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Influence of phosphorus levels, application timing and methods on productivity and profitability of soybean (*Glycine max* L.) under Vertisols of Chhattisgarh state

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Abstract

The field experiment was conducted during *kharif* seasons of 2005–06 and 2006–07 at the Instructional Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. The experimental soil was clayey in texture (*Vertisols*), low in available nitrogen, medium in available phosphorus and organic carbon, and high in available potassium. Soybean (*Glycine max* L.) cultivar JS-335 was grown in a split-plot design with three replications. The main plots consisted of two phosphorus application levels: 40 kg P₂O₅ ha⁻¹ and 60 kg P₂O₅ ha⁻¹ and the sub-plots included five phosphorus application schedules and methods: (i) broadcast (ii) drilling (iii) two equal splits (50% basal as drilling + 50% side dressing at 30 DAS) (iv) two equal splits with blending in FYM (50% basal as drilling after blending with FYM + 50% side dressing at 30 DAS after blending with FYM), and (v) three splits (50% basal as drilling + 25% side dressing at 30 DAS + 25% side dressing at 50 DAS). Results indicated that application of 60 kg P₂O₅ ha⁻¹, in combination with two splits (with or without FYM blending), consistently produced significantly higher seed yield, straw yield, harvest index, phosphorus recovery index, phosphorus use efficiency, gross returns, net returns, and benefit-cost ratio in both the years. The highest return per rupee invested on phosphorus fertilizer was recorded under 40 kg P₂O₅ ha⁻¹ with two splits (with or without FYM blending) or drilling application.

Keywords: Soybean, phosphorus, split application, blending, yield, HI, PRI, PE, B:C ratio

Introduction

Soybean (*Glycine max* L.) is the third most important oilseed crop in India, following groundnut and rapeseed-mustard. It is predominantly cultivated during the *kharif* season and is valued for its high protein (~40%) and oil (20%) content. Globally, major soybean-producing regions include the United States of America (31 M ha), Brazil (22 M ha), Argentina (17 M ha), India (11 M ha), and China (9 M ha) (Vass and Gupta, 2017) [20]. More than 25 countries produce over one million tonnes of soybean annually. Owing to its versatility as a major protein source for human consumption and animal feed, soybean is often referred to as the “miracle crop” or “golden bean.” In India, soybean productivity in recent years has ranged between 1000 and 1200 kg ha⁻¹, which is approximately 60% of the global average and among the lowest in major soybean-producing nations.

Phosphorus (P) is a vital nutrient for plant growth, playing a key role in energy transfer, respiration, and photosynthesis. It is an essential structural component of nucleic acids, coenzymes, phosphoproteins, and phospholipids (Ozanne, 1980) [8]. Inadequate phosphorus supply limits crop productivity and hampers normal reproductive development. Widespread phosphorus deficiency is considered the second most important nutrient constraint to crop yields after nitrogen. In India, low P use efficiency and high P fixation in soils exacerbate the problem. Only a small fraction of total soil phosphorus is available for plant uptake, with soil solution P concentrations typically below 0.1 ppm (0.5 kg P₂O₅ ha⁻¹ in the plough layer), except in sodic or heavily fertilized soils (Tandon, 1987) [18].

Soil total P content is influenced by parent material, climate, land use, cropping intensity, and management practices, and varies widely across agro-ecological regions from less than 200 to

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over 2000 ppm, and in some cases from 44 to 3580 ppm (Tomar, 2000) ^[19]. Phosphorus occurs in both organic and inorganic forms, with most research focused on inorganic P. The rate of P fixation in black soils (*Vertisols*) of Chhattisgarh involves both rapid and slow reactions (Motiramani et al., 1964) ^[6], with maximum fixation observed after 30 days of reaction, followed by partial release due to microbial activity and mineralization of organic P after 60 days (Dravid and Apte, 1975) ^[4].

Efficient utilization of phosphorus fertilizer depends not only on the application rate but also on the timing and method of application. Mixing superphosphate with organic manure before field application has been shown to improve efficiency (Reddy et al., 1990) ^[10]. Placement methods such as banding or drilling behind the plough are generally more effective than broadcasting (Singh and Gupta, 1969) ^[15]. The recovery of applied P by crops is typically low, ranging from 10% to 20%, leaving 80%–90% of the applied P in the soil, which may benefit subsequent crops (Kothari and Saraf, 1987) ^[8]. In soybean-based systems, fertilizer P has been reported to have significant residual effects on succeeding wheat crops (Subba Rao et al., 1998) ^[16].

Given the high cost of phosphorus fertilizers, the finite nature of global phosphate reserves, and the low recovery rates in Indian soils, optimizing phosphorus use through appropriate application rates, timings, and methods is essential. The present study was therefore undertaken to investigate the “Influence of Phosphorus Levels, Application Timing and Methods on Productivity and Profitability of Soybean (*Glycine max* L.) under *Vertisols* of Chhattisgarh State”

Material and Methods

The field experiment was conducted for two consecutive *kharif* seasons (2005–06 and 2006–07) on soybean (*Glycine max* L.) under irrigated conditions at the Instructional Farm, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India. The treatments were designed to enhance crop productivity and improve phosphorus use efficiency. Raipur, a prominent rice-growing region in eastern India, is located at 21°16' N latitude and 81°36' E longitude, at an altitude of 298 m above mean sea level. The site lies in the Eastern Plateau and Hills agro-climatic zone (Zone VII) of India and is characterized as sub-humid with hot summers and cool winters. The long-term (80-year mean) average annual rainfall is 1326 mm, with a coefficient of variation of 23.4%, of which approximately 85% is received during the southwest monsoon season (June–September). Mean maximum temperature during summer reaches up to 45°C, whereas mean minimum temperature during winter drops to around 6°C. Relative humidity during the *kharif* season averages about 91%, declining to around 40% during the *rabi* season.

The experimental soil was clayey in texture (*Vertisols*), low in available nitrogen, medium in available phosphorus and organic carbon, and high in available potassium. Soybean (*Glycine max* L.) cultivar JS-335 was grown during the *kharif* seasons of 2005 and 2006. The study comprised ten treatment combinations arranged in a split-plot design with three replications. The main plot treatments consisted of two phosphorus application levels: 40 kg P₂O₅ ha⁻¹ and 60 kg P₂O₅ ha⁻¹. The sub-plot treatments included five phosphorus application schedules and methods: (1) Broadcast application, (2) Drilling, (3) Two equal splits (50% basal as drilling + 50% side dressing at 30 DAS), (4) Two equal splits with blending in FYM (50% basal as drilling after blending with FYM + 50% side dressing at 30 DAS after blending with FYM), and (5) Three splits (50% basal as drilling

+ 25% side dressing at 30 DAS + 25% side dressing at 50 DAS). Uniform nitrogen and potassium (K₂O) application was made to all treatments. In treatment TM₄, phosphorus blending with FYM was carried out under anaerobic conditions for 72 hours prior to sowing, as well as before the side-dressing at 30 DAS.

Results and Discussion

Yield attributing characters and yield

Seed and Straw Yield

Soybean (*Glycine max* L.) cv. JS-335 was evaluated for its response to phosphorus (P) levels and their time and method of application under *Vertisols*. In 2005, application of 60 kg P₂O₅ ha⁻¹ significantly increased seed yield compared to 40 kg P₂O₅ ha⁻¹. However, in 2006, as well as in the pooled analysis, seed yield was not significantly influenced by P level. Straw yield followed a similar trend, with significant differences only in 2005. With respect to the time and method of P application, two equal splits of P blended with farmyard manure (FYM) recorded significantly higher seed yield in 2005, while two splits without FYM blending produced the highest seed yield in 2006. In pooled analysis, both these treatments were statistically at par. Drilling of Phosphorus also produced yields comparable to the best treatments in 2005. A similar trend was observed for straw yield, except in 2006 where differences were non-significant.

Yield Attributes

Analysis of yield attributes (Table 1) indicated that the number of pods plant⁻¹, 100-seed weight, seed yield plant⁻¹, and straw yield plant⁻¹ were maximized under two splits of P blended with FYM, followed by two splits without FYM blending. The improved performance of these treatments may be attributed to enhanced vegetative growth and branching, providing more potential sites for pod formation. Improved nutrient availability likely supported these outcomes, as phosphorus is essential for key metabolic processes such as photosynthesis, glycolysis, and respiration, mediated through phosphorus-dependent coenzymes like NAD and NADP (Singh et al., 1995; Detroja et al., 1995) ^[17, 3]. Similar beneficial effects of inorganic P blended with FYM on growth and yield attributes have been reported in finger millet (Shailendranath and Rao, 1979; Nayak, 1993) ^[13, 7] and mustard (Roul, 2002) ^[11]. In contrast, surface broadcasting of P resulted in lower performance, possibly due to greater contact with soil particles, leading to fixation in the topsoil and reduced plant availability. In comparison, drilling P near the root zone and applying it in two or three splits (with or without FYM blending) likely ensured continuous P availability throughout the crop growth period, enhancing P uptake. These findings corroborate earlier studies by Singh and Gupta (1969) ^[15], Singh and Sarkar (1985) ^[14], and Purushothaman et al. (1990) ^[9].

Physiological Basis of Yield Response

Phosphorus, being a constituent of adenosine diphosphate, coenzyme II, phosphoglyceraldehyde, and ribulose phosphate, plays a vital role in photosynthesis, energy transfer, and other metabolic processes (Agarwala and Sharma, 1973) ^[1]. Higher P application rates and split applications likely enhanced dry matter accumulation by improving metabolic activity, resulting in greater sink development (pods plant⁻¹, seeds plant⁻¹, and test weight). Increased P₂O₅ rates may have promoted root growth and seedling vigor, enabling better nutrient absorption from deeper soil layers and supporting greater vegetative growth. These findings align with Akbari et al. (2001) ^[2], who reported enhanced dry matter production and nutrient uptake under higher P levels. The superiority of FYM-blended SSP may be

attributed to the coating effect of organic matter, which slows dissolution, reduces fixation, and extends P availability (Sharma *et al.*, 2002)^[12]. However, unblended split applications at higher P levels also performed comparably, likely due to improved root development and nutrient uptake.

Harvest Index, Productivity Rating Index (PRI), and Production Efficiency (PE)

Harvest index (HI) was unaffected by P level in both years and in the pooled analysis, but was significantly influenced by the time and method of application in 2006, with the highest HI recorded under two splits without FYM blending. Residual P from the previous season, combined with current application, may have increased P availability, resulting in higher grain yield. PRI and PE were significantly higher under 60 kg P₂O₅ ha⁻¹ in 2005, but were not affected by P level in 2006 or in the pooled analysis. Time and method of application had a pronounced effect, with two splits (with or without FYM blending) producing significantly higher PRI values in the pooled analysis. The enhanced performance under these

treatments is likely due to synergistic effects of higher P on root proliferation, nodule formation, and nutrient uptake, leading to improved growth and yield.

Economics

Economic analysis (Table 3) indicated that gross returns were highest under 60 kg P₂O₅ ha⁻¹ in 2005, but P level did not significantly affect gross returns in 2006 or in the pooled analysis. Regarding time and method of application, two splits without FYM blending produced the highest gross returns, which were statistically comparable to two splits with FYM blending in pooled analysis. This can be attributed to the higher yields obtained in these treatments. Net returns and benefit-cost (B:C) ratio followed similar trends, with higher B:C ratios indicating lower production cost per unit yield. Return on investment in P fertilizer (Rs Re⁻¹) was significantly higher under 40 kg P₂O₅ ha⁻¹ and with drilling method of application. In the pooled analysis, drilling and two splits without blending were at par. The advantage of these treatments lies in the lower fertilizer cost combined with relatively high net returns.

Table 1: Yield attributing characters of soybean as influenced by phosphorus levels and their time and method of application

Treatment	No. of pods plant ⁻¹			Seed pod ⁻¹			Pod length, cm			Test weight, g			Seed yield plant ⁻¹ , g			Straw yield plant ⁻¹ , g		
	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled
Phosphorus level																		
P ₄₀	33.95	43.45	38.70	2.83	2.48	2.66	3.84	3.62	3.73	12.75	14.05	13.40	11.84	12.17	12.01	9.90	12.92	11.41
P ₆₀	34.79	45.35	40.07	2.79	2.62	2.71	3.85	3.55	3.70	12.76	14.08	13.42	11.63	12.53	12.08	10.66	19.17	14.92
SEm ±	0.60	0.86	0.34	0.04	0.07	0.01	0.02	0.08	0.04	0.10	0.15	0.13	0.41	0.32	0.36	0.15	0.34	0.24
CD _(0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	2.05	1.45
Time and method of phosphorus application																		
Broadcast	30.77	42.00	36.38	2.78	2.63	2.71	3.84	3.39	3.61	13.02	13.83	13.42	11.61	11.25	11.43	9.24	14.61	11.93
Drilling	32.40	42.77	37.58	2.82	2.67	2.74	3.86	3.78	3.82	12.13	13.95	13.04	10.99	11.35	11.17	9.41	15.81	12.61
Two split	36.80	44.10	40.45	2.83	2.45	2.64	3.86	3.53	3.70	13.15	14.30	13.72	10.90	13.21	12.06	10.30	15.97	13.13
Two split (blending)	37.47	47.17	42.32	2.85	2.40	2.62	3.88	3.56	3.72	12.72	14.25	13.48	12.92	13.36	13.14	10.89	18.02	14.46
Three split	34.40	45.97	40.18	2.78	2.60	2.69	3.77	3.66	3.72	12.75	13.98	13.37	12.27	12.57	12.42	11.55	15.81	13.68
SEm ±	1.53	1.15	1.03	0.04	0.12	0.07	0.07	0.14	0.09	0.34	0.35	0.25	0.48	0.57	0.42	0.48	1.24	0.58
CD _(0.05)	4.59	3.46	3.10	NS	NS	NS	NS	NS	NS	NS	NS	NS	1.45	1.70	1.27	1.44	NS	NS
Mean	34.37	44.40	39.38	2.81	2.55	2.68	3.84	3.58	3.71	12.75	14.06	13.41	11.73	12.35	12.04	10.28	16.04	13.16

Table 2: Seed and straw yield, harvest index, productivity rating index (PRI) and production efficiency of soybean as influenced by phosphorus levels and their time and method of application

Treatment	Seed yield, q ha ⁻¹			Straw yield, q ha ⁻¹			Harvest index, %			PRI			Production efficiency, kg ha ⁻¹ day ⁻¹		
	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled
Phosphorus level															
P ₄₀	24.58	31.58	28.08	53.08	42.87	47.97	31.85	42.37	37.11	1.23	1.58	1.40	22.14	25.89	24.01
P ₆₀	27.17	31.84	29.50	54.52	40.62	47.57	33.24	43.90	38.57	1.36	1.59	1.47	24.47	26.10	25.29
SEm ±	0.32	0.78	0.42	2.14	0.44	0.94	1.02	0.67	0.68	0.02	0.04	0.02	0.29	0.64	0.35
CD _(0.05)	1.96	NS	NS	NS	NS	NS	NS	NS	NS	0.10	NS	NS	1.77	NS	NS
Time and method of phosphorus application															
Broadcast	22.66	28.51	25.58	45.78	40.12	42.95	33.29	41.52	37.41	1.13	1.42	1.28	20.41	23.37	21.89
Drilling	26.82	30.43	28.63	56.06	41.55	48.80	32.38	42.28	37.33	1.34	1.52	1.43	24.16	24.95	24.55
Two split	27.05	35.37	31.21	58.64	42.45	50.54	31.58	45.52	38.55	1.35	1.77	1.56	24.37	28.99	26.68
Two split (blending)	27.99	32.19	30.09	56.06	42.93	49.49	33.30	42.87	38.08	1.40	1.61	1.50	25.21	26.39	25.80
Three split	24.84	32.05	28.45	52.46	41.66	47.06	32.18	43.47	37.83	1.24	1.60	1.42	22.38	26.27	24.33
SEm ±	0.70	0.45	0.50	1.77	0.77	0.96	0.69	0.56	0.48	0.03	0.02	0.02	0.63	0.37	0.43
CD _(0.05)	2.09	1.36	1.49	5.30	NS	2.89	NS	1.69	NS	0.10	0.07	0.07	1.88	1.11	1.30
Mean	25.87	31.71	28.79	53.80	41.78	47.77	32.54	43.13	37.84	1.29	1.58	1.44	23.30	25.99	24.65

Table 3: Economics of soybean as influenced by phosphorus levels and their time and method of application

Treatment	Cost incurred, '000 Rs ha ⁻¹		Gross return, '000 Rs. ha ⁻¹			Net return, '000 Rs. ha ⁻¹			Benefit: cost ratio			Return Rs ⁻¹ investment on P fertilizer (Rs. Re ⁻¹)		
	2005-06	2006-07	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled	2005-06	2006-07	Pooled
Phosphorus level														
P ₄₀	12.89	12.89	32.15	40.04	36.10	19.26	27.15	23.20	1.49	2.10	1.80	18.92	26.45	22.68
P ₆₀	13.28	13.28	35.33	40.24	37.78	22.05	26.96	24.50	1.66	2.03	1.84	15.58	19.11	17.34
SEm ±	-	-	0.33	0.93	0.46	0.33	0.93	0.46	0.02	0.07	0.03	0.32	0.78	0.34
CD _(0.05)	-	-	2.01	NS	NS	2.01	NS	NS	0.15	NS	NS	1.96	4.74	2.10
Time and method of phosphorus application														
Broadcast	12.90	12.90	29.48	36.22	32.85	16.57	23.32	19.95	1.28	1.81	1.54	16.34	22.95	19.64
Drilling	12.97	12.97	34.99	38.60	36.79	22.01	25.62	23.82	1.70	1.97	1.84	20.34	23.71	22.02
Two split	13.12	13.12	35.39	44.57	39.98	22.27	31.45	26.86	1.70	2.40	2.04	17.71	25.44	21.58
Two split (blending)	13.15	13.15	36.39	40.78	38.58	23.24	27.63	25.43	1.76	2.10	1.93	18.15	21.99	20.07
Three split	13.27	13.27	32.43	40.54	36.49	19.16	27.27	23.22	1.44	2.06	1.75	13.71	19.80	16.76
SEm ±	-	-	0.88	0.55	0.62	0.88	0.55	0.62	0.07	0.04	0.05	0.77	0.50	0.53
CD _(0.05)	-	-	2.64	1.64	1.86	2.64	1.64	1.86	0.20	0.13	0.14	2.31	1.51	1.58
Mean	13.08	13.08	33.74	40.14	36.94	20.65	27.06	23.85	1.57	2.06	1.82	17.25	22.78	20.01

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