NASS
NAN YANG ACADEMY OF SCIENCES (SINGAPORE)

NASS Journal of Agricultural Sciences
http://ojs.nassg.org/index.php/NJAS

ARTICLE

Effect of Different Levels of Water Soluble Phosphorus in Complex Fertilizers on Crop Productivity and Soil Health

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ARTICLE INFO

Article history:
Received: 8th November 2018
Accepted: 3rd December 2018
Published Online: 1st January 2019

Keywords:
Water soluble phosphorus
Nitrophosphates
Cropping system
Yield
Soil fertility
Nutrient uptake

ABSTRACT

Field experiments were undertaken on sandy soils with three cropping systems at Giridih, Jharkhand, India for two years during 2012-2014. The experiments were executed in split plot design by assigning water soluble phosphorus (WSP) fertilizers in main-plot and recommended dose of phosphorus (RDP) in sub-plot with three replications. The maximum economical yield of rice (4705 kg/ha), baby corn (842 kg/ha) and Chickpea (920 kg/ha) were recorded with the application of 30% WSP. The maximum economical yield of successive crops - wheat (3185 kg/ha), mustard (1720 kg/ha) and groundnut (1578 kg/ha) were recorded with the application of 30% WSP and 100% RDP treatment. Almost similar trends were noticed in terms of by-product yield, nutrient uptake and residual soil fertility status. All the levels of WSP (30% - 89%) in complex fertilizers were found to be equally effective for grain yield, straw yield, nutrient uptake, and residual soil fertility.

1. Introduction

Phosphorus is the second most deficient nutrient in agriculture production systems around the world next to nitrogen (Balemi and Negisho, 2012)[3]. It is an essential element for plant growth. It plays an important role in photosynthesis, energy transfer and storage. Plant growth is restricted unless the soil contains adequate level of phosphorus or it is supplied to soil from external source (Tekchand and Tomar, 1993; Tomar, 2000; Setia and Sharma, 2007)[28][29][26]. The fraction of soil phosphorus utilized for crop growth is called as 'Available Phosphorus'. Phosphorus is absorbed by plants mostly the primary and secondary orthophosphate ions ($H_2PO_4^-$ and HPO_4^{2-}) which are present in soil solution. The amount of each form present depends primarily on soil pH. At pH 7.22 there are approximately equal amount of $H_2PO_4^-$ and HPO_4^{2-}. Plant uptake of HPO_4^{2-} is much slower than $H_2PO_4^-$. The amount of P held in the cycling pools of soil P (i.e. plant-available P) is the working capital of the soil that determines crop productivity.

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High quality rock phosphate is a finite source and there is an on-going debate about the longevity of global P resources (Cordell *et al*. 2009; Van Kauwenbergh 2010)[7][14]. Phosphorus is important for sustainable agricultural production and global food security. To ensure equitable use of scarce P resources, inefficiencies in P use in agriculture needs to be addressed. Diammonium phosphate (DAP) is the most commonly used P-fertilizer throughout South-East Asia. However, raw materials required for its production are being imported resulting in drain of foreign exchange. Keeping this and the anticipated short supply of sulphur in the world market, fertilizer manufacturers have introduced nitrophosphates as an alternative (Khurana *et al*. 2003)[15].

Nitrophosphates with a combination of water soluble phosphate (30–60%) and citrate-soluble phosphate offer an optimal solution to increase P-fertilizer use efficiency for majority of crops on varied soils (Wichmann 1977)[32]. Energy requirements of nitrophosphate production are 20% lower than sulphur-based P-fertilizers. From environmental point of view, nitrophosphate manufacturing does not lead to the generation of sulfur dioxide, large volumes of solid wastes and waste waters (Anonymous 1988)[1]. On the other hand, phosphoric acid- and sulphuric acid-based P-fertilizers have a major problem of phosphogypsum disposal (Reuvers and Lee 1994)[22]. Carbon dioxide produced during nitrophosphate manufacturing is consumed in N fertilizer production (Anonymous 1994)[2]. In addition, nitrophosphate production process has the ability to accommodate low-grade phosphate rock by removing inerts (Bonekamp 1984)[5].

There has an interest in the research that how much water soluble P should be present in different kind of fertilizer for getting higher P-use efficiency and optimum crop yield. With this background, experiments were designed to study the effect of different levels of water soluble P in complex fertilizers in different cropping systems at Giridih, Jharkhand, India.

2. Methodology

2.1 Experimental Site

The three experiments on different cropping systems were conducted at Giridih, Jharkhand, India (Table). The mean maximum temperature is generally recorded in the month of June (40–45 ˚C) and minimum temperature in January (2–5 ˚C). The average annual rainfall is 1349 mm of which 82% occurs within the monsoon period (June–September). Relative humidity ranges from 78% to 95%. Annual potential evapo-transpiration (PET) is 1293 mm. The mean daily evaporation reaches a maximum of 12–15 mm per day in June and a minimum of 0.5–0.7 mm per day in January. The mean wind velocity varies from 3.5 km hr^{-1} during October to 6.4 km hr^{-1} during April. The physico-chemcial parameters of study soils are given in Table 1.

Table 1. The physico-chemcial parameters of study soils.

Parameter	Rice-wheat	Baby corn-Mustard	Chick-pea-Groundnut
pH	6.10	5.80	5.60
Conductivity (dSm^{-1})	0.12	0.17	0.14
Organic carbon (%)	0.33	0.29	0.25
Available N	135	169	226
Available P_2O_5	9.30	11	7.0
Available K_2O	225	244	258

2.2 Experimental Design

A split plot design with three replications was used in the study by allocating levels of water soluble Phosphorus (WSP) in complex P-fertilizers in main-plots and three recommended dose of phosphate treatments in sub-plots. Four levels of water soluble Phosphorus (WSP) in complex fertilizers viz T_1: 30 % WSP, T_2: 60 % WSP, T_3: 80 % WSP, T_4: 100 % WSP along with a T_0: Absolute Control was taken in main-plot. To observe the residual effect, three levels of recommended doses of phosphate (RDP) viz P_1: 50 % RD of phosphorus, P_2: 100 % RD of phosphorus along with P_0: Control was accommodated in sub-plot. Source of P-fertilizers and their properties are mentioned in Table 2. Overnight water-soaked seeds of each different crop were sown at a depth of 3–5 cm below the soil surface. The full dose of P and K, and 50% N was applied at the time of sowing. The remaining 50% N was applied in two equal doses as band application at 20 and 40 days after sowing. Weeding was done twice to keep the field weed free.

2.3 Soil Sampling and Analysis

Soil samples from 0 to 20 cm depth were collected after each crop harvest, air dried, and sieved (2 mm mesh). Soil organic carbon (SOC) was analyzed by the wet oxidation method (Walkley and Black 1934)[31]. Soil available nitrogen was estimated by alkaline potassium permanganate (Subbiah and Asija 1956)[27], phosphorus by sodium bicarbonate (Olsen *et al*. 1954)[20] and potassium by ammonium acetate (Hanway and Heidel 1952)[9] method. A suspension of soil and water 1:2.5 and 1:5 was used to determine the pH and electrical conductivity (EC), respectively (Jackson 1973)[13].

2.4 Sstatistical Analysis

Collected data were subjected to statistical analysis in a split-plot design (Gomez and Gomez 1984)[8]. Least sig-

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Table 2. Source of fertilizer and their properties

SPECIFICATION	Nitrophosphate with potash "Suphala" (15:15:15)	Nitrophosphate "Suphala" (20:20:0)	Urea Ammonium Phosphate (20:20:0)	Diammonium phosphate (18:46:0)
Total nitrogen (%)	15.0	20	20	18.0
Ammonical nitrogen (%)	7.5	10	6.4	15.5
Nitrate nitrogen (%)	7.5	10	0.0	0.0
Urea nitrogen (%)	0.0	0.0	13.6	2.5
Neutral ammonium citrate soluble P_2O_5(%)	15.0	20	20	46.0
Water soluble P_2O_5 (%)	4.0 (27%)*	12 (60%)*	17 (85%)*	41.0 (89%)*
Water soluble K_2O (%)	15	0.0	0	0
Fertilizer treatment	T_1	T_2	T_3	T_4

**Figures in parenthesis are percent water soluble phosphorus.*

nificant difference (LSD) was worked out where variance ratio (*F* test) was significant and presented/tested at 5% level of significance.

3. Results

3.1 Grain and Straw Yield

Rice and baby corn grown in *Kharif* season and chickpea in *Rabi* with four levels of WSP- water soluble phosphorus in complex fertilizers along with control plots to note their effects on grain and straw yields. A minor variation was recorded in the yield data over the years may be due to the environmental conditions. The maximum economical yield of rice (4705 kg/ha), baby corn (842 kg/ha) and Chickpea (920 kg/ha) were recorded with the application of 30% WSP. Similar trend was noticed in terms by-product yield of rice (6675 kg/ha), baby corn (3264 kg/ha) and Chickpea (1694 kg/ha). Although there was no significant difference observed among the fertilizer treatments with respect to grain and straw yield. The minimum yields were noted where no phosphatic fertilizer was applied (Table 3-5).

Wheat and mustard in *Rabi* season and groundnut in *Kharif* were grown on residual soil fertility of previous phosphorus treatments and three levels of recommended dose of phosphorus (RDP) viz 0%, 50% and 100%. A minor variation was recorded in the yield data over the years may be due to the environmental conditions. Irrespective of crop, economic yield and by-product yield were increased with increasing the levels of RDP. The maximum economical yield of wheat (3185 kg/ha), mustard (1720 kg/ha) and groundnut (1578 kg/ha) were recorded with the application of 30% WSP and 100% RDP treatment. Similar trend was noticed in terms by-product yield of wheat (4496 kg/ha), mustard (2365 kg/ha) and groundnut (2667 kg/ha). Although there was no significant difference observed amongst the fertilizer treatments and RDP in terms of economic and by-product yields. The minimum yields were observed where no P-fertilizer was applied (Table 3-5).

3.2 Nutrient uptake

Direct and residual effect of different levels of WSP in complex fertilizers on nutrients uptake (i.e. N, P & K) by crops are presented in Table 6-8. The maximum nutrients (NPK) up taken by rice (87.3 N, 14.4 P and 105.9 K kg/ha), baby corn (70.9 N, 8.67 P & 111.9 K kg/ha) and Chickpea (66.7 N, 15.4 P & 84.1 K kg/ha) were recorded with the application of 30% WSP. Although there was no significant difference observed amongst the fertilizer treatments. The minimum nutrients uptake was noted where no phosphatic fertilizer was applied (Table 6-8).

Follow-up crops; wheat, mustard and groundnut were grown on residual soil fertility of previous phosphorus treatments and with three levels of RDP viz 0%, 50% and 100%. Irrespective of crop, nutrients uptake was increased with increasing the levels of RDP. The maximum uptake of nutrient by wheat (50.9 N, 12.1 P & 96.4 K kg/ha), by mustard (72.8 N, 8.2 P & 101.3 K kg/ha) and by groundnut (91.5 N, 16.3 P & 93.4 K kg/ha) were recorded with the application of 30% WSP and 100% RDP treatment. However, there was no significant difference observed amongst the fertilizer treatments. The minimum nutrients uptake was observed where no P-fertilizer was applied (Table 6-8).

3.3 Residual soil fertility

Residual soil fertility in terms of N, P & K was remarkably influenced by direct and residual effect of different levels of WSP in complex fertilizers Table 9-11. The max-

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Table 3. Direct effect of different levels of water soluble phosphorus in complex fertilizer on rice yield and residual effect on wheat yield and system productivity.

Treatment	Rice				Wheat			
	Grain yield (kg/ha)		Straw yield (kg/ha)		Grain yield (kg/ha)		Straw yield (kg/ha)	
	2012	2013	2013	2014	2012	2013	2013	2014
P_0T_0	3034	4020	4339	5668	2220	2620	3130	3713
P_0T_1	4090	5320	5849	7501	2430	3030	3426	4294
P_0T_2	4050	5259	5792	7416	2400	2970	3384	4208
P_0T_3	4000	4950	5720	6980	2370	2760	3342	3911
P_0T_4	3940	4674	5634	6590	2280	2710	3215	3840
P_1T_0	--	--	--	--	2340	2937	3311	4317
P_1T_1	--	--	--	--	2650	3143	3750	4620
P_1T_2	--	--	--	--	2610	2841	3693	4177
P_1T_3	--	--	--	--	2580	2790	3651	4101
P_1T_4	--	--	--	--	2550	2770	3608	4072
P_2T_0	--	--	--	--	2440	3095	3418	4333
P_2T_1	--	--	--	--	2870	3550	4021	4970
P_2T_2	--	--	--	--	2820	3470	3951	4858
P_2T_3	--	--	--	--	2790	3390	3909	4746
P_2T_4	--	--	--	--	2800	3410	3923	4774
Sem± (Main)	34.71	32.88	52.07	54.91	27.33	23.71	36.22	32.40
Sem± (Sub)					12.56	12.21	20.74	19.50
CD (p= 0.05) Main	80.05	75.83	120.08	126.64	63.03	54.68	83.52	74.71
CD (p= 0.05) Sub					26.20	25.48	43.27	40.67

imum residual soil fertility after harvesting of rice (187.4 N, 25.4 P and 280.9 K kg/ha), baby corn (231.3 N, 17.1 P & 288.6 K kg/ha) and Chickpea (304.2 N, 9.2 P & 354.6 K kg/ha) were recorded with the application of 30% WSP. Although there was no significant difference observed amongst the fertilizer treatments. The minimum nutrients uptake was noted where no phosphatic fertilizer was applied.

Follow-up crops; wheat, mustard and groundnut were grown on residual soil fertility of previous phosphorus treatments and with three levels of RDP viz 0%, 50% and 100%. Irrespective of crop, residual soil nutrients were increased with increasing the levels of RDP. The residual soil fertility was recorded the highest with the application of 30% WSP and 100% RDP treatment for wheat (218.6 N, 19.2 P & 323.9 K kg/ha), mustard (261.7 N, 20.1 P & 299.6 K kg/ha) and groundnut (287.8 N, 10.2 P & 322.9 K kg/ha). However, there was no significant difference observed amongst the fertilizer treatments. The minimum residual soil nutrients were observed where no P-fertilizer was applied (Table 6-8).

4. Discussions

4.1 Grain and Straw Yield

Irrespective of crops or/and cropping system, crop grain and straw yield were statically at par with the application P-fertilizers having different WSP (30-89%). Similar results were also observed by Saha *et al*., 2014[25]; Khurana *et al*., 2003 & 2004[16]. The phosphorus nutrition of plants is predominantly controlled by P dynamics in the soil/ rhi-

Table 4. Direct effect of different levels of water soluble phosphorus in complex fertilizer on baby corn and residual effect on mustard and system productivity.

Treatment	Baby corn				Mustard			
	Cob yield (kg/ha)		Straw yield (kg/ha)		Grain yield (kg/ha)		Straw yield (kg/ha)	
	2012	2013	2013	2014	2012	2013	2013	2014
P_0T_0	436	510	1683	1984	1010	1105	1374	1503
P_0T_1	810	874	3127	3400	1252	1471	1703	2001
P_0T_2	783	843	3022	3279	1195	1411	1625	1919
P_0T_3	757	844	2922	3283	1180	1389	1605	1889
P_0T_4	717	840	2768	3268	1167	1376	1587	1871
P_1T_0	--	--	--	--	1181	1230	1618	1685
P_1T_1	--	--	--	--	1398	1555	1915	2130
P_1T_2	--	--	--	--	1384	1505	1896	2062
P_1T_3	--	--	--	--	1329	1478	1821	2025
P_1T_4	--	--	--	--	1294	1448	1773	1984
P_2T_0	--	--	--	--	1248	1335	1716	1836
P_2T_1	--	--	--	--	1667	1773	2292	2438
P_2T_2	--	--	--	--	1599	1737	2199	2388
P_2T_3	--	--	--	--	1514	1703	2082	2342
P_2T_4	--	--	--	--	1501	1698	2064	2335
Sem± (Main)	23.07	31.05	89.01	121.34	24.12	24.77	29.66	32.95
Sem± (Sub)					14.88	12.68	18.30	16.86
CD (p= 0.05) Main	53.21	86.25	205.21	336.16	55.61	57.12	68.40	75.97
CD (p= 0.05) Sub					31.03	26.45	38.17	35.18

zosphere- plant continuum. The concentration of available soil phosphorus seldom exceeds 10 mM (Bieleski, 1973)[4], which is much lower than that in plant tissues where the concentration is approximately 5 to 20 mM phosphorus (Raghothama, 1999)[21]. Because of the low concentration and poor mobility of plant-available phosphorus in soils, applications of P-fertilizers are needed to improve crop growth and yield. The chemical and biological processes in the rhizosphere determine mobilization and acquisition of soil nutrients as well as microbial dynamics. These processes also control nutrient use efficiency of crops, and thus profoundly influence crop productivity (Hinsinger *et al*., 2009; Richardson *et al*., 2009; Wissuwa *et al*., 2009; Zhang *et al*., 2010)[11][23][33][34]. In a long-term study on calcareous soils of Haryana, Meelu *et al*. (1977)[19] and Chaudhary *et al*. (1979)[6] did not found significant difference in grain yield @ 120 kg P_2O_5 ha^{-1} application through water soluble sources SSP, DAP, UAP and nitrophosphate of 30% WSP. Similarly, Saha *et al*., 2013[24] and Khuran *et al*., 2004[16] reported effectiveness of nitrophosphate at par with SSP, DAP and UAP in terms of crop yield.

4.2 Nutrient Uptake

Irrespective of crop or/and cropping system, data recorded on nutrients uptake in terms of NPK did not show significant differences among the WSP treatments. Because of the unique properties of P in soil such as low solubility, low mobility, and high fixation by the soil matrix, the availability of P to plants is dominantly controlled by two key processes: (1) spatial availability and acquisition of P in terms of plant root architecture and (2) bioavailability and acquisition of P based on the rhizosphere

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Table 5. Direct effect of different levels of water soluble phosphorus in complex fertilizer on chickpea and residual effect on groundnut and system productivity.

Treatment	Chickpea				Groundnut			
	Cob yield (kg/ha)		Straw yield (kg/ha)		Grain yield (kg/ha)		Straw yield (kg/ha)	
	2012	2013	2013	2014	2012	2013	2013	2014
P_0T_0	680	739	1251	1375	1050	1082	1733	1785
P_0T_1	862	969	1586	1802	1312	1402	2165	2313
P_0T_2	823	963	1514	1791	1297	1374	2140	2267
P_0T_3	787	957	1448	1780	1250	1286	2063	2122
P_0T_4	762	956	1402	1778	1275	1310	2104	2162
P_1T_0	--	--	--	--	1221	1355	2039	2263
P_1T_1	--	--	--	--	1498	1592	2502	2659
P_1T_2	--	--	--	--	1344	1491	2244	2490
P_1T_3	--	--	--	--	1302	1432	2174	2391
P_1T_4	--	--	--	--	1294	1438	2161	2401
P_2T_0	--	--	--	--	1325	1372	2239	2319
P_2T_1	--	--	--	--	1410	1746	2383	2951
P_2T_2	--	--	--	--	1325	1685	2239	2848
P_2T_3	--	--	--	--	1403	1644	2371	2778
P_2T_4	--	--	--	--	1365	1583	2307	2675
					159	115	80	93
Sem± (Main)	41	47	89	90	59	33	30	27
Sem± (Sub)					368	265	184	214
CD (p= 0.05) Main	95	98	205	206	124	69	62	56
CD (p= 0.05) Sub					1050	1082	1733	1785

chemical and biological processes. Plants are able to respond to P starvation by changing their root architecture, including root morphology, topology, and distribution patterns (Vance et al., 2003)[30]. Root-induced chemical and biological changes in the rhizosphere play a vital role in enhancing the bioavailability of soil P (Hinsinger, 2001)[10]. Root-induced acidification can decrease rhizosphere pH by 2 to 3 units relative to the bulk soil, resulting in substantial dissolution of sparingly available soil P (Marschner, 1995)[18]. The pH change in the rhizosphere is mainly affected by cation/anion uptake ratios and nitrogen assimilation. Organic acid excretion and function in increasing P mobilization is well documented (Raghothama, 1999; Vance et al., 2003; Hinsinger *et al*., 2005)[21][30][11]. The total P uptake was maximum with water soluble sources (SSP, DAP and UAP) followed by partially water soluble nitrophosphate. The trend of yield with respect to P sources also reflected in the total P uptake by wheat. Such a trend might be explained on the basis of availability of P and solubility of fertilizer in the soil system. Effectiveness of nitrophosphate was statistically at par with other WSP fertilizers (Saha *et al*., 2014; Khurana *et al*., 2003 & 2004)[25][17].

4.3 Residual soil fertility

Irrespective of crops or/and cropping system, residual soil fertility in terms of NPK was recorded higher due to application of nitrophosphates (30% WSP) followed by UAP and DAP. Under P deficiency, plants can develop adaptive responses to facilitate efficient P acquisition and translocation. The phosphorus utilize efficiently by ad-

Table 6. Direct effect and residual effect of different levels of water soluble phosphorus in complex fertilizer on nutrient uptake by rice and wheat.

Treatment	Nutrient uptake by rice (Kg/ha)						Nutrient uptake by wheat (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	62.71	57.88	11.22	10.13	83.74	64.65	44.95	43.36	8.68	8.22	54.97	53.26
P_0T_1	93.90	80.71	15.32	13.55	116.68	95.13	67.68	52.96	9.80	8.20	81.77	71.03
P_0T_2	89.90	76.87	15.03	13.15	110.23	91.56	62.23	53.02	9.19	7.63	79.59	74.09
P_0T_3	87.97	73.04	14.80	12.95	104.78	89.46	50.62	50.84	8.14	7.34	77.32	71.19
P_0T_4	86.64	75.78	14.44	13.05	103.56	86.98	50.44	47.38	9.04	8.75	62.94	61.15
P_1T_0	--	--	--	--	--	--	45.59	33.27	9.72	7.93	68.84	69.01
P_1T_1	--	--	--	--	--	--	80.58	56.30	10.91	10.21	91.67	84.44
P_1T_2	--	--	--	--	--	--	58.88	49.01	10.62	10.27	90.60	84.67
P_1T_3	--	--	--	--	--	--	41.43	39.07	10.30	10.12	96.36	89.82
P_1T_4	--	--	--	--	--	--	46.87	42.88	10.33	10.02	94.54	82.29
P_2T_0	--	--	--	--	--	--	48.17	47.37	10.91	10.35	73.57	76.97
P_2T_1	--	--	--	--	--	--	62.38	39.56	12.33	11.84	99.38	93.44
P_2T_2	--	--	--	--	--	--	59.27	46.55	12.29	11.59	96.71	94.12
P_2T_3	--	--	--	--	--	--	59.06	40.15	12.41	11.80	95.28	94.08
P_2T_4	--	--	--	--	--	--	51.01	44.47	12.45	11.76	97.04	95.17
Sem± (Main)	9.84	9.29	1.36	2.82	8.69	9.77	6.08	5.24	0.48	0.64	3.95	4.36
Sem± (Sub)							2.75	3.75	0.51	0.44	3.16	3.78
CD (p= 0.05) Main	22.73	21.43	3.15	5.26	19.85	20.93	14.05	11.58	1.19	1.39	9.18	10.70
CD (p= 0.05) Sub							5.75	6.62	1.71	0.94	6.59	6.42

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Table 7. Direct and residual effect of different levels of water soluble phosphorus in complex fertilizer on nutrient uptake by baby corn and mustard.

Treatment	Nutrient uptake by baby corn (Kg/ha)						Nutrient uptake by mustard (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	56.22	63.42	6.15	6.30	83.16	93.21	45.61	53.54	4.13	4.29	70.20	74.27
P_0T_1	65.54	68.72	8.35	8.99	101.46	108.87	55.86	63.54	5.70	5.53	83.11	87.08
P_0T_2	68.50	66.23	8.10	9.02	104.46	115.44	58.53	67.69	5.97	5.74	87.72	88.72
P_0T_3	69.80	67.39	8.50	8.75	109.73	114.25	59.44	65.76	5.40	5.66	90.90	92.56
P_0T_4	71.69	70.04	8.28	8.59	108.01	113.51	61.73	64.16	5.76	5.45	90.79	96.23
P_1T_0	--	--	--	--	--	--	50.97	56.90	5.68	5.38	77.93	78.39
P_1T_1	--	--	--	--	--	--	61.73	67.35	6.68	6.75	93.87	92.98
P_1T_2	--	--	--	--	--	--	63.44	68.03	7.00	6.05	97.51	91.09
P_1T_3	--	--	--	--	--	--	65.87	67.72	6.51	6.85	97.93	98.82
P_1T_4	--	--	--	--	--	--	64.00	70.33	6.31	6.19	98.04	97.05
P_2T_0	--	--	--	--	--	--	51.70	57.28	6.31	6.39	81.16	83.06
P_2T_1	--	--	--	--	--	--	68.53	76.76	7.70	8.10	97.68	97.68
P_2T_2	--	--	--	--	--	--	66.37	76.68	7.33	8.02	98.16	101.52
P_2T_3	--	--	--	--	--	--	69.08	76.54	7.93	8.52	103.67	99.07
P_2T_4	--	--	--	--	--	--	67.11	69.65	7.11	8.59	101.04	102.27
Sem± (Main)	5.89	6.80	2.53	3.34	6.57	7.00	4.28	7.66	0.78	1.50	2.56	5.04
Sem± (Sub)							2.30	2.34	0.40	0.39	1.70	1.42
CD (p= 0.05) Main	13.44	15.68	5.85	7.71	15.16	16.15	9.86	17.66	1.79	3.45	5.90	11.62
CD (p= 0.05) Sub							4.79	4.88	0.83	0.81	3.54	2.96

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Table 8. Direct and residual effect of different levels of water soluble phosphorus in complex fertilizer on nutrient uptake by chickpea and groundnut.

Treatment	Nutrient uptake by Chickpea (Kg/ha)						Nutrient uptake by Groundnut (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	54.12	59.55	13.35	3.81	67.24	68.54	60.14	62.18	11.46	12.29	67.01	69.07
P_0T_1	65.05	68.33	16.00	6.48	81.49	86.66	73.39	79.45	13.50	14.90	82.79	89.04
P_0T_2	62.95	67.95	15.53	6.62	81.16	85.37	72.00	78.20	13.29	14.56	80.79	87.29
P_0T_3	62.45	66.45	15.53	6.79	80.80	84.06	68.25	75.71	12.93	14.21	79.35	87.49
P_0T_4	61.38	64.38	15.73	7.51	80.80	82.93	71.05	76.45	12.39	13.84	77.78	86.91
P_1T_0	--	--	--	--	--	--	65.42	68.48	12.68	13.98	72.74	79.29
P_1T_1	--	--	--	--	--	--	82.98	86.71	14.52	15.95	89.25	92.84
P_1T_2	--	--	--	--	--	--	81.66	82.58	14.76	15.30	87.56	90.86
P_1T_3	--	--	--	--	--	--	78.11	79.81	13.76	15.13	85.54	88.08
P_1T_4	--	--	--	--	--	--	79.72	78.65	13.86	14.87	82.24	89.16
P_2T_0	--	--	--	--	--	--	72.96	72.03	13.65	14.35	76.66	82.05
P_2T_1	--	--	--	--	--	--	89.12	93.83	15.35	17.18	92.73	94.03
P_2T_2	--	--	--	--	--	--	87.09	91.50	14.87	16.93	87.35	92.80
P_2T_3	--	--	--	--	--	--	85.76	89.62	14.94	16.76	86.31	91.00
P_2T_4	--	--	--	--	--	--	86.30	88.96	14.99	16.81	85.64	90.68
Sem± (Main)	4.265	3.583	0.563	0.773	1.103	1.236	10.23	7.13	3.08	2.92	4.46	5.60
Sem± (Sub)							5.14	4.66	1.01	1.29	2.79	3.25
CD (p= 0.05) Main	9.834	8.262	1.297	1.783	2.544	2.852	23.62	16.44	7.15	6.73	10.28	8.95
CD (p= 0.05) Sub							10.73	9.73	2.10	2.56	5.83	2.54

 DOI:

Table 9. Direct and residual effect of different levels of water soluble phosphorus in complex fertilizer on residual soil fertility after harvest of rice and wheat.

Treatment	Residual soil fertility after rice (Kg/ha)						Residual soil fertility after wheat (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	158.16	167.37	12.76	13.81	235.35	247.45	162.26	170.01	10.98	12.32	270.50	277.39
P_0T_1	185.69	189.06	23.93	26.80	275.58	286.15	201.02	198.61	15.52	15.78	284.38	291.57
P_0T_2	182.96	183.81	21.76	24.45	270.62	283.77	197.03	193.85	15.12	15.67	285.65	287.81
P_0T_3	178.16	179.38	21.64	23.39	265.88	276.11	187.34	192.26	14.87	15.34	280.58	282.53
P_0T_4	174.15	183.13	20.74	23.06	266.45	274.83	171.42	177.96	14.91	15.12	281.42	281.20
P_1T_0	--	--	--	--	--	--	189.10	193.85	12.28	14.22	275.34	284.48
P_1T_1	--	--	--	--	--	--	211.35	201.79	18.12	19.12	300.44	308.09
P_1T_2	--	--	--	--	--	--	201.12	206.56	17.97	18.89	295.84	305.63
P_1T_3	--	--	--	--	--	--	179.34	176.37	17.52	18.57	300.44	307.47
P_1T_4	--	--	--	--	--	--	162.32	177.96	17.5	17.84	302.38	304.48
P_2T_0	--	--	--	--	--	--	170.24	174.78	13.38	16.72	280.65	293.81
P_2T_1	--	--	--	--	--	--	232.27	204.97	19.54	18.94	305.48	342.35
P_2T_2	--	--	--	--	--	--	209.11	198.61	18.98	19.08	300.65	323.43
P_2T_3	--	--	--	--	--	--	196.15	196.42	18.43	18.87	297.77	328.48
P_2T_4	--	--	--	--	--	--	194.95	190.67	18.03	18.67	300.86	326.24
Sem± (Main)	14.59	16.62	9.07	3.98	13.41	15.98	9.55	34.47	8.57	6.16	31.30	22.69
Sem± (Sub)							6.14	22.44	6.49	4.86	24.18	18.28
CD (p= 0.05) Main	33.57	38.33	20.86	9.19	30.95	36.86	21.96	79.49	19.76	14.15	72.17	52.29
CD (p= 0.05) Sub							12.79	46.81	13.54	10.14	50.44	38.06

Table 10. Direct and residual effect of different levels of water soluble phosphorus in complex fertilizer on residual soil fertility after harvest of baby corn and mustard.

Treatment	Residual soil fertility after baby corn (Kg/ha)						Residual soil fertility after mustard (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	204.15	206.44	13.42	12.77	263.35	271.01	184.43	199.00	11.80	12.45	253.55	268.99
P_0T_1	225.24	231.38	16.59	17.41	281.59	295.55	198.61	239.23	15.36	16.40	270.55	277.33
P_0T_2	227.43	235.12	15.99	17.95	278.56	297.39	202.52	242.06	14.88	16.77	276.85	279.20
P_0T_3	226.98	233.45	16.70	17.58	282.99	290.26	210.33	236.42	15.35	17.09	275.38	283.36
P_0T_4	229.52	235.77	16.47	17.82	284.38	293.34	212.34	241.12	14.96	16.15	278.36	280.44
P_1T_0	--	--	--	--	--	--	204.89	208.64	12.89	15.67	262.45	272.69
P_1T_1	--	--	--	--	--	--	214.89	242.08	17.38	18.94	290.37	280.00
P_1T_2	--	--	--	--	--	--	219.52	249.56	16.88	18.71	288.12	283.40
P_1T_3	--	--	--	--	--	--	217.88	247.09	17.66	19.10	282.36	285.87
P_1T_4	--	--	--	--	--	--	219.07	241.20	16.94	18.97	286.60	279.68
P_2T_0	--	--	--	--	--	--	216.33	216.78	14.56	16.24	275.38	283.49
P_2T_1	--	--	--	--	--	--	247.15	269.42	20.36	19.90	298.80	292.88
P_2T_2	--	--	--	--	--	--	250.53	259.00	19.44	19.85	302.88	293.40
P_2T_3	--	--	--	--	--	--	254.70	257.50	19.65	19.80	300.85	298.37
P_2T_4	--	--	--	--	--	--	259.43	263.98	19.84	19.21	305.38	293.75
Sem± (Main)	17.85	17.29	5.10	3.22	8.29	23.75	6.46	20.67	11.56	3.88	4.59	12.37
Sem± (Sub)							6.40	8.76	5.60	2.14	7.54	12.46
CD (p= 0.05) Main	41.16	39.86	11.75	7.42	19.12	54.76	14.90	47.67	26.67	8.94	10.58	28.53
CD (p= 0.05) Sub							13.35	18.28	11.68	4.46	15.72	25.98

 DOI:

Table 11. Direct and residual effect of different levels of water soluble phosphorus in complex fertilizer on residual soil fertility after harvest of Chickpea and Groundnut.

Treatment	Residual soil fertility after Chickpea (Kg/ha)						Residual soil fertility after Groundnut (Kg/ha)					
	Nitrogen		Phosphorus		Potassium		Nitrogen		Phosphorus		Potassium	
	2012	2013	2013	2014	2012	2013	2013	2014	2013	2014	2013	2014
P_0T_0	257.46	268.46	7.81	8.24	303.33	324.41	228.83	239.16	7.02	7.51	273.33	279.89
P_0T_1	299.22	309.23	8.82	9.51	335.50	373.65	260.95	269.43	8.44	8.92	298.91	308.75
P_0T_2	294.56	304.97	8.00	9.37	329.83	365.71	259.92	267.85	8.83	8.87	293.75	302.17
P_0T_3	291.97	301.56	7.84	9.11	322.67	357.41	257.95	261.33	7.96	8.77	291.28	297.33
P_0T_4	289.23	299.22	7.67	8.92	316.17	356.29	253.37	259.36	8.07	8.59	187.41	296.68
P_1T_0	--	--	--	--	--	--	249.40	255.35	7.62	7.73	286.07	293.71
P_1T_1	--	--	--	--	--	--	267.77	281.71	8.87	9.97	313.67	319.87
P_1T_2	--	--	--	--	--	--	266.44	278.54	8.97	9.87	308.88	314.61
P_1T_3	--	--	--	--	--	--	265.20	275.18	8.78	9.86	304.98	310.02
P_1T_4	--	--	--	--	--	--	262.26	274.03	8.59	8.69	302.92	308.37
P_2T_0	--	--	--	--	--	--	253.45	256.94	7.93	8.11	291.06	302.35
P_2T_1	--	--	--	--	--	--	281.54	294.14	9.87	10.50	319.22	326.54
P_2T_2	--	--	--	--	--	--	278.86	289.66	9.55	10.10	312.60	321.87
P_2T_3	--	--	--	--	--	--	279.04	286.59	8.95	9.87	309.88	314.62
P_2T_4	--	--	--	--	--	--	274.86	284.06	8.69	9.65	306.97	311.77
Sem± (Main)	23.83	22.98	5.40	8.38	14.72	24.12	23.67	20.48	5.85	7.96	21.49	82.61
Sem± (Sub)							14.67	19.48	3.78	4.57	13.14	43.16
CD (p= 0.05) Main	54.96	52.99	12.45	19.32	33.95	55.62	54.59	47.23	13.48	18.36	49.55	42.10
CD (p= 0.05) Sub							30.61	40.63	7.88	9.54	27.42	29.62

justing P recycling internally, limiting P consumption, and reallocating P from old tissues to young and/or actively growing tissues (Marschner, 1995)[18]. Taken together, plants have developed a series of adaptive responses to take up and utilize P efficiently, including morphological, physiological, and biochemical responses.

5. Conclusion

Study data showed that all four levels of WSP in P-fertilizers (i.e. 30 %, 60%, 85% and 89%) and three cropping systems namely Rice-wheat, Baby corn-Mustard and Chickpea-Groundnut at Giridih, Jharkhand, India were found to be equally effective for crop yield, nutrient uptake, and soil fertility. However, all studied parameters were increased with increasing the levels of phosphorus (i.e. 0%, 50% RDF and 100% RDF).

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