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RESEARCH PAPER

Variation in phosphorus uptake and its utilization in soybean genotypes under phosphorus limiting condition

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Abstract: A pot experiment was conducted to find out the variation in soybean genotypes for phosphorus uptake and PUE under phosphorus limiting condition and also to find out the efficient ones. Hundred genotypes of soybean [*Glycine max* (L.) Merrill] were raised for 45 days in a P limited condition and compared with P sufficient condition. The soybean genotypes differed greatly in growth and P uptake. Under P limiting condition the biomass production and P uptake were reduced. Whereas root length and PUE increased. The P efficient genotypes were found to be associated with high biomass production, root length and P uptake under P deficiency. The shoot dry weight under P limiting condition and relative shoot dry weight (DM in limiting P/DM in adequate P supply) were found effective and simple indicators for screening P efficient genotypes at seedling stage.

Key words: Assessment, Genotypes, Phosphorus, Soybean

Introduction

Phosphorus is one of the most limiting nutrients for plant growth in soil and its availability depends on soil characteristics and contents of labile P fraction. It is estimated that P availability to plant roots is limited in two thirds of the cultivated soil in the world (Pan *et al.,* 2008). Phosphorus application is essential and common practice to minimize yield loss. However, 80 per cent of P applied to soil is converted into unavailable forms that cannot be easily utilized by plants. Hence, development of P efficient genotypes with a great ability to make it bioavailable, uptake and utilize efficiently in metabolism in P limiting soil is of greater significance in mineral nutrition.

Soybean (*Glycine max*) is the world's most important legume crop grown in a wide range of climatic and edaphic conditions producing fodder as well as food, but yields are limited by acidic and highly weathered soils low in available phosphorus. There are great genetic variations in response to P supply and in P efficiency (Vance *et al.,* 2003; Zhao *et al.,* 2004 ; Yan *et al.,* 2006). It is necessary to screen soybean genotypes for P efficiency from large germplasm. Plants that are efficient in absorption and utilization of the absorbed nutrients greatly enhance the efficiency of applied fertilizers. A more comprehensive understanding of the molecular and physiological basis of mineral nutrient uptake and utilization in plants is leading to strategies for development of better nutrient efficient cultivars suited for optimal production with less fertilizer inputs. Adaptation of such cultivars with higher nutrient use efficiency is relatively easy, since no additional costs are involved, and no major changes in cropping systems are necessary. Also, nutrient efficient varieties contribute to sustainability in many other ways. They have a greater degree of disease resistance due to enhanced membrane function and cell integrity, a greater ability to develop deep roots to penetrate sub-soil in infertile soils and greater seedling vigor which in turn gives higher seed yields (Graham and Welch, 1996).

With this background soybean genotypes were screened to investigate the extent of genetic variability in P efficiency and to determine the characteristics of P efficient soybean genotypes at early growth stages.

Material and methods

The pot experiment was conducted during the year 2009 by following completely randomized design (CRD) with two replications and two treatments of P limiting and P sufficient condition at Department of Crop Physiology, College of Agriculture, Dharwad. The calcareous soil was mixed with river sand at the ratio of 3 to 1 after having sieved through a 2 mm sieve. The pH of the soil was 7.8 (Soil: H_2O ratio of 1:2.5) with 19 mg kg^{-1} of Olsen P. Plastic pots were filled with sand mixed with soil. Two levels of P were maintained as one with phosphorus (+P) that is recommended dose and other without phosphorus (-P). The other recommended dose of nutrients (N & K) was mixed thoroughly with the soil. Six uniform seeds of each genotype (Table 1) were sown. At 45 days after emergence, two plants were uprooted and separated into roots and shoot after thoroughly washing in water. Shoot length and root length were recorded. Leaf P content, phosphorus use efficiency (PUE) and phosphorus uptake were measured. Roots and shoots were then oven dried and dry weight of shoot and root were measured.

Phosphorus content in the leaf samples was determined by following Vanadomolybdate yellow colour method as outlined by Jackson (1973). A fully expanded third leaf from the top was sampled in each genotype for phosphorus estimation. The ratios of root to shoot length, root to shoot dry weight, phosphorus uptake (mg pl^{-1}), phosphorus use efficiency (g dm mg P^{-1}) were calculated. Phosphorus use efficiency (indicates the efficiency of plant to utilize the absorbed P within the plant), Phosphorus uptake (indicates total amount of P per unit weight of plant) have been used to assess the genotypes for P efficiency (Pan *et al.,* 2008).

Table 1. List of soybean genotypes included in the study

Sl. No.	Genotypes	Sl. No.	Genotypes	Sl. No.	Genotypes
1	ADT-1	35	MACS-57	69	SL-295
2	Alankar	36	MACS-58	70	TAMS-38
3	Ankur	37	MACS-124	71	TAMS-9821
4	Birsa Soya-1	38	MACS-450	72	VL-Soya-2
5	Bragg	39	MAUS-1	73	VL-Soya-47
6	CO-1	40	MAUS-2	74	VL Soya 59
7	CO-3	41	MAUS-32	75	VL Soya 63
8	Durga	42	MAUS-61	76	Hara Soya
9	DS-9712	43	MAUS-61-2	77	Palam Soya
10	DS-228	44	MAUS-71	78	Monetta
11	DSb-1	45	MAUS-81	79	NRC-2
12	DSb-11	46	PK-262	80	NRC-37
13	DSb-12	47	PK-308	81	J-30 5-1
14	Gourav	48	PK-416	82	J 30 7-22
15	Gujarath Soybean-1	49	PK-471	83	J 30 46-3
16	Gujarath Soybean-2	50	PK-472	84	J 30 14-1
17	Hardee	51	PS-564	85	J 20 47-18
18	Indira Soya-9	52	PS-1024	86	J 20 63-1
19	Improved pelicum	53	PS-1029	87	JE 20-11
20	JS-71-05	54	PS-1042	88	J 20 33-4
21	JS-75-06	55	PS-1092	89	J 20 100-7
22	JS-76-205	56	PS-1241	90	JE 31-28
23	JS-79-81	57	PS-1347	91	K 20 58-5
24	JS-8021	58	Pusa-16	92	K 20 47-1
25	JS-90-41	59	Pusa 20	93	K 20 122-6
26	JS-335	60	Pusa 22	94	KE 8-48
27	JS-95-60	61	Pusa-24	95	K 20 115-2
28	JS-95-52	62	Pusa-37	96	K 20 76-5
29	Kalitur	63	Pusa-40	97	K 20 143-2
30	KB-79	64	RAUS-5	98	K 20 65-3
31	KHSb-2	65	Samrat	99	K 20 174-2
32	Lee	66	Silajeet	100	KE 4-11
33	LSb-1	67	Shivalik		
34	MACS-13	68	SL-96		

Fisher's method of analysis of variance was applied for the analysis and interpretation of the experimental data suggested by Panse and Sukhatme (1967). The level of significant used in 'F' and't' test was P = 0.5. The critical difference (CD) values were calculated at 5 per cent level, wherever 'F' test was significant. The bi-plot analysis for various related characters was done following the procedure of Gabriel (1971). Bi-plot analysis was done by plotting the relative shoot dry weight against the parameters recorded in the experiment.

Results and discussion

There are two ways in which variation in P use efficiencies can arise;The efficiency with which P is utilized to produce yield, i.e. the amount of P needed in the plant to produce one unit of dry matter. This is often called internal P requirement and is the P concentration in plants to produce 80% of maximum yield. Plant adaptations to P limited soils can be partially attributed to inherent genotypic differences in Phosphorus Use Efficiency (PUE) (Hansa Hena Begam and Md. Tofazzal Islam, 2005). PUE is defined as the amount of total biomass &/or economic yield produced per unit of acquired P. Practically all plants show as increase in PUE under P deficiency conditions (Fageria and Costa, 2000). Because a larger proportion of plant biomass is allocated to tissues with low P concentrations and P storage in vacuoles declines and structural and non structural carbohydrates increase (Rao, 1997). So in the present investigation the mean PUE in -P condition (0.44 g dm mg P $^{-1}$) was found to be significantly higher (Table 2.) than with +P condition (0.38g dm mg P $^{-1}$). The genotype Silajeet recorded significantly higher PUE (0.63g dm mg P $^{-1}$) followed by the genotype LSb-1 (0.57g dm mg P $^{-1}$). Whereas the genotype JS 95-52 recorded significantly lower PUE, followed by MAUS-2 (0.26) and Hara Soya (0.28).

The uptake efficiency of the plant, which is the ability of root system to acquire P from soil and accumulate it in the shoots. This depends on the capability of roots to absorb P, the active life time of roots and on the amount of root per unit of shoot (Hansa Hena Begam and Md. Tofazzal Islam, 2005). The components of uptake efficiency have been evaluated by Loneragan and Asher (1967). The P uptake (Table 3) of the Soybean genotypes was significantly higher with the application of Phosphorus (10.1 mg pl^{-1}) than without Phosphorus application (5.92mg pl^{-1}). Among the genotypes, the uptake ranged from 1.75 to 13.1 mg pl^{-1}in control (without P) and 3.1 to 23.3 mg pl^{-1}with application of P. There was 48% increase in the uptake with application of Phosphorus than without application of P. The genotype Pusa-24 was recorded significantly higher uptake (16.1mg pl^{-1}) followed by the genotypes TAMS-38 (14.5mg pl^{-1}), Hara Soya (14.8mg pl^{-1}) and J20 47-18 (13.2). From the results of PUE and uptake of the genotypes, it has been noticed that no genotype is having the higher values of these two in the same genotypes, which shows that these two efficiencies are governed by two different parts of the plant one *i.e.,* hidden in the ground that is root and the PUE is dependent on shoot, which is above the ground and these are negatively correlated in the present study. Hence, it could be thought of combining these characters in the same genotype either by breeding or by transgenic means to further improve the PUE in soybean genotypes.

Application of phosphorus resulted in increase in the shoot length, root length, shoot dry weight, root dry weight, leaf P content and P uptake except PUE. Thus, it has been shown that PUE decreases and uptake and other parameters increase with application of P and is further evident by existence of negative correlation between shoot length and PUE and leaf P content .Whereas uptake is positively correlated with shoot dry weight, root dry weight and leaf P content. These results were in agreement with the findings of Pan *et al.* (2008) in soybean and Krishnappa *et al.* (2011) in pigeonpea genotypes.

As it is known, we need high PUE and higher dry matter production; hence, biplot technique using the PUE and relative values of shoot dry weight of the genotypes was adopted (Fig. 1). The genotypes *viz.,* Silajeet, Bragg, Pusa 20, Gujarat Soybean -1, Gourav, K20 65-3 and K20 143-2 were to select, better genotypes with ease select the genotypes the biplot

Table 2. Influence of phosphorus on PUE (g dm/mg P) in soybean genotypes at 45 DAS

Sl. No.	Genotypes	(- P)	(+P)	Mean	Sl. No.	Genotypes	(- P)	(+P)	Mean
1	ADT-1	0.31	0.28	0.29	51	PS-564	0.46	0.44	0.45
2	Alankar	0.39	0.39	0.39	52	PS-1024	0.43	0.42	0.43
3	Ankur	0.39	0.38	0.39	53	PS-1029	0.50	0.37	0.44
4	Birsa Soya-1	0.45	0.38	0.42	54	PS-1042	0.67	0.45	0.56
5	Bragg	0.53	0.50	0.51	55	PS-1092	0.48	0.36	0.42
6	CO-1	0.45	0.36	0.41	56	PS-1241	0.47	0.46	0.46
7	CO-3	0.50	0.37	0.44	57	PS-1347	0.41	0.37	0.39
8	Durga	0.43	0.34	0.39	58	Pusa-16	0.39	0.37	0.38
9	DS-9712	0.43	0.30	0.37	59	Pusa 20	0.37	0.33	0.35
10	DS-228	0.53	0.45	0.49	60	Pusa 22	0.59	0.34	0.47
11	DSb-1	0.45	0.43	0.44	61	Pusa-24	0.35	0.26	0.30
12	DSb-11	0.33	0.30	0.32	62	Pusa-37	0.37	0.34	0.36
13	DSb-12	0.34	0.31	0.33	63	Pusa-40	0.42	0.38	0.40
14	Gourav	0.56	0.50	0.53	64	RAUS-5	0.45	0.42	0.44
15	Gujarath Soybean-1	0.59	0.40	0.49	65	Samrat	0.42	0.40	0.41
16	Gujarath Soybean-2	0.38	0.39	0.38	66	Silajeet	0.67	0.59	0.63
17	Hardee	0.45	0.46	0.46	67	Shivalik	0.48	0.42	0.45
18	Indira Soya-9	0.36	0.36	0.36	68	SL-96	0.41	0.38	0.40
19	Improved pelicum	0.53	0.45	0.49	69	SL-295	0.43	0.44	0.44
20	JS-71-05	0.42	0.34	0.38	70	TAMS-38	0.34	0.33	0.34
21	JS-75-06	0.48	0.43	0.46	71	TAMS-9821	0.42	0.32	0.37
22	JS-76-205	0.56	0.48	0.52	72	VL-Soya-2	0.31	0.27	0.29
23	JS-79-81	0.42	0.40	0.41	73	VL-Soya-47	0.42	0.42	0.42
24	JS-8021	0.40	0.39	0.40	74	VL Soya 59	0.50	0.48	0.49
25	JS-90-41	0.33	0.29	0.31	75	VL Soya 63	0.36	0.33	0.35
26	JS-335	0.33	0.32	0.33	76	Hara Soya	0.33	0.23	0.28
27	JS-95-60	0.50	0.42	0.46	77	Palam Soya	0.41	0.32	0.36
28	JS-95-52	0.23	0.22	0.22	78	Monetta	0.45	0.43	0.44
29	Kalitur	0.36	0.31	0.33	79	NRC-2	0.40	0.37	0.39
30	KB-79	0.42	0.32	0.37	80	NRC-37	0.43	0.38	0.41
31	KHSb-2	0.38	0.37	0.38	81	J-30 5-1	0.42	0.32	0.37
32	Lee	0.48	0.45	0.47	82	J 30 7-22	0.48	0.47	0.48
33	LSb-1	0.57	0.57	0.57	83	J 30 46-3	0.42	0.37	0.40
34	MACS-13	0.48	0.45	0.47	84	J 30 14-1	0.50	0.42	0.46
35	MACS-57	0.31	0.27	0.29	85	J 20 47-18	0.38	0.32	0.35
36	MACS-58	0.41	0.36	0.38	86	J 20 63-1	0.37	0.27	0.32
37	MACS-124	0.31	0.30	0.31	87	JE 20-11	0.50	0.46	0.48
38	MACS-450	0.36	0.36	0.36	88	J 20 33-4	0.50	0.41	0.46
39	MAUS-1	0.45	0.43	0.44	89	J 20 100-7	0.48	0.47	0.48
40	MAUS-2	0.27	0.26	0.26	90	JE 31-28	0.50	0.45	0.48
41	MAUS-32	0.48	0.40	0.44	91	K 20 58-5	0.49	0.47	0.48
42	MAUS-61	0.46	0.40	0.43	92	K 20 47-1	0.42	0.33	0.37
43	MAUS-61-2	0.43	0.36	0.40	93	K 20 122-6	0.37	0.28	0.32
44	MAUS-71	0.38	0.34	0.36	94	KE 8-48	0.44	0.42	0.43
45	MAUS-81	0.48	0.38	0.43	95	K 20 115-2	0.38	0.36	0.37
46	PK-262	0.45	0.42	0.43	96	K 20 76-5	0.32	0.32	0.32
47	PK-308	0.48	0.37	0.42	97	K 20 143-2	0.53	0.42	0.47
48	PK-416	0.35	0.28	0.32	98	K 20 65-3	0.59	0.48	0.53
49	PK-471	0.48	0.43	0.46	99	K 20 174-2	0.42	0.40	0.41
50	PK-472	0.59	0.53	0.56	100	KE 4-11	0.59	0.53	0.56
						Mean	0.44	0.38	0.41

		S.Em±	C.D. at 5%
For comparing	P level (P)	0.003	0.008
	Variety (V)	0.025	0.07
	P x V	0.035	NS

analysis with the mean root dry weight (0.48 g pl^{-1}) compared to control (0.32g pl^{-1}). The mean shoot length of the genotypes ranged from 22 cm (J 30 46-3) to 45 cm (JE 31-28) and differed significantly among the genotypes. The mutant JE 31-28 recorded significantly higher shoot length (43) followed by the genotypes KHSb-2 (43.5) and CO-3 (43.0).Whereas the mutant J30 14-1 recorded significantly lower shoot length (22.0) followed by the genotypes Ankur (26.3).

Table 3. Influence of phosphorus on uptake (mg/plant) in soybean genotypes at 45 DAS

Sl. No.	Genotypes	(- P)	(+P)	Mean	Sl. No.	Genotypes	(- P)	(+P)	Mean
1	ADT-1	6.47	8.99	7.73	51	PS-564	6.30	10.17	8.24
2	Alankar	7.99	13.74	10.86	52	PS-1024	5.61	11.70	8.66
3	Ankur	7.60	15.59	11.60	53	PS-1029	3.80	6.89	5.34
4	Birsa Soya-1	6.60	15.47	11.04	54	PS-1042	8.25	14.3	11.28
5	Bragg	6.20	7.29	6.74	65	PS-1092	7.25	12.2	9.71
6	CO-1	5.50	10.50	8.00	56	PS-1241	5.91	12.1	9.02
7	CO-3	4.40	8.51	6.45	57	PS-1347	6.65	10.12	8.38
8	Durga	5.98	7.98	6.98	58	Pusa-16	7.50	15.5	11.5
9	DS-9712	4.60	12.38	8.49	59	Pusa 20	5.51	8.09	6.80
10	DS-228	3.42	6.60	5.01	60	Pusa 22	4.42	11.3	7.87
11	DSb-1	4.47	9.32	6.89	61	Pusa-24	8.83	23.3	16.1
12	DSb-11	7.32	11.72	9.52	62	Pusa-37	10.13	12.0	11.1
13	DSb-12	5.08	11.35	8.21	63	Pusa-40	6.24	13.3	9.8
14	Gourav	3.24	3.95	3.60	64	RAUS-5	7.36	15.4	11.4
15	Gujarath Soybean-1	3.15	5.38	4.26	65	Samrat	6.76	7.50	7.13
16	Gujarath Soybean-2	6.09	7.39	6.74	66	Silajeet	2.90	6.55	4.72
17	Hardee	6.23	6.83	6.53	67	Shivalik	5.78	10.20	7.99
18	Indira Soya-9	8.83	10.24	9.54	68	SL-96	8.05	17.74	12.90
19	Improved pelicum	4.62	10.67	7.64	69	SL-295	5.64	9.44	7.54
20	JS-71-05	1.97	4.71	3.34	70	TAMS-38	13.07	15.84	14.45
21	JS-75-06	5.99	7.25	6.62	71	TAMS-9821	5.52	8.06	6.79
22	JS-76-205	2.39	5.59	3.99	72	VL-Soya-2	9.61	12.43	11.02
23	JS-79-81	3.60	4.78	4.19	73	VL-Soya-47	3.75	7.55	5.65
24	JS-8021	2.61	4.74	3.67	74	VL Soya 59	6.60	9.56	8.08
25	JS-90-41	6.45	9.35	7.90	75	VL Soya 63	5.46	8.25	6.86
26	JS-335	9.60	11.47	10.54	76	Hara Soya	7.68	21.93	14.81
27	JS-95-60	3.20	7.68	5.44	77	Palam Soya	8.90	16.58	12.74
28	JS-95-52	11.52	12.49	12.00	78	Monetta	7.04	14.15	10.59
29	Kalitur	4.72	6.20	5.46	79	NRC-2	8.93	10.95	9.94
30	KB-79	3.48	8.99	6.24	80	NRC-37	5.87	6.76	6.31
31	KHSb-2	5.72	7.56	6.64	81	J-30 5-1	4.93	8.01	6.47
32	Lee	4.22	8.80	6.51	82	J 30 7-22	6.84	9.48	8.16
33	LSb-1	3.76	6.78	5.27	83	J 30 46-3	7.58	16.63	12.10
34	MACS-13	5.99	7.70	6.84	84	J 30 14-1	6.55	8.92	7.73
35	MACS-57	5.31	8.25	6.78	85	J 20 47-18	8.51	17.96	13.23
36	MACS-58	5.25	7.50	6.38	86	J 20 63-1	8.78	18.69	13.73
37	MACS-124	7.63	8.56	8.09	87	JE 20-11	3.92	7.30	5.61
38	MACS-450	6.35	12.70	9.52	88	J 20 33-4	4.74	7.83	6.29
39	MAUS-1	6.93	8.05	7.49	89	J 20 100-7	4.57	9.13	6.85
40	MAUS-2	9.99	12.48	11.24	90	JE 31-28	3.75	4.62	4.19
41	MAUS-32	5.99	10.88	8.43	91	K 20 58-5	6.74	10.90	8.82
42	MAUS-61	1.75	3.11	2.43	92	K 20 47-1	5.36	13.30	9.33
43	MAUS-61-2	8.28	10.92	9.60	93	K 20 122-6	6.49	17.12	11.81
44	MAUS-71	4.24	9.43	6.83	94	KE 8-48	3.87	8.14	6.01
45	MAUS-81	3.15	7.28	5.22	95	K 20 115-2	4.35	7.71	6.03
46	PK-262	5.95	7.35	6.65	96	K 20 76-5	4.20	7.15	5.67
47	PK-308	5.46	14.18	9.82	97	K 20 143-2	4.37	6.84	5.61
48	PK-416	7.06	11.37	9.22	98	K 20 65-3	2.47	3.68	3.07
49	PK-471	4.31	5.18	4.74	99	K 20 174-2	6.59	7.90	7.25
50	PK-472	6.46	11.12	8.79	100	KE 4-11	4.93	10.93	7.93
						Mean	5.92	10.08	8.00
						S.Em±		C.D. at 5%	
For comparing				P level (P)		0.1		0.45	
				Variety (V)		1.130		3.16	
				P x V		1.6		4.48	

The application of P increased leaf 'P' content (Table 4) significantly higher (0.27 %) than the –P condition (0.23%). There was 15.1% increase in the leaf P content with application of Phosphorus than without application of Phosphorus. The mean leaf P content at flowering ranged from 0.16 % (Silajeet) to 0.45 % (JS 95-52). The leaf P content differed significantly

Table 4. Influence of phosphorus on leaf P content (%) in Soybean genotypes at 45 DAS

Sl. No.	Genotypes	(- P)	(+P)	Mean	R V	Sl. No.	Genotypes	(- P)	(+P)	Mean	R V
1	ADT-1	0.32	0.36	0.34	0.9	51	PS-564	0.22	0.23	0.22	1.0
2	Alankar	0.26	0.26	0.26	1.0	52	PS-1024	0.23	0.24	0.24	1.0
3	Ankur	0.25	0.26	0.26	1.0	53	PS-1029	0.20	0.27	0.24	0.7
4	Birsa Soya-1	0.22	0.26	0.24	0.8	54	PS-1042	0.15	0.22	0.19	0.7
5	Bragg	0.19	0.20	0.19	0.9	55	PS-1092	0.21	0.28	0.25	0.8
6	CO-1	0.22	0.28	0.25	0.8	56	PS-1241	0.21	0.22	0.22	1.0
7	CO-3	0.20	0.27	0.24	0.7	57	PS-1347	0.24	0.27	0.26	0.9
8	Durga	0.23	0.29	0.26	0.8	58	Pusa-16	0.26	0.27	0.26	1.0
9	DS-9712	0.23	0.33	0.28	0.7	59	Pusa 20	0.27	0.30	0.29	0.9
10	DS-228	0.19	0.22	0.21	0.9	60	Pusa 22	0.17	0.29	0.23	0.6
11	DSb-1	0.22	0.23	0.23	1.0	61	Pusa-24	0.28	0.39	0.34	0.7
12	DSb-11	0.30	0.33	0.32	0.9	62	Pusa-37	0.27	0.29	0.28	0.9
13	DSb-12	0.29	0.32	0.31	0.9	63	Pusa-40	0.24	0.26	0.25	0.9
14	Gourav	0.18	0.20	0.19	0.9	64	RAUS-5	0.22	0.24	0.23	0.9
15	Gujarath Soybean-1	0.17	0.25	0.21	0.7	65	Samrat	0.24	0.25	0.24	1.0
16	Gujarath Soybean-2	0.26	0.26	0.26	1.0	66	Silajeet	0.15	0.17	0.16	0.9
17	Hardee	0.22	0.22	0.22	1.0	67	Shivalik	0.21	0.24	0.23	0.9
18	Indira Soya-9	0.28	0.28	0.28	1.0	68	SL-96	0.24	0.26	0.25	0.9
19	Improved pelicum	0.19	0.22	0.21	0.9	69	SL-295	0.23	0.23	0.23	1.0
20	JS-71-05	0.24	0.29	0.27	0.8	70	TAMS-38	0.29	0.30	0.30	1.0
21	JS-75-06	0.21	0.23	0.22	0.9	71	TAMS-9821	0.24	0.31	0.28	0.8
22	JS-76-205	0.18	0.21	0.20	0.9	72	VL-Soya-2	0.32	0.37	0.35	0.9
23	JS-79-81	0.24	0.25	0.25	1.0	73	VL-Soya-47	0.24	0.24	0.24	1.0
24	JS-8021	0.25	0.26	0.25	1.0	74	VL Soya 59	0.20	0.21	0.20	1.0
25	JS-90-41	0.30	0.34	0.32	0.9	75	VL Soya 63	0.28	0.30	0.29	0.9
26	JS-335	0.32	0.33	0.32	1.0	76	Hara Soya	0.30	0.43	0.37	0.7
27	JS-95-60	0.20	0.24	0.22	0.8	77	Palam Soya	0.25	0.31	0.28	0.8
28	JS-95-52	0.44	0.46	0.45	1.0	78	Monetta	0.22	0.23	0.23	1.0
29	Kalitur	0.28	0.33	0.30	0.8	79	NRC-2	0.25	0.27	0.26	0.9
30	KB-79	0.24	0.31	0.28	0.8	80	NRC-37	0.23	0.26	0.25	0.9
31	KHSb-2	0.26	0.27	0.27	1.0	81	J-30 5-1	0.24	0.31	0.27	0.8
32	Lee	0.21	0.22	0.22	1.0	82	J 30 7-22	0.21	0.21	0.21	1.0
33	LSb-1	0.17	0.18	0.18	1.0	83	J 30 46-3	0.24	0.27	0.25	0.9
34	MACS-13	0.21	0.22	0.22	1.0	84	J 30 14-1	0.20	0.24	0.22	0.8
35	MACS-57	0.32	0.37	0.34	0.9	85	J 20 47-18	0.26	0.31	0.29	0.8
36	MACS-58	0.24	0.28	0.26	0.9	86	J 20 63-1	0.27	0.37	0.32	0.7
37	MACS-124	0.23	0.28	0.26	0.8	87	JE 20-11	0.20	0.22	0.21	0.9
38	MACS-450	0.28	0.28	0.28	1.0	88	J 20 33-4	0.20	0.24	0.22	0.8
39	MAUS-1	0.22	0.23	0.23	1.0	89	J 20 100-7	0.21	0.21	0.21	1.0
40	MAUS-2	0.37	0.39	0.38	0.9	90	JE 31-28	0.20	0.22	0.21	0.9
41	MAUS-32	0.21	0.25	0.23	0.8	91	K 20 58-5	0.20	0.21	0.21	1.0
42	MAUS-61	0.22	0.25	0.23	0.9	92	K 20 47-1	0.24	0.30	0.27	0.8
43	MAUS-61-2	0.30	0.31	0.31	1.0	93	K 20 122-6	0.27	0.36	0.32	0.8
44	MAUS-71	0.26	0.29	0.28	0.9	94	KE 8-48	0.22	0.24	0.23	1.0
45	MAUS-81	0.21	0.26	0.24	0.8	95	K 20 115-2	0.26	0.28	0.27	0.9
46	PK-262	0.22	0.24	0.23	0.9	96	K 20 76-5	0.31	0.31	0.31	1.0
47	PK-308	0.21	0.27	0.24	0.8	97	K 20 143-2	0.19	0.24	0.22	0.8
48	PK-416	0.28	0.36	0.32	0.8	98	K 20 65-3	0.17	0.21	0.19	0.8
49	PK-471	0.21	0.23	0.22	0.9	99	K 20 174-2	0.24	0.25	0.25	1.0
50	PK-472	0.17	0.19	0.18	0.9	100	KE 4-11	0.17	0.19	0.18	0.9
							Mean	0.23	0.27	0.25	
							SEm±		CD at 5%		
For comparing				P level (P)			0.002		0.01		
				Variety (V)			0.002		0.01		
				P x V			0.02		NS		

among the genotypes. The genotypes Silajeet recorded significantly lowest and the genotype JS-90-41 significantly highest leaf P content among the genotypes.

The mean root length of the Soybean genotypes varied significantly with application of phosphorus (17.7 cm) and without Phosphorus (14.2 cm). The mean root length of the

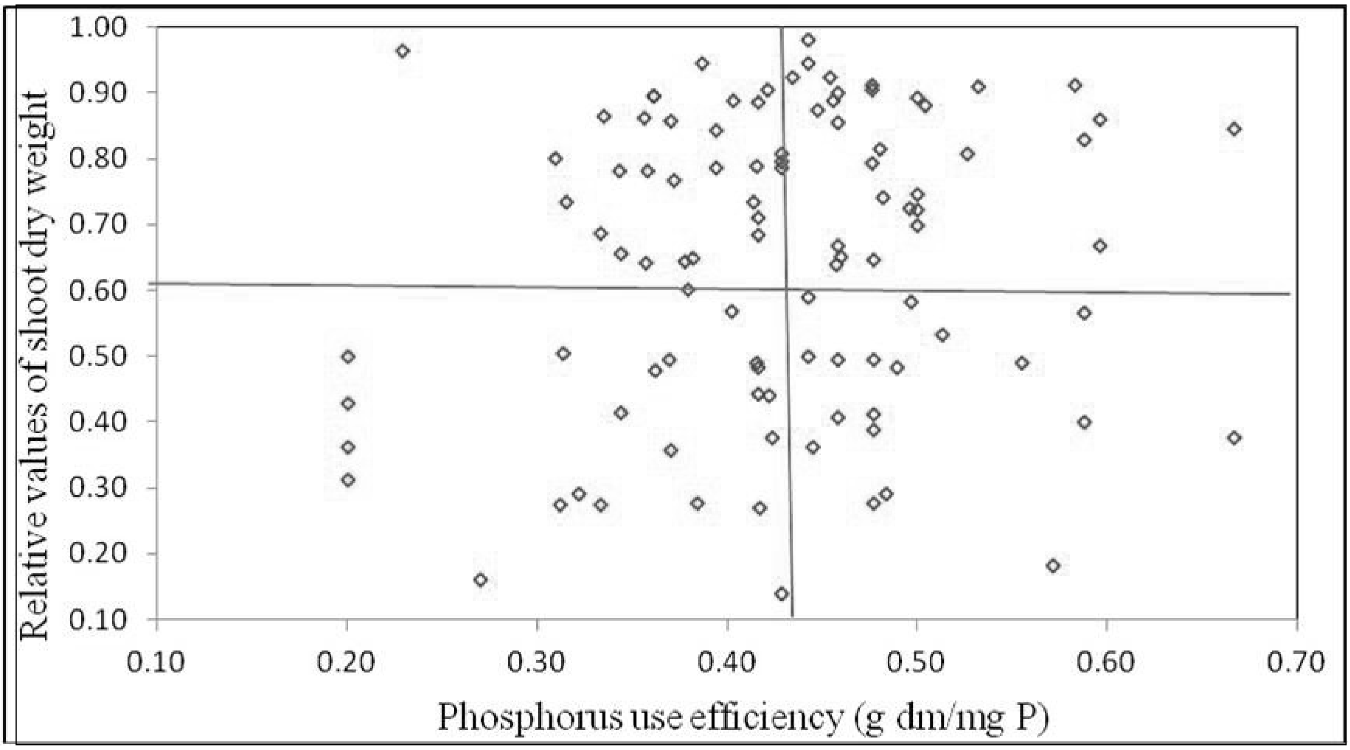

Fig.1. Bi-plot analysis of phosphorus use efficiency (g dm/mg P) at -P against relative values of shoot dry weight

genotypes (Table 5) ranged from 10.9 cm (JS-71-05) to 23.8 cm (Shivalik) and differed significantly among the genotypes. The genotype Shivalik recorded significantly higher root length (23.8 cm) followed by the genotypes DSb-12 (19.8 cm) and JS-72-205 (20 cm).

Shoot dry weight (Table 5) ranged from 1.03 to 6.00 g per plant. Phosphorus application recorded significantly higher shoot dry weight (3.73 g pl^{-1}) than without phosphorus application (2.50 g pl^{-1}). Shoot dry weight and P uptake were always high under P application than without P application. Because shoot dry weight and yield are important parameters in breeding (Pan *et al.*, 2008) and shoot dry weight is an important determinant of grain yield at the seedling stage. In the present study, forty nine per cent higher shoot dry weights was recorded with P application as compared to P limiting condition. Among the hundred soybean genotypes PS-1042 recorded significantly higher shoot dry weight (5.5 g) at –P condition.

Phosphorus application significantly increased the root dry weight (Table 5). The genotypes differed significantly in root dry weight. The genotypes Gujarat soybean-2 and Hardee recorded significantly higher root dry weight (0.72 g pl^{-1}), whereas the genotype MAUS-61 recorded significantly lower root weight (0.18 g pl^{-1}) followed by the genotype JE 31-28 (0.21g pl^{-1}) .

Higher shoot dry weight and higher relative shoot dry weight are the ideal indicators of phosphorus use efficiency in P limiting condition. This is basically in accordance with the results of other crops such as wheat (Osborne & Rengel, 2002; Gunes *et al.,* 2006), maize (Li *et al.,* 2003) and rice (Guo *et al.,* 2002).

Table 5. The mean values of different parameters in soybean genotypes with different P levels

Parameters	With P application	Without P application
Shoot length (cm)	34.8	27.7
Root length (cm)	17.7	14.2
Shoot dry weight (g)	3.73	2.50
Root dry weight (g)	0.48	0.32
Root to Shoot length ratio	0.51	0.53

They ranked / classified the cereal genotypes by following three criteria *i.e.,* shoot growth at deficient P supply, the relative shoot growth rate (dry weight at deficient P / dry weight at sufficient P) and PUE (amount of dry matter produced per unit of P accumulated in shoots corrected for seed P content). They found considerable genotypic variation in growth and PUE in the cereal germplasm. Similarly the results of Xihuan *et al.,* (2010) and Pan *et al.* (2008) indicated that screening of soybean genotypes showed that the shoot dry weight under P deficiency and relative shoot dry weight were effective and simple indicators for P tolerance genotypes in soybean for breeding a P-efficient soybean genotypes at seedling stage.

Shoot length, shoot dry weight, root dry weight decreased in P limited condition whereas root to shoot length ratio increased significantly (Table 5.) and is one of the adaptive mechanism to overcome the P limiting condition in the soil. Leaf P content and P uptake was reduced and PUE was increased under P limiting condition. Twenty per cent decrease in shoot length is evident in - P condition indicating the role of P in the growth of shoot and also higher P availability enhances higher shoot growth in plants due to higher uptake of P.

The results of the screening showed that shoot dry weight and relative shoot dry weight at seedling stage were effective and simple parameters for breeding/screening P efficient genotypes of soybean. It was indicated that the P efficient genotypes facilitated biomass accumulation, root growth, P uptake, shoot P utilization under phosphorus deficiency.

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