The Pharma Innovation Journal 2021; 10(5): 1548-1557

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277-7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(5): 1548-1557

www.thepharmajournal.com
Received: 18-02-2021
Accepted: 29-03-2021

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Effect of source and levels of phosphorus on nutrient content, uptake, availability, partial factor productivity and economics of no till sorghum (*Sorghum bicolor* (L.)) in rice-sorghum sequence

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Abstract
An experiment was conducted during *kharif* 2016-17 and 2017-18 to determine the impact of phosphorus management *i.e.*, the influence of source and levels of phosphorus on nutrient content, uptake, availability, partial factor productivity and economics of no till sorghum in Agricultural College Farm, Bapatla. Significant improvement in nutrient uptake, availability (NPK), and economics of no till sorghum was observed in green manuring *in situ* with dhaincha along with PSB treatment. Partial factor productivity of no till sorghum was higher with 50% RDP than 100% RDP. Availability of NPK was enhanced with increased rate of P_2O_5 application up to some extent but optimum grain yield, nutrient uptake and availability after harvest of no till sorghum crop was observed with the 50% RDP which was on a par with 100% RDP.

Keywords: Rice, no-till sorghum, phosphorus source, levels of phosphorus, nutrient content, nutrient uptake, nutrient availability, partial factor productivity and economics

Introduction
Phosphorus has become a major constraint to agricultural production in India because of scarce natural deposits, steep hike in price of phosphatic fertilizers due to energy crisis throughout the world and also a major portion of raw materials for phosphatic fertilizers has to be imported from foreign countries. The phosphorus deficiency is common in almost all the soils and crops (Raju *et al*., 2005) [17].
The loss of nutrients from the soil in mainly due to exhaustive cropping systems like rice-maize or rice-oil seeds. Recommended dose of NPK fertilizers alone does not sustain soil productivity under continuous intensive cropping (Kumar *et al.,* 2009) [7], whereas inclusion of organic manures improve soil fertility and crop yields and biological status of soil. Green manure crops like dhaincha (*Sesbania aculeata*) have an advantage and proven ability to enhance the productivity of major cropping systems (Singh and Kumar, 2009) [7].
Rice-pulse sequence was a dominant cropping sequence in Krishna agro-climatic zone of Andhra Pradesh. The area under this sequence has declined due to late planting of rice in consequence of delay in onset of monsoon and severe incidence of yellow mosaic virus on pulse crop (Mishra *et al*., 2013) [11]. In the changed scenario, farmers are now growing sorghum in rice-fallows as an alternative to pulses. No-till has potential to allow saving in time, energy, water and labour in crop establishment that reduces soil disturbance, increases soil organic matter accumulation and can also increase crop yield. Sorghum can withstand harsh climatic situations and it is tolerant to adverse conditions such as drought, low soil fertility and high temperature. The higher production potential of sorghum in rainfed areas might be owing to deeper root-system, better extraction of soil moisture and its efficient utilization, efficient photosynthetic mechanism and rapid translocation of photosynthates from leaves to grain. Sorghum has high nutritional value, with high levels of unsaturated fats, protein, fiber, and minerals like phosphorus, potassium, calcium, and iron. It also has more antioxidants that can able to neutralize and eliminate free radicals in the body, which often cause healthy cells in the body to mutate into cancerous cells.
Incorporation of green manures and use of biofertilizers like phosphorus solubilizing Bacteria (PSB) will increase the bioavailability of native and added phosphorus which improves the phosphorus use efficiency and results in overall plant growth and higher productivity.

Keeping these points in view, this experiment was conducted to study the bioavailability of phosphorus in soil and its accumulation in above ground biomass of sorghum (nutrient uptake and availability) and to evaluate the partial factor productivity in combination with green manuring and phosphorus solubilizing bacteria (PSB) in sorghum crop in rice-sorghum sequence for two years.

Material and Methods

The experimental trial was carried out with three replications in a split-split plot design with 12 treatments in *kharif* and 36 treatments in *rabi*. The main plot includes sources of phosphorus *viz.*, inorganic fertilizer phosphorus through SSP, green manuring *in-situ* with dhaincha @25 kg ha^{-1}, phosphorus solubilizing bacteria biofertilizer @ 750 ml ha^{-1} and green manuring *in-situ* with dhaincha @ 25 kg ha^{-1} + phosphorus solubilizing bacteria biofertilizer @ 750 ml ha^{-1} and levels of phosphorus *viz.*, 50%, 100% and 150% RDP were allotted to sub plots during *kharif* season. The sub plots were again sub divided into three sub-sub plots after rice which includes phosphorus levels *viz.*, control (no phosphorus), 50% and 100% RDP in no-till sorghum during 2016-17. The experiment was repeated in another field during *kharif* and *rabi* seasons of 2017-18. Green manuring crop of dhaincha at 45 DAS was incorporated fifteen days prior to transplanting of rice in the respective treatments, during both the years of study.

Soil samples from 0-30 cm depth were collected at random from the experimental site before layout of the experiment. A composite soil sample was analyzed for physical and physico-chemical properties by following standard methods. The results of soil analysis indicated that the experimental soil was clay loam in texture (Bouyoucos hydrometer method (Piper, 1960) [14], slightly alkaline in reaction (Glass electrode method (Jackson, 1973) [8] and low in organic carbon (Modified Walkley and BlackMethod (Walkley and Black, 1934)) [25], low in available nitrogen (Alkaline permanganate method (Subbiah and Asija, 1956)) [22], medium in available phosphorus (Olsen's method (Olsen *et al.*, 1954)) [12] and high in potassium (Neutral normal ammonium acetate method (Muhr *et al.*, 1963)) [12].

Sorghum cultivar, CSH-16 was used for this experiment. Data regarding plant analysis (N-Microkjeldahl distillation method (Bremner, 1965) [3], P-Vanado molybdo phosphoric yellow colour method (Koeing and Johnson, 1942) [6], K-Flame photometer method, Jackson (1973) [8], nutrient uptake (NPK) and partial factor productivity (PFP) of no till sorghum was determined according to following methods and formulas**.**

Nutrient uptake

From the results of plant analysis, nitrogen, phosphorus and potassium uptake was calculated as indicated below.

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{Nutrient concentration (\%)} \times \text{Weight of dry matter (kg ha}^{-1})}{100}$$

Partial factor productivity

The partial factor productivity (PFP) from applied nutrients is a useful measure of nutrient use efficiency because it provides integrative index that quantifies total economic output related to utilization of all nutrient resources added to the system (Cassmen *et al.*, 1996) [4]. It is the ratio of yield in kg ha^{-1} to applied nutrient in kg ha^{-1} and expressed as,

$$\text{Partial factor productivity (PFP)} = \frac{Y}{Nr}$$

Where, Y is the yield in kg ha^{-1} and Nr is the amount of fertilizer nutrients applied kg ha^{-1}

Due to absence of absolute control for phosphorus, partial factor productivity was included instead of phosphorus use efficiency.

Economics

The gross returns from each treatment were worked out with the prevailing market prices. The net returns from each treatment were calculated by deducting the cost of cultivation from gross returns. Return per rupee invested for all the treatments was also worked out on the basis of net returns and cost of cultivation.

Gross returns = Value of the product (Grain + Straw)

Net returns = Gross returns-Total cost of cultivation

$$\text{Return per rupee invested} = \frac{\text{Net returns}}{\text{Cost of cultivation}}$$

Results and Discussion

Grain yield was significantly influenced by different sources of phosphorus imposed to *kharif* rice crop. The highest grain yield of no till sorghum was recorded due to green manuring + PSB imposed to rice crop during *kharif*, which was statistically at par with the green manuring alone. A significant decrease in grain yield was recorded with the inorganic phosphorus applied through SSP over other P sources (Table 1). The residual and cumulative beneficial effect of green manuring and PSB on yield attributes was finally reflected in the grain yield during first and second years of study on succeeding no till sorghum crop. Phosphate solubilizing bacteria in PSB might have helped in increasing the phosphorus availability. The solubilisation effect of PSB is generally due to the production of organic acids by these organisms. They are also known to produce amino acids, vitamins and growth promoting substances like indole acetic acid, gibberellic acid which helped in better crop growth and ultimately higher yield attributes and yield. Phosphorus availability also directly affects the energy transformation and grain formation.

Table 1: Grain yield (kg ha^{-1}) of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-17, 2017-18 and pooled data

Treatment	2016-17	2017-18	Pooled data
Residual response of source of phosphorus			
M_1-Inorganic P	4723	4915	4819
M_2-GM	5814	6096	5955

M_3-PSB	5316	5437	5377
M_4-GM+PSB	5992	6167	6080
S.Em±	93.6	122.5	100.7
CD (p = 0.05)	324	424	349
CV (%)	8.9	11.3	9.4
Residual response of levels of phosphorus			
S_1-50% RDP	5427	5538	5483
S_2-100% RDP	5475	5710	5593
S_3-150% RDP	5483	5713	5598
S.Em±	65.1	80.1	65.8
CD (p = 0.05)	NS	NS	NS
CV (%)	7.2	8.5	7.1
Levels of phosphorus applied to sorghum			
F_1-0% RDP	4856	5041	4949
F_2-50% RDP	5740	5948	5844
F_3-100% RDP	5788	5972	5880
S.Em±	64.1	75.6	75.6
CD (p = 0.05)	183	215	215
CV (%)	7.1	8.0	8.0
Interaction	NS	NS	NS

Progressive increase in grain yield of succeeding no till sorghum was observed numerically with each successive increment in phosphorus levels given to preceding rice. Application of 150% RDP resulted in higher grain yield of no till sorghum over rest of the phosphorus levels (50% and 100% RDP) in the two successive years of study and in pooled data, as it might have promoted the growth of roots as well as functional activity resulting in higher extraction of nutrients from soil environment to aerial plant parts.

With increase in phosphorus level given to no till sorghum, the grain yield increased significantly over no P application. The highest grain yield was recorded with application of 100% RDP (5788, 5972 and 5880 kg ha^{-1}) which was at par with the 50% RDP (5740, 5948 and 5844 kg ha^{-1}) and found significantly superior to control (4856, 5041 and 4949 kg ha^{-1}) during the years 2016-17, 2017-18 and in pooled data respectively. The percent increase in grain yield due to 100% RDP over 0% and 50% RDP was 16.1% and 0.8% during first year, 15.6% and 0.4% during second year and 15.8% and 0.6% in pooled data respectively. Overall, improvement in growth of no till sorghum was observed with increasing phosphorus levels which could be attributed to the potential role of phosphorus in modifying the soil and plant environment which in turn helped in better morphological growth by improving the metabolic and physiological processes in the plant system. Being a component of ATP, phosphorus is needed for the conversion of light energy to chemical energy (ATP) during photosynthesis. It is also involved in better root growth, enhanced nutrient uptake and translocation of photosynthates from source to sink. (Sumeria *et al*., 2002, Amer and Kewan, 2014, Masebo and Menamo, 2016 and Sareen *et al*., 2017) [20].

Nutrient content and uptake in sorghum

Nitrogen, phosphorus and potassium content in no till sorghum was not significantly influenced by source and levels of phosphorus during both the years of study and in pooled data **(**Table 2, 3, 4).

Table 2: Nitrogen content (%) and uptake (kg ha^{-1}) of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-17, 2017-18 and pooled data

Treatment	2016-17					2017-18					Pooled data				
	Grain		Stover		Total	Grain		Stover		Total	Grain		Stover		Total
	Content	Uptake	Content	Uptake	uptake	Content	Uptake	Content	Uptake	uptake	Content	Uptake	Content	Uptake	uptake
Residual response of source of phosphorus															
M_1-Inorganic P	1.55	73.3	0.73	58.6	131.9	1.57	77.3	0.74	61.0	138.2	1.56	75.3	0.74	59.8	135.0
M_2-GM	1.58	92.0	0.75	72.5	164.5	1.60	97.6	0.75	73.5	171.1	1.59	94.8	0.75	73.0	167.8
M_3-PSB	1.57	83.6	0.74	65.5	149.0	1.58	86.0	0.75	67.3	153.3	1.58	84.8	0.74	66.4	151.2
M_4-GM+PSB	1.59	95.5	0.75	73.6	169.1	1.60	98.9	0.76	75.5	174.4	1.60	97.2	0.76	74.6	171.7
S.Em±	0.01	1.25	0.01	1.05	1.08	0.01	1.89	0.01	1.06	2.23	0.01	1.45	0.01	1.06	1.61
CD (p = 0.05)	NS	4.3	NS	3.6	3.8	NS	6.5	NS	3.7	7.7	NS	5.0	NS	3.6	5.6
CV (%)	3.0	7.6	3.7	8.1	3.7	2.9	10.9	3.6	7.9	7.3	2.8	8.5	3.6	8.1	5.5
Residual response of levels of phosphorus															
S_1-50% RDP	1.58	85.7	0.74	66.4	152.1	1.58	88.2	0.75	67.8	156.0	1.58	86.9	0.74	67.1	154.1
S_2-100% RDP	1.57	86.0	0.75	68.2	154.2	1.58	90.5	0.75	69.6	160.1	1.58	88.2	0.75	68.9	157.1
S_3-150% RDP	1.58	86.6	0.75	68.0	154.6	1.59	91.1	0.76	70.5	161.6	1.58	88.9	0.75	69.2	158.0
S.Em±	0.01	1.32	0.01	1.04	1.50	0.01	1.36	0.01	1.05	1.85	0.01	1.22	0.01	1.06	1.59
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.7	9.2	3.3	9.3	5.9	4.1	9.1	3.3	9.1	6.9	4.3	8.3	3.3	9.2	6.1
Levels of phosphorus applied to sorghum															
F_1-0% RDP	1.56	75.9	0.73	60.1	136.6	1.58	79.6	0.73	62.7	142.4	1.57	77.7	0.73	61.7	139.5
F_2-50% RDP	1.57	90.4	0.75	70.7	161.1	1.59	94.5	0.76	72.2	166.7	1.58	92.5	0.76	71.4	163.9
F_3-100% RDP	1.58	91.8	0.75	71.2	163.0	1.60	95.6	0.76	72.9	168.5	1.59	93.7	0.75	72.1	165.7
S.Em±	0.01	1.11	0.01	1.01	1.43	0.01	1.30	0.01	1.03	1.51	0.01	1.11	0.01	1.02	1.38

CD (p = 0.05)	NS	3.2	NS	2.9	4.1	NS	3.7	NS	2.9	4.3	NS	3.2	NS	2.9	3.9
CV (%)	4.6	7.8	7.4	9.1	5.6	4.5	8.7	7.3	8.9	5.7	4.5	7.6	7.3	8.9	5.3
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 3: Phosphorus content (%) and uptake (kg ha^{-1}) of sorghum in rice-sorghum sequence as influenced by phosphorus management during *rabi* 2016-17, 2017-18 and pooled data

Treatment	2016-17					2017-18					Pooled data				
	Grain		Stover		Total uptake	Grain		Stover		Total uptake	Grain		Stover		Total uptake
	Content	Uptake	Content	Uptake		Content	Uptake	Content	Uptake		Content	Uptake	Content	Uptake	
Residual response of source of phosphorus															
M_1-Inorganic P	0.47	22.2	0.16	13.5	35.8	0.48	23.4	0.17	14.1	37.4	0.47	22.8	0.16	13.8	36.6
M_2-GM	0.50	29.2	0.17	16.5	45.6	0.52	31.4	0.18	16.9	48.3	0.51	30.3	0.17	16.7	46.9
M_3-PSB	0.49	26.1	0.16	15.0	41.1	0.50	27.0	0.17	15.4	42.4	0.49	26.6	0.16	15.2	41.7
M_4-GM+PSB	0.53	31.7	0.17	16.7	48.4	0.52	32.3	0.18	17.2	49.5	0.53	32.0	0.17	17.0	48.9
S.Em±	0.01	0.42	0.01	0.13	0.46	0.01	0.77	0.01	0.12	0.81	0.01	0.58	0.01	0.11	0.63
CD (p = 0.05)	NS	1.5	NS	0.5	1.6	NS	2.6	NS	0.4	2.8	NS	2.0	NS	0.4	2.2
CV (%)	11.5	8.0	2.9	4.6	5.7	10.4	14.1	3.0	4.0	9.5	11.4	10.8	2.0	3.7	7.5
Residual response of levels of phosphorus															
S_1-50% RDP	0.49	26.6	0.16	15.3	41.2	0.49	27.6	0.17	15.6	43.2	0.49	27.3	0.17	15.4	42.5
S_2-100% RDP	0.49	26.8	0.17	15.4	42.2	0.49	28.5	0.17	15.9	44.4	0.50	27.9	0.17	15.6	43.3
S_3-150% RDP	0.50	27.4	0.17	15.6	43.0	0.51	29.4	0.18	16.2	45.5	0.50	28.5	0.18	15.9	43.7
S.Em±	0.01	0.73	0.01	0.20	0.77	0.01	0.73	0.01	0.28	0.88	0.01	0.71	0.01	0.23	0.80
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	14.1	16.0	4.0	7.9	10.8	13.9	15.5	4.6	10.9	11.9	14.0	15.3	3.0	9.0	11.1
Levels of phosphorus applied to sorghum															
F_1-0% RDP	0.49	23.8	0.17	14.1	37.9	0.49	29.4	0.17	14.6	39.6	0.49	24.4	0.17	14.4	38.8
F_2-50% RDP	0.50	28.6	0.17	15.9	44.6	0.50	29.9	0.18	16.3	46.3	0.50	29.3	0.18	16.1	45.4
F_3 -100% RDP	0.51	29.4	0.18	16.2	45.6	0.51	30.5	0.18	16.7	47.2	0.51	29.9	0.18	16.5	46.4
S.Em±	0.01	0.60	0.01	0.18	0.63	0.01	0.65	0.01	0.18	0.65	0.01	0.60	0.01	0.17	0.61
CD (p = 0.05)	NS	1.7	NS	0.5	1.8	NS	1.8	NS	0.5	1.8	NS	1.7	NS	0.5	1.8
CV (%)	12.6	13.3	4.8	7.2	8.9	12.5	13.6	3.9	7.1	8.8	12.6	13.0	3.6	6.7	8.5
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4: Potassium content (%) and uptake (kg ha^{-1}) of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-2017, 2017-2018 and pooled data

Treatment	2016-17					2017-18					Pooled data				
	Grain		Stover		Total uptake	Grain		Stover		Total uptake	Grain		Stover		Total uptake
	Content	Uptake	Content	Uptake		Content	Uptake	Content	Uptake		Content	Uptake	Content	Uptake	
Residual response of source of phosphorus															
M_1-Inorganic P	0.48	22.7	1.30	103.9	126.7	0.50	24.8	1.32	109.1	133.9	0.49	23.8	1.31	106.5	130.3
M_2-GM	0.51	29.7	1.33	128.1	157.8	0.53	32.6	1.35	132.7	165.3	0.52	31.2	1.34	130.4	161.5
M_3-PSB	0.50	26.8	1.32	117.0	143.6	0.52	28.6	1.34	121.2	149.8	0.51	27.6	1.33	119.1	146.7
M_4-GM+PSB	0.52	31.3	1.34	130.7	162.0	0.54	33.1	1.36	135.2	168.3	0.53	32.2	1.35	132.9	165.2
S.Em±	0.01	0.48	0.01	1.26	0.95	0.01	0.55	0.01	1.48	1.72	0.01	0.38	0.01	1.36	1.32
CD (p = 0.05)	NS	1.7	NS	4.4	3.3	NS	1.9	NS	5.1	5.9	NS	1.3	NS	4.7	4.5
CV (%)	8.3	9.1	2.9	5.4	3.4	8.4	9.6	3.1	6.2	5.8	7.5	7.0	2.9	5.8	4.5
Residual response of levels of phosphorus															
S_1-50% RDP	0.50	27.1	1.32	119.1	146.2	0.52	29.1	1.34	122.2	151.3	0.51	28.3	1.33	120.7	149.0
S_2-100% RDP	0.50	27.4	1.32	120.0	147.4	0.52	29.5	1.35	125.5	155.1	0.51	28.4	1.33	122.7	151.3
S_3-150% RDP	0.51	28.0	1.33	120.8	148.8	0.53	30.7	1.35	125.8	156.5	0.52	29.3	1.34	123.3	152.7
S.Em±	0.01	0.57	0.01	1.9	2.04	0.01	0.53	0.01	2.12	2.39	0.01	0.48	0.01	2.01	2.19
CD (p = 0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	10.4	12.4	3.4	9.5	8.3	8.1	10.8	3.5	10.2	9.3	8.9	10.1	3.3	9.8	8.7
Levels of phosphorus applied to sorghum															
F_1-0% RDP	0.49	24.0	1.31	108.9	132.9	0.51	25.9	1.33	114.2	140.2	0.50	25.0	1.32	111.6	136.5
F_2-50% RDP	0.50	29.0	1.33	124.5	153.6	0.51	31.3	1.35	128.6	159.9	0.52	30.2	1.34	126.6	156.7
F_3 -100% RDP	0.51	29.8	1.33	126.9	156.1	0.53	32.1	1.36	130.8	162.8	0.52	31.0	1.35	128.5	159.4
S.Em±	0.01	0.64	0.01	1.52	1.92	0.01	0.66	0.01	1.42	1.73	0.01	0.62	0.01	1.46	1.81
CD (p = 0.05)	NS	1.8	NS	4.3	5.5	NS	1.9	NS	4.0	4.9	NS	1.78	NS	4.1	5.1
CV (%)	13.7	13.9	4.9	7.6	7.8	11.8	13.4	4.5	6.8	6.7	12.5	13.0	4.7	7.1	7.2
Interaction	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Nitrogen uptake of sorghum measured at maturity was significantly influenced by source of phosphorus but not by levels of phosphorus given to preceding rice and phosphorus levels given to succeeding sorghum has significant influence on nitrogen uptake during both the years of study and in pooled data. In general, N uptake by sorghum increased with the availability of source of phosphorus during both the years of investigation and in pooled data. Among the source of phosphorus preceding to sorghum, green manuring + PSB has registered the highest uptake of nitrogen by sorghum which was statistically at par with the green manuring alone and significantly superior to other treatments. The nitrogen uptake observed with the application of inorganic phosphorus through SSP was significantly the lowest compared with other levels of phosphorus during both the years of study.

With increase in the levels of phosphorus to preceding rice could not significantly influence the nitrogen uptake of succeeding sorghum. However, higher nitrogen uptake was observed with the 150% RDP which was at par with other levels of 100 and 50% RDP. Nitrogen uptake at maturity by grain and stover of sorghum was (95.5 and 73.6 kg ha^{-1}) in the first year, (98.9 and 75.5 kg ha^{-1}) in the second year and in pooled data (97.2 and 74.6 kg ha^{-1}) when green manuring + PSB was used as a source of phosphorus to preceding rice crop. A significant improvement in N uptake of sorghum by both grain and stover was observed up to 100% RDP (91.8 and 71.2 kg ha^{-1}) during 2016-17, (95.6 and 72.9 kg ha^{-1}) in 2017-18 and in pooled data (93.1 and 72.1 kg ha^{-1}), which was statistically on a par with application of 50% RDP (90.4 and 70.7 kg ha^{-1}) during 1^{st} year, 94.5 and 72.2 kg ha^{-1} during 2^{nd} year and 92.5 and 71.4 kg ha^{-1} in pooled data.

Phosphorus along with green manures and biofertilizers enhanced the photosynthetic activity and translocation of nutrients thus increasing the grain yield and nitrogen uptake by grain. Higher photosynthetic activity with higher drymatter production right from initial stages of the crop growth indicated adequate availability of nutrient in the rhizosphere. This might have helped in better root growth and their activity resulting in higher absorption of nutrient from soil and their translocation to aerial parts thus increasing the uptake of nitrogen by stover. (Sareen and Sharma, 2010, Sumeriya, 2010 and Pushpendra Singh *et al.*, 2012) [17, 21, 25].

Among the source of phosphorus, maximum phosphorus uptake of sorghum was observed in the treatment receiving combined application of green manuring + PSB during 1^{st} (31.7 and 16.7 kg ha^{-1}), 2^{nd} year (32.3 and 17.2 kg ha^{-1}) and in pooled data (32.0 and 17.0 kg ha^{-1}) in grain and stover, respectively which was on a par with the green manuring alone. The marked influence of application of manures on phosphorus uptake by no till sorghum could be due to increased biomass obtained as a result of more availability of nutrients released during decomposition of organic manures and also solubilisation of native phosphorus by phosphate solubilizing microbes. (Ravankar *et al.*, 2000 and Patidar and Mali, 2004) [14, 19]. Higher uptake of P was observed with application of 100% RDP (29.4 and 16.2 kg ha^{-1}) given to sorghum and it was statistically at par with 50% RDP (30.5 and 16.7 kg ha^{-1}) and proved significantly superior to other level of phosphorus *i.e.*, 0% RDP (29.9 and 16.5 kg ha^{-1}) during 2016-17, 2017-18 and in pooled data (Fig. 1). It might be due to increase in level of P fertilizer application that might have promoted growth of roots as well as functional activity resulting in higher extraction of nutrients from soil to aerial plant parts. (Pushpendra Singh *et al.*, 2012 and Pratyusha, 2014) [16, 17].

Potassium uptake followed the similar trend as in case of nitrogen and phosphorus uptake during both the years of study and in pooled data. The increase in uptake of potassium in green manure treated plots (161.5 kg/ha and165.2 kg/ha) might be due to release of K from organic manures during decomposition and solubilisation and release of native and fixed forms of potassium, charging the soil solution with K^+ ions. The increase in uptake with growth may be ascribed to basal application of potassic fertilizers in no till sorghum and the role of organics in increasing the use efficiency of applied fertilizers. (Mahavishnan *et al.*, 2003) [9]. This might be due to favourable effect of phosphorus on uptake of potassium and also due to the synergistic effect between these two major nutrients which in turn helped in prolonged period of absorption of nutrients. (Pushpendra Singh *et al.*, 2012 and Pratyusha, 2014) [16, 17].

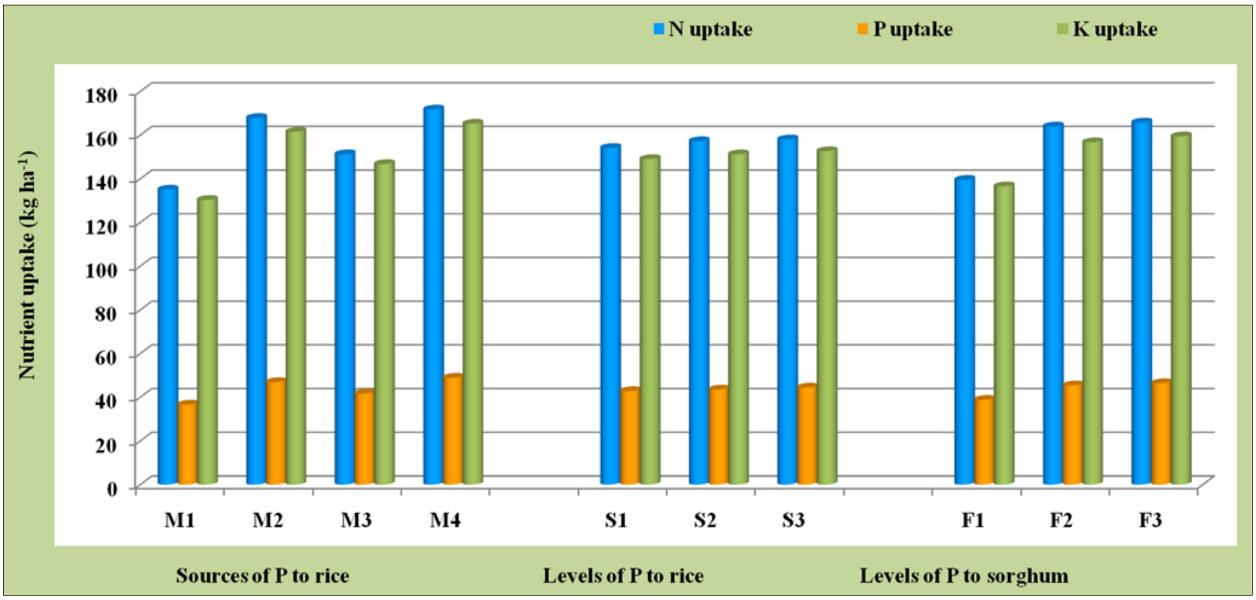

Fig 1: Nitrogen, phosphorus and potassium uptake (kg ha^{-1}) of sorghum as influenced by phosphorus management in rice-sorghum sequence of pooled data

Partial factor productivity

Data (Fig. 2) pertaining to partial factor productivity (kg grain yield kg $P_2O_5^{-1}$ applied) of sorghum revealed that with increase in phosphorus level, a decrease in partial factor productivity was observed. Application of inorganic phosphorus in combination with biological sources resulted in realization of potential yield on sustained basis at each phosphorus level. Soil application of PSB recorded higher partial factor productivity (59.06, 60.43 and 59.75) compared to that of other biological sources (M_2-(56.56, 58.04 and

57.30) and M_4 (58.3, 58.73 and 58.51)) during both the years and in pooled data respectively. Application of PSB solubilize and mineralize the residual or fixed phosphorus, increased phosphorus availability in soil and stimulated greater root growth which favoured better absorption of phosphorus. Averagely the higher partial factor productivity was recorded with 150% RDP (56.8, 58.5 and 57.7) than 50% RDP (55.1, 56 and 55.5) and 100% RDP (56.7, 58.5 and 57.6) given to preceding rice in succeeding no till sorghum. in rice-sorghum sequence during both the years of study and in pooled data. With increase in phosphorus level given to no till sorghum, higher partial factor productivity was observed with 100% RDP (59.9, 61.2 and 60.6) than 0 (50.3, 51.6 and 50.9) and 50% RDP (59.4, 60.9 and 60.2). The higher quantity of biomass added through green manures might have improved the partial factor productivity as more quantity of organic matter will be added which will be able to solubilize the phosphorus and reduce the P – fixation with increased levels of phosphorus application. Increased microbial population due to organic matter addition will help in nutrient transformation in the soil and transform the nutrients in available form which can be taken up by the plants (Amanullah and Almas, 2009) [1].

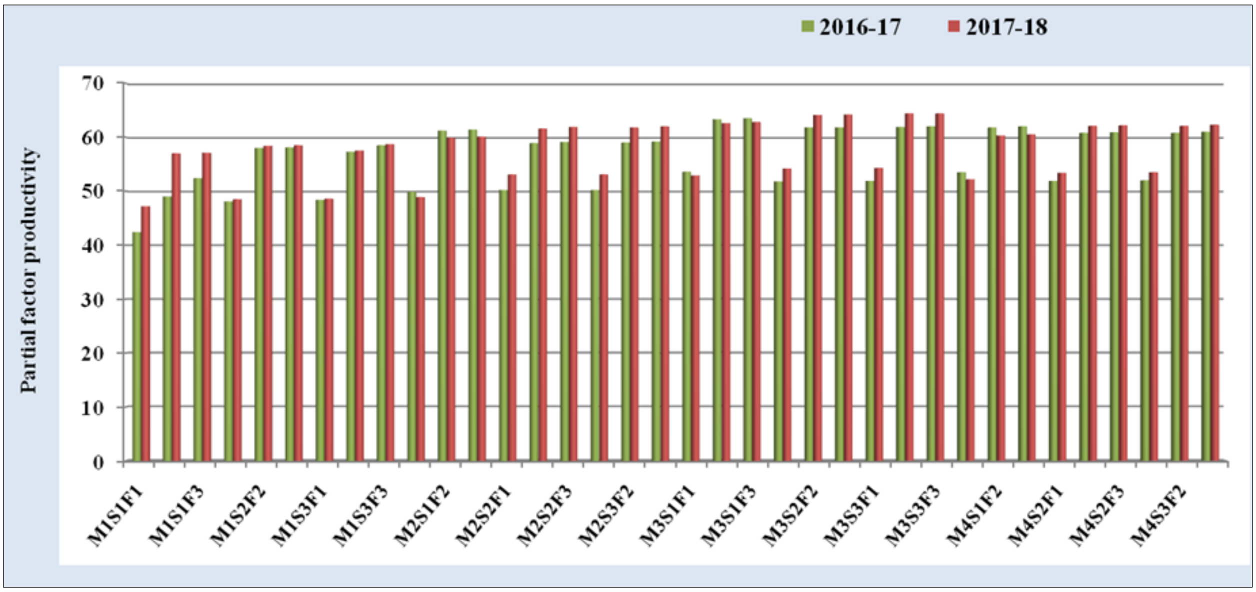

Fig 2: Partial factor productivity (kg grain yield kg $P_2O_5^{-1}$ applied) of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-17, 2017-18 and pooled data

Post-harvest status of available soil N, P and K after harvest of sorghum

Considerable variation in the soil available N, P and K status was observed in both the years of study and in pooled data after harvest of sorghum, presented in Table 5. The highest soil available NPK after harvest of sorghum was recorded with green manuring + PSB (M_4) applied in preceding rice during 1st year (158.8, 23.0 and 473.2 kg ha^{-1}), 2nd year (148.5, 22.0 and 465.0 kg ha^{-1}) and in pooled data (153.6, 22.9 and 469.1 kg ha^{-1}) respectively and found to be significantly superior over M_1 and M_3.

Table 5: N, P and K availability (kg ha^{-1}) after harvest of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-17, 2017-18 and pooled data

Treatment	2016-17			2017-18			Pooled data		
	N	P	K	N	P	K	N	P	K
Residual response of source of phosphorus									
M_1-Inorganic P	140.3	18.5	406.2	127.9	15.2	390.0	134.1	16.8	398.1
M_2-Green manuring	149.7	22.5	440.2	141.4	21.3	430.1	145.6	21.9	435.2
M_3-Soil application of PSB	140.7	20.1	414.0	132.4	17.3	401.8	136.6	18.7	407.9
M_4-GM+PSB	158.8	23.0	473.2	148.5	22.8	465.0	153.6	22.9	469.1
S.Em±	3.26	0.63	9.29	3.23	0.63	9.29	3.23	0.53	9.29
CD (p = 0.05)	11.2	2.2	32.1	11.2	2.2	32.1	11.2	1.8	32.1
CV (%)	11.4	15.7	11.1	12.2	17.3	11.4	11.8	13.8	11.3
Residual response of levels of phosphorus									
S_1-50% RDP	144.5	18.0	415.8	134.0	16.0	404.1	139.2	17.0	410.0
S_2-100% RDP	147.0	19.7	441.6	136.5	17.9	429.9	141.7	18.8	435.7
S_3-150% RDP	150.7	25.4	442.8	142.2	23.5	431.1	146.4	24.4	436.9
S.Em±	2.67	0.85	9.23	2.67	0.85	9.23	2.67	0.66	9.23
CD (p = 0.05)	NS	2.4	NS	NS	2.5	NS	NS	1.9	NS
CV (%)	10.9	20.1	12.7	11.6	20.9	13.1	11.2	19.7	13.0
Levels of phosphorus applied to sorghum									
F_1-0% RDP	135.8	19.4	407.9	126.8	16.7	402.3	131.4	18.1	405.2
F_2-50% RDP	142.9	21.2	419.7	133.1	19.7	408.1	138.0	20.4	413.9

F_3 -100% RDP	146.5	22.4	422.4	136.6	20.9	410.7	141.5	21.7	416.5
S.Em±	1.37	0.45	1.21	1.37	0.45	1.21	1.37	0.40	1.21
CD (p = 0.05)	3.9	1.3	3.4	3.9	1.3	3.5	3.9	1.1	3.5
CV (%)	5.6	12.9	2.4	6.0	14.2	2.3	5.8	12.0	2.7
Interaction									
M*S	NS	NS	NS	NS	NS	NS	NS	NS	NS
M*F	NS	NS	NS	NS	NS	NS	NS	NS	NS
S*F	NS	S	NS	NS	NS	NS	NS	S	NS
M*S*F	NS	NS	NS	NS	NS	NS	NS	NS	NS

The levels of phosphorus given to preceding rice did not influence the availability of soil N and K but P availability after harvest of sorghum showed a significant response. Available NPK in soil after harvest of sorghum was significantly influenced by levels of phosphorus given to sorghum. The highest available NPK was recorded with 100% RDP (146.5, 22.4 and 422.4 kg ha^{-1}) during first year, (136.6, 20.9 and 410.7 kg ha^{-1}) second year and in pooled data (141.5, 21.7 and 416.5 kg ha^{-1}) followed by 50% RDP and found significantly superior to no phosphorus application (Sumeriya *et al.*, 2010) [17] and (Pratyusha, 2014) [16].

Perusal of data presented in table 5a revealed that when P applied @ 50% RDP applied in the form of SSP alone to rice found to be significantly inferior at each level of phosphorus applied to succeeding sorghum. In case of soil application of PSB alone along with 150% RDP (22, 24.9 and 25.1 kg ha^{-1}) found to be significantly superior over 100% (16.8, 18.4 and 20.5 kg ha^{-1}) and 50% RDP (17.7, 17.7 and 18 kg ha^{-1}) application across P levels given to sorghum. However green manuring alone or in combination with PSB incorporation with application of 150% RDP (20.1, 23.2 and 24.1 kg ha^{-1} or 25.2, 26.8 and 26.8 kg ha^{-1}) found to be significantly superior with higher P availability at each level of P given to sorghum however, at higher levels of P applied to sorghum the differences between S_1 and S_2 were not significant in case of M_2 and M_4. Similar trend was observed in pooled data in Table 5b, where at higher levels of P application *i.e.*, 100% RDP to sorghum (F_3), S_1 and S_2 given to rice were found to be significant at all the sources of P given to rice compared to lower levels of P applied to sorghum (F_1 and F_2).

Table 5a: Interaction between levels of phosphorus to rice and succeeding sorghum on phosphorus availability after harvest of sorghum as influenced by phosphorus management in rice-sorghum sequence during 2016-17

Levels of phosphorus applied to sorghum	2016-17																Mean		
	Phosphorus through SSP (M_1)				Green manuring (M_2)				Soil application of PSB (M_3)				Green manuring + PSB (M_4)						
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	M	S	F
F_1-0% RDP	13.3	14.5	20.7	16.1	17.3	18.5	24.7	20.1	17.7	16.8	22.0	18.8	19.6	23.0	25.2	22.6	18.5	18.0	19.4
F_2-50% RDP	14.9	17.9	24.8	19.2	18.9	21.9	28.8	23.2	17.7	18.4	24.9	20.3	19.6	19.9	26.8	22.1	22.5	19.7	21.2
F_3-100% RDP	15.4	19.6	25.2	20.1	19.4	23.6	29.2	24.1	18.0	20.5	25.1	21.2	20.0	26.0	26.8	24.3	20.1	25.4	22.4
Mean	14.5	17.3	23.6	18.5	18.5	21.3	27.6	22.5	17.5	18.9	24.0	20.1	19.7	23.0	26.3	23.0	23.0		

Interactions	S.Em±	CD (p = 0.05)	CV (%)
Residual response of source of phosphorus (M)	0.53	1.8	13.8
Residual response of levels of phosphorus (S)	0.66	1.9	19.7
Levels of phosphorus applied to sorghum (F)	0.40	1.1	12.0
M*S	1.70	NS	
M*F	0.91	NS	
S*F	0.78	2.2	
M*S*F	1.57	NS	

Table 5b: Interaction between levels of phosphorus to rice and succeeding sorghum on phosphorus availability after harvest of sorghum as influenced by phosphorus management in rice-sorghum sequence pooled data

Levels of phosphorus applied to sorghum	2016-17																Mean		
	Phosphorus through SSP (M_1)				Green manuring (M_2)				Soil application of PSB (M_3)				Green manuring + PSB (M_4)						
	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	S_1	S_2	S_3	Mean	M	S	F
F_1-0% RDP	11.57	12.78	18.99	14.45	17.51	18.63	23.47	19.87	14.69	15.6	19.88	16.72	19.19	19.4	25.14	21.24	16.8	17.0	18.1
F_2-50% RDP	13.33	16.26	23.19	17.6	18.94	20.24	27.32	22.16	16.55	17.31	23.84	19.24	19.71	21.02	28.09	22.94	21.9	18.8	20.4
F_3-100% RDP	13.8	18.03	23.61	18.48	19.2	24.32	27.52	23.68	16.89	19.42	24.04	20.11	19.98	25.1	28.29	24.46	18.7	24.4	21.7
Mean	14.5	17.3	23.6	18.5	18.5	21.3	27.6	22.5	16.0	17.4	22.6	18.7	19.6	21.8	27.2	22.9	22.9		

Interactions	S.Em±	CD (p = 0.05)	CV (%)
Residual response of source of phosphorus (M)	0.64	2.2	15.7
Residual response of levels of phosphorus (S)	0.85	2.4	20.1
Levels of phosphorus applied to sorghum (F)	0.46	1.3	12.9
M*S	1.70	NS	
M*F	0.91	NS	
S*F	0.79	2.1	
M*S*F	1.58	NS	

Economics

The data related to gross returns presented in Table. 6 revealed that a significant increase in gross returns were observed with green manuring + PSB which was found to be at par with green manuring alone over the other sources of phosphorus (M_1 and M_3).

A significant influence of phosphorus levels given to sorghum was observed on gross returns but phosphorus levels applied to rice did not show any statistical difference on succeeding sorghum.

The interaction of phosphorus sources and levels of phosphorus given to preceding rice showed a significant difference on consequent sorghum with regard to gross returns during 2016-17 only. Though significant differences were not observed at each level of phosphorus across the main plot treatments (phosphorus sources); application of 50% RDP (98859, 90500 and 101926 Rs.ha^{-1}) along with biological sources showed significantly higher gross returns than 150% RDP alone (81570 Rs.ha^{-1}). The residual effect of P performs better towards increasing the grain yield even at 50% RDP along with biological resources which was on a par with higher levels phosphorus at the same level of phosphorus source (Table 6a).

Table 6a: Cost of cultivation (Rs. ha^{-1}), gross returns (Rs. ha^{-1}), net returns (Rs. ha^{-1}) and returns per rupee invested of sorghum as influenced by phosphorus management in rice-sorghum sequence during *rabi* 2016-17, 2017-18 and pooled data

Treatment	2016-17				2017-18				Pooled data			
	Cost of cultivation	Gross return	Net return	Return per rupee invested	Cost of cultivation	Gross return	Net return	Return per rupee invested	Cost of cultivation	Gross return	Net return	Return per rupee invested
Residual response of source of phosphorus												
M_1-Inorganic P	30556	80497	49941	1.63	32290	87672	55382	1.72	31423	84085	52662	1.68
M_2-GM	32673	98998	66325	2.03	34587	107724	73137	2.11	33630	103361	69731	2.07
M_3- PSB	31239	90550	59311	1.90	33250	96936	63686	1.92	32245	93743	61499	1.91
M_4- GM+PSB	33415	101958	68543	2.05	35274	109701	74427	2.11	34345	105830	71485	2.08
S.Em±	-	1504.5	1504.5	0.03	-	2095.0	2095.0	0.05	-	1679.7	1679.7	0.04
CD (p = 0.05)	-	5206	5206	0.1	-	7250	7251	0.18	-	5813	5813	0.13
CV (%)	-	8.4	12.8	8.2	-	10.8	16.2	13.5	-	9.0	13.6	10.3
Residual response of levels of phosphorus												
S_1 - 50% RDP	30580	92411	61831	2.02	31348	98693	67345	2.14	30964	95552	64588	2.06
S_2 - 100% RDP	32076	93230	61154	1.91	34556	101721	67165	1.94	33316	97476	64159	1.96
S_3 - 150% RDP	33255	93361	60105	1.81	35723	101785	66063	1.85	34489	97573	63084	1.87
S.Em±	-	1048.3	1048.3	0.01	-	1379.0	1379	0.03	-	1102.9	1102.9	0.02
CD (p = 0.05)	-	NS	NS	0.03	-	NS	NS	0.09	-	NS	NS	0.05
CV (%)	-	6.8	10.3	3.5	-	8.2	12.3	8.6	-	6.8	10.3	5.3
Levels of phosphorus applied to sorghum												
F_1 - 0% RDP	28836	82828	53992	1.87	30719	89979	59260	1.92	29620	86404	56784	1.90
F_2 - 50% RDP	33270	97687	64417	1.94	35244	105890	70646	2.01	34257	101789	67531	2.02
F_3 - 100% RDP	34106	98486	64381	1.89	35680	106329	70650	1.98	34893	102408	67515	1.98
S.Em±	-	1041.0	1041	0.02	-	1280.7	1280.7	0.03	-	1040.5	1040.5	0.02
CD (p = 0.05)	-	2960	2960	0.06	-	3642	3642	0.09	-	2959	2959	0.06
CV (%)	-	6.8	10.2	7.1	-	7.6	11.4	8.7	-	6.4	9.7	6.9
Interaction												
M*S	-	S	S	S	-	NS	NS	NS	-	NS	NS	NS
M*F	-	NS	NS	NS	-	NS	NS	NS	-	NS	NS	NS
S*F	-	NS	NS	NS	-	NS	NS	S	-	NS	NS	S
M*S*F	-	NS	NS	NS	-	NS	NS	NS	-	NS	NS	NS

The data related to net returns formulated in Table. 6 showed that, sources of phosphorus were having a significant influence on net returns during both the years of study and in pooled data. Green manuring + PSB (68543, 74427 and 71485 Rs.ha^{-1}) resulted in maximum net return followed by green manuring alone (66325, 73137 and 69731 Rs.ha^{-1}) and found to be superior over the other sources of phosphorus (M_1 and M_3).

In spite of the fact that yield obtained was higher with 150% RDP (S_3), an increase in net returns of sorghum was observed with 50% RDP (61831, 67345 and 64588 Rs.ha^{-1}) which might be attributed to the low cost of cultivation and comparable yield with that of S_3 (60105, 66063 and 63084 Rs.ha^{-1}). Among the levels of phosphorus given to sorghum, the highest net returns were observed with the 100% RDP (64381, 70650 and 67515 Rs.ha^{-1}) which was found to be significant over control (53992, 59260 and 56784 Rs.ha^{-1}) and statistically on a par with 50% RDP (64417, 70646 and 67531 Rs.ha^{-1}) during two years of study and in pooled data. Interaction effect between the sources and levels of phosphorus applied to rice was found to be significant during 2016-17 only (Table 6a).

The residual effect of P sources and levels given to rice had significant interaction in increasing net returns in sorghum cultivation, only with the application of SSP alone across P levels, where S_1 recorded significantly lower net returns compare with S_2 and S_3. However, at every P source except SSP remaining all sources performed better interaction with S_1 where significantly higher net returns were observed due to low cost of cultivation and optimal utilization of all nutrient resources from soil along with phosphorus. A significant response was observed with sources and levels of phosphorus to preceding rice and P levels to succeeding sorghum.

A significant interaction was observed with levels of phosphorus to rice and levels of phosphorus to sorghum. Application of 150% RDP found to be with higher returns per rupee invested however it was on a par with 100% RDP at every source of phosphorus. Though 50% RDP recorded lower returns per rupee invested was found on a par with 100% RDP across all sources of P except soil application of

PSB where 50% RDP with PSB (2.06) observed with higher returns per rupee invested compared to 100% (1.85) and 150% RDP (1.80) due to residual effect of P sources and levels given to rice (Table 6b and 6c).

Table 6b: Interaction between sources and levels of phosphorus to rice on return per rupee invested of succeeding sorghum as influenced by phosphorus management in rice-sorghum sequence during 2016-17

Residual response of source of phosphorus	Residual response of levels of phosphorus (2016-17)			Mean
	S_1 - 50% RDP	S_2 - 100% RDP	S_3 - 150% RDP	
M_1-Inorganic phosphorus	1.58	1.72	1.60	1.63
M_2-Green manuring	2.18	2.01	1.90	2.03
M_3-Soil application of PSB	2.06	1.85	1.80	1.90
M_4-Green manuring + PSB	2.20	2.04	1.92	2.05
Mean	2.02	1.91	1.81	
	S.Em±	CD (p = 0.05)	CV (%)	
Residual response of source of phosphorus (M)	0.03	0.10	8.2	
Residual response of levels of phosphorus(S)	0.01	0.03	3.5	
Interaction				
M*S	0.06	0.19		

Table 6c: Interaction between levels of phosphorus to rice and levels of phosphorus to sorghum on return per rupee invested of succeeding sorghum as influenced by phosphorus management in rice-sorghum sequence during 2017-18

Residual response of source of phosphorus	Levels of phosphorus applied to sorghum (2017-18)			Mean	Levels of phosphorus applied to sorghum (Pooled data of 2016-17 and 2017-18)			Mean
	F_1 - 0% RDP	F_2 - 50% RDP	F_3 - 100% RDP		F_1 - 0% RDP	F_2 - 50% RDP	F_3 - 100% RDP	
S_1 - 50% RDP	1.94	2.25	2.22	2.14	1.94	2.15	2.10	2.06
S_2 - 100% RDP	1.94	1.95	1.92	1.94	1.89	2.00	1.99	1.96
S_3 - 150% RDP	1.90	1.83	1.82	1.85	1.87	1.90	1.84	1.87
Mean	1.92	2.01	1.98		1.90	2.02	1.98	
	S.Em±	CD (p = 0.05)	CV (%)		S.Em±	CD (p = 0.05)	CV (%)	
Residual response of source of phosphorus (S)	0.03	0.09	8.6		0.02	0.05	5.3	
Levels of phosphorus applied to sorghum (F)	0.03	0.09	8.7		0.02	0.06	6.9	
Interaction								
S*F	0.06	0.19			0.05	0.16		

This might be due to low cost of cultivation as green manuring and PSB involves less cost for fertilization. The higher gross returns were mainly due higher grain and straw yields; higher net returns were due to lower cost of cultivation. (Sumeriya, 2010, Pushpendra Singh *et al.*, 2012, Fromme *et al*., 2012 and Yadav *et al*., 2016) [5, 17, 25, 27].

Conclusion

Application of green manuring + PSB with 50% RDP to rice and 50% RDP to succeeding sorghum found to be optimum for obtaining significant response in grain yield, NPK uptake, partial factor productivity, NPK availability and economics of no till sorghum. It can be concluded that instead of going for higher levels of phosphatic fertilizers, application of 50% RDP along with biological sources of phosphorus (green manures, phosphorus solubilizing bacteria) was found to be optimum with respect to soil health and residual effect on succeeding sorghum. This indicated that residual effect of sources and levels of phosphorus can reduce the fertility requirement of rice-sorghum sequence thereby saving 50% RDP in rice and 50% RDP in sorghum in the rice-sorghum sequence without compromising the yield of both rice and sorghum.

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