following high rainfall during Septermber (208 mm) and October months (378 mm) coupled with high relative humidity (85% AM and 63% PM), which coincided with primary and secondary spike development stage.

The seed yield of castor was significantly influenced by different treatments during 2012-13 and also on pooled data basis. During 2012-13, though application of 40 kg P_2O_5 ha^{-1} resulted in significantly higher seed yield (1687 kg ha^{1}) than other treatments barring highest P dose (60 kg P_2O_5 ha^{-1}) and no P applied (Table 3). Further, the highest seed yield of castor was registered with lowest P dose (20 kg P_2O_5 ha^{-1}+biophos) in the deficit rainfall year (2011-12), medium P dose (40 kg P_2O_5 ha^{-1} and 40 kg P_2O_5 ha^{-1}+biophos) in the normal and excess rainfall years (2012-13 and 2013-14). It means, response of castor to P was in tune with the rainfall. However, the three years pooled results revealed that significantly higher seed yield (1439 kg ha^{-1}) of castor was obtained when the crop received 20 kg P_2O_5 ha^{-1} as basal coupled with seed treatment with biophos (Table 3). This was mainly owing to relatively greater growth and yield parameters. However, it was statistically similar with that of 40 kg P_2O_5 ha^{-1} + biophos (1421 kg ha^{-1}), 40 kg P_2O_5 ha^{-1} (1416 kg ha^{-1}), 20 kg P_2O_5 ha^{-1} (1373 kg ha^{-1}) and 60 kg P_2O_5 ha^{-1}+biophos (1279 kg ha^{-1}), but, it has significantly outyielded 60 kg P_2O_5 ha^{-1} (1254 kg ha^{-1}) and control (1098 kg ha^{-1}).

The efficiency of 'seed treatment with biophos' was found better at 20 or 40 kg P_2O_5 ha^{-1} than at 60 kg P_2O_5 ha^{-1}. The yield improvement due to biophos seed treatment declined progressively from 4.81% to 0.035% to 0.02% at a given P level from lower P to higher P chemical fertilizer dose applied. Irresepctive of the year of study, the seed yield linearly increased from control to 40 kg P_2O_5 ha^{-1} beyond which it declined whether biophos was used or not. It means, effectiveness of biophos was high at low to medium level of P and less in the presence of sufficienct or excess amount of P in soil. Further, pooled data indicated that yield improvement was high in the deficit rainfall year i.e. 2011-12 (24.2%) than that of normal year 2012-13 (18.4%) and excess rainfall year 2013-14 (13.3%) due to seed treatment with biophos alone over no P application (control). Thus, seed treatment with biophos demonstrated the it's positive effects on improvement in castor seed. It might be due to release of fixed P following exudation of P solubilizing enzymes and subsequent improvement in mobilization of dissolved P thus accessibility to the plants. This inturn might have enhanced the P availability and balanced nutrition to the plants (Ponmurugan and Gopi, 2006; Tarafdar and Gharu, 2006, Padmavathi et al., 2015; Singh et al., 2017). Further, Kumawat et al., (2013) reported better plant growth and yield due to increased P availability following combined integrated use of P fertilizer and biophos. Furthermore, solubilization might have imporved the availability of nutrients over a longer period during crop growth period. This might have accelerated the crop growth and photosynthetic activity, enhancement in no. of flowers and their fertilization resulting in higher number of capsules plant^{-1}, better seed formation and finally seed yield (Rathore et al., 2016; Fei et al., 2019). This phenomenon is very important for better performance of this long duration oil plant.

Phosphorus use efficiency (PUE) is the ratio of seed yield obtained to kg P_2O_5 applied per ha. It was higher (71.95 kg

Table 3: Effect of Biophos on total spike length, effective spike length, 100 seed weight and seed yield of castor (*kharif* 2011, 2012 and 2013)

Treatments	Total spike length (cm)				Eff. Spike length (cm)			
	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled
T_1	43.3	45.3	40.1	42.9	29.0	40.6	34.3	34.6
T_2	49.7	51.7	42.3	47.9	41.7	48.3	36.6	42.2
T_3	58.0	58.7	43.9	53.5	50.7	53.3	38.7	47.6
T_4	57.7	59.0	44.5	53.7	56.0	57.0	39.3	50.8
T_5	67.7	69.7	40.9	59.4	61.7	67.0	35.3	54.6
T_6	71.3	61.3	42.3	58.3	62.7	53.7	36.1	50.8
T_7	61.0	50.8	40.2	50.7	52.3	48.0	33.9	44.7
T_8	59.0	53.5	37.7	50.1	57.7	51.0	34.8	48.3
SEm±	2.8	3.4	3.3	2.2	3.4	2.4	3.3	2.0
CD (p=0.05)	8.4	10.3	NS	NS	10.2	7.4	NS	5.6

Table 3: Continue...

Treatments	100 seed weight (g)				Seed yield (kg ha^{-1})				PUE* (kg kg^{-1})
	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled	
T_1	29.3	27.3	29.3	28.7	714	1350	1230	1098	-
T_2	28.7	28.7	29.7	29.0	887	1598	1393	1373	-
T_3	29.0	28.3	29.0	28.8	926	1650	1543	1439	68.66
T_4	28.8	29.3	29.3	29.2	1011	1681	1625	1416	71.95
T_5	28.9	27.7	29.0	28.5	1003	1687	1559	1421	35.41
T_6	28.8	28.7	29.7	29.0	945	1625	1693	1254	35.53
T_7	28.7	28.8	29.3	28.9	839	1500	1424	1279	20.90
T_8	28.9	28.7	29.3	29.0	878	1530	1428	1293	21.31
SEm±	0.5	0.5	0.8	0.3	65.3	61	118	53	-
CD (p=0.05)	NS	NS	NS	0.9	NS	184	NS	160	-

*Phosphorus use efficiency (kg seed kg^{-1} P_2O_5 applied) based on pooled data; T_1: Control (No phosphorus and no biophos), T_2: Seed treatment with biophos @ 30 g inoculant per 50 g seed, T_3: 20 kg P_2O_5 ha^{-1}, T_4: 20 kg P_2O_5 ha^{-1}+T_2, T_5: 40 kg P_2O_5 ha^{-1}, T_6: 40 kg P_2O_5 ha^{-1}+T_2, T_7: 60 kg P_2O_5 ha^{-1} and T_8: 60 kg P_2O_5 ha^{-1}+T_2

kg^{-1}) due to supply of 20 kg P_2O_5 ha^{-1} as basal besides seed treatment with biophos. A close glance on the treatments tested revealed supplementation of P chemical fertilizer with biohphos seed treatment recorded higher PUE than chemical P fertilizer alone, irrespective of the phosphorus dose adopted. In general, the PUE declined steadily due to increase in phosphours dose from 20 to 40 to 60 kg P_2O_5 ha^{-1} (Table 3).

3.3. Changes in economic returns due to P application

The information on cost of cultivation, income and benefit-cost ratios are the best and ultimate indicators of the economic feasibility and viability of any technology in Agriculture. The economic returns followed the trend set by seed yield of castor. The economic analysis of pooled data of three years (Table 4) revealed that, application of 20 kg P_2O_5 ha^{-1}+seed treatment with biophos to rainfed castor resulted in accruing of higher amount of gross returns (INR 46,555 ha^{-1}), net returns (INR 26,071 ha^{-1}) and B:C ratio (2.26). It was was closely followed by application of 40 kg P_2O_5 ha^{-1}+biophos (INR 46,088 ha^{-1}; INR 25,302 ha^{-1}; 2.20). Further, seed treatment with biophos alone could enhance the net returns by 37.1% over control. Furthermore, the improvement in net returns was 8.93% due to integrated application of 20 kg P_2O_5 ha^{-1} and seed treatment with biophos over 20 kg P_2O_5 ha^{-1} alone. The performance of castor crop was poor interms of economic returns (INR 35,469 ha^{-1}, INR 15,969 ha^{-1}; 1.80), when received neither phosphorus chemical fertilizer nor biophos seed treatment. This was mainly due to it's inferior performance in terms of yield. The results clearly demonstrated superiority of P application alone or biophos seed treatment alone or combination of both over control treatment (Table 4). Earlier, Vaghasia et al. (2017) reported higher net returns and B:C ratio due to application

Table 4: Effect of biophos application on economics of castor (*kharif* 2011, 2012 and 2013)

Treatments	Gross returns (INR ha^{-1})				Net returns (INR ha^{-1})				BC ratio			
	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled	2011-12	2012-13	2013-14	Pooled
T_1	22839	40509	43059	35469	4839	20509	22559	15969	1.27	2.03	2.10	1.80
T_2	28395	47941	48760	41699	10095	27641	27960	21899	1.55	2.36	2.34	2.09
T_3	29629	49509	54019	44386	10009	28889	32899	23933	1.51	2.40	2.56	2.16
T_4	32352	50441	56871	46555	12702	29791	35721	26071	1.65	2.44	2.69	2.26
T_5	32099	50602	54570	45757	12179	29682	33150	25004	1.61	2.42	2.55	2.19
T_6	30247	48769	59247	46088	10297	27819	37797	25304	1.52	2.33	2.76	2.20
T_7	26852	45003	49825	40560	6632	23783	28105	19506	1.33	2.12	2.29	1.91
T_8	28086	45895	49994	41325	7836	24645	28244	20242	1.39	2.16	2.30	1.95

Market rate: Castor seed: INR 32 kg^{-1} in 2011-12; INR 30 kg^{-1} in 2012-13 and INR 35 kg^{-1} in 2013-14; Biophos: INR 100 kg^{-1}; T_1: Control (No phosphorus and no biophos), T_2: Seed treatment with biophos @ 30 g inoculant per 50 g seed, T_3: 20 kg P_2O_5 ha^{-1}, T_4: 20 kg P_2O_5 ha^{-1}+T_2, T_5: 40 kg P_2O_5 ha^{-1}, T_6: 40 kg P_2O_5 ha^{-1}+T_2, T_7: 60 kg P_2O_5 ha^{-1} and T_8: 60 kg P_2O_5 ha^{-1}+T_2

of 40 kg P_2O_5 ha^{-1} along with seed inoculation with biophos on low P containing clayey soils of Gujarat.

4. Conclusion

The seed treatment with biophos had a synergistic effect at low P fertilizer application (20 kg P_2O_5 ha^{-1}) which inturn resulted in better plant growth, higher yield and monetary returns besides saving 20 kg P_2O_5 ha^{-1} as compared to that of recommended P dose (40 P_2O_5 ha^{-1}). Furthermore, use of simple and low monetary technique of seed treatment with biophos, if implemented, can help save foreign exchange due to import of P based raw material and fertilizer in final form.

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