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Response of Phosphorus on Growth and Yield of Pearl Millet, Microbial Population and System Productivity in Pearl Millet Based Cropping Systems

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Authors' contributions

This work was carried out in collaboration among all authors. Author PR designed the study. Author AS conducted the experiment and collected data and performed the statistical analysis and wrote the first draft of the manuscript. Author SR managed the analyses of the study and corrections in the draft. Author AS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The present study evaluated the use of various phosphorus management practices with and without PSB on pearl millet and its residual effect on succeeding pulse crops like green gram, blackgram and chickpea. It was conducted at agricultural college farm, Bapatla during both *kharif* and *rabi* seasons of 2017-18 and 2018-19. The treatments consisted of T1: No Phosphorus, T2: 50% RDP T3: 75% RDP, T4: 100% RDP, T5: 50% RDP + seed inoculation with PSB, T6 :75% RDP + seed inoculation with PSB, T7 : 100% RDP + seed inoculation with PSB in RBD design with three replications in *kharif* pearl millet crop. The results indicated that, the treatment T_7 (100% RDP + seed inoculation with PSB) recorded significantly the highest growth parameters like LAI, CGR, RGR and NAR at different phenological stages of crop growth period and yield of pearl millet (2996 kg ha^{-1} and 2876 kg ha^{-1} during 2017 and 2018 respectively) and it was at par with T4 (100%

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RDP). Similarly, the total fungi, bacteria and *rhizobium* counts were increased with increase in fertilizer level and PSB treated plots (T_7, T_6 and T_5) when compared to un-inoculated PSB plots (T_4, T_3 and T_2). The highest number of bacteria (46.2 and 49.2 cfu per gram soil), fungi (25.4 and 24.4 cfu per gram soil) and *rhizobium (*33.5 and 34.4cfu per gram soil) was found in the treatment T_7 (100% RDP+ seed inoculation with PSB) during 2017-18 and 2018-19, respectively. Among the different *kharif* residual treatments, the highest pearl millet equivalent yield of *rabi* crops was recorded with residual effect of 100 % RDP + PSB (M_7).

Keywords: System productivity; pearl millet; LAI; CGR; RGR; NAR and microbial population.

1. INTRODUCTION

Among the coarse cereals grown, pearl millet (*Pennisetum glaucum* L.) occupies pivotal position in the arid and semi-arid regions of India. In India, pearl millet is the fifth most important cereal crop grown next to rice, wheat, maize and sorghum. About 58% of pearl millet area is cultivated in Rajasthan, contributing towards 44% of total production. In recent times, it is gaining more interest of farmers, researchers and traders in rainfed areas due to increasing evidence of less seasonal rainfall and water requirement, terminal heat, frequent occurrence of extreme weather events coupled with scanty water resources [1] and also considered more efficient in utilization of soil moisture and has a higher level of heat tolerance than even sorghum or maize crops.

Although the grain is used mainly as a human food crop, it is also used to feed livestock. Additionally, the plant is used for grazing, hay, silage, as building material, and as a source of fuel. Pearl millet forage is highly digestible in the vegetative stage and it is HCN free forage. It is high in oil, protein, and energy, has balanced amino acids (except low in S-containing amino acids). It is high in Ca and Fe, and contains no tannins.

In India, pulses have long been considered as the poor man's diet which is the major source of protein and contributes to increase in soil fertility. Benefits from adopting pulses as a rotational crop, increases the supply of soil nitrogen through nitrogen fixation leads to supplement agronomic benefits to soil microenvironment, quality and yield. Pulses require very less water as compared to other water intensive crops. The productivity of upland/dryland crops is very low because of low, erratic and uncertainty of rainfall besides poor adoption of improved technologies. To bridge this gap, the crop diversification is required for increasing the productivity and profitability per unit area and per unit time. Pearl millet is one of the promising crops which can perform well even under upland areas. In India, growing of pearl millet-wheat and pearl millet-mustard sequence over a long period without any provision for adequate replenishment of nutrients resulted in decline of soil fertility. Hence, to restore the soil fertility, a new cropping systems *i.e.* pearl millet- pulses was tested (blackgram, greengram and chickpea) which have the ability to provide optimum yields under residual moisture, nutrients and above all possess the qualities to fit as sequence crops after millets.

Among major nutrients phosphorus is the most essential nutrient for biological growth and development of crop especially for pulses. It is an important constituent of nucleic acids, proteins, enzymes and phospholipids. It is essential for translocation of photosynthates from source to sink and important component of ATP, ADP, chloroplast and mitochondria.

Phosphorus is extensively distributed in nature in the forms of organic and inorganic bound state which is not readily available to plants. For the growth of plants they only utilize a part of the phosphorus supplemented through fertilizers and the recovery efficiency of phosphorus in crops is generally 10-30% [2]. The concentrations of soluble P in soil are usually very low and the large proportion of P in soil is found in insoluble rocks, minerals and other deposits. In spite of that, these sources constitute the biggest reservoirs of P in soil because under appropriate conditions, they can be solubilized and made available for plants. The insoluble phosphate which is not directly available to plants usually comprises around 95-99 per cent of the total soil phosphorus.In essence, available phosphorus is frequently decreasing nutrient for plant growth in most of Indian soils. Thus, insufficient phosphorus supply is considered as one of the major limiting factor in crop production. For this we need to improve use efficiency and availability of phosphorus through use of biofertilizers in pearl millet -pulse cropping system.

2. MATERIALS AND METHODS

2.1 Experimental Site

The experimental location is situated at a latitude of 15^0 54' N and 80^0 25'E longitude, at an altitude of 5.49 m above the mean sea level and is 7 km away from the Bay of Bengal.

2.2 Weather Conditions Prevailed During *kharif* 2017 and 2018

The weekly mean maximum temperatures ranged from 31.8 to 37.6^{0}C and 30.0 to 37.6°C during 2017 and 2018, respectively. The weekly mean minimum temperatures for the corresponding period ranged from 21.7 to 26.4°C and 22.5 to 26.8°C, respectively while the average weekly maximum and minimum temperatures during the same period were 33.2 and 24.8°C during 2017 and 33.5 and 24.7°C during 2018, respectively. The weekly mean relative humidity ranged from 63.1 to 86.2% during 2017 and 56.5 to 86.0% during 2018, while the average weekly relative humidity was 77.0 and 76.5% during 2017 and 2018, respectively. A total rainfall of 660.9 and 363.2 mm was received during 2017 and 2018 in 25 and 22 rainy days, respectively. Overall, the weather conditions prevailed during crop period was favorable to growth and development in both the seasons.

2.3 Weather Conditions Prevailed During *rabi* 2017-18 and 2018-19

The weekly mean maximum temperatures ranged from 29.9 to 31.7°C and 29.0 to 31.5°C during *rabi* season of 2017-18 and 2018-19, respectively. The mean minimum temperatures for the corresponding periods ranged from 14.2 to 22.9°C and 14.6 to 22.0°C, respectively. The weekly average maximum and minimum temperatures during the corresponding year were 30.6°C and 18.4°C. The weekly mean relative humidity ranged from 64.3 to 81.4% and 72.9 to 81.4% during *rabi* seasons of 2017-18 and 2018-19, respectively. A event of 30.8 mm rainfall was received in a single rainy day during *rabi*2017-18 while a rainfall event of 67.9 mm was received in four rainy days during *rabi* 2018-19.

2.4 Experimental Details

The experiment was conducted during *kharif* and *rabi* seasons of 2017-18 and 2018-19. In *kharif* the experiment was conducted in RBD with three replications consisted seven phosphorus management practices viz., T1: No P, T2: 50% RDP, T3: 75% RDP, T4: 100% RDP, T5: 50% RDP + seed inoculation with Phosphate Solubilzing Biofertilizer, T6: 75% RDP + seed inoculation with phosphate Solubilzing Biofertilizer, T7: 100% RDP + seed inoculation with Phosphate Solubilzing Biofertilizer. PSB inoculated seeds of pearlmillet hybrid (Rana) were sown in lines by manually @ two seeds per hill with a spacing of 45 cm x 15 cm during 2017 and 2018, respectively. While in *rabi*, the experiment was conducted in split plot design. Each of the *kharif* treatmental plot was subdivided into three plots to accommodate three different pulses. Thus, for *rabi* season study, residual phosphorus management practices were considered as main plot treatments and the three crops as sub-plot treatments. The five random plants were selected from each plot, excluding the border row, for recording biometric observations of kharif pearlmillet and rabi pulses.

The following formulae were used to calculate the growth parameters like LAI, RGR, CGR, NAI and System productivity.

2.5 Leaf Area Index (LAI)

Leaf area index is defined as leaf area per unit land area. LAI was derived by dividing the total leaf area with the corresponding ground area occupied by the plant as given by Watson [3],

$$LAI = (\text{Leaf area} / \text{Ground area})$$

2.6 Relative Growth Rate (g/g/day)

The dry matter produced in any time interval are added to the capital for the growth in subsequent period. The rate of increment is called as relative growth rate (RGR) as suggested by Blackman [4] pointed and was calculated by formula as given below and expressed in g $g^{-1}day^{-1}$.

$$RGR = (\text{Log}_e W_2 - \log_e W_1) / (t_2 - t_1)$$

Where,

W_1 =Initial dry weight of plant
W_2 = Final dry weight of plant
t_1 = Initial time period
t_2 = Final time period

2.7 Crop Growth Rate ($gm^{-2}day^{-1}$)

The CGR is the rate of dry matter produced per unit ground area in a unit time interval. It determines production efficiency of a crop. The CGR was calculated as suggested by Watson [3].

$$CGR = ((W_2 - W_1) / (t_2 - t_1)) \times (1/P)$$

Where,

W_1 and W_2 are total dry weight of plant at times t_1 and t_2 and P is the land area.

2.8 Net Assimilation Rate ($gm^{-2}day^{-1}$)

The NAR is the measure of quantity of photosynthates accumulated per unit leaf area per unit time interval. It gives the net photosynthesis produced in the crop. It is the rate of increase in dry matter per unit leaf area per unit time. It was calculated by using formula given by Gregory [5].

$$NAR = ((\log_e A_2 - \log_e A_1) / (A_2 - A_1)) \times ((W_2 - W_1) / (t_2 - t_1))$$

Where,

W_1 : Total dry weight of plant at time t_1
W_2 : Total dry weight of plant at time t_2
A_1 : Leaf area at time t_1
A_2 : Leaf area at t_2
$t_2 - t_1$: Time interval (days)

2.9 Chlorophyll Content (SPAD Chlorophyll Meter)

SPAD values per plant indicate the leaf colour and chlorophyll intensity. It was recorded on five randomly selected tagged plants on third fully expanded leaf from top. In each plant, five readings were recorded from single leaf and were averaged across each plot and expressed as SPAD values per plant.

2.10 Soil Microbial Properties

The enumeration of total bacteria, fungi and *Rhizobium* in the soil samples collected from the experimental plots before sowing of pearl millet and after harvest of different pulses, was estimated by following the standard dilution plate count technique by pour plate technique Nutrient agar (NA) for bacteria, Martin's rose bengal with streptomycin sulphate agar (MRBA) for fungi, Yeast Extract Mannitol agar (YEMA) with congo red for *Rhizobium* were used for enumeration. The petri plates were incubated after plating at 30^0C for two to four days and population was counted and expressed as cfu g^{-1} of soil (Chart 1).

2.11 System Productivity

System productivity in terms of pearl millet equivalent yield (PMEY) was calculated by multiplying the economic yield of greengram, blackgram and chickpea with the price per kg of individual crops and divided by price per kg of pearl millet in the local market by making use of the following formula as stated by Munda et al. [6].

System productivity = ((Yield of greengram / blackgram/ chickpea (kg)) X (price kg^{-1} of greengram / blackgram/ chickpea)) / Price of pearl millet kg^{-1}

3. RESULTS AND DISCUSSION

3.1 Leaf Area Index and SPAD Readings

Leaf area index influenced the production of biomass in any crop and its relationship with biological yield and productivity was well

Chart 1.Composition of media used for microbial analysis in soil

Nutrient Agar (NA) media: Ingredients used for making 1 L media	Martin's Rose Bengal Agar Media (MRBA): Ingredients used for making 1 L media	Yeast Extract Mannitol Agar (YEMA) Media: Ingredients used for making 1 L media
Glucose : 5 g NaCl : 5g Beef extract: 3g Peptone: 5g Agar agar: 16g Distilled Water: 1 L	K_2HPO_4 : 1.25g KH_2PO_4 : 1.25g $MgSO_4.7H_2O$: 1.25g Dextrose: 25g Peptone: 12.5g Yeast extract: 1.25g Rose Bengal: 25µg Streptomycin: 3µg Agar agar: 16g Distilled Water : 1 L	K_2HPO_4 : 0.625g K_2SO_4 : 0.25g NaCl : 0.125g Mannitol : 12.5g Yeast extract: 1.25g Congo red : 1% Solution (3.25ml) Agar agar: 16g Distilled Water : 1 L

established in cereals (Welbank et al., 1966) [7]. In general, with advancement of crop age, the leaf area index was increased up to 55 DAS and thereafter declined till harvest in all the treatments. It is due to senescence of leaves at harvest. Leaf area index is used to predict photosynthetic production as a reference tool for crop growth.

From perusal data of Table 1, the LAI was significantly influenced by different treatments over control. The highest LAI (At 30 DAS 2.13 and 2.24, at 60 DAS 2.97 and 2.83 and at harvest 1.64 and 1.58 during 2017 and 2018, respectively) was recorded in the treatment T_7 (100 % RDP + seed inoculation with PSB) and T4 (100 % RDP) which were found to be statistically at par with remaining treatments during both the years of study. The highest LAI recorded Leaf area index (LAI) is the main physiological determinant of the crop yield. The high LAI at 60 DAS might be due to more light interception, enhanced photosynthetic rate (NAR), more leaf numbers production, leaf length and breadth.These results are supported with findings of Pallavi et al. [8].

SPAD meter readings means availability of nitrogen content in the leaf during crop growth period. The data on SPAD values are presented in Table 1 which revealed that SPAD values of pearl millet were not significantly differed with different phosphorus treatments imposed to pearl millet.

3.2 Crop Growth Rate (CGR), Relative Growth Rate (RGR) and Net Assimilation Rate (NAR)

Table 2 represents the data of CGR, RGR and NAR values of pearl millet during experimentation.Crop growth rate is a function of light interception by the green leaf area of crop which was used to determine the crop production. The leaf photosynthetic rate and leaf area index appeared to be major determinants of crop growth rate. From the two years of study it was revealed that amongst the different treatments, higher crop growth rate was recorded with T_7 (100 % RDP + seed inoculation with PSB) treatment during 2017 i.e. at 30 DAS to 60 DAS (9.87 g m^{-2} d^{-1})and at 60 DAS to harvest (7.73 g m^{-2} d^{-1}) while in 2018 the recorded highest CGR values at 30 DAS to 60 DAS (9.4 g m^{-2} d^{-1}) and at 60 DAS to harvest (7.66 g m^{-2} d^{-1}) closely followed by T_4 (100 % RDP).Like wise, the RGR indicated higher magnitudes at very early stage of growth *i.e*. 60 DAS followed by a reduction in later growth period. It might be due to the higher LAI in the early growth period and reduction of LAI in the later phase of growth. Significantly higher relative crop growth rate was recorded with T_7 (100 % RDP + seed inoculation with PSB) treatment during 2017 i.e. at 30 DAS to 60 DAS (0.097 g g^{-1} d^{-1}) and at 60 DAS to harvest (0.089 g g^{-1} d^{-1}) and in 2018 the recorded highest RGR values at 30 DAS to 60 DAS (0.099 g g^{-1} d^{-1}) and at 60 DAS to harvest (0.091 g g^{-1} d^{-1}) closely followed by T_4 (100 % RDP). The lowest growth rate was recorded in T_1 (no phosphorus) during both the years of experimentation and pooled data.

The crop growth rate can be analyzed as the product of incident light receipt efficiency of light penetration and efficiency of use of intercepted light in dry matter production [9]. Generally, it interacts with light and higher LAI values [10].

The maximum effect might be due to higher accumulation of photosynthates in various sinks which resulted in higher rate of crop growth rate and more availability of nutrients due to PSB which solubilize unavailable phosphorus and thus increase the availability of P. The increased available P resulted in higher growth rate was obtained

A Perusal of the data (Table 2) on Net assimilation rate (NAR) indicated that there were significant differences in different treatments and similar trend was also followed as like other growth parameters. This might be due to high level of nutrients have facilitated better uptake and accumulation of nutrients for better growth of crop which might have helped in increased photosynthesis and NAR. Maximum NAR in general was obtained at 30-60 DAS and there after reduced gradually to reach a minimum level at maturity, which may be due to severe mutual shading and senescence of older leaves with increase in the age or growth advances. The increased demand for assimilates is due to rapid growth of stem and grain filling. Uniform distribution of solar radiation throughout the crop canopy and efficient absorption of nutrients ensure more NAR and RGR, which may lead to higher productivity of crop. These results are in conformity with the findings of Pallavi et al. [8] and Kumar et al. [11].

3.3 GrainYield (kg ha^{-1})

A perusal of data (Table 3) on grain yield of pearl millet revealed that grain yield was significantly influenced by different P treatments. Among the different treatments, the treatment which received 100% RDP (T_4) and 100% RDP + seed inoculation with PSB (T_7) recorded significantly higher grain yield and remained at par with each other *i.e* 2952 kg ha^{-1}, 2996 kg ha^{-1} and 2809 kg ha^{-1}, 2876 kg ha^{-1} during 2017 and 2018 respectively. Relatively lesser grain yields were recorded with the treatments T_2 (50% RDP) and T_5 (50% RDP + seed inoculation with PSB) during both the years of study. The lowest grain yield (1619 kg ha^{-1} and 1482 kg ha^{-1}) was registered with the treatment T_1 (no phosphorus) during 2017 and 2018, respectively.

The improvement in grain yield might be due to increased yield attributing parameters of pearlmillet *viz*., number of effective tillers, ear head size and test weight. Phosphorus is one of the major essential nutrients which is needed in adequate amounts in the available form and plays vital functions for many characteristics of growth and production of plants. It is also involved in better root growth, enhanced nutrient uptake and translocation of photosynthates from source to sink, which might have aided in production of growth promoting substances. Further, these are translocated to sink due to better development of source-sink relations. Phosphate solubilizing microorganisms also produce fungistatic and growth promoting substances, these reactions takes place in the rhizosphere and because of micro organisms render more phosphorus into soil solution than required for their own growth and metabolisms, the surplus is available for plant to be absorbed which might have influenced plant growth which in turn, might have helped in ultimately higher growth attributes and yield. The beneficial effect of phosphorus on microorganisms in India was also reported by Gaur et al*.,* [12] on maize, wheat, berseem, pigeonpea, chickpea, potato, soybean, lentil, pea, urd and rice. Singh and Agrawal [13], Vyas et al. [14] and Yakadari et al. [15] also reported in the same line.

3.4 Biological Properties (Cfu Per Gram of Soil) After Harvest of Pearl Millet (Bacteria X 10^{-6}, Fungi X 10^{-3} and *Rhizobium* X10^{-4})

Microbial population was influenced significantly due to different P treatments imposed to pearl millet. The data (Table 3) indicated increase in the population of bacteria, fungi and *rhizobium* after harvest of pearl millet when compared to initial population *i.e* before sowing of pearl millet.

The total fungi, bacteria and *rhizobium* counts were increased with increase in P fertilizer level and increased in PSB treated plots (T_7, T_6 and T_5) when compared to un-inoculated PSB plots (T_4, T_3 and T_2). The highest number of bacteria, fungi and *rhizobium* (cfu per gram soil) was found in the treatment T_7 (100% RDP+ seed inoculation with PSB) followed by T_6 (75% RDP + seed inoculation with PSB) and T_5 (50% RDP + seed inoculation with PSB). Less number of bacteria, fungi and *rhizobium* (cfu per gram soil) was found in inorganic fertilizer treatment plots alone (un-inocualtion PSB). However, in the inorganic fertilizer treated plots also there was increase in order of bacteria, fungi and *rhizobium* (cfu per gram soil) T_2 (50% RDP), T_3 (75% RDP) and T_4 (100% RDP). The lowest number of bacteria (cfu per gram soil) was recorded in the control plot (T_1) during both the years of experimentation.

The bacteriarange was *i.e* lowest to highest from 28.6 cfu per gram of soil (X 10^{-6}) to 46.2 cfu per gram of soil (X 10^{-6}) and 26.6 cfu per gram of soil (X 10^{-6}) to 49.7 cfu per gram of soil (X 10^{-6}) during both the years, respectively. Similarly, the fungi ranged *i.e* lowest to highest from 9.2 cfu per gram of soil (X 10^{-3}) to 25.4 cfu per gram of soil (X 10^{-3}) and 10.7 cfu per gram of soil (X 10^{-3}) to 24.4 cfu per gram of soil (X 10^{-3}) and *rhizobium* was from 15.2 cfu per gram of soil (X 10^{-3}) to 33.5 cfu per gram of soil (X 10^{-3}) and 14.3 cfu per gram of soil (X 10^{-3}) to 34.4 cfu per gram of soil (X 10^{-3}) during first year and second year of study, respectively. Higher level of nutrients combined with PSB in soil for plant use resulting to the release of more exudates. This might be due to secretion of phytochemicals and proteins from roots, which is an important way for plants to respond to and alter their environment, thus helping in enhancing production by favouring association with beneficial soil microbes. Root exudation is positively correlated with root growth; it means that actively growing root systems secrete more exudates. Root exudates mediate positive interactions which include symbiotic associations with beneficial microbes, such as mycorrhizae, *rhizobia* and plant growth-promoting rhizobacteria (PGPR). The release of these various compounds provides the primary sources of C for microorganisms in soil which might have helped in increasing in microbial population in the soil.Similar results were also reported by Badri and Vivanco [16] and Richard et al. [17].

Table 1. Leaf area index and SPAD chlorophyll meter values of *kharif* pearl millet as influenced by phosphorus treatments

Treatment	*Kharif* 2017						*Kharif* 2018					
	LAI			SPAD values			LAI			SPAD values		
	At 30 DAS	At 60 DAS	At Harvest	At 30 DAS	At 60 DAS	At Harvest	At 30 DAS	At 60 DAS	At Harvest	At 30 DAS	At 60 DAS	At Harvest
T_1- No P (control)	1.34	2.22	1.11	37.1	41.3	30.2	1.49	2.26	1.21	36.6	41.8	30.6
T_2- 50 % RDP	1.55	2.38	1.36	38.2	43.5	30.7	1.62	2.29	1.32	39.5	42.7	31.4
T_3- 75 % RDP	1.82	2.64	1.43	39.8	43.7	32.6	1.78	2.58	1.45	40.3	44.2	33.2
T_4-100 % RDP	2.12	2.98	1.61	41.2	45.9	34.4	2.21	2.84	1.57	40.7	45.2	34.3
T_5- 50 % RDP+PSB	1.63	2.51	1.40	38.8	42.8	31.5	1.70	2.44	1.37	39.9	43.2	32.6
T_6- 75 % RDP+PSB	1.91	2.79	1.55	40.7	44.1	33.4	1.86	2.71	1.46	41.2	44.1	34.0
T_7- 100 % RDP+PSB	2.13	2.97	1.64	42.4	46.5	34.5	2.24	2.83	1.58	41.6	45.1	35.4
SEm±	0.121	0.139	0.077	1.08	1.10	1.04	0.135	0.125	0.078	1.24	1.40	1.12
CD (p =0.05)	0.37	0.43	0.24	NS	NS	NS	0.42	0.39	NS	NS	NS	NS
CV (%)	11.8	9.1	9.3	5.0	6.1	5.6	12.7	8.4	9.5	6.0	5.5	5.9

Table 2. Crop growth rate (g m^{-2} d^{-1}), Relative growth rate (g $^{-1}$ $g^{-1}day^{-1}$) and Net assimilation rate (g dm^{-2} d^{-1}) of *kharif* pearl millet as influenced by phosphorus treatments

Treatment	*Kharif* 2017						*Kharif* 2018					
	CGR		RGR		NAR		CGR		RGR		NAR	
	30- 60 DAS	60 - Harvest	30- 60 DAS	60 - Harvest	30- 60 DAS	60 - Harvest	30- 60 DAS	60 - Harvest	30- 60 DAS	60 - Harvest	30- 60 DAS	60 - Harvest
T_1- No P	6.89	4.03	0.062	0.058	0.043	0.031	5.94	3.82	0.065	0.061	0.041	0.031
T_2- 50 % RDP	7.25	4.84	0.068	0.064	0.045	0.035	6.10	4.07	0.072	0.067	0.040	0.034
T_3- 75 % RDP	8.17	6.16	0.083	0.077	0.050	0.041	7.59	5.55	0.080	0.073	0.046	0.040
T_4-100 % RDP	9.76	7.47	0.096	0.087	0.061	0.056	9.18	7.81	0.094	0.089	0.057	0.055
T_5- 50% RDP+PSB	7.97	5.66	0.080	0.071	0.049	0.036	7.02	4.62	0.073	0.064	0.048	0.035
T_6- 75% RDP+PSB	8.72	6.41	0.093	0.079	0.053	0.044	8.11	6.09	0.091	0.076	0.051	0.047
T_7- 100% RDP+PSB	9.87	7.73	0.097	0.089	0.064	0.058	9.40	7.66	0.099	0.091	0.063	0.060
SEm±	0.32	0.35	0.003	0.003	0.002	0.003	0.33	0.32	0.002	0.002	0.004	0.003
CD (p =0.05)	1.01	1.08	0.009	0.011	0.008	0.010	1.04	1.00	0.007	0.008	0.014	0.010

Table 3. Grain yield of pearl millet (kg ha^{-1}) and microbial counts after harvest of pearl millet in soil as influenced by phosphorus treatments

Treatment	2017	2018	2017			2018		
	Grain Yield	Grain Yield	Bacteria (10 $^{-6}$)	Fungi (10^{-3})	*Rhizobium* (10^{-4})	Bacteria (10 $^{-6}$)	Fungi (10^{-3})	*Rhizobium* (10^{-4})
T_1- No P (control)	1619	1482	28.6	9.2	15.2	26.6	10.7	14.3
T_2- 50 % RDP	1958	1818	30.9	11.4	18.4	32.2	10.3	19.0
T_3- 75 % RDP	2514	2460	32.2	13.6	18.7	30.1	15.5	17.3
T_4-100 % RDP	2952	2809	37.6	15.9	21.2	35.0	18.4	25.0
T_5- 50 % RDP+PSB	2173	1931	39.4	18.5	26.8	42.8	17.0	25.6
T_6- 75 % RDP+PSB	2602	2537	43.6	22.7	30.4	40.8	20.2	27.6
T_7- 100 % RDP+PSB	2996	2876	46.2	25.4	33.5	49.7	24.4	34.4
SEm±	124.1	127.0	--	--	--	--	--	--
CD (P =0.05)	382	391	--	--	--	--	--	--

Table 4. System productivity in terms of pearl millet equivalent yield (kg ha^{-1}) of the cropping systems as influenced by phosphorus management practices to pearl millet and its residual effect on *rabi* pulses

Treatments imposed to *kharif* pearl millet	2017-18				2018-19			
	Cropping systems				Cropping systems			
	Pearl millet-Blackgram	Pearl millet-Greengram	Pearl millet-Chickpea	MEAN	Pearl millet-Blackgram	Pearl millet-Greengram	Pearl millet-Chickpea	MEAN
M_1; No P	1372	1903	2180	1818	1369	1621	1834	1608
M_2; 50% RDP	1724	2356	2594	2225	1643	2047	2222	1971
M_3; 75% RDP	2091	2626	3261	2659	2135	2414	2857	2469
M_4; 100% RDP	2634	3081	3959	3225	2534	3035	3529	3033
M_5;50% RDP+PSB	1947	2598	3071	2538	1858	2216	2599	2225
M_6 ;75% RDP+PSB	2578	3028	3414	3007	2302	2756	3373	2810
M_7; 100% RDP+PSB	3027	3378	4176	3527	2722	3100	3937	3253
Mean	2196	2710	3236		2081	2456	2907	
	SEm±	CD (p =0.05)		CV (%)	SEm±	CD (p =0.05)		CV (%)
Main treatments (M)	119.3	367		13.2	121.6	375		14.7
Sub treatments (S)	85.2	247		14.4	73.2	212		13.5

3.5 System Productivity (Pearl Millet – Equivalent Yield – PMEY)

Pearl millet equivalent yield of different *rabi* pulses was significantly influenced by residual effect of phosphorus management practices imposed to *kharif* pearl millet during both the years of study (Table 4). Among the different *kharif* residual treatments, the highest pearl millet equivalent yield of *rabi* crops was recorded with residual effect of 100 % RDP + PSB (M_7) which inturn remained at par under the treatments which received 100 % RDP (M_4). Next best treatments were M_6 (75 % RDP + PSB) and M_3 (75 % RDP). Relatively lesser pearl millet equivalent grain yields were recorded with the treatmentsM_2 (50 % RDP) and M_5 (50 % RDP + seed inoculation with PSB) during two years of study. The lowest pearl millet equivalent yields of *rabi* crops was recorded with the treatment M_1 (no phosphorus). Similar results were obtained by Choudhary and Gautam [18], Satyajeet et al. [19,20] and Verma et al. [21].The *rabi* pulses varied among themselves incase of pearl millet equivalent yields. The highest PMEY was recorded with chickpea (3236 kg ha^{-1} and 2907 kg ha^{-1}) followed by greengram (2710 kg ha^{-1} and 2456 kg ha^{-1}) and blackgram (2196 kg ha^{-1} and 2081 kg ha^{-1}) during both the years of experimentation.

4. CONCLUSION

On the basis of two years experimentation in pearl millet based cropping systems (greengram, blackgram and chickpea) under various phosphorus management practices (with and without biofertilizer PSB) integration of chemical source of fertilizers and biofertilizers enhanced the growth parameters, yield as well as soil microbial population in the soil. Soil microbial population (bacteria, fungi and *rhizobium*) were increased with increase in fertilizer level and in PSB treated plots when compared to un-inoculated PSB plots. Thus, higher fertility level with combination of PSB increased the total microbial counts. It leads to highest solubilization of available nutrients in the soil which is useful for the raising next season crop and by introduction of pulse crops after pearl millet farmers income may also be increased. In three cropping sequences, pearl millet- chickpea was profitable sequence, followed by pearl millet-greengram with a maximum effect of application of 100% RDP+seed inoculation with PSB.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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