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Varietal Influence on Phosphorus Uptake and Use Efficiency in Soybean at Varying Phosphorus Regimes in Vertisols of Central India

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ABSTRACT

A field experiment was carried out in Indian Institute of Soil Science, Bhopal to study the effect of different dose of phosphorus on the phosphorus acquisition pattern in different varieties of soybean (*Glycine max* L.) under rainfed conditions in black soil. The experiment was laid out in factorial RBD with 3 replications. There were four phosphorus levels *viz.* 0, 30, 60 and 90 kg ha^{-1} phosphorus and four varieties of soybean *viz.*, JS 9560, JS 9305, JS 335 and JS 9752. The results revealed that the variety JS 9752 is better in phosphorus acquisition and yield. Grain yield showed a linear increase only up to 60 kg ha^{-1} phosphorus in all the varieties. Among the varieties, JS 9752 has given the highest grain yield on supply of 60 kg ha^{-1} phosphorus. Phosphorus uptake and use efficiency were also were highest for the variety JS 9752 followed by JS 9560 in all the treatments. Hence it is concluded that JS 9752 is the most efficient variety among the four in terms of yield and phosphorus uptake followed by JS 9560.

Introduction

Soybean (*Glycine max* (L.) Merrill) know as the 'Golden bean or the Super bean' of the twentieth century is one of the main oil yielding crops in the world. Soybean belongs to the family Leguminosae, sub-family Papilionaceae and the genus Glycine. The crop has a well-known place as the world's most important seed legume, which accounts 25% to the global vegetable oil production, about two thirds of the world's protein concentrate for livestock feeding and is a major constituent in formulated feeds for poultry and fish. Soybean plays a crucial role in agricultural economy of India. Annually about 85% of the world's soybeans are processed into soybean meal and oil. Soybean oil plays a good role as edible oil as well as raw material in industries like soap and biodiesel production. Soybean contributes substantially to the Indian edible oil pool and currently soybean contributes 43% to the total oilseeds and 25% to soybean in the world.

In India soybean is traditionally grown in the *'Kharif'* or monsoon season as a rainfed crop and assumed as one of the most stable *kharif* pulses under different agro-climatic conditions (Kumar *et al.,* 2008). Among the Indian states, Madhya Pradesh is known as the 'soybean belt' which alone accounts for 81% of the area under soybean cultivation. Among the Indian states, Maharashtra and Madhya Pradesh are the major soybean producers and about 89 per cent of the total production is contributed by these states. Soybean can improve soil fertility by fixing atmospheric nitrogen through root nodules. Low productivity of soybean in India is due to several constraints, one among the important is unbalanced nutrition (Sharma *et al.,* 1996).

Soybean can be grown on almost all well-drained soils; although, the crop is more productive on fertile loam soils. Plant nutrition is a important input to boost the productivity of soybean crop. Phosphorus is one of the limiting plant nutrients for production of soybean (Rao *et al.,* 1995). Phosphorus has a wide range of functions in plant processes from permitting cell division to development of good root system. Pod setting, seed formation and protein synthesis are major functions of phosphorus in pulses. Phosphorus uptake and utilization by soybean crop is important for ensuring proper growth and maintaining good quality and yield of the crop. Phosphorus deficiency can cause a limit nodulation in legumes and P fertilizer application can overcome this deficiency (Carsky *et al.,* 2001).

Phosphorus has consistently increased grain yield of soybean on phosphorus deficient soils (Pal *et al.,* 1983; Chiezey *et al.,* 1991) as it also encourages production and retention of more pods per plant (Chiezey, 2001).

In general phosphorus fertilizers have low efficiency of utilization due to chemical fixation in soil (Russell, 1973). Low phosphorous availability is a major constraint to soybean growth and production. Alongside, there will be a great shortage of P fertilizer resources as the P deposits are depleting in an alarming rate (Yan *et al.,* 2009). Hence, developing new varieties with high P efficiency or find out P efficient varieties in the existing varietal germplasm, that can utilize native P and added P in the soil would be a sustainable and cost-effective approach to soybean production. Keeping these views, the present investigation was carried out to study the performance of different soybean cultivars at varying P regimes through applied P fertilizer.

Materials and Methods

Experimental site and soil

The field experiment was conducted at Indian Institute of Soil Science, Bhopal (Between 23°18'14" and 23°18'48" N latitude and 77°24'17" and 77°24'58" E longitude on Vindhyan plateau of western Madhya Pradesh) to study the effect of different phosphorus levels viz., 0, 30, 60 and 90 kg ha^{-1} on phosphorous acquisition and use efficiency of four major varieties of soybean in Vertisols of central India. The experimental soil contained 5 g kg^{-1} organic carbon, 110.27 ppm nitrogen, 1.6 ppm available phosphorus and 250.6 ppm available K with pH 8.35. The experiment was conducted in a factorial randomized complete block design with plot size 3.0 m x 5.0 m and replicated thrice. Seedbed was prepared by 2-3 times ploughing followed by planking. Four varieties of soybean *viz.,* JS 9560, JS 9752, JS 9305 and JS 335 as V1, V2, V3 and V4 respectively were used for the study. The breeder seeds of these different varieties were collected from Directorate of Soybean, Indore. The sowing was done manually with seed rate of 80 kg ha^{-1} at a row to row distance of 45 cm.

Fertilizer application and other cultural practices

A recommended starter dose of N @ 20 kg ha^{-1}, K @ 20 kg ha^{-1} and Zn @ 5 kg ha^{-1} were applied at sowing time as Urea (46% N), Muriate of Potash (50% K_2O) and Zinc Sulphate (21% Zn and 18% S). Phosphorus was applied at four graded levels (P1: 0 kg, P2: 30 kg, P3: 60 kg and P4: 90 kg P_2O_5 ha^{-1}) supplied through single super phosphate (16% P_2O_5). Thinning was done at 15 days after germination to maintain a plant to plant distance of 10 cm and optimum plant population. Hoeing was done thrice to keep the crop weed free. No irrigation was given as the crop was raised as rainfed crop. All other cultural practices were kept normal and uniform for all the treatments. Different varieties were harvested on different dates according to their maturity (Table 1).

Data recording and analysis

Five plants were selected at random from each net plot for recording observation. Days to 50% flowering was recorded by counting the total number of days required for 50% of the total population to reach flowering stage, days to physiological maturity was recorded by counting number of days required the entire plants to reach yellow and dry stage and grain yield by taking the total seed yield $plant^{-1}$ from each treatment. For nutrient analysis the plant samples were collected by uprooting 5 plants randomly at physiological maturity and dried in the oven at 70°C and samples were powdered separately as leaf, stem, pod and grain for total phosphorus analysis. Phosphorus content in the plant parts were analyzed by vanado-molybdophosphoric yellow colour method (Jackson, 1973). The uptake of nutrients was calculated by multiplying the plant/ seed dry weight in kg ha^{-1} and nutrient concentration in the respective plant part divided by 100. The phosphorus use efficiency (PUE) was calculated by dividing the yield and phosphorus in soil. The phosphorus uptake efficiency (PUpE) was calculated as phosphorus in plant divided by phosphorus in soil. The phosphorus harvest index was calculated by dividing the grain phosphorus uptake by total phosphorus uptake. Statistical analysis of the data was done as per the procedure given by Gomez and Gomez (1984). The weather data during the experiment is presented in Figure 1.

Results and Discussion

Days to 50% flowering and physiological maturity showed significant difference between varieties as well as phosphorus doses (Table 2). The duration required for flowering and maturity primarily depend on the genetic makeup of the variety (Hodges and French, 1985). But environmental factors like photoperiods, light intensity, temperature etc also affect the time of flowering and maturity of soybean (Miladinovic and Dordevic, 2011). In this study it was observed that the treatment with no phosphorus took more time for flower initiation and 50% flowering. Similar findings were observed by Julia *et al.*, (2016) in rice.

As the phosphorus dose increased, the total time required to reach 50% flowering as well as physiological maturity showed a linear decrease up to P3 (60 kg ha^{-1}) phosphorus in all the varieties. The highest dose of P4 (90 kg ha^{-1}) slightly increased the days to reach flowering and maturity. Among the four varieties JS 9560 showed the lowest duration for both flowering and maturity as it is a short duration variety. Those varieties received lower doses of phosphorus took fewer number of days to flowering. This corroborates the findings of Chauhan *et al.,* (1992) reported that phosphorus deficiency reduced the crop growth, delayed flowering and maturity in pigeon pea. The interaction effect of variety and phosphorus treatment is not significant in case of days to physiological maturity.

The phosphorus content in leaf and stem showed significant difference between phosphorus doses as well as varieties (Figure 2). As the phosphorus doses increased the phosphorus content of leaf and stem also increased. The highest phosphorus content recorded in P4 (90 kg $P_2 O_5$ ha^{-1}) treatment in all the varieties. These findings are in agreement with that of Pal *et al.,* (1989). The variety JS 9752 showed a higher leaf phosphorus status even in the low doses of phosphorus supply, at the same time the stem phosphorus content showed a marked decrease compared to other varieties in all the phosphorus treatments. According to Park *et al.,* (2000) it was the stem P which decide the P storage in leaf and other tissues. The variety JS 9305 showed the highest content of stem phosphorus in all the treatments followed by JS 335. A study conducted by Furlani *et al.,* (2002) reported that the most P efficient genotypes showed a lower phosphorus concentration in their stem tissues. Here the variety JS 9752 recorded the lowest stem phosphorus content.

The phosphorus content of pod and grain showed significant difference between phosphorus treatments and varieties (Figure 3). The lowest pod and grain phosphorus content was recorded in treatment with no phosphorus application in all the varieties. Also there was a gradual increase in pod and grain P from P2 to P4 (30 kg ha^{-1} to 90 kg ha^{-1}) irrespective of varieties. According to Saha *et al.,* (2005) increasing levels of phosphorus significantly increased the grain and plant phosphorus content. The highest content of pod phosphorus was recorded by the variety JS 9560 followed by JS 9752 in all the treatments. The grain P was the highest for the variety JS 9305 followed by JS 9560. The lowest grain phosphorus content was recorded by the variety JS 9752 followed by JS 9305. The effective translocation of P from leaves and stems to grain was not taken place in the variety JS 9752. According to Park *et al.,* (2000) the stem tissue, regulate the P concentration of leaves, which in turn strongly depends on the supply of P. But the variety JS 9305 was effectively mobilized the leaf and stem P to grain and hence recorded a higher grain P. There is no significant difference between the interaction effect of variety and phosphorus treatments in case of grain P.

The total dry matter production was found significantly different between varieties and treatments (Table 3). The highest total dry matter production was recorded by the variety JS 9752 followed by JS 9560. The lowest dry matter production was recorded by the variety JS 9305 followed by JS 335. The biomass distribution pattern is a biological trait that mainly depends on genotype and will affect growth, development and yield of the individual population (Ao *et al.,* 2013). In case of phosphorus treatments there is a linear increase in dry matter production was recorded and the highest was for P4 (90 kg P_2O_5 ha^{-1}) treatment. According to Cai *et al.,* (2004) phosphorus application has a direct effect on soybean biomass yield but excess P application may suppress the growth. The treatment with no phosphorus application recorded the lowest biomass production in all varieties. This is in confirmation with the findings of Julia *et al.,* (2016). Those varieties with greater dry matter production at low P conditions are considered as P efficient genotypes. In this study the variety JS 9752 recorded the highest dry matter production at the lowest supply of P (0 kg ha^{-1}) followed by JS 9560. So these varieties are P efficient varieties and can be used in breeding programmes also. Higher P acquisition through root exudation of organic acids under P starvation condition also reported in soybean by several researchers (Dong *et al.*, 2004; Dinkelaker *et al.*, 1989; Johnson *et al.*, 1996).

Table.1 Varietal characters used in the study

Character	Varieties			
	JS 9560	JS 9752	JS 9305	JS 335
Duration	85-90	98-102	90-95	95-100
Potential Yield (q ha^{-1})	25-30	25-30	20-25	25-30
Growth habit	Determinate, very small pubescence, susceptible to drought	Semi determinate, pods and stem are pubescent	Semi determinate, resistant to shattering, have very small and spares pubescence on stem and leaves, glabrous pods.	Semi determinate, resistant to shattering, glabrous pods, yellow seed coat.
Flower Colour	Purple flower	White flower	Purple colour	Purple flower

Table.2 Days to 50% flowering and physiological maturity (Days)

Days to 50% flowering						**Days to physiological maturity**				
Phosphorus levels (kg ha^{-1})						**Phosphorus levels (kg ha^{-1})**				
Variety	**P1**	**P2**	**P3**	**P4**	**Mean**	**P1**	**P2**	**P3**	**P4**	**Mean**
JS 9560	36.7	36.0	35.7	36.3	36.2	85.3	84.7	84.3	86.3	85.2
JS 9752	59.0	57.0	54.3	56.3	56.7	97.7	97.0	96.0	99.0	97.4
JS 9305	52.0	49.0	47.0	47.7	48.9	96.7	96.3	95.3	97.3	96.4
JS 335	54.3	54.3	48.0	49.0	51.4	95.7	95.3	94.3	98.3	95.9
Mean	50.5	49.1	46.3	47.3		93.3	92.8	92.2	94.4	
Source	SE (m)	CD (p=0.05)				SE (m)	CD (p=0.05)			
Variety	0.236	0.685				0.203	0.59			
P level	0.236	0.685				0.203	0.59			
V X P	0.472	1.37				0.407	N/A			

Table.3 Total DMP and Total Phosphorus uptake as affected by treatments

Total DMP (g plant^{-1})						Total phosphorus uptake (kg ha^{-1})				
Phosphorus levels (kg ha^{-1})						Phosphorus levels (kg ha^{-1})				
Variety	**P1**	**P2**	**P3**	**P4**	**Mean**	**P1**	**P2**	**P3**	**P4**	**Mean**
JS 9560	11.72	21.86	24.35	24.22	20.54	5.85	11.58	14.14	15.44	11.75
JS 9752	15.17	25.76	31.80	32.09	26.20	6.29	13.18	17.72	18.93	14.03
JS 9305	10.51	18.45	20.71	21.67	17.83	6.29	11.46	13.72	14.79	11.56
JS 335	11.20	19.55	23.46	23.12	19.33	5.20	10.06	13.45	14.15	10.71
Mean	12.15	21.40	25.08	25.27		5.91	11.57	14.76	15.83	
Source	SE (m)	CD (p=0.05)				SE (m)	CD (p=0.05)			
Variety	0.10	0.30				0.09	0.27			
P level	0.10	0.30				0.09	0.27			
V X P	0.21	0.59				0.18	0.53			

Table.4 Grain yield and Harvest Index as affected by treatments

Grain Yield (g plant^{-1})						Harvest Index				
Phosphorus levels (kg ha^{-1})						Phosphorus levels (kg ha^{-1})				
Variety	**P1**	**P2**	**P3**	**P4**	**Mean**	**P1**	**P2**	**P3**	**P4**	**Mean**
JS 9560	3.36	6.47	7.63	7.14	6.15	0.29	0.29	0.31	0.29	0.30
JS 9752	3.89	7.75	9.92	9.86	7.86	0.26	0.30	0.31	0.31	0.29
JS 9305	2.87	4.97	5.88	6.12	4.96	0.27	0.27	0.29	0.28	0.28
JS 335	2.88	4.95	6.18	6.08	5.02	0.26	0.25	0.26	0.26	0.26
Mean	3.25	6.03	7.40	7.30		0.27	0.28	0.29	0.29	
Source	SE (m)	CD (p=0.05)				SE (m)	CD(p=0.05)			
Variety	0.023	0.066				0.002	0.005			
P level	0.023	0.066				0.002	0.005			
V X P	0.045	0.132				0.003	0.01			

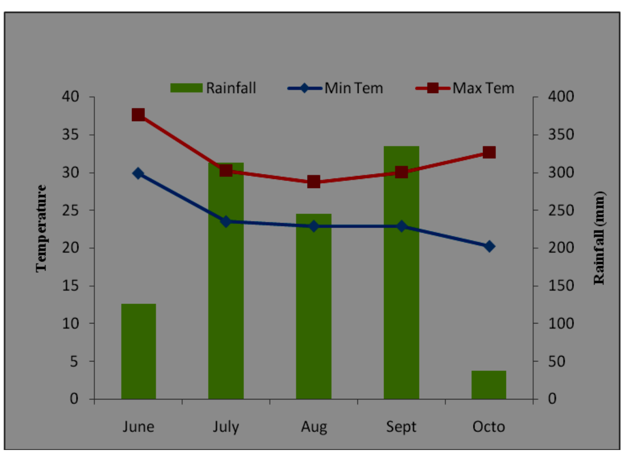

Figure.1 Weather data during the experiment

Table.5 Phosphorus Uptake Efficiency and Phosphorus Use Efficiency as affected by treatments

Phosphorus Uptake Efficiency						Phosphorus Use Efficiency				
Phosphorus levels (kg ha^{-1})						Phosphorus levels (kg ha^{-1})				
Variety	**P1**	**P2**	**P3**	**P4**	**Mean**	**P1**	**P2**	**P3**	**P4**	**Mean**
JS 9560	0.36	0.45	0.52	0.48	0.45	46.13	56.17	61.91	49.91	57.94
JS 9752	0.43	0.57	0.75	0.73	0.62	58.70	74.65	93.75	84.41	77.88
JS 9305	0.30	0.55	0.61	0.46	0.48	30.47	52.98	58.46	42.57	46.12
JS 335	0.31	0.52	0.65	0.52	0.50	38.33	56.88	66.03	49.46	52.68
Mean	0.35	0.52	0.63	0.55		47.82	60.17	70.04	56.59	
Source	SE (m)	CD (p=0.05)				SE (m)	CD (p=0.05)			
Variety	0.006	0.019				0.52	1.45			
P level	0.006	0.019				0.52	1.45			
V X P	0.013	0.037				1.04	2.90			

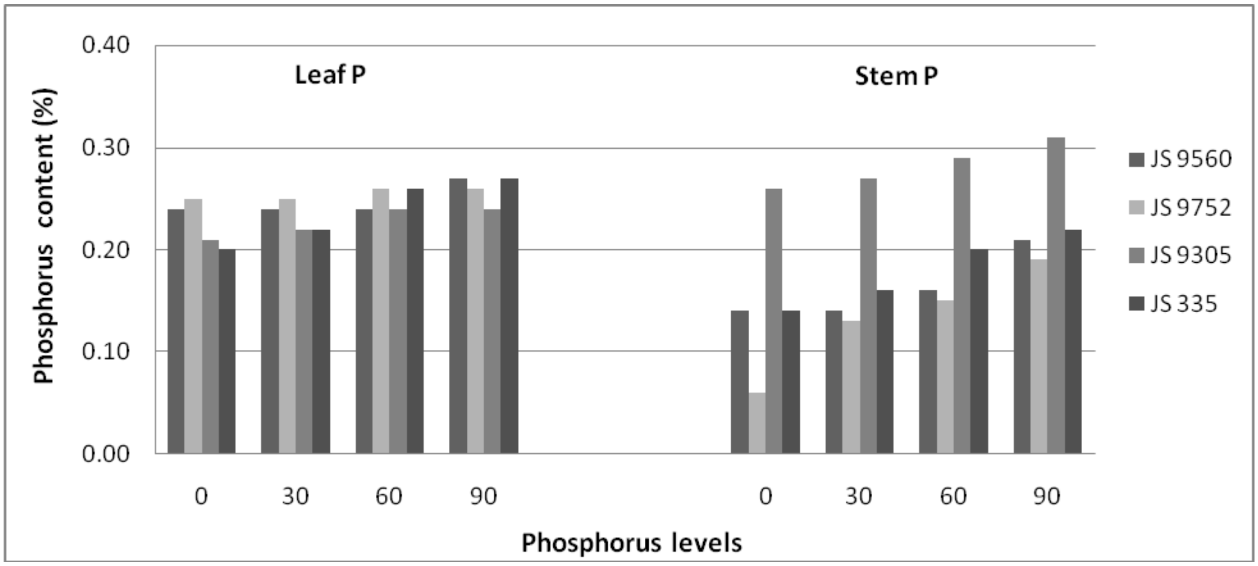

Figure.2 Leaf and Stem phosphorus content as affected by phosphorus treatments and varieties

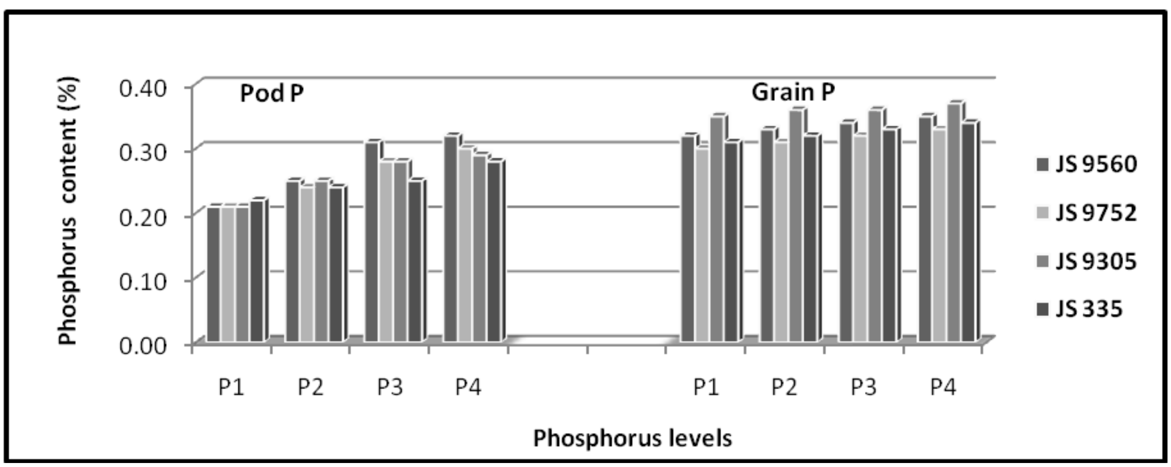

Figure.3 Pod and Grain phosphorus content as affected by phosphorus treatments and varieties

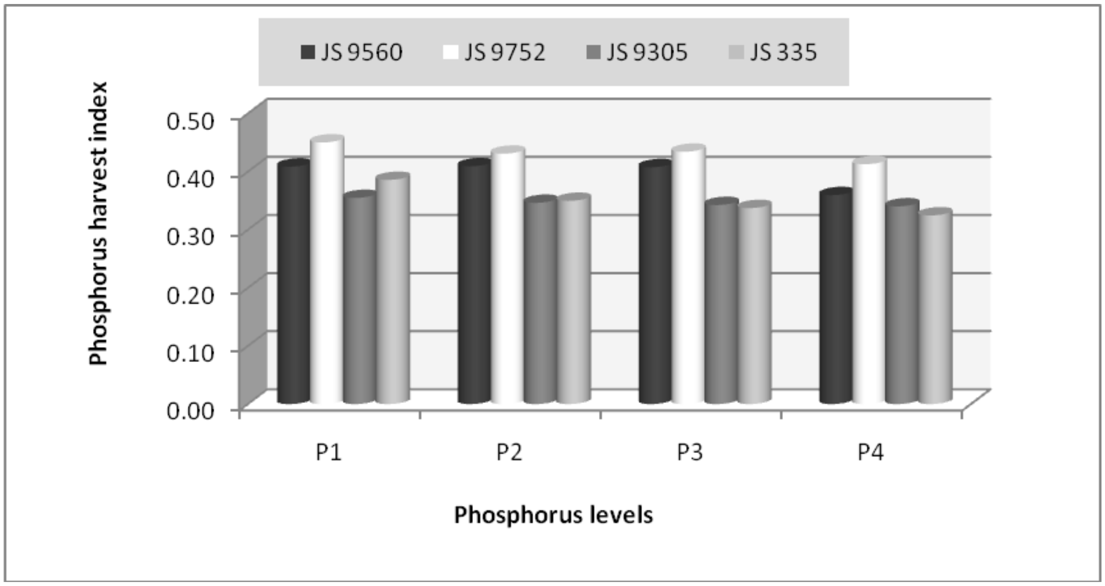

Figure.4 Phosphorus Harvest Index as affected by varieties and phosphorus application

The total phosphorus uptake also showed significant difference between treatments (Table 3). Among the varieties the highest total phosphorus uptake was recorded by JS 9752 followed by JS 9560. The phosphorus application significantly increased total phosphorus uptake by all the varieties. Similar findings were reported by Andraski and Bundy (2003) and Goswami *et al.,* (1999). The highest P uptake at P deficient condition was shown by the variety JS 9752 and JS 9305. The uptake of the variety depends on the dry matter produced by variety and the phosphorus concentration in the tissue. Hence the more dry matter accumulation as well as the higher tissue P concentrations resulted in the highest uptake. Here the highest uptake was recorded by the treatment P4 (90 kg P_2O_5 ha^{-1}). In soybean, there will be substantial reduction of dry matter production and P uptake if phosphorus is deficient during the initial growth periods (Li *et al.,* 2010). Here the total dry matter production and the tissue phosphorus concentration showed an inverse relation because of the dilution effect inside the plant system. Similar findings were reported by Furlani *et al.,* (2002)

The grain yield showed significant difference between treatments and varieties (Table 4). The highest grain yield was recorded by the variety JS 9752 followed by JS 9560. The phosphorus treatments also showed significant difference in case of grain yield. The highest grain yield was recorded by the treatment P3 (60 kg P_2O_5 ha^{-1}), ie.. there is a gradual increase in grain yield up to 60 kg P_2O_5 ha^{-1} and thereafter it is decreased. Similar findings were reported by Sharma *et al.,* (1991). With no P application the highest yield was recorded by the variety JS 9752 followed by JS 9560.

The harvest index was also showed significant difference between treatments and varieties (Table 4). The highest harvest was recorded by the variety JS 9752 followed by JS 9560. The lowest harvest index was recorded by the variety JS 335. The application of phosphorus increased the harvest index upto P3 (60 kg P_2O_5 ha^{-1}) and after that no increase in HI was observed. This may be due to the beneficial effect of phosphorus in producing higher grain yield and maintaining proper grain and plant biomass ratio. According to Malik *et al.,* (2006) harvest index significantly varied due to phosphorus application in soybean.

The phosphorus uptake efficiency (PUpE) presented in table 5 showed significant difference between phosphorus treatments and varieties. The highest phosphorus uptake efficiency was recorded by the variety JS 9752 followed by JS 335. Fagaria *et al.,* (2008) reported that nutrient efficient plants can produce higher yield per nutrient applied compared to other plants. The lowest value for phosphorus uptake efficiency was recorded by the variety JS 9560 followed by JS 9305. In the case of phosphorus treatments the highest phosphorus uptake efficiency (PUpE) was recorded by the treatment receiving P3 (60 kg P_2O_5 ha^{-1}) and the lowest (PUpE) was shown by the treatment P1 (0 kg P_2O_5 ha^{-1}). Several researchers (Shah *et al.,* 2001; Kumar and Kushwaha, 2006; Shakralingappa *et al.,* 2000) reported that phosphorus uptake efficiency and yield increased with phosphorus application mainly because of the higher amount of biomass production and resultant phosphorus accumulation in plant.

Phosphorus Use Efficiency (PUE) is considered as an important index in determining use of applied fertilizer by a crop species. In this study phosphorus use efficiency showed significant difference between phosphorus treatment and varieties. The highest PUE was recorded by the variety JS 9752 followed by JS 9560. The lowest PUE was recorded by the variety Js 9305 showing the least efficient variety among the four in phosphorus utilization. Among the phosphorus treatments, the highest phosphorus use efficiency was observed in the treatment P3 (60 kg P_2O_5 ha^{-1}) followed by P2 (30 kg P_2O_5 ha^{-1}). Phosphorus use efficiency parameters decreased with increasing rate of phosphorus in rice reported by Fragaria and Barbosa Filho (2007).

The phosphorus harvest index (PHI) showed significant difference between the treatments and varieties (Figure 4). The highest PHI was recorded by the variety JS 9752 followed by JS 9560. The lowest PHI was recorded by the variety JS 9305 and this might be due to the low grain phosphorus uptake of the variety. Among the phosphorus rates the treatment P1showed the highest PHI followed by P2 and P3. The lowest PHI was recorded by the treatment P4. Ao *et al.,* (2014) reported that under moderate and high P levels, the high P efficiency cultivars were showed exceptional phosphorus agronomic efficiency and PHI.

Conclusions are as follows:

Based on the phosphorus content in different plant tissues, total dry matter production and the different phosphorus efficiency indices studied were helped to derive the most phosphorus efficient variety among the 4 high yielding promising varieties. Various studies conducted by several researchers in soybean reported the importance of the above parameters to decide the phosphorus efficient genotype. From this study it was concluded that the best cultivar which recorded the highest dry matter yields and the highest phosphorus uptake and use efficiency and have the lowest stem P concentration was JS 9752. Hence this variety can be used in breeding programme for evolving more P efficient cultivars.

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