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Genetic Variation and Correlation among Seedling and Mature Plant Traits of Soybean Evaluated in Acid Sand Culture and on Acid/Neutral Soil Fields of Nigeria

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Abstract

Experiments in acid sand culture, acid and neutral soil fields were carried out in 2003 with the objective of studying genetic variability and correlation among seedling and mature plant traits with a view of guiding breeders on appropriate selection options in breeding for aluminium/acid stress tolerant soybean in Nigeria. Genotypic variance was high for all the sand culture traits (root dry weight, shoot dry weight and relative root surface area), leading to the high heritability estimates of 77.85% to 83.72%. Genetic advance as a percentage of the mean (GA) was very high (85.51%-155.84%) for the sand culture traits. As expected, a better performance in terms of grain yield and yield components was observed for the neutral soil field compared to the acid soil field. However, higher heritability estimates were observed for the field traits measured on the acid soil field compared to the neutral soil field. Heritability estimates for the days to flowering and plant height were high (66.44%-79.63%) compared to the moderate heritability (47.42%-58.89%) observed for the number of pods/plant and grain yield on both soils. Conversely, the GA for days to flowering and plant height was lower (12.08%-26.49%) compared to the values (27.27%-41.56%) observed for number of pods/plant and grain yield on both fields. Higher genotypic and phenotypic coefficients of variation (GCV and PCV) were observed for the sand culture traits compared to the field traits. On the acid and neutral soil fields GCV and PCV values were lower for the days to flowering and plant height compared to the values observed for the number of pods/plant and grain yield, with highly significant correlation between/within the sand culture traits and the field traits. These results indicate that selection of soybean genotypes with high seedling root dry weight and relative root surface area in acid sand culture at 450 μM Al^{3+} will enhance progress in the selection of high yielding acid tolerant tropically adapted genotypes of soybean on acid soils of Nigeria.

Keywords: genotypic and phenotypic variances, PCV, GCV, heritability, GA

1. Introduction

Soybean is a very important world crop because of its usefulness in human and livestock nutrition and in the industry. It is a rich source of high quality edible oil with a very high percentage of crude protein compared to other leguminous crops. As a legume, soybean enhances the productivity of the soil in crop rotation and can be produced with little or no fertilizer. Hence, it is extensively produced in temperate, tropical and subtropical regions of the World (Ojo et al., 2010) with a steady worldwide annual increase in production (Liu, 1997) aimed at reducing the demand-supply deficit.

Despite this global effort, Nigeria has a very low annual production of 439,000 t/ha, accounting for only 0.25% of the world annual output of 173 million tons between 1999 and 2003 (FAO, 2005). The low annual production output of soybean grains in Nigeria could be attributed to small area of land devoted to the cultivation of the crop and low productivity.

The high demand for soybean by oil mills due to the increasing popularity of high quality edible oil and its associated by-product of oil extraction (the soybean cake) for the poultry industry in Nigeria is a challenge to the farming population to meet up with the required needs. While the problem of small area of land devoted to the crop could be solved by simply increasing the hectarage, the problem of low productivity could only be resolved through concerted breeding effort (Ojo et al., 2013). The average annual grain yield of 0.946 t/ha from only 625,667 ha reported for Nigeria for the 2006 to 2008 period (Tefera, 2011) cannot offset the demand for soybean in Nigeria. There is therefore the need to increase both the production area and the productivity of the crop in Nigeria. These challenges are currently being overcome by extending the production of soybean beyond its traditional area of production (Guinea Savanna ecology) to the drier ecology of Sudan Savanna by planting early maturing high yielding varieties. However commercial production of soybean on the acid soils of the South-East and South-South rain forest agro ecological zone of Nigeria still remain a mirage.

Previous studies had identified aluminium/acid stress tolerant tropically adapted genotypes of soybean in sand culture (Ojo & Ayuba, 2012) and acid soil field (Ojo et al., 2010) respectively, without any information on genetic variability in the population and whether these results correlate with each other. The presence and magnitude of genetic variability in a gene pool is the pre-requisite of a breeding programme (Aditya et al., 2011) because the selection of superior genotypes is proportional to the amount of genetic variability and the extent to which the characters are inherited (Omoigui et al., 2006). Estimates of heritability and genetic advance are important selection parameters (Ogunbayo et al., 2014) and the magnitudes of such estimates suggest the extent to which improvement is possible through selection (Omoigui et al., 2006) while the knowledge of correlations among various characters is useful for multiple character selection (Kehinde & Idehen, 2007).

Studies elsewhere (Hanson & Kamprath, 1979; Bianchi-Hall, 1998) indicates that aluminium stress tolerance in soybean is a highly heritable trait. However, results from controlled experiments hardly correlate with that of the field (Fountain, 1990; Hanson, 1991; Ferrufino et al., 2000; Spehar, 1999). There is dearth of information on genetic variability for aluminium/acid stress tolerance and correlation between controlled and field experiments in tropically adapted genotypes of soybean in Nigeria. The question of whether results of field experiments on tropically adapted soybean varieties from neutral soil fields of the Southern Guinea Savanna ecology (traditional area of production of soybean where its research is concentrated) of Nigeria correlate with that of the acid soil fields of the South-East and South-South rain forest agro ecological zones of the country also needs to be addressed. Such information will guide the breeder on the various selection options and probably reduce the cost of evaluation.

The current study was therefore initiated to study genetic variability in tropically adapted soybean seedling and mature plant traits in acid sand culture and on acid and neutral soil fields of Nigeria respectively. A second objective was to correlate genotypic means of traits within and between the three growth media with a view of guiding breeders on appropriate selection options in breeding for aluminium/acid stress tolerant soybean in Nigeria.

2. Materials and Methods

2.1 Soybean Genotypes

Forty nine (49) early, medium and late maturing tropically adapted soybean genotypes with diverse response to aluminium stress tolerance (Ojo, 2010) were selected for acid sand culture, acid and neutral soil field experiments. The 49 soybean genotypes were obtained from the International Institute for Tropical Agriculture (IITA), Ibadan, Nigeria and maintained by the Soybean Research Unit of the Federal University of Agriculture, Makurdi, prior to the commencement of the experiment.

2.2 Sand Culture Experiment

The sand culture experiment is part of the work published by Ojo and Ayuba (2012). Below is a brief description of the experiment. The experimental design was a randomized complete block design with three replications, and the treatments were factorial combinations of 49 genotypes and two levels of aluminium activity (0 µM Al^{3+} and 450 µM Al^{3+}). The experimental procedure was according to Villagarcia et al. (2001), with some modification on the time of imposition of aluminium treatment and duration of the experiment.

Polyethylene bags measuring 20 cm in diameter were each filled with 10kg builders' grade sharp sand and flushed with deionised water adjusted to pH 4.05±0.05. The sand was flushed again with deionised water adjusted to pH 7.0 to remove the acidity and allowed to drain for 24 hours. Thereafter, the sand was heavily watered with deionised water and six seeds were planted in each bag and lightly covered with the sharp sand. The pots were then watered daily with deionised water (pH 7.0) until five days after planting (5 DAP) when emerged seedlings were thinned down to three/pot. The watering with deionised water (pH 7.0) continued till 7 DAP. Thereafter, nutrient solution (Table 1) with either of the two levels of aluminium activity (0 µM Al^{3+} or 450 µM Al^{3+}) were used to water each of the pots for the next eighteen days, with each pot receiving one litre of solution per day. To avoid a build-up of nutrients, each pot was flushed daily with deionised water (pH 4.05±0.05) and a time lag of two hours was allowed for the pots to drain prior to watering with the nutrient solution.

Nutrient stock solution concentration was developed following the procedure of Howell and Bernard (1961) and Villagarcia et al. (2001) (Table 1).

Table 1. Composition of nutrients in sand culture

Chemical	**Concentration in Moles Litre^{-1}**
KH_2PO_4	1.5 mM
K_2SO_4	1.5 mM
$NaH_2PO_4 \cdot 2H_2O$	1.0 mM
NH_4NO_3	2.0 mM
$CaSO_4 \cdot ½H_2O$	3.0 mM
$MgSO_4$	100 µM
$Fe(NO_3)_2$	20 µM
H_3BO_3	10 µM
$ZnSO_4 \cdot 7H_2O$	1.5 µM
$MnCl_2 \cdot 4H_2O$	1.5 µM
$CuSO_4 \cdot 5H_2O$	0.5 µM
$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.8 µM

Note. mM = Millimole µM = Micromole. The 450 µM Al^{3+} level of aluminium activity was supplied in the form of $Al_2(SO_4)_3$ while aluminium was excluded from 0 µM Al^{3+} level of aluminium activity.

The 0 µM Al^{3+} aluminium activity was regarded as the control in which aluminium was excluded from the nutrient solution. The Experiment was conducted during the dry season of January to March, 2003. Plants were harvested at 25 DAP and data were taken on root dry weight (RDW), shoot dry weight (SDW) and relative root surface area (RRSA). Plants were separated into root and shoot and data on RRSA was taken according to Carley and Watson (1966) prior to oven drying. Thereafter, root and shoot were separately dried to a constant weight at 70 °C and their weights taken as RDW and SDW respectively.

2.3 Acid Soil Field Experiment

The acid soil field experiment is part of the work published by Ojo et al. (2010). Below is a brief description of the experiment. The National Root Crops Research Institute (NRCRI), Umudike, Nigeria, was selected as the acid soil field site in the rain forest zone of South-East Nigeria. The physical and chemical properties of the acid soil field are presented in Table 2. Umudike is situated on Latitude 5°29′N and Longitude 7°32′E at an altitude of 122 m above sea level.

Forty nine genotypes of soybean were planted out in a randomized complete block design with three replications on the 8th July, 2003.

Table 2. Physical and chemical properties of the soil used for acid soil field experiment in Nigeria during the 2003 cropping season

Sand (%)	77.6
Silt (%)	13.6
Clay (%)	8.8
Textural Class	Loamy sand
PH	4.50
Organic Carbon (%)	2.16
Organic Matter (%)	3.73
Total Nitrogen (%)	0.20
Available P(mg kg^{-1})	8.9
Ca^{++} (cmol kg^{-1})	1.60
Mg^{++} (cmol kg^{-1})	0.80
K^{+} (cmol kg^{-1})	0.04
Na^{++}(cmol kg^{-1})	0.15
H^{+}(cmol kg^{-1})	0.55
Al^{3+}(cmol kg^{-1})	1.65
Exchangeable acidity (cmol kg^{-1})	2.20
ECEC	4.79

The area of each plot was 15 m^2. Each plot consisted of 3 ridges of 5 m length, spaced 1.0 m apart. Seeds were drilled into the crest of ridges and later thinned down to 26 plants per meter after emergence. The field was sprayed with a pre-emergence herbicide immediately after planting and manually weeded at five weeks after planting (5 WAP). Fertilizer was applied at the rate of 10 kg N/ha, 36 kg P_2O_5/ha and 20 kg K_2O/ha within the first two weeks after planting (2 WAP). Harvesting was carried out in November of the same year and data were taken from the two centre rows of each plot on:

(i) Days to flowering, recorded at flowering of 50% of plants within a plot.

(ii) Plant height at maturity from the mean of ten randomly selected plants in each plot.

(iii) Number of pods per plant, determined from the mean of five randomly selected plants in each plot.

(iv) Grain yield, in tons/ha estimated from grain yield per plot.

2.4 Neutral Soil Field Experiment

The experiment was carried out at the Teaching and Research Farm of the Federal University of Agriculture Makurdi (lat. 7°41′N, long. 8°28′E). The physical and chemical properties of the neutral soil field are presented in Table 3. The location falls within the southern Guinea Savanna agro-ecological zone of Nigeria.

Forty nine genotypes of soybean were planted out in a randomized complete block design with three replications on the 20th of June 2003. The area of each plot was 12 m^2. Each plot consisted of 4 ridges of 4m length, spaced 0.75 m apart. Seeds were drilled into the crest of the ridges at a depth of 2 cm and later thinned down to 26 plants per meter after emergence. The field was manually weeded at two (2 WAP) and five weeks after planting (5 WAP). Fertilizer was applied at the rate of 10 kg N/ha, 36 kg P_2O_5/ha and 20 kg K_2O/ha within the first two weeks after planting (2 WAP). Harvesting was carried out in November of the same year.

Table 3. Physical and chemical properties of the soil used for neutral soil field experiment in Nigeria during the 2003 cropping season

Sand (%)	87.4
Silt (%)	8.4
Clay (%)	4.2
Textural Class	Sandy loam
PH (water)	6.16
PH (KCl)	5.00
Organic Matter (%)	2.80
Total Nitrogen (g/kg)	1.0
Available P (mg kg^{-1})	5.5
Ca^{++} (cmol kg^{-1})	3.4
Mg^{++} (cmol kg^{-1})	0.92
K^{+} (cmol kg^{-1})	0.3
Na^{++} (cmol kg^{-1})	0.16
Exchangeable acidity (cmol kg^{-1})	2.30
CEC	2.3

The following observations were recorded during the conduct of the experiment:

(i) Days to flowering, recorded at flowering of 50% of plants within a plot.

(ii) Plant height at maturity, from the mean of ten randomly selected plants in each plot.

(iii) Number of pods per plant, determined from the mean of five randomly selected plants in each plot.

(iv) Grain yield in tons/ha, estimated from grain yield per plot.

2.5 Data Analysis

Data generated from all the experiments were subjected to analysis of variance by the General Linear Model (GLM) and the Analysis of variance (ANOVA) procedures of SAS (1990) while SPSS statistics 17 was used to correlate genotypic means of phenotypic traits.

Components of variance were estimated according to Bliss et al. (1973). Variance components were obtained by equating the mean square for a source of variation to its expectation and solving for the unknown as given below:

$$\delta^2_e = M_3 \quad (1)$$

$$\delta^2_{ge} = M_2 - M_3/r \quad (2)$$

$$\delta^2_g = M_1 - M_2/rt \quad (3)$$

Where, δ^2_e, δ^2_{ge}, and δ^2_g are components of variance for error, genotype by aluminium interaction and genotype, respectively. M_1, M_2, and M_3 are the observed values of the mean squares for the genotype, interaction and error, respectively (Fehr, 1987).

Broad sense heritability (h^2_{BS}) was calculated as the ratio of the genotypic variance to phenotypic variance using the formula of Allard (1960) and expressed in percentage:

$$\delta^2_g/\delta^2_{ph} \times 100 \quad (4)$$

Where, h^2_{BS} = broad sense heritability (%); δ^2_g = genotypic variance; δ^2_{ph} = phenotypic variance, $\delta^2_{ph} = \delta^2_e + \delta^2_{ge} + \delta^2_g$ as defined by Fehr (1987).

PCV (phenotypic coefficient of variation) and GCV (genotypic coefficient of variation) were calculated from the formula:

$$PCV = \text{phenotypic standard deviation/mean} \quad (5)$$

$$GCV = \text{genotypic standard deviation/mean} \quad (6)$$

Genetic advance as percentage of the mean was calculated at 10% selection intensity (I = 1.76).

3. Results

Highly significant aluminium, genotype and aluminium × genotype interaction effect was observed for the root dry weight, shoot dry weight and relative root surface area of soybean seedlings evaluated in acid sand culture (Table 4). Similarly, highly significant genotypic effect was observed for the number of days to flowering, plant height, number of pods/plant and grain yield evaluated on the acid and neutral soil fields (Table 5).

Table 4. Mean squares for root and shoot characteristics of 49 tropically adapted soybean genotypes screened at two levels of aluminium activity (0 µM Al^{3+} and 450 µM Al^{3+}) in acid sand culture in 2003

Source of variation	Df	Root dry weight	Shoot dry weight	Relative root surface area
Reps	2	0.0004	0.0008	0.0031
Aluminium	1	0.2600^{**}	3.0300^{**}	184.6000^{**}
Genotype	48	0.0902^{**}	0.3569^{**}	7.9819^{**}
Aluminium × Genotype	48	0.0168^{**}	0.0720^{**}	2.2100^{**}
Error	194	0.0028	0.0029	0.0805

Genotypic variance was high for all the sand culture traits (root dry weight, shoot dry weight and relative root surface area), leading to the high heritability estimates of 77.85% to 83.72% (Table 6). Genetic advance as a percentage of the mean (GA) was very high (85.51%-155.84%) for the sand culture traits. As expected, a better performance in terms of grain yield and yield components was observed for the neutral soil field compared to the acid soil field. However, higher heritability estimates were observed for the field traits measured on the acid soil field compared to the neutral soil field. Heritability estimates for the days to flowering and plant height were high (66.44%-79.63%) compared to the moderate heritability (47.42%-58.89%) observed for the number of pods/plant and grain yield on both soils. The trend in the GA is completely different from that of heritability estimate. The GA for days to flowering and plant height was lower (12.08%-26.49%) compared to the values (27.27%-41.56%) observed for number of pods/plant and grain yield on both fields. Higher genotypic and phenotypic coefficients of variation (GCV and PCV) were observed for the sand culture traits compared to the field traits. GCV ranged from 55.07% for the relative root surface area to 96.77% for root and shoot dry weights in the sand culture. Similarly, PCV ranged from 62.41% for the relative root surface area to a very high value of 182.15% for the root dry weight in the same medium. On the acid and neutral soil fields, GCV and PCV values were lower for the days to flowering and plant height compared to the values observed for the number of pods/plant and grain yield. Lower GCV values of 7.63% to 17.36% were observed for days to flowering and plant height compared to higher values of 21.81% to 30.77% recorded for number of pods/plant and grain yield on both fields. Similarly PCV values were higher (30.70%-40.10%) for number of pods/plant and grain yield compared to lower values of 8.62% to 20.03% recorded for days to flowering and plant height on both fields.

Table 5. Mean squares for grain yield and other quantitative traits in 49 tropically adapted soybean genotypes evaluated on acid and neutral soil fields of Nigeria during the 2003 croppinng season

Source of variation	Df	Acid Soil Field				Neutral Soil field			
		Days to flowering	Plant Height	Number of pods/plant	Grain yield	Days to flowering	Plant Height	Number of pods/plant	Grain yield
Reps	2	0.4515	6.3705	87.2200	0.0147	0.5826	8.9324	95.1126	0.0723
Genotypes	48	36.5283^{**}	145.7317^{**}	912.2708^{**}	0.4669^{**}	38.1364^{**}	150.1145^{**}	1222.1904^{**}	1.8824^{**}
Error	96	2.8729	14.4630	172.2259	0.1031	3.9981	21.6345	301.3345	0.5109

Table 6. Means, range, variance components, coefficients of variation, heritability and genetic advance for seedling and mature plant traits of tropically adapted soybean genotypes evaluated in acid sand culture, acid and neutral soil fields of Nigeria in 2003

Trait	Mean	Range	δ^2_g	δ^2_{ge}	δ^2_e	δ^2_{ph}	GCV (%)	PCV (%)	h^2_{BS} (%)	GA (%)
Acid Sand Culture										
Root dry weight	0.31	0.81-0.70	0.09	0.02	$2.8x10^{-3}$	0.11	96.77	106.98	81.82	154.07
Shoot dry weight	0.62	0.30-1.13	0.36	0.07	$2.9x10^{-3}$	0.43	96.77	182.15	83.72	155.84
Relative root surface area	5.13	2.90-8.08	7.98	2.18	0.08	10.25	55.07	62.41	77.85	85.51
Acid Soil Field										
Days to flowering	43.55	35.10-53.61	11.22	-	2.88	14.09	7.69	8.62	79.63	12.08
Plant height	38.10	23.98-51.00	43.76	-	14.46	58.22	17.36	20.03	75.16	26.49
Number of pods/plant	51.04	17.80-88.95	246.68	-	172.23	418.91	30.77	40.10	58.89	41.56
Grain yield	1.31	0.68-2.20	0.12	-	0.10	0.22	26.44	35.80	54.55	34.38
Neutral Soil Field										
Days to flowering	44.19	35.17-53.50	11.38	-	4.00	15.38	7.63	8.87	73.99	11.56
Plant height	45.68	30.22-58-20	42.83	-	21.63	64.46	14.33	17.58	66.44	20.55
Number of pods/plant	80.33	58.33-133.0	306.95	-	301.33	608.28	21.81	30.70	50.46	27.27
Grain yield	2.59	1.86-3.23	0.46	-	0.51	0.97	26.19	38.03	47.42	31.74

Table 7. Phenotypic correlation of genotypic means among juvenile plant traits in acid sand culture and mature plant traits evaluated on acid and neutral soil fields in Nigeria

Trait	R450	S0	S450	A0	A450	DF^a	PH^a	PPP^a	GY^a	DF^n	PH^n	PPP^n	GY^n
R0	.83**	.24	.08	.59**	.75**	.22	.24	.54**	.47**	.21	.14	-.13	-.32
R450		.05	.19	.39**	.79**	.15	.21	.65**	.63**	.15	.14	-.05	-.19
S0			.69**	.14	.11	.01	.02	.08	.14	.01	-.07	.22	-.05
S450				.13	.24	.23	.22	.18	.24	.23	.19	.36*	.13
A0					.67**	.57**	.58**	.49**	.38**	.57**	.47**	.01	-.27
A450						.38**	.41**	.61**	.56**	.38**	.35*	.13	-.23
DF^a							.87**	.18	.04	.95**	.86**	.08	-.16
PH^a								.16	.06	.87**	.89**	.21	-.06
PPP^a									.85**	.18	.12	.03	-.17
GY^a										.04	-.03	.07	-.17
DF^n											.86**	.08	-.16
PH^n												.09	-.11
PPP^n													.56**

Note. R0: Root dry weight at 0 μM Al^{3+} in sand culture; R450: Root dry weight at 450 μM Al^{3+} in sand culture; S0: Shoot dry weight at 0 μM Al^{3+} in sand culture; S450: Shoot dry weight at 450 μM Al^{3+} in sand culture; A0: Relative root surface area at 0 μM Al^{3+} in sand culture; A450: Relative root surface area at 450 μM Al^{3+} in sand culture; DF^a: Days to flowering on acid soil; PH^a: Plant height on acid soil; PPP^a: Number of pods/plant on acid soil; GY^a: Grain yield on acid soil; DF^n: Days to flowering on neutral soil; PH^n: Plant height on neutral soil; PPP^n: Number of pods/plant on neutral soil; GY^n: Grain yield on neutral soil.

The correlation statistics of genotypic means among seedling and mature plant traits evaluated in acid sand culture and the field (acid and neutral soil fields) are summarized in Table 7. Sand culture traits of root dry weight shoot dry weight and relative root surface area at 0 μM Al^{3+} (R0, S0 and A0) were highly significantly correlated with root dry weight, shoot dry weight and relative root surface area at 450μMAl^{3+} (R450, S450 and A450) respectively, with the highest correlation of 0.83 observed between R0 and R450. A0 and A450 were highly significantly correlated with almost all the field traits on the acid and neutral soil fields except number of pods/plant and grain yield on the neutral soil field (PPP^n and GY^n). Days to flowering on the acid soil field (DF^a) was highly significantly correlated with all the field traits of plant height on acid soil (PH^a), days to flowering and plant height on the neutral soil field (DF^n and PH^n). PH^a was also highly significantly correlated with DF^n and PH^n. Highly significant correlation was observed between number of pods/plant and grain yield in their respective soils i.e. between number of pods/plant and grain yield on the acid soil field (PPP^a with GY^a) and between number of pods/plant and grain yield on the neutral soil field (PPP^n and GY^n).

4. Discussion

The highly significant aluminium, genotype and aluminium × genotypes interaction observed for all the traits (root dry weight, shoot dry weight and relative root surface area) in the current acid sand culture experiment, had been previously observed (Ojo et al., 2012), and attributed to genetic diversity of the evaluated genotypes for the traits studied. The high GCV, heritability and GA observed for all the traits measured in the sand culture is an indication that there will be progress in selection and it is consistent with the findings of Bianchi-Hall et al. (1998) that aluminium tolerance is a highly heritable trait. It is also in agreement with the observation of Ogunbayo et al. (2014) that selection based on phenotypic performance will be effective and reliable when the GCV, heritability and GA are all high. Hence, these three traits (root dry weight, shoot dry weight and relative root surface area) can be used as selection indices for aluminium/acid stress tolerance in tropically adapted genotypes of soybean. The large GCVs observed for the seedling traits in the current study had been previously observed and attributed to small means relative to large error terms, or vice versa (Omoigui et al., 2006).

The highly significant/significant correlation between days to flowering/plant height in the field experiments (acid and neutral soil fields) and A0/A450 in the acid sand culture, is an indication that root surface area in seedlings can be used to select for tall late maturing plants on the field. The higher correlation observed between A0 and days to flowering/plant height in the field experiments (acid and neutral soil fields) is an indication that there will be higher precision in using seedling root surface area to select for these field traits when aluminium is excluded from the acid sand culture. The highly significant correlation observed between the root traits in the sand culture (R0, R450, A0 and A450) and the acid soil traits of number of pods/plant (PPP^a) and grain yield (GY^a) is an indication that these root traits can be used to effectively select for acid stress tolerant high yielding genotypes on acid soils of Nigeria. The higher correlation observed between R450/A450 and PPP^a/GY^a is an indication that there will be higher precision in using soybean seedlings grown at the 450 µM Al^{3+} level of aluminium activity in acid sand culture to select for high grain yield and high number of pods on acid soil fields of Nigeria. The highly significant correlation observed among the two field traits of days to flowering and plant height within and between soils is an indication that maturity date and plant height in neutral soils can be used as selection indices for acid stress tolerance on acid soil fields of Nigeria.

The current study has established that there is sufficient variability and heritability in acid sand culture screening using the root dry weight, shoot dry weight and the relative root surface area as indicators of aluminium stress tolerance in soybean. It has also established that there is sufficient variability and heritability in the studied genotypes for the field traits of days to flowering, plant height, number of pods/plant and grain yield in both the acid and neutral soil fields of Nigeria. The highly significant correlation observed between the root traits in sand culture and the field traits in the current study is inconsistent with previous observations (Fountain, 1990; Hanson, 1991; Ferrufino et al., 2000; Spehar, 1999). These differences could be attributed to differences in the genetic base of the populations used. Unlike the genotypes used in the previous studies, the genotypes used in the current study are tropically adapted genetically broad based genotypes derived from crosses. The current findings indicate that selection of soybean genotypes with high seedling root dry weight and relative root surface area in acid sand culture at 450 µM Al^{3+} will enhance progress in the selection of high yielding acid tolerant tropically adapted genotypes of soybean on acid soils of Nigeria. This will reduce the number of genotypes for field evaluation, obviate the effect of spatial variability on the field and enhance precision of the results of field experiments in aluminium/acid stress tolerance research work. It will also minimize cost as some genotypes will be eliminated before the acid soil field evaluation.

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