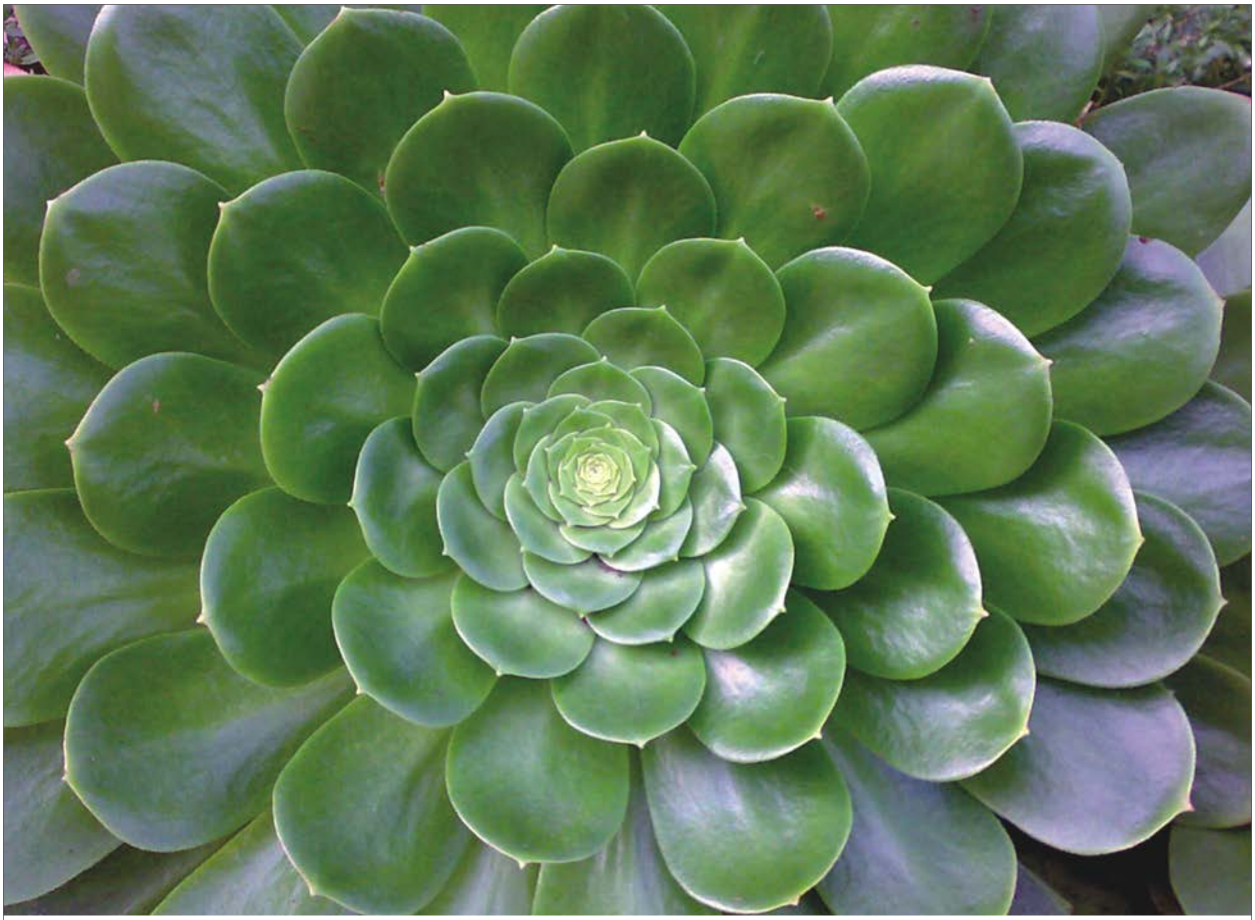

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Increasing Grain Size Improves Grain Yield of Acid-Adaptive Soybean Lines in Optimal Soil Condition

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ABSTRACT

The objective of the research was to study the response of acid-adaptive soybean lines in Ultisols and Vertisols soil types. Nine acid-adaptive soybean lines were grown on Ultisols in Sumatera Island and on Vertisols in Java Island. The design was randomized complete block design with three replications. Results showed that all the observed characters were affected by different soil types, except plant height. Genotype×environment interaction was found on number of pods plant^{-1} and grain yield. In Vertisols, some of agronomical characters increased such as days to maturing, number of branches plant^{-1} , number of filled pods plant^{-1}, grain size and grain yield but one agronomical character, plant height, decreased. Increasing grain size was found in most of the genotypes grown in Vertisols. A positive correlation was found between grain size and grain yield that described increasing grain yield caused by grain size. Two genotypes G2 and G8 achieved the highest grain yield up to 2.54 and 2.48 t ha^{-1} in Vertisols suggesting these genotypes can be developed in this soil type.

Key words: Agronomical characters, soybean, Ultisols, Vertisols

INTRODUCTION

Potential yield of a genotype in different agro-ecologies varies based on the response of the genotype to those agro-ecologies. This differential response is caused by two factors, i.e., genotype and environment. Every genotype has unique genetics constitution that distinguishes a genotype to other genotypes. Similar to genotype, environment has also variability that will influence plant grown in that environment. One of the environmental variability is soil type. Different soil type leads different physical, chemical and biological properties. Response of a genotype in a soil type differs to other soil type. When a genotype derived from suboptimal soil condition grown in optimal soil condition, potential yield of the genotype may differ depending on the response of the genotype to the optimal soil condition.

One of the suboptimal soil types is Ultisols. Generally, natural fertility of this soil type is on horizon A with low organic material. The soil has low macronutrients, with soil reaction from acid to very acid and high aluminum (Al) saturation that can inhibit plant growth and development. In addition, there is an argilic horizon that influences soil properties such as decreasing micro and macro pores and increasing run off and soil erosion. The pore structure of Ultisols is affected by free iron oxide and clay contents (Lu *et al*., 2014). Further, there is a fluctuation in physical properties of Ultisol (Yulnafatmawita and Adrinal, 2014) that affect plant growth and development. To resolve these problems, some efforts such as liming, alley cropping system and organic and inorganic fertilizers can be followed (Prasetyo and Suriadikarta, 2006). Liming can improve soil pH, exchangeable soil Calcium (Ca) and Magnesium (Mg) contents, base saturation and effective cation exchange capacity and decreases total acidity (H^+), Al, Zn, Fe contents (Fageria *et al.*, 2014). Further, exchangeable Mg^{2+}, Fe_2O_3 and Al_2O_3 were positively related to soil moisture as well as clay content (Igwe *et al.*, 2013). Usually, the clay content of Ultisol is low.

Vertisols is a black soil and the mineralogical composition depends on their parent material (Prasetyo, 2007). This soil is fertile with heavy structure and has a capacity to swell and shrink lead by the wetting and drying of the soil mass. The important cause of the shrink-swell processes is the high content of expanding clay minerals, called smectites (Anderson, 2010). This soil condition is always moist but when soils become very hard and cracks in dry condition (Prasetyo, 2007). The degree of soil cracking is important in partitioning rainfall into soil infiltration and runoff in Vertisols, where the soil shrink-swell is negatively correlated with soil carbonate content (Dinka *et al.*, 2013). Shrink-swell may be limited by a non-expansive silty surface layer that acts as a buffer and allowing expansive subsoils to dry more slowly (Hartley *et al.*, 2014). Even though Vertisols included as fertile soil types but the organic (Srinivasarao *et al.*, 2012) and inorganic (Chitale *et al.*, 2013) fertilizers are still needed to increase plant growth and development.

Performance of soybean grown in Ultisols is different than that in the optimal soil. It is because soybean grown in acid soil faces growth constraint due to macro nutrient deficiency such as N, P, K, Ca and Mg and micro nutrient toxicity such as Al and Mn. In optimal soil conditions, there are no nutrient constraints, resulting in better growth and development for acid-adaptive plants. In optimal soil, such as Vertisol soil types, the differences of environment affect the plant growth and development. A plant grown on a soil type with different fertility level will produce different performance. Similarly, a plant grown on different soil types will perform different response, depending on the nature of the soil. In this research, acid-adaptive soybean genotypes that normally grown on Ultisols were studied on Vertisols soil types.

MATERIALS AND METHODS

Plant materials: A total of nine acid-adaptive soybean lines derived from Tanggamus x Anjasmoro were used as plant materials (Table 1). Tanggamus is an acid-adaptive soybean variety with small grain size, whilst Anjasmoro is a large grain soybean variety for optimal land condition. Crossing was conducted to find out acid-adaptive soybean lines with larger grain size than Tanggamus. The F3 to F6 progenies were selected in Ultisols with pH 4.5-5.5.

Experimental site: The study was carried out at Natar Research Station (05°14'33"N, 105°10'44"E, altitude 86 m above sea level) in rainy season from February to May 2011 and Ngale Research Station (7°24'24"S, 111°22'19"E, altitude 168 m above sea level) in dry season from June to September 2011. The different planting season was conducted to accommodate farmer cultural practices, where soybean is grown on rainfed field in Natar site and on lowland field after

Table 1: Code and genotype names

Code	Genotype
G1	Tgm/Anj-844
G2	Tgm/Anj-847
G3	Tgm/Anj-856
G4	Tgm/Anj-889
G5	Tgm/Anj-908
G6	Tgm/Anj-909
G7	Tgm/Anj-910
G8	Tgm/Anj-933
G9	Tgm/Anj-957

rice harvesting in Ngale site. Natar Research Station is located in Sumatera Island with Ultisols soil type and pH 5.5, while Ngale Research Station is located in Java Island with Vertisols soil type.

Land preparation and planting: In Natar Research Station the land was ploughed and harrowed to obtain good soil condition. There was no soil tillage in Ngale Research Station, where the previous plant in this site was irrigated rice. Every 3 m, drainage canals were made with 20 cm depth and 40 cm width. Every genotype was grown in 1.6×3.0 m with plant spacing of 0.4×0.15 m, two plants hill^{-1}. Fertilizers were applied using 56.25 kg N, 90 kg P_2O_5, 75 kg K_2O ha^{-1} in Ultisols of Natar Research Station and 22.5 kg N, 27 kg P_2O_5, 37.5 kg K_2O ha^{-1} in Vertisols of Ngale Research Station. The weed control was carried out manually at 14 and 28 day after planting (dap). Insecticides with 5 days interval were applied to control pod sucking pests after pod initiation stage to the end of seed filling stage.

Data collection and analysis: A randomized complete blocks design with three replications was applied in each experimental site. Agronomical data such as grain yield ha^{-1}, days to 90% maturing, plant height, number of branches plant^{-1}, number of filled pods plant^{-1} and grain size were observed. Grain size was measured by measuring 100 grains weight. Data were analyzed by using analysis of variance and followed by Least Significant Difference (LSD) α 5%.

RESULTS

Acid-adaptive soybean lines grown in Ultisols and Vertisols showed genotype×environment interaction on grain yield and number of pods plant^{-1}. Even though location and genotype were significantly different but there was no genotype × environment interaction on days to maturing, plant height, number of branches plant^{-1} and 100 grain weight (Table 2). In the genotype×environment interaction, the ranking of the genotypes in Ultisols differed to those in Vertisols.

Days to maturing increased in Vertisols but decrease in Ultisols. There was no genotypes×environment interaction. The days to maturing become longer in Vertisols than in Ultisols (Table 3). There were three genotypes having the longest days to maturing in Vertisols, i.e., G1, G2 and G6 with 82 days, whilst the shortest were shown by G8 and G9 in Ultisols with 75 days (Fig. 1). These three genotypes also showed the longest days to maturing in Ultisols.

Table 2: Combined analysis of acid-adaptive soybean lines in Ultisols and Vertisols

Sources	db	Mature	Height (cm)	Branch	Pod	100 gr. wt.	Yield (t ha^{-1})
Environment	1	174.24**	205.73	22.69**	2918.69**	33.92**	3.62**
Genotype	8	11.12**	257.28**	3.17**	313.33**	7.97**	0.21**
G×E	8	0.37	99.82	0.85	169.35**	2.05	0.16**
Error	32	0.5	48.03	0.81	36.85	0.97	0.04
CV(%)		0.91	11.23	25.68	11.21	8.08	11.08

**Significant at 1%, Mature: Days to maturing days, Height: Plant height, Branch: No. of branches plant^{-1}, Pod: No. of pods plant^{-1}, 100 gr. wt: 100 grains weight, Yield: Grain yield (t ha^{-1})

Table 3: Average of some agronomical character of acid-adaptive soybean lines in Ultisols and Vertisols

Character	Ultisols	Vertisols
Days to maturing (days)	76.48^b	80.07^a
Plant height (cm)	63.64^a	59.73^a
Number of branches plant^{-1}	2.85^b	4.15^a
Number of filled pods plant^{-1}	46.81^b	61.52^a
100 grains weight (g)	11.40^b	12.99^a
Grain yield (t ha^{-1})	1.58^b	2.10^a

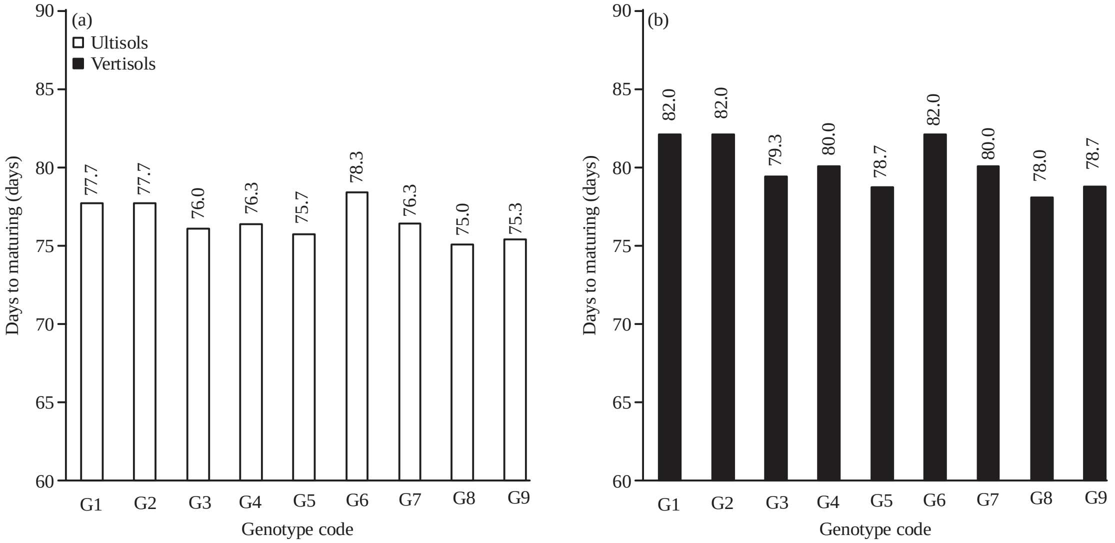

Fig. 1(a-b): Days to maturing of acid-adaptive soybean lines in (a) Ultisols and (b) Vertisols

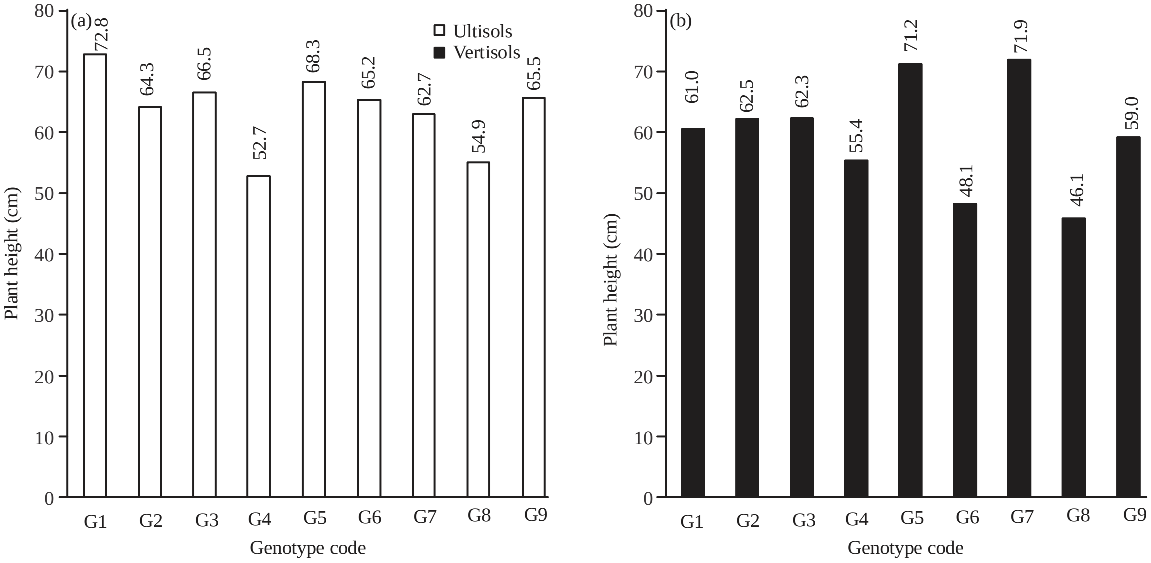

Fig. 2(a-b): Plant height of acid-adaptive soybean lines in (a) Ultisols and (b) Vertisols

Plant height in Ultisols was higher than in Vertisols. There was no genetic environment interaction in plant height. The highest plant height was shown by G1 in Ultisols, while the lowest was shown by G8 in Vertisols. The highest genotype in Vertisols was similar to the highest genotype in Vertisols reaching 72.8 and 71.9 cm, respectively (Fig. 2). In this study, effect of low pH could not decrease soybean plant height. Even though, there were two genotypes, G6 and G8, demonstrating relatively lower plant height in Vertisols than in Ultisols. Average plant height in Ultisols was 63.6 cm, while in Vertisols was 59.7 cm indicating no significantly different (Table 3).

There was environment difference and genotype difference on number of branches plant^{-1} but no genetic environment interaction. It meant that statistically there were differences among the

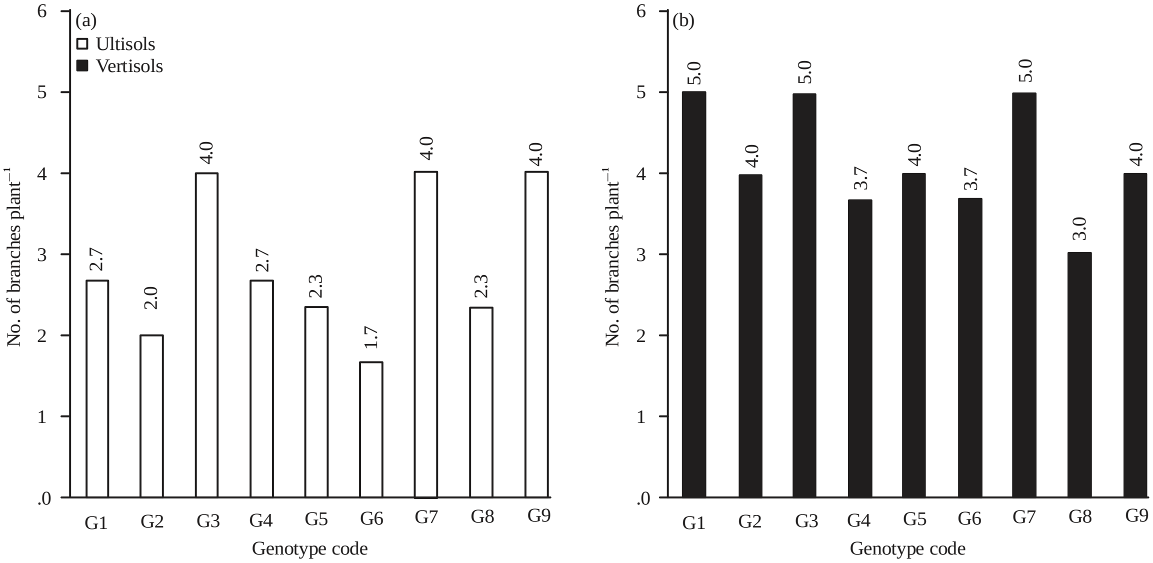

Fig. 3(a-b): Number of branches plant^{-1} of acid-adaptive soybean lines in (a) Ultisols and (b) Vertisols

genotypes and between the two environments. A difference was found between the two soil types. The average of number of branches plant^{-1} was higher in Vertisols than in Ultisols, i.e., 4.15 and 2.85 branches plant^{-1}, respectively (Table 3). Based on this character there were two genotypes, G3 and G7, that performed consistently in two different soil types (Fig. 3). These two genotypes showed the highest number of branches plant^{-1} in Ultisols as well as in Vertisols. The lowest number of branches plant^{-1} was shown by G6 in Ultisols. However, this genotype showed increasing number of branches plant^{-1} in Vertisols.

The highest number of filled pods plant^{-1} was shown by G1, G2 and G7 in Vertisols, while the lowest number was shown by G4 in Ultisols (Fig. 4). Similar to number of branches plant^{-1} , effect of low pH could decrease number of filled pods plant^{-1}, where the average number of filled pods plant^{-1} in Vertisols was higher than in Ultisols (Table 3). However, G7 was able to reach number of filled pods plant^{-1} in Ultisols higher than the average in Vertisols. The lowest number of filled pods plant^{-1} was shown by G4 in Ultisols. This genotype also showed the lowest number of filled pods plant^{-1} in Vertisols with G6. G9 was the genotype with consistent number of filled pods in Ultisols and Vertisols.

Grain size is associated to grain weight. Heavier 100 grains weight indicates larger grain size and vice versa. Therefore, in this study grain size was measured based on 100 grains weight. The grain size increased when the soybean genotypes were grown in Vertisols rather than in Ultisols (Table 3) and there was no genotype×environment interaction effect on grain size (Table 1). The largest grain size was achieved by G2 and G8 in Vertisols, while the smallest was achieved by G3 in Ultisols (Fig. 5). Two genotype with the lowest grain size in Vertisols, G3 and G4, were remain higher than the average in Ultisols. Genotype G8 consistently showed the highest grain size in Ultisols as well as in Vertisols.

Genetic×environment interaction found on grain yield character. However, the grain yield of all of the nine genotypes increased in Vertisols (Fig. 6). Grain yield of the nine genotypes in Vertisols were higher than in Ultisols. The highest grain yield was shown by G2 and G8 with 2.54 and 2.48 t.ha^{-1} respectively. Those two genotypes showed the highest decreasing grain yield

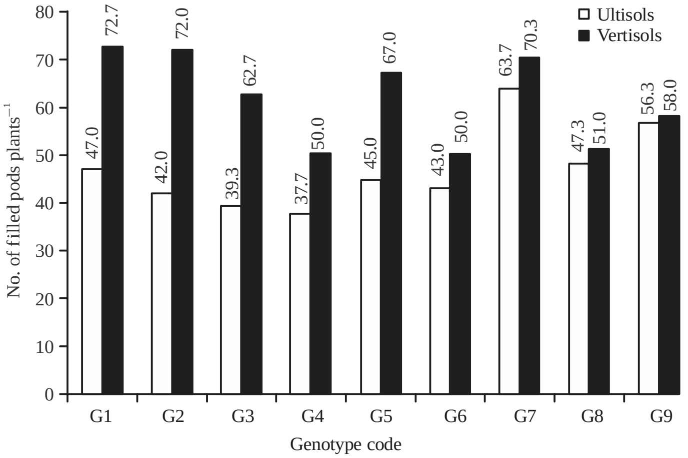

Fig. 4: Number of filled pods plant^{-1} of acid-adaptive soybean lines in ultisols and vertisols

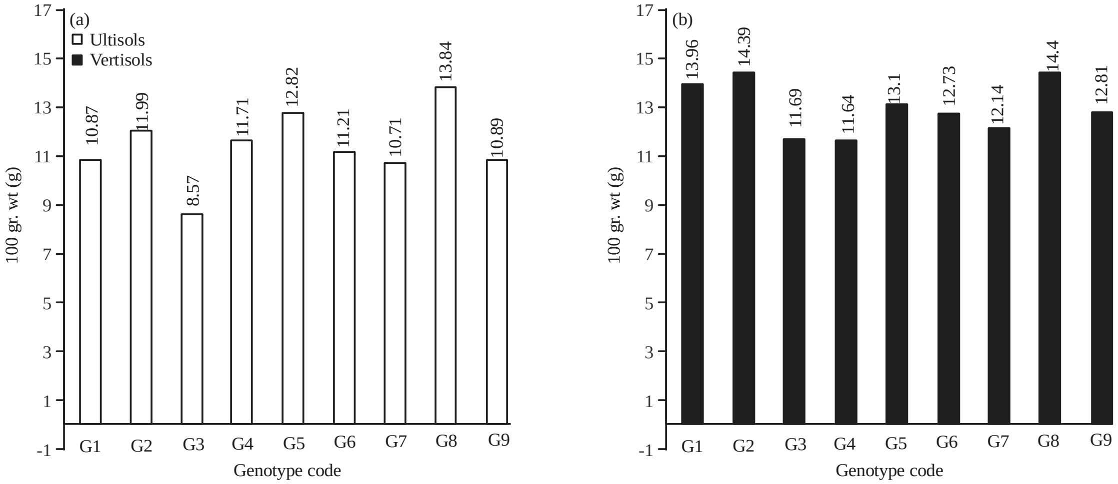

Fig. 5(a-b): 100 grains weight of acid-adaptive soybean lines in (a) Ultisols and (b) Vertisols

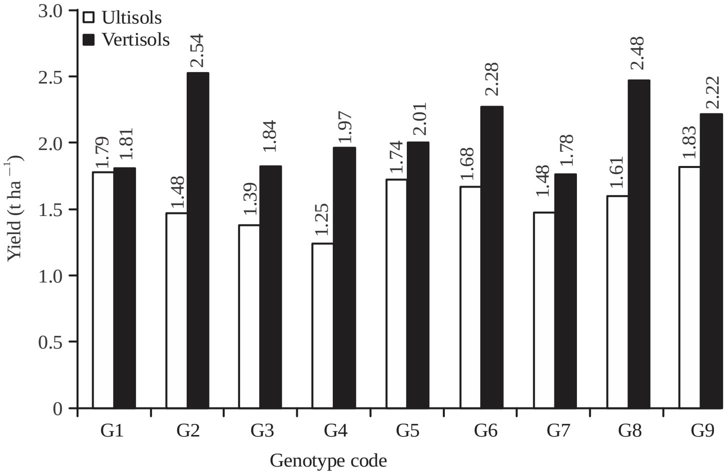

Fig. 6: Grain yield of acid-adaptive soybean lines in Ultisols and Vertisols

Table 4: Correlations among some agronomical characters of acid-adaptive soybean lines in Ultisols and Vertisols

Correlation parameters	Height	Branch	Pod	100 gr. wt.	Yield
Mature	0.379	-0.501	-0.264	-0.222	0.006
	-0.037	0.287	0.314	0.174	0.009
Height		0.096	0.145	-0.420	0.619*
		0.690*	0.800**	-0.230	-0.562
Branch			0.535	-0.636*	-0.109
			0.724*	-0.337	-0.778*
Pod				-0.017	0.382
				0.261	-0.328
100GW					0.210
					0.637

*Upper: Ultisols, Lower: Vertisols, *Significant at 5%, **Significant at 1%, Mature: Days to maturing days, Height: Plant height (cm), Branch: No. of branches plant^{-1} , Pod: No. of pods plant^{-1} , 100 gr. wt.: 100 grains weight, Yield: Grain yield (t ha^{-1})

than other genotypes. The lowest decreasing was shown by G1, where it was no significantly different between in Vertisols and Ultisols. The lowest grain yield was shown by G4 in Ultisols that reached 1.25 t ha^{-1} which was not shown in Vertisols. However, there was one genotype with the grain yield in Ultisols (G9) higher than the lowest in Verstisols (G7). This genotype, G9, was also consistent in Vertisols. Therefore, this genotype can be considered as stable genotype in these two soil types.

Relationship of yield and yield components showed that in Ultisols yield positively correlated to plant height, while in Vertisols yield positively correlated to grain size but negatively correlated to number of branches plant^{-1}. There were one relationships among the yield components in Ultisols, i.e., relationship between number of branches plant^{-1} with grain size. Negative correlation was found between number of branches plant^{-1} with grain size. In Vertisols, three relationships among yield components were found, i.e., relationship between plant height with number of branches and filled pods plant^{-1} and number of branches plant^{-1} with number of pods plant^{-1} (Table 4).

DISCUSSION

Days to maturity increased when acid-adaptive soybean lines grown in Vertisols (Fig. 1). Vertisols is an optimal soil where there is no nutrient deficiency or toxicity, thus plant can grow optimally. On the other hand, Ultisols is a suboptimal soil with many nutrients deficiency or toxicity. Phosphorus is one of the nutrients that influence maturity age, where phosphorus deficiency leads late maturity age (Foy *et al*., 1978; Bian *et al*., 2013). It indicates that decreasing plant duration in this study was not influenced by phosphorus availability. Presumably, soil moisture is more important than phosphorus. The high content of expanding clay minerals (Anderson, 2010) causes Vertisols having soil moisture higher than Ultisols and can be a big problem in rainfall area (Dhakad *et al*., 2013). The low soil moisture can decrease maturity age (Kuswantoro and Zen, 2013). Plant decreases its life cycle duration to avoid the severer condition in this suboptimal soil. Decreasing life cycle duration allows plant to provide seed for the next generation. However, decreasing life cycle duration, especially in days to maturing will decrease grain yield, because days to maturing has direct effect on grain yield (Mahbub *et al*., 2015).

Generally, acidity leads plant height decreases but in this study the average of plant height in Ultisols was same as in Vertisols with normal pH (Table 2 and 3). Probably, it occurred because in Ultisols the soybean lines were grown in rainy season, while in Vertisols soybean lines were grown in dry season. Kuswantoro *et al*. (2014) also reported higher plant height in Utlisols than in optimal land (associated Entisols-Inceptisol soil type) in similar planting seasons. Plant height is affected by vegetative growth duration. The duration of vegetative growth in full rainy season is longer than in less rainy season (Kuswantoro and Zen, 2013), leads higher plant height. Higher plant height also can be influenced by the nutrients fulfillment, where by adding organic manure plant height in Ultisols performs higher than in Entisols (Bondansari and Susilo, 2011).

Number of branches plant^{-1} was significantly different between the two environments and among the genotypes but genotype×environment interaction was not significant (Table 2). It suggests that environment and genotype played equal role on the performance of the soybean lines. It also indicates equally adding or subtracting value on each genotype causing similar ranking of the genotypes in Ultisols and Vertisols (Fig. 3). The non significance of the genotype × environment interaction is an indication of consistent relative performance of the genotypes (Ojo *et al.*, 2010). The toxicity of the soil can be observed from the previous or recent plantations. This study was conducted in Vertisols after rice plantation and there were no toxicity symptoms in previous plantation and recent plantation. However, no deficiency and toxicity in Vertisols, lead higher number of branches plant^{-1} in Vertisols than in Ultisols (Table 3).

Number of filled pods of acid-adaptive soybean lines in Vertisols was higher than in Ultisols (Table 3). Similar result was reported that the number of pods plant^{-1} was higher in Entisols than in Ultisols (Bondansari and Susilo, 2011). Entisols is a soil type with normal pH, allowing nutrients availability in optimum condition for plant growth. Hence, the soil properties of Entisols is similar to Vertisol rather than Ultisols. This increasing number of filled pods due to the nutrients requirement could be fulfilled in Vertisols. Meanwhile deficiency and toxicity in Ultisols led pod setting and pod filling in Ultisols disrupted and caused decreasing number of filled pods. This result is higher than result of Uguru *et al.* (2012) and Kuswantoro and Zen (2103) that reported 9.7 number of pods plan but lower compared to Kuswantoro and Zen (2013) that reported up to 114 pods plant^{-1} in full rainy season. Therefore, water also presumably the main factor regulating pod setting apart from the soil pH.

Grain size was measured through 100 grain weight. Larger average of 100 grains weight in Vertisols than in Ultisols (Table 3) described that grain size increased in Vertisols. Similar result is also reported by Kuswantoro *et al.* (2014) when comparing grain size performance in Ultisols and associated Entisols-Inceptisols soil types. Vertisols is a soil type with rich soil nutrients and there is no macronutrient deficiency or micronutrient toxicity, thus increasing grain size in Vertisols due to the optimal nutrients availability in Vertisols. Unlikely, nutrients availability in Ultisols is low and macronutrients deficiency. Entering essential nutrients in plant is also suppressed by Al (Bose *et al.*, 2011) causes plant nutrients requirement cannot be fulfilled. In addition, there is micronutrients toxicities such as Al and Manganese (Mn) that can harm plant organ, especially the root organs (Prijambada and Proklamasiningsih, 2010; Merino-Gergichevich *et al.*, 2010). Liming can increase root length density, nutrient uptake and shoot biomass production of the soybean in acid soil (Joris *et al.*, 2013), because liming increase soil pH and lead acid soil similar to optimal soil type.

Grain yield in Vertisols was higher than in Ultisols (Table 3) due to the higher availability of soil nutrients in Vertisols. Kuswantoro *et al.* (2014) also reported the increasing grain yield in optimal land condition. Decreasing soil acidity can improve nutrition and increase soybean grain yields (Joris *et al.*, 2013). The availabilities of P and Zn in higher pH soil are some of the causes of the higher soybean grain yield (Anthony *et al.*, 2012). Genotype×environment interaction on grain yield suggests that the rank of a soybean line in Ultisols differed to those in Vertisols and at least one genotype grew well in a specific environment. This different performance is caused by different genetics constitution. Even though the materials in this study were from the same crossing but the genetics constitutions are different due to the genes segregation in F2 generation. Hence, response of the genotypes may differ in the same soil types. The soybean genes must be able to interact positively in different agro-ecologies to stabilize the performance. In acid soil, Liang *et al.* (2013) reported a gene, GmALMT1, that can produce malate exudation to improve soybean adaptation to acid soils. In addition, phosphorus availability is more pronounced in limiting soybean growth and production (Bian *et al.*, 2013; Foy *et al.*, 1978; Wang *et al.*, 2010) and phosphorus is more important factor in increasing yield on acid soils compare to nitrogen because soybean is able to fix nitrogen (Zheng, 2010). Therefore soybean should able to uptake phosphorus in acid soil or efficient in P usage. In acid soils rotating with the P efficient soybean genotype could benefit in soil nutrient status (Conde *et al.*, 2014).

The magnitude of grain yield depends on the other agronomical characters, where the most important characters are number of pods plant^{-1} and grain size. In optimal soil type, some researcher reported significant relationship between grain yield and number of pods plant^{-1} (Arshad *et al*, 2014; Egli, 2013; Koladiya *et al.*, 2012; Jain, 2014; Teodoro *et al.*, 2015) and grain size (Athoni and Basavaraja, 2012; El-Badawy and Mehasen, 2012; Malik *et al.*, 2011). In Vertisols, the optimal soil type, significant correlation between grain yield with grain size was also found in this study; but no correlation were found between number of filled pods plant^{-1} and grain size with grain yield in Ultisols (Table 4). These results are different to previous study in Ultisols that found significant relationship between grain yield with number of pod plant^{-1} (Ikeogu and Nwofia, 2013; Kuswantoro and Zen, 2013) and grain yield with grain size (Kuswantoro *et al.*, 2014). In this study, grain size was more important than number of pods plant^{-1} , because it correlated directly to grain yield. The other character that showed positive correlation to grain yield was plant height in Ultisols. Kuswantoro *et al.* (2014) reported correlation between plant height and grain yield in optimal land but not in suboptimal land. This different result probably because the plants were in adaptation process, where in this study plant materials were from acid soil while in Kuswantoro *et al.* (2014) plant materials were from optimal land. Some authors also reported positive direct effect between 100 grains weight and plant height on grain yield (Ascencio-Luciano *et al.*, 2013; Mahbub *et al.*, 2015).

CONCLUSION

Vertisols constructively affected all of the observed characters, except plant height. Even though genotype and soil type fact were significantly different on most of the observed characters but genotype × environment interaction was found only on number of filled pods plant^{-1} and grain yield. There was no significant correlation between grain yield and No. of filled pods but a positive correlation was found between grain size and grain yield in Vertisols. Increasing grain size was found on most of the genotypes grown in Vertisols as well as grain yield. It indicates that grain size improved grain yield in Vertisols. Two genotypes G2 and G8 achieved the highest grain yield up to 2.54 and 2.48 t ha^{-1} in Vertisols, suggesting these acid-adaptive genotypes have adaptation capacity in this soil type.

REFERENCES

Anderson, D., 2010. Vertisolic soils of the prairie region. Prairie Soils Crops J., 3: 29-36.

Anthony, P., G. Malzer, S. Sparrow and M. Zhang, 2012. Soybean yield and quality in relation to soil properties. Agron. J., 104: 1443-1458.

Arshad, W., M. Zeeshan, M.I. Khan, S. Ali, M. Hussain and S. Rahman, 2014. Character association and causal effect analysis for yield and yield components among early maturing genotypes of soybean (*Glycine max* L. Merrill). J. Renewable Agric., 2: 1-4.

Ascencio-Luciano, A., N. Maldonado-Moreno, J.G. Garcia-Olivares and H.R. Gill-Langarica, 2013. AMMI and sequential path analyses of soybean [*Glycine max* (L.) Merrill] experimental lines in a breeding program in the Mexican tropics. Aust. J. Crop Sci., 7: 1772-1779.

Athoni, B.K. and G.T. Basavaraja, 2012. Association analysis, genetic variability and genetic diversity studies in soybean (*Glycine max* (L.) Merrill). Asian J. Bio Sci., 7: 114-118.

Bian, M., M. Zhou, D. Sun and C. Li, 2013. Molecular approaches unravel the mechanism of acid soil tolerance in plants. Crop J., 1: 91-104.

Bondansari and B.W. Susilo, 2011. [Effect of zeolit and organic manure to some of Ultisols and Entisols soil properties on soybean plantation (*Glycine max* L. Merrill)]. Agronomika, 11: 122-135, (In Indonesian).

Bose, J., O. Babourina and Z. Renge, 2011. Role of magnesium in alleviation of aluminium toxicity in plants. J. Exp. Bot., 62: 2251-2264.

Chitale, S., A. Tiwari, S. Bhoi, R.M. Savu, H.S. Tomar and J.S. Urkurkar, 2013. Performance of soybean (*Glycine max*)-based cropping sequences under organic, inorganic and integrated nutrient supply systems in a *Vertisols*. Indian J. Agron., 58: 163-167.

Conde, L.D., Z. Chen, H. Chen and H. Liao, 2014. Effects of phosphorus availability on plant growth and soil nutrient status in the rice/soybean rotation system on newly cultivated acidic soils. Am. J. Agric. For., 2: 309-316.

Dhakad, S.S., K.V.R. Rao, K.P. Mishra and D.K. Paliwal, 2013. Effect of mole drain spacing and depths on the growth character and yield of soybean in vertisols of MP. Int. J. Agric. Eng., 6: 173-176.

Dinka, T.M., C.L.S. Morgan, K.J. McInnes, A.S. Kishne and R.D. Harmel, 2013. Shrink-swell behavior of soil across a Vertisol catena. J. Hydrol., 476: 352-359.

Egli, D.B., 2013. The relationship between the number of nodes and pods in soybean communities. Crop Sci., 53: 1668-1676.

El-Badawy, M.E.M. and S.A.S. Mehasen, 2012. Correlation and path coefficient analysis for yield and yield components of soybean genotypes under different planting density. Asian J. Crop Sci., 4: 150-158.

Fageria, N.K., A. Moreira, L.A.C. Moraes and M.F. Moraes, 2014. Influence of lime and gypsum on yield and yield components of soybean and changes in soil chemical properties. Commun. Soil Sci. Plant Anal., 45: 271-283.

Foy, C.D., R.L. Chaney and M.C. White, 1978. The physiology of metal toxicity in plants. Ann. Rev. Plant Physiol., 29: 511-566.

Hartley, P.E., D.R. Presley, M.D. Ransom, G.M. Hettiarachchi and L.T. West, 2014. Vertisols and vertic properties of soils of the cherokee prairies of Kansas. Soil Sci. Soc. Am. J., 78: 556-566.

Igwe, C.A., M. Zarei and K. Stahr, 2013. Soil hydraulic and physico-chemical properties of ultisols and inceptisols in South-Eastern Nigeria. Arch. Agron. Soil Sci., 59: 491-504.

Ikeogu, U.N. and G.E. Nwofia, 2013. Yield parameters and stabilty of soybean [*Glycine max.* (L.) merril] as influenced by phosphorus fertilizer rates in two ultisols. J. Plant Breed. Crop Sci., 5: 54-63.

Jain, S., 2014. Factors determining seed yield in soybean [*Glycine max* (L.) Merrill]. Trends Biosci., 7: 558-561.

Joris, H.A.W., E.F. Caires, A.R. Bini, D.A. Scharr and A. Haliski, 2013. Effects of soil acidity and water stress on corn and soybean performance under a no-till system. Plant Soil, 365: 409-424.

Koladiya, P.B., S.N. Saravaiya, D.A. Patel, K.N. Chaudhari and B.N. Patel, 2012. Correlation and path coefficient analysis for yield and yield contributing traits in soybean (*Glycine max* (L.) MERRILL). Veg. Sci., 39: 95-97.

Kuswantoro, H. and S. Zen, 2013. Performance of acid-tolerant soybean promising lines in two planting seasons. Int. J. Biol., 5: 49-56.

Kuswantoro, H., S. Zubaidah and Sulisetijono, 2014. Decreasing grain size caused declining grain yield of CpMMV-resistant soybean lines grown in ultisols. J. Biol. Sci., 14: 508-514.

Liang, C., M.A. Pineros, J. Tian, Z. Yao and L. Sun *et al.*, 2013. Low pH, aluminum, and phosphorus coordinately regulate malate exudation through GmALMT1 to improve soybean adaptation to acid soils. Plant Physiol., 161: 1347-1361.

Lu, S.G., Z. Malik, D.P. Chen and C.F. Wu, 2014. Porosity and pore size distribution of Ultisols and correlations to soil iron oxides. Catena, 123: 79-87.

Mahbub, M.M., M.M. Rahman, M.S. Hossain, F. Mahmud and M.M. Mir Kabir, 2015. Genetic variability, correlation and path analysis for yield and yield components in soybean. Am.Eurasian J. Agric. Environ. Sci., 15: 231-236.

Malik, M.F.A., M. Ashraf, A.S. Qureshi and M.R. Khan, 2011. Investigation and comparison of some morphological traits of the soybean populations using cluster analysis. Pak. J. Bot., 43: 1249-1255.

Merino-Gergichevich, C., M. Alberdi, A.G. Ivanov and M. Reyes-Diaz, 2010. Al^{3+}-Ca^{2+} interaction in plants growing in acid soils: Al-phytotoxicity response to calcareous amendments. J. Soil. Sci. Plant Nutr., 10: 217-243.

Ojo, G.O.S., L.L. Bello and M.O. Adeyemo, 2010. Genotypic variation for acid stress tolerance in soybean in the humid rain forest acid soil of South Eastern Nigeria. J. Applied Biosci., 36: 2360-2366.

Prasetyo, B.H. and D.A. Suriadikarta, 2006. [Characteristics, potential and management of ultisols for agrilcultural upland development in Indonesia]. Jurnal Litbang Pertanian, 25: 39-47, (In Indonesian).

Prasetyo, B.H., 2007. [Differentiation in properties of vertisol from various parent materials]. Jurnal Ilmu-Ilmu Pertanian Indonesia, 9: 20-31, (In Indonesian).

Prijambada, I.D. and E. Proklamasiningsih, 2010. Effect of organic acids amendment on the growth and yield of soybean (*Glycine max*) in Ultisol. Int. J. Agric. Biol., 12: 566-570.

Srinivasarao, C., B. Venkateswarlu, R. Lal, A.K. Singh and S. Kundu *et al.*, 2012. Sustaining agronomic productivity and quality of a Vertisolic soil (vertisol) under soybean-safflower cropping system in semi-arid Central India. Can. J. Soil Sci., 92: 771-785.

Teodoro, P.E., L.P. Ribeiro, C.C.G. Correa, R.A.A. da Luz Jr., A.D.S. Zanuncio, D.P. Capristo and F.E. Torres, 2015. Path analysis in soybean genotypes as function of growth habit. Biosci. J., 31: 794-799.

Uguru, M.I., B.C. Oyiga and E.A. Jandong, 2012. Responses of some soybean genotypes to different soil pH regimes in two planting seasons. Afr. J. Plant Sci. Biotechnol., 6: 26-37.

Wang, X., X. Yan and H. Liao, 2010. Genetic improvement for phosphorus efficiency in soybean: A radical approach. Ann. Bot., 106: 215-222.

Yulnafatmawita and Adrinal, 2014. Physical characteristics of ultisols and the impact on soil loss during soybean (*Glycine max* Merr) cultivation in wet tropical area. Agrivita, 36: 57-64.

Zheng, S.J., 2010. Crop production on acidic soils: Overcoming aluminium toxicity and phosphorus deficiency. Ann. Bot., 106: 183-184.