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Genetic Study for Selection and Characterization of Phosphorus Efficient Soybean Genotypes

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Abstract

Soybean is one of the most important leguminous crops. Low phosphorus (P) availability is a major constraint to soybean growth and production. Analysis of variance (ANOVA) revealed that there was significant variation for all the traits. Days to germination, days to flowering, plant height at 1st flowering, days to pod setting, no. of cluster plant^{-1}, no. of pods cluster^{-1}, leaf area index (LAI), tap root length, tap root diameter, yield plant^{-1} were highly heritable and number of seeds pod^{-1} showed medium heritability. Genotype-environment interaction was showed that environment 1 (with P-fertilizer) was more suitable for all these genotypes except SBM-17 that was suitable for cultivation in environment 2 (without P-fertilizer). The highest P-absorption rate was found in Binasoybean3 in both environmental conditions. The lowest P-absorption rate was found in SBM-22 in 1 (with P-fertilizer) and SBM-15 in environment 2 (without P-fertilizer). All variety had higher yield in environment 1 compare to environment 2. But, SBM-17 had higher yield in environment 2 than environment 1. Therefore, it was concluded that short root length and thick root diameter were important traits for phosphorus efficiency and SBM-17 and AVRDC-73 considered as phosphorus efficient genotypes. These root traits may be used for more efficient screening for P-efficient genotype or these traits could be tagged with appropriate molecular markers and then incorporated into other varieties through MAS or transgenic approaches.

Keywords: Soybean; Genetic improvement; Phosphorus efficiency

Introduction

The soybean is economically a major bean, which provide us the vegetable protein, oil and it is also an important source of ingredient for hundreds of chemical product [1]. Soybean is considered by many agencies to be a source of complete protein [2]. It consists of 40% protein, 20% oil, 35% carbohydrate and about 5% ash. Soybean is not only important for human diet but also for animal feed. Soybean cake and forage are excellent source of nutritive food for livestock. Soybean oil is one of the few common vegetable oils that contain a significant amount of a LNA (alpha-linolic acid). However, soybean oil does not contain EPA (eicosapentaenoic acid) or DHA (docosahexaenoic acid). Soybean oil has greater amount of omega-6 fatty acids [3].

Low production and acreage of soybean in Bangladesh results from lack of high yielding variety, competitions for a place in existing cropping pattern and lack of available phosphate nutrients in soil [4]. In soybean, adequate P levels are required to enhance shoot and root growth and promote early maturity [5]. As phosphorus is important element for soybean growth low phosphorus (P) availability is a major constraint to soybean growth and production. At the same time, the world is facing a future shortage of P fertilizer resources, as P fertilizers are increasing in cost and P ore deposits that can be economically mined and processed into fertilizer are limited and will eventually be depleted [6]. Therefore, P-efficient varieties should play a major role in increasing soybean growth and yield.

Developing P-efficient soybean varieties that can efficiently utilize native P and added P in the soils would be a sustainable and economical approach to soybean production as well as cropping intensity to improve the nutritional level i.e., the socio-economic condition of the people [7]. This research will help to know the possible mechanisms for P efficiency and breeding strategies to improve P efficiency in soybean [8-11]. It also highlights potential obstacles and depicts future perspectives in soybean breeding for root length and diameter. We need to determine new insights into the mechanism of P efficiency and breeding strategies for soybean. The major objectives of these research programmes were determine the root trait that is suitable for P uptake in soybean, select P efficient soybean genotype and determine the P transportation rate from soil to soybean seed.

Materials and Methods

The field experiment was conducted at the Experimental Farm, Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh during the period between April and August 2014. Ten soybean genotypes were used as experimental materials of which Binasoybean1, Binasoybean2, Binasoybean3, and Binasoybean4, were parent materials and rest of all (SBM-9, SBM-15, SBM-17, SBM-18, SBM-22, AVRDC-73) were mutants. All the materials were collected from Plant Breeding Division, Bangladesh Institute of Nuclear Agriculture (BINA), Mymensingh. The experiment was laid out in Randomized Complete Block Design (RCBD) two factors with three replications, one factor is the genotypes and another factor is phosphorus application. One set of the genotypes was grown in pot without applying phosphorus fertilizers. However, another set of all genotypes was grown with applying phosphorus fertilizers 1.16 gm per pot. In that two dosage of P-fertilizer that was also considered as two different environment. All the data were subjected to statistical analysis using PLABStat [12]. The data were analyzed for variance, heritability, correlation and path coefficient. Treatment differences were compared using the Least Significant Difference (LSD) procedure at 5% level of probability. Genotypic and phenotypic variances were estimated according to the formula given. Heritability in broad sense (h^2_b) was estimated according to the formula suggested [13,14]. Genotypic and phenotypic co-efficient of variations were estimated [15,16]. Estimation of genetic advance was done following formula given [13,17]. Genetic advance in percent of mean was calculated by the formula of Comstock and Robinson [18]. Simple phenotypic correlations were estimated by the formula suggested [19]. Direct and indirect path co-efficient were calculated as described [20].

The phosphorus content was measured in the Department of Soil Science, Bangladesh Institute of Nuclear Agriculture in percentage (%) from seed sample and soil using UV Spectrophotometer (U-2900 Double-Beam Spectrophotometer, 2014). The mean is obtained by dividing the sum of observed values by the number of observations; n. T test uses means and standard deviations of two samples to make a comparison.

Results and Discussion

Evaluation of performance of soybean genotypes

The analysis of variance of 10 soybean genotypes for all characters under study is shown in Table 1. Considerable variations were found among the studied 10 soybean genotypes in respect of yield components and root traits. It was observed that genotypic effects were highly significant for characters viz. days to flowering, plant height at 1st flowering, days to pod setting, no. of cluster plant^{-1}, no. of pods cluster^{-1}, tap root diameter and yield plant^{-1} indicating the presence of variation among the genotypes for these characters. Leaf Area Index (LAI), tap root length and no. of seeds pod-1 were also significant. This variation is probably because the presence of sufficient amount of genetic variability among the genotypes for all the studied traits. The results are in agreement with Malek and Ojo who observed variation among genotypes for plant height, no. of branches plant^{-1}, no. of cluster plant^{-1}, no. of pods cluster^{-1}, no. of seeds pod^{-1}, 100-seed weight, yield plant^{-1} [21,22]. Gohil observed variation for plant height, no. of cluster plant^{-1}, no. of pods cluster^{-1} and yield plant^{-1} [23].

The mean performances of 10 soybean genotypes were evaluated for 11 characters are presented in Table 2. Genotype SBM-17 (10.17) took the lowest days to germinate whereas SBM-22 (11.33) took the highest days to germinate. Genotype SBM-9 (60.33) took the lowest days for flowering and Binasoybean3 (66.83) took the highest days for flowering. Genotype SBM-18 (14.13) was the shortest and genotype AVRDC-73 (22.04) was the tallest which is similar to SBM-9. Genotype SBM-9 (64.33) took the lowest days for pod setting similar to SBM-15. Genotype Binasoybean4 (69.17) took the highest days for pod setting. Genotype Binasoybean2 (8.00) had the lowest number of cluster plant-1 whereas AVRDC-73 (13.67) had the highest. Genotype Binasoybean4 (2.00) had the lowest number of pods cluster-1 and SBM-17 (2.83) had the highest number of pods cluster-1. Genotype SBM-9 (78.11) had the lowest LAI and AVRDC-73 (112.68) had the highest LAI. Binasoybean2 (17.03) had the lowest tap root length whereas Genotype SBM-18 (22.70) had the highest tap root length. Genotype SBM-9 (0.53) had the lowest tap root diameter and AVRDC-73 (0.67) had the highest tap root diameter. SBM-9 (1.83) had the lowest number of seeds plant-1 whereas Binasoybean2 (2.50) had the highest number of seeds plant-1. Genotype Binasoybean4 (4.67) had the lowest yield plant^{-1} and SBM-17 (11.57) had the highest yield plant^{-1}.

Days to germinate	Days to flowering	Plant height at 1st flowering	Days to pod setting	No. of cluster plant^{-1}	No. of pods cluster^{-1}	LAI	Tap root length (cm)	Tap root diameter (cm)	No. of seeds pod^{-1}	Yield plant^{-1} (g)
0.81	33.93**	45.69**	20.74**	21.71**	0.52**	685.4*	19.73*	0.02**	0.19*	25.31**
2.21	2.46	7.41	3.82	2.72	0.6	14.9	5.64	0.001	0.02	15.38
0.27	8.82	5.49	10.42	6.02	0.27	160.09	4.43	0.001	0.07	15.81
1.04	0.75	5.64	2.34	9.27**	0.23	181.21	5.22	0.002	0.07	12.07
0.95	1.6	7.98	2.35	3.9	0.21	189.6	5.03	0.002	0.08	6.75

Table 1: Analysis of variance (mean square value) for 11 qualitative traits of 10 Soybean genotypes.

Genotypes	Days to germinate	Days to flowering	Plant height at 1st flowering	Days to pod setting	No. of cluster plant^{-1}	No. of pods cluster^{-1}	LAI	Tap root length (cm)	Tap root diameter (cm)	No. of seeds pod^{-1}	Yield plant^{-1} (g)
SBM-9	10.83	60.33	22.04	64.33	11.17	2.5	78.11	19.66	0.53	1.83	7.14
SBM-15	11.17	61	20.13	64.33	10.17	2.67	88.83	21.78	0.57	2	7.56
SBM-18	11	61.83	14.13	65.67	10.83	2.5	104.9	22.7	0.58	2.17	8.38
SBM-22	11.33	63.83	18.78	67.17	10.67	2.83	98.9	19.94	0.56	2	8.49
SBM-17	10.17	62.33	17.33	66.17	13.5	2.83	108.64	19.97	0.65	2	11.57

AVRDC-73	10.83	65.5	22.04	68.83	13.67	2.5	112.68	20.19	0.67	2.17	9.85
Binasoybean1	10.83	65.33	18.46	68.33	11.5	2.67	101.87	17.06	0.64	2	8.54
Binasoybean2	11.33	60.5	14.13	65.33	8	2.5	87.53	17.03	0.56	2.5	7.26
Binasoybean3	10.5	66.83	18.78	68.5	9.33	2	102.94	19.81	0.67	2	5.04
Binasoybean4	10.67	65.33	17.33	69.17	8.33	2	93.27	18.36	0.61	2	4.67
Minimum	9	57	12.25	61	6	2	58.96	12.83	0.47	1	3.36
Maximum	13	67	28.75	71	21	3	133.67	26.17	0.72	3	17.64
Mean	10.87	63.28	18.31	66.78	10.72	2.5	97.77	19.65	0.6	2.07	7.85
$LSD_{(0.05)}$	1.33	1.13	3.1	2	3.98	0.63	17.58	2.98	0.06	0.34	4.54

Table 2: Mean performance of 10 Soybean genotypes for yield and yield contributing characters.

Effects of genotype- environment interaction on performance of soybean genotypes

Table 3 indicates the effect of genotype- environment interactions on different traits. Significant variation was found among genotypes over environment with respect to their stability in different environment [24]. All varieties had long root length and thin root diameter in without P-fertilizer condition compare to with P-fertilizer condition. But SBM-17 and AVRDC-73 had short root length and thick root diameter. All genotypes produced lower yield in without P-fertilizer condition than with P-fertilizer condition whereas, SBM-17 produced higher yield in no P-fertilizer condition. The results were due to short root length and thick root diameter of the genotype and they uptake P in zero P-fertilizer condition by expanding absorptive surface area of root. So, short root length and thick root diameter considered as important morphological trait for phosphorus efficiency. This result also supported by the observation [25].

Genotypes	Environments	Days to germinate	Days to flowering	Plant height at 1st flowering	Days to pod setting	No. of cluster plant^{-1}	No. of pods cluster^{-1}
SBM-9	ENV1	11.67	59.67	22.5	63.67	10.33	3
	ENV2	10	61	21.58	65	12	2
SBM-15	ENV1	11	61	22.42	64.33	11	2.67
	ENV2	11.33	61	17.83	64.33	9.33	2.67
SBM-18	ENV1	11	61.33	15	65	10	2.67
	ENV2	11	62.33	13.25	66.33	11.67	2.33
SBM-22	ENV1	11.67	63.33	18.33	67	11.33	2.67
	ENV2	11	64.33	19.22	67.33	10	3
SBM-17	ENV1	10.67	62.67	16.5	66.67	12	2.67
	ENV2	9.67	62	18.17	65.67	15	3
AVRDC-73	ENV1	10.33	64.67	22.5	67.67	16.67	2.67
	ENV2	11.33	66.33	21.58	70	10.67	2.33
Binasoybean1	ENV1	10.67	64.67	19.08	67.67	12	2.67
	ENV2	11	66	17.83	69	11	2.33
Binasoybean2	ENV1	11.67	60	15	64	8.67	2.67
	ENV2	11	61	13.25	66.67	7.33	2.33
Binasoybean3	ENV1	10.33	66.67	18.33	69	10	2

	ENV2	10.67	67	19.22	68	8.67	2
Binasoybean4	ENV1	10.33	65	16.5	68.67	8.33	2
	ENV2	11	65.67	18.17	69.67	8.33	2

Table 3: Environment wise mean performance of 10 Soybean genotypes considering genotype-environment interaction (Contd.).

Analysis of genetic parameters for 10 soybean genotypes

The presence of genetic variability in breeding materials is essential for a successful breeding program. In this experiment all characters showed significant phenotypic and genotypic variance (Table 4).

Traits	Genotypic variance	Phenotypic variance	GCV (%)	PCV (%)	Heritability h^2_b (%)	Genetic Advance	GA (%)
	δ^2_g	δ^2_p					
Days to germinate	0.09	0.12	0.83	1.1	75	0.55	5.06
Days to flowering	2.41	2.65	3.81	4.19	90.94	4.33	6.84
Plant height at 1st flowering	3.27	3.65	17.86	19.93	89.59	4.95	27.03
Days to pod setting	1.48	1.76	0.22	2.64	84.09	3.13	4.68
No. of cluster plant-1	1.67	1.93	15.58	18	86.52	3.29	30.69
No. of pods cluster-1	0.04	0.05	1.6	2	80	0.46	18.4
LAI	50.38	62.47	51.53	63.89	80.65	17.24	17.63
Tap root length (cm)	1.45	1.59	7.38	8.09	91.19	3.3	16.67
Tap root diameter (cm)	0.001	0.001	0.17	0.17	100	0.1	16.67

Table 4: Genetic parameters of different traits of 10 soybean genotypes.

Variability parameters: The presence of genetic variability in breeding materials is essential for a successful breeding program. In this experiment all characters showed significant phenotypic and genotypic variance (Table 4). The difference between genotypic and phenotypic coefficient of variability indicates the environmental influence. Table indicates that among all the traits leaf area index (LAI) exhibited the highest estimates of genotypic coefficient of variation (GCV; 51.53%) and tap root diameter exhibited the lowest genotypic coefficient of variation (GCV; 0.17%). In case of phenotypic coefficient of variation (PCV) leaf area index (LAI) exhibited the highest value (63.89%) and the lowest value (0.17%) was found for leaf area index. The result is due to expression of different traits under study was less influenced by environmental factors. Karnwal and Singh also reported similar results [26].

Heritability: Heritability estimates have been extensively used by plant breeders in selecting promising genotypes. The heritability (h^2b) for all the traits of 10 soybean genotypes under study is presented in Table 4. Estimation of heritability indicates that days to germinate, days to flowering, plant height at 1st flowering, days to pod setting, no. of cluster plant^{-1}, no. of pods cluster^{-1}, leaf area index (LAI), tap root length, tap root diameter, yield plant^{-1} were highly heritable. Number of seeds pod^{-1} showed medium (50.00%). Heritability and GA together with GCV could provide the best image of the amount of advancement to be expected through phenotypic selection [26].

Genetic advance: Only heritability does not give the clear indication of desirable genotypes. The highest value was found in trait leaf area index (17.24). The lowest genetic advance was in tap root diameter (0.10). Expected genetic advance as percent of mean indicates the mode of gene action in the expression of traits, which helps in selection. The highest value in genetic advance as percent of mean was found for the trait yield plant^{-1} (42.29%); while the lowest value (4.68%) for days to pod setting (Table 4).

Estimation of correlation coefficient: Relationship between physiological and yield contributing characters was studied through analysis of correlation between them. The correlation coefficients between all the 11 characters were presented in Table 5. In the present study out of 55 associations 6 associations were highly significant. Among them, 5 associations were positively significant and the rest 1 was negatively significant. From rest of the 47 associations 2 associations were significant. Among them, 1 association was positively significant and the rest 1 were negatively significant. Besides, 24 relationships were positive and non-significant and 23 relationships were negative and non-significant. The result of the present experiment indicated that no. of cluster plant^{-1}, no. of pods cluster^{-1} and no. of seeds pod^{-1} was most important characters which exhibited positive. The result was in agreement with Arshad and Machikowa and Laosuwan [27,28].

Traits	Days to germinate	Days to flowering	Plant height at 1st flowering	Days to pod setting	No. of cluster plant^{-1}	No. of pods cluster^{-1}	LAI	Tap root length (cm)	Tap root diameter (cm)	No. of seeds pod^{-1}
Days to flowering	-0.38									
Plant height at 1st flowering	-0.14	0.2								
Days to pod setting	-0.34	0.95**	0.09							
No. of cluster plant-1	-0.41	0.07	0.45	0.05						
No. of pods cluster-1	-0.26	-0.47	0.06	-0.46	0.56					
LAI	-0.41	0.6	-0.09	0.59	0.57	0.1				
Tap root length (cm)	-0.03	-0.23	0.08	-0.37	0.3	0.16	0.21			
Tap root diameter (cm)	-0.66*	0.79**	0.15	0.75*	0.41	-0.24	0.81**	-0.11		
No. of seeds pod-1	-0.24	-0.34	-0.80**	-0.2	-0.31	0.11	0.06	-0.24	-0.09	
Yield plant-1 (g)	-0.15	-0.23	0.06	-0.19	0.85**	0.83**	0.5	0.21	0.19	0.16

Note: * and ** indicates significant at 0.05 and 0.01 probability, respectively

Table 5: Coefficient of Correlation among different yield components of 10 soybean genotypes.

Path co-efficient study: The relations between grain yield and yield contributing characters were studied in detail by path coefficient analysis. The Path coefficient analysis was performed using correlation co-efficient to determine direct and indirect influence considering ten characters. Yield plant^{-1} being the complex outcome of different characters, was considered as the resultant variable and other characters as causal variable. Estimates of direct and indirect effects of ten yield contributing characters are shown in Table 6. From the Table 6, it was observed that Leaf Area Index (1.18) had maximum positive direct effects on yield plant^{-1}. This character influence yield plant^{-1} indirectly mostly in positive direction. Other characters such as plant height at 1st flowering (0.11), no. of cluster plant^{-1} (0.22), no. of pods cluster^{-1} (0.17) also had high positive direct effects. It suggests that these are the main contributors to yield of the plant. A study was conducted by Turkec to determine the correlations among seed yield and some yield components as well as the direct and indirect effects of these characters on seed yield in soybean [29].

Traits	Days to germinate	Days to flowering	Plant height at 1st flowering	Days to pod setting	No. of cluster plant^{-1}	No. of pods cluster^{-1}	LAI	Tap root length (cm)	Tap root diameter (cm)	No. of seeds pod^{-1}	Correlation value to yield plant^{-1} (g)
Days to germinate	-0.07	0.03	0.01	0.02	0.03	0.02	0.03	0.03	0.05	0.02	-0.15
Days to flowering	0.27	-0.72	-0.14	-0.69	-0.05	0.34	-0.43	0.17	-0.57	0.24	-0.23
Plant height at 1st flowering	-0.02	0.02	0.11	0.09	0.05	0.05	-8.61	0.09	0.02	-0.09	0.06
Days to pod setting	0.07	-0.19	-0.02	-0.2	-0.08	0.09	-0.12	0.08	-0.15	0.04	-0.19
No. of cluster plant^{-1}	-0.09	0.02	0.09	0.09	0.22	0.12	0.12	0.07	0.09	-0.07	0.85**
No. of pods cluster^{-1}	-0.05	-0.08	0.09	-0.08	0.09	0.17	0.02	0.03	-0.04	0.02	0.83**
LAI	-0.48	0.71	-0.09	0.69	0.67	0.12	1.18	0.24	0.96	0.07	0.51

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Tap root length (cm)	0.02	0.1	-0.04	0.16	-0.14	-0.1	-0.09	-0.45	0.05	0.11	0.21
Tap root diameter (cm)	0.15	-0.17	-0.03	-0.16	-0.09	0.05	-0.18	0.02	-0.22	0.02	0.19
No. of seeds pod^{-1}	0.05	0.07	0.16	0.04	0.06	-0	-0.01	0.05	0.02	-0.2	0.16
Residual effect = 0.13											

Table 6: Partitioning of phenotypic correlations into direct and indirect effects by path analysis (Bold figure indicate the direct effect).

Effects of phosphorus on performance of soybean genotypes

Phosphorus efficient varieties should play a major role in increasing soybean yield. The relation between phosphorus absorption rate and yield plant^{-1} was shown in Table 7. Among the genotypes in environment 1, the highest absorption was found in genotype Binasoybean3 (22) and the lowest absorption was found in genotype SBM-22 (14.52). In environment 2, the highest absorption was found in genotype Binasoybean3 (18.2) and the lowest absorption was found in genotype SBM 15 (11.46). The highest P uptake by plant was found in genotype SBM-15 (8.75) and the lowest P uptake by plant was found in genotype AVRDC-73 (0.28). The highest phosphorus use efficiency was found for SBM-15 (28.80). The lowest phosphorus use efficiency was found for AVRDC-73 (0.92). In phosphorus added condition, the highest yield plant^{-1} was found in genotype AVRDC-73 (12.69) and the lowest yield plant^{-1} was found in Binasoybean4 (4.67). On the other hand without phosphorus condition, the highest yield plant^{-1} was found in genotype SBM-17 (14.28) and the lowest yield plant^{-1} was found in Binasoybean4 (4.67). The result is probably due to change in root morphology including tap root length and tap root diameter which expand the absorptive surface area of the root and increasing the soil volume explored by the roots. As a result plant can uptake more nutrient from soil and ultimately yield is increased. The result is in agreement with Gahoonia and Nielsen [11]

Phosphorus use efficiency (PUE) was good indexes for evaluating P-efficiency of soybean genotypes. The highest P use efficiency was found of SBM-15 followed by Binasoybean1, Binasoybean4, and SBM-22. Soybean genotype with shallow root system increase P use efficiency [30].

Therefore, it was clearly remarked that SBM-17 was the best variety in low P-soil, where P-fertilizer had very low contribution to increase its yield. However, AVRDC-73 performed best in P-fertilizer condition, this result also supported from their root length and diameter. Both of the genotypes had short root length with thick roots. This results also supported by the observation of Liu.

Genotypes	P in soil as fertilizer (with P) ppm	P in soil as fertilizer (without P) ppm	P absorbed by plant (with P) ppm	P absorbed by plant (without P) ppm	P uptake by plant from fertilizer (ppm)	P use efficiency from fertilizer (%)	Yield plant^{-1} (g)	Yield plant^{-1} (g)
							(with P)	(without P)
SBM-9	30.38	0	15.96	14.27	1.67	5.49	8.68	5.6
SBM-15	30.38	0	20.21	11.46	8.75	28.8	8.31	6.81
SBM-18	30.38	0	14.63	12.46	2.17	7.14	9.1	7.65
SBM-22	30.38	0	14.52	13.58	0.94	3.09	8.59	8.4
SBM-17	30.38	0	18.78	16.28	2.5	8.23	8.87	14.28
AVRDC-73	30.38	0	15.82	15.54	0.28	0.92	12.69	7
Binasoybean1	30.38	0	16.94	12.62	3.78	12.44	8.96	8.12
Binasoybean2	30.38	0	16.84	12.87	3.97	13.07	8.54	5.97
Binasoybean3	30.38	0	22	18.2	3.8	12.51	5.23	4.85
Binasoybean4	30.38	0	16.59	12.77	3.82	12.54	4.67	4.67
MEAN	30.38	0	17.23	14.01	3.16	10.42	8.36	7.34
LSD (0.05)	2.16	0	1.39	1.2	1.35	4.49	1.26	1.59

Table 7: Phosphorus absorption rate in two environments (with phosphorus and without phosphorus.

Conclusion

The present research work was designed with a view to identify the phosphorus efficient soybean genotypes in respect of yield contributing characters and P-efficiency traits. There were significant variations among the genotypes for the characters. Among the genotypes SBM-17, AVRDC-73 had been selected as stable and phosphorus efficient soybean genotypes enhancing yield. In zero P-fertilizer condition, SBM-17 and AVRDC-73 had short root length and thick root diameter compare to other genotypes. For this trait, they uptake P from soil by expanding absorptive surface area of the root and produced higher yield in zero P-fertilizer condition than P-fertilizer condition. Therefore, it was clearly remarked that short root length and thick root diameter was important root trait for phosphorus efficiency and SBM-17 and AVRDC-73 was considered as phosphorus efficient genotypes. These short root length and thick root diameter traits could be used for more efficient screening in no P-fertilizer environments, or tagged with molecular markers and then incorporated into other varieties through MAS or transgenic approaches. This variability may be also used for selection of superior genotypes for commercial cultivation at farmer's level in low P-fertilizer situation as well as for breeding new genotypes of soybean in our country.

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