EVALUATING SOYBEAN GERMPLASM FROM USA, CHINA, AND BRAZIL FOR TOLERANCE TO ACIDIC SOILS IN INDONESIA

By

Agus Hasbianto

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

Crop and Soil Sciences—Doctor of Philosophy

2019

ABSTRACT

EVALUATING SOYBEAN GERMPLASM FROM USA, CHINA, AND BRAZIL FOR TOLERANCE TO ACIDIC SOILS IN INDONESIA

By

Agus Hasbianto

The soybean production increases more slowly than the demand within the country. The opportunity to increase soybean production exists by planting soybean in the lands available outside the Java island, on acidic Ultisol soils. However, the number of soybean accessions that are tolerant to acidic soils is limited and these accessions do not have desirable traits to meet the market demands. The objective of the first study was to test the adaptability of selected soybean germplasm to acidic soils under greenhouse conditions. A total of 706 soybean accessions originating from the USA, China, and Brazil, were screened to select 20 best performing genotypes through two phases of greenhouse trials. In Phase 1, 60 best performing soybean genotypes were selected in a Peat moss medium at pH 5.0 using plant height and number of days taken for each line to reach V2 stage as the selection criteria. In phase 2, 20 best performing lines out of the previous 60 were selected based on their performance on at least two of three pH regimes; 4.5, 5.0 and 5.5. Of the 60 genotypes, the selected lines from USA and China reached the V2 stage in 12 - 24 days after planting while the selected lines from Brazil took slightly longer to reach the V2 stage with 16 - 30 days after planting. The goal of the second study was to evaluate the 20 selected lines from the previous study for tolerance to aluminum toxicity, a major concern in Indonesian low pH soils. We used the same medium but added aluminum hydroxide to the medium since Peat moss does not contain aluminum (Al). We conducted a greenhouse study where the previously selected 20 soybean lines were subjected to two levels of Al; 0.0% and 5% Al (by weight). Root length, number of root nodules, and plant height were taken as the

dependent variables 35 days after planting as criteria for selection. All data were analyzed using ANOVA and LSD. The measured variables were significantly different at $P < 0.0001$. Plant height and root length of the 20 lines were higher in the medium with 5% Al compared to the control with 0.0% aluminum. The results indicated that the 20 selected lines would be tolerant to soils with low pH and Al^{3+} levels up to 5% by weight and could perform well under Indonesian acidic soils. The third study was intended to evaluate the 20 selected lines for tolerance to acidic soils in Indonesia and select promising lines for use that can be grown by farmers and/or used as parents in a soybean breeding program in Indonesia. We designed a field research for two seasons in 2017 and 2018, in two locations. To select the best performing out of the 20 lines under current farmer practices, a split-split plot design with three factors was used with lime as the main plot, organic fertilizer as the subplot, and soybean genotypes as the sub-subplot. Two farmer preferred varieties, ANJASMORO and DERING, were used as check varieties. Plant height, root length, number of root nodules, number of pods, and yield were used to evaluate the performance of the 20 lines. All data were analyzed using ANOVA and LSD. In 2017 season, the best four genotypes of the 20 lines tested with the highest yields were PI675661 with 3.08 tons/ha (for farmers who applied only lime), PI628880 with 2.46 tons/ha and PI628929 with 2.41 tons/ha (both: for farmers who applied only organic fertilizer), and PI628871 with 2.32 tons/ha (for farmers who applied a combination of both lime and organic fertilizer). In the 2018 season, the yield reported was the highest in PI628925 with 2.38 tons/ha (for farmers who applied a combination of lime and organic fertilizer), and PI675661 with 2.17 tons/ha and PI628929 with 2.03 tons/ha (both: for farmers who did not apply lime, but applied only organic fertilizer). PI675661 and PI628929 can be considered as the promising lines with superior traits: number of pods, yield, and larger seed size.

I dedicate this dissertation to my beloved parents, my wife and all my family, and my teachers.

ACKNOWLEDGEMENTS

I am greatly thankful to ALLAH Subhanahu wa Ta'ala, the almighty God for His protection and compassion, and I truly thank my parents and my wife for their support, prayer, and encouragement that have never stopped.

I would like to thank IAARD for providing scholarship through the Sustainable Management of Agricultural Research and Technology Dissemination (SMARTD) program and giving me a precious opportunity to join Michigan State University.

I would like to express my deepest appreciation and sincere gratitude to my mentor and committee chair Dr. Cholani K. Weebadde, for her unlimited support, patience, and encouragement. She continues to strengthen my enthusiasm for research and course work. Her guidance and persistent support have made this dissertation being real. She has become one of the influential figures who inspire my scientific life. I would like to thank Dr. Russell Freed, Dr. Dechun Wang, Dr. Karim Maredia, and Dr. Brian Teppen for their support, advice, and willingness to serve on the committee. I would also like to thank Dr. Suneth Sooriyapathirana for his time and effort in helping me improve this dissertation.

I would like to thank Randall L. Nelson and Todd Bedford from the National Soybean Research Center of USDA (USDA-NSRC) in Illinois for providing the seeds for our greenhouse and field studies. I thank Dr. Karen Cichy for providing spaces in the greenhouse and John Dahl for assisting in soil analysis. I thank Dr. Siddharth Chandra and the Asian Study Center of Michigan State University to fund our second field research in Indonesia.

I would like to thank Dr. Muhammad Yasin, Director of the South Kalimantan Assessment Institute for Agricultural Technology (AIAT), Ir. Taufik Rahman (sub-division administration), Dr. Akhmad Hamdan (Banjarbaru Research Station), Dr. Aidi Noor, Mr.

Masdar, Mr. Agung Sutanto, and Mrs. Jumarni (Pelaihari Research Station). I would also like to thank Dr. Nurul Hidayatun, the Gene Bank Manager of ICABIOGRD Bogor, for her willingness and support towards keeping the seed of the soybean accessions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

AIAT	Assessment Institute for Agricultural Technology
ANOVA	One-way analysis of variance
$Al(OH)_3$	Aluminum hydroxide
BSN	Badan Standarisasi Nasional (National Standardization Agency)
ha	Hectare
IAARD	Indonesian Agency for Agricultural Research and Development
ICABIOGRD	Indonesian Center for Agricultural Biotechnology and Genetic Resource Research and Development
ILETRI	Indonesian Legume and Tuber Research Institute
ISARI	Indonesian Swampland Agriculture Research Institute
kg	Kilogram
LSD	Least Significant Difference
MSU	Michigan State University
MoA	Ministry of Agriculture Republic of Indonesia
MG	Maturity group
NaOH	Sodium hydroxide
USDA-NSRC	National Soybean Research Center of the U.S. Department of Agriculture
SOM	Soil organic matter
VE	Emergence stage
V2	Second trifoliate stage

CHAPTER 1. GENERAL INTRODUCTION

Background

Soybean has long been a part of the traditional cuisine of Indonesian people since the 12th century (Sidharta, 2008). It is the main ingredient used for a number of processed food items that represent a part of the basic diet in Indonesia. Two types of processed foods, tempeh and tofu, are consumed as side dishes and as vegetables on a daily basis. Soybean is widely accepted by all levels of the society as a high protein food (Astuti et al., 2000; Sumarno and Adie, 2010). Therefore, soybean is a valuable grain crop in Indonesia mainly as a source of protein and a cash crop.

The protein content of Indonesian soybean varieties varies from 36.9 to 45.6% (Ginting and Tastra, 2007; Widowati, 2013), while some soybean varieties in the world contain up to 50% protein and more than 20% oil (Friedman and Brandon, 2001). Soybeans have become the preferred source of vegetable protein, because it costs much less than animal protein (Yun et al., 2005). The high protein content and the comparatively lower prices of soybean than other protein sources are the main factors that influence the demand for soybean. These factors also provide a strong basis for the government to choose soybean as the main affordable option to meet the protein needs of the society.

The processed food industries are not only generating high protein food items but also providing employment for the community. Soybean-based food industries are operated by small scale households in both rural and urban areas and become beneficial as a source of household income for lower to middle economic class levels. The number of soy-based food businesses are estimated to be more than eight thousand units which employ hundreds of thousands of workers

(Astuti et al., 2000; BSN, 2012). Therefore, soybean is not only important for improving nutrition but also for improving the economy of the society.

As an important source of protein for food and feed, soybean demand is always high and exceeds the national production capacity (Schilling, 2000). High demand for soybean is not only in the form of dry grain, but also soybean meal as a result of the rise in livestock populations. The soybean meal is one of the essential ingredients added in animal feed as the main protein source when mixed in with other items (Sudaryanto and Swastika, 2007). The Ministry of Agriculture of the Republic of Indonesia (MoA) (2015) reported that the national soybean demand in 2014 reached 2.235 million tons of dry grain, 5.67% higher than that of 2013. However, the total soybean production in the country was only 954,997 tons (Statistic Indonesia, 2014). Therefore, the deficit production of around 1.3 million tons requires imports to ensure food security.

Given that production does not meet high demand for consumption, Indonesia has become one of the net soybean importers in the world and this has negatively affected the national economy. Saliem and Nuryanti (2011) noted that from 1990-2009, the expenditure of foreign exchange to import soybean reached $298 million per year with the highest expenditure of $698 million in 2008. This routine expense has been judged as a burden for Indonesia's financial stability. The government is facing the issue of not being able to reduce import costs without affecting soybean availability.

Soybean Production in Indonesia

Considering the importance of soybean as a protein source for the majority of the Indonesian people, the government has taken steps to increase soybean production along with rice and corn to ensure the national food security (MoA, 2015). Since 1980s, increasing soybean production has been met through two main strategies: increasing productivity and planting area. In 1970, a decade before these programs were carried out, soybean was planted on 0.69 million hectares with an average yield of 0.72 tons/ha. In 1990, a decade after running the programs, the planting area for soybean reached 1.33 million hectares with an average yield of 1.11 tons/ha (Sudaryanto and Swastika, 2007; Sumarno and Adie, 2010).

Soybean production reached the highest level in 1992 with 1.7 million hectares of planting area and generated 1.9 million tons of soybean grain. Since then, soybean planting area continued to decrease due to the implementation of a monumental effort on achieving self-sufficiency in rice and corn and imbalanced competition with non-agriculture related developmental activities in the country (Sudaryanto and Swastika, 2007; Mulyani et al., 2009). Decline in soybean production is highly influenced by reduction of planting area in Java since the Java island became the central production area for soybean and other staple crops in Indonesia for decades (Sudaryanto and Swastika, 2007; Mulyani et al., 2009; Arnawa et al., 2015). Moreover, soybean is a secondary crop that is commonly planted after rice in rice- rice -soybean or rice -soybean-soybean rotation within a year (Suhartina et al., 2014). The fact that Java is the center for many staple crops makes it difficult for government to increase soybean production on this land. Therefore, expanding planting areas to outside of the Java island would be a necessity to enhance soybean production in Indonesia (Sumarno and Adie, 2010).

Challenges in Soybean Production

Efforts at increasing soybean production by the government has to face three primary challenges; low fertility of the available land, lack of market driven quality traits in existing soybean varieties, and the unfavorable price paid for locally produced soybean. Shifting the soybean planting to areas outside of the Java island was conducted since the 1980s. The available soil for crop production including soybean is more than 40 million ha outside of the Java island but are dominated by Ultisols. This type of soil is found in Sumatra, Java, Bali, Kalimantan, Sulawesi, and Papua islands (Rachman et al. 2007; Mulyani et al., 2009; Rochayati and Dariah, 2012).

Ultisols have potential to be developed as cropland, but it has several constraints such as acidity, low content of organic matter, and low Phosphorus (P) availability (Trakoonyingcharoen et al., 2005; Rochayati and Dariah, 2012). The low fertility issue of Ultisols can be addressed through fertilization, liming, and addition of organic matter (Mulyani et al., 2009). In some areas of Indonesia, application of 6.0 tons/ha of lime to acidic soils could raise soil pH to a higher-level ranging from 0.3 - 1.0 (Subandi and Wijanarko, 2013). Besides liming, adding organic matter has also shown to be substantial to increase soil organic matter (SOM) and to help plant growth and development. Furthermore, applying organic fertilizer to the soil has a positive effect to correct the soil pH (Whalen et al., 2000). Another benefit of organic fertilizer is that it helps enhance soil quality by increasing the activity of soil microorganisms (Subowo, 2010).

However, the two soybean improvement programs implemented included the increasing of planting areas and liming, were not enough to increase soybean production without having high-yielding varieties that perform well on acidic soils. Seeds of the currently available soybean varieties in Indonesia such as WILIS and TANGGAMUS, are small to medium sized (Arsyad et al., 2007; Kristanto et al., 2013; IAARD, 2017), and does not meet the market demand (Schilling, 2000; Krisnawati and Adie, 2015). With these varieties, increasing soybean production is almost impossible because without a guaranteed market, farmers would not choose soybean as a crop to grow. Therefore, providing soybean varieties that could meet market demand is critical and can be met by improving existing germplasm through a breeding program.

In Indonesia, the soybean breeding program began in 1900s. By 2015, the program had released more than 80 soybean varieties with broad adaptations including some varieties with good tolerance to a low pH of 5.5 but with small and medium-sized seeds (Arsyad et al., 2007). If Indonesia is to benefit from producing soybean in the land that is currently available with Ultisols, the breeding efforts should focus on developing large seeded varieties with tolerance to acidic soils to encourage production.

Soybean price is one of the significant factors influencing soybean production. In Indonesia, soybean production is managed manually making production less efficient. In the Indonesian market, the price of imported soybean is always lower than the locally produced soybean. The minimum price that is profitable for farmers is around Rp 9,000/kg or US$ 0.6/kg (US$ 1 = Rp 14,000). By selling soybean grain at this level, farmers are able to cover their expenses with some profit (Aldillah, 2015). However, the price of imported soybean is around Rp 6,000 to Rp 7,500/kg (Aldillah, 2015; Brata and Yasa, 2015). Therefore, the current situation of production for soybeans in not profitable for the economy. Perhaps planting better adapted, better yielding and market preferred varieties would help improve the profitability of current production systems.

Soybean Breeding Efforts in Indonesia

Improving soybean characteristics through plant breeding efforts in Indonesia started in 1918 with the sole focus of developing high yielding varieties with broad adaptability (Arsyad et al., 2007; IAARD, 2017). For developing better yielding soybean varieties, breeders used a single source of germplasm with 13 varieties obtained from Taiwan (Mejaya, 2010; IAARD, 2017). Given that high yielding lines with broad adaptability were not necessarily useful to increase production in less favorable soil conditions, in the 1990s, there was a shift in the breeding programs to focus on developing specific characteristics such as adaptability of soybean lines for specific soil types. As a result, the Indonesian Agency for Agricultural Research and Development (IAARD) was able to release some varieties with superior traits. However, due to the limited germplasm accessions available in the country, the rate of improving soybean varieties with superior traits is rather limited. For example, the soybean breeding program at IAARD was only able to release nine improved soybean lines from 1918 – 1980 (IAARD, 2017).

Some efforts were previously made to obtain soybean germplasm resources from Thailand, the Philippines, Columbia, Nigeria, Taiwan, and USA (Mejaya, 2010). As a result, the number of lines used in the soybean breeding program increased dramatically from 1981 through 2016. In 2010, there were 900 soybean lines in the IAARD germplasm collection (Chaerani et al., 2011). This allowed the release of 85 new superior soybean varieties by 2016 (IAARD, 2017). As the result, soybean yield increased compared to what it was at the beginning of the breeding program. In 2012, the average of soybean yield was 1.40 tons/ha which was 0.3 tons/ha higher than it was in 1992 (Nainggolan and Rachmat, 2014).

Importance of the Present Study

Although there was an increase in productivity, the area of soybean plantations continued to decline. Moreover, the newly released varieties had small and medium sized seeds which do not have a high demand in the market. Therefore, the breeding program needed a new direction for accelerating varietal improvement oriented towards developing varieties with consumer preferred larger seed size, and adapted to acidic Ultisols, the land available to increase production.

Evaluation of the land that can be used to expand soybean production in Indonesia revealed that much of this land contained acidic soils (Abdurrahman et al., 2007). In 1995, efforts focused on improving soybean varieties that are tolerant to acidic dry land generated some varieties such as SINDORO, SINGGALANG, SLAMET, TANGGAMUS, and DEMAS, that performed well on soils with a pH of 5.5 (Arsyad et al., 2007; IAARD, 2017). Of these, both TANGGAMUS and DEMAS released by IAARD, have good tolerance to acidic soils. However, the seed size of both these varieties does not meet with market standards that require larger seed sizes of over 13 g/100 seeds. Thus, developing large seeded soybean varieties that perform well in acidic soils is essential for Indonesia. However, there is only a total of 900 soybean germplasm accessions collected by IAARD; and of these only 12 lines are recorded as having some tolerance to acidic soils (Chaerani et al., 2011). Given that germplasm that can be used as parents is a primary constraint in the breeding program, it is critical that Indonesia accesses soybean germplasm resources as the first step towards improving the breeding program (Arsyad et al., 2007; Agrawal et al., 2013).

The success of any breeding program depends on having access to a diverse pool of germplasm. Therefore, it is essential to obtain access to soybean germplasm from other parts of the world to improve the soybean breeding program in Indonesia - especially the large-seeded germplasm that show tolerance to acidic soils. Considering that the USA, China and Brazil successfully grow large-seeded soybean varieties on acidic soils; it is worthwhile to reach out to these countries and request access to the improved germplasm accessions in the hope of integrating these favorable traits into the local Indonesian varieties through breeding.

Organization of the Dissertation and Objectives

This dissertation is organized into five chapters. The Chapter 1 is to provide a general introduction and objectives.

The objectives of Chapter 2 are to

1. select 20 best performing soybean genotypes at pH 5.0 from each of the three regions the USA, China and Brazil and
2. select a total of 20 best performing soybean genotypes using three low pH regimes.

The objective of Chapter 3 is to

1. evaluate the 20 selected lines from the previous study for tolerance to aluminum toxicity.

The objectives of Chapter 4 are to

1. evaluate the 20 selected lines for tolerance to acidic soils in Indonesia and
2. select promising lines that can be grown by farmers and/or can be used as parents in a soybean breeding program in Indonesia.

The Chapter 5 presents the overall conclusions and the future directions.

REFERENCES

REFERENCES

Abdurrahman, Mulyani A., Irawan. 2007. Land resources for soybeans in Indonesia ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 168-184. In Bahasa Indonesia

Agarwal D.K., Billore S.D., Sharma A.N., Dupare B.U., Srivastava S.K. 2013. Soybean: Introduction, Improvement, and Utilization in India—Problems and Prospects. Agric Res (December 2013) 2(4):293–300. DOI 10.1007/s40003-013-0088-0

Aldillah R., 2015. Projections for Indonesian soybean production and consumption. Journal of Applicable Quantitative Economic. Vol. 8 No. 1, February 2015. ISSN: 2301-8968. In Bahasa Indonesia

Arnawa K., Tamba I.M., Anindita R. 2015. The impact of market power on soybean price in Indonesia. Asia Pacific Journal of Sustainable Agriculture Food and Energy (APJSAFE). ISSN: 2338-1345 –Vol. 3 (1) 1-6.

Arsyad D.M., Adie M.M. and Kuswantoro H. 2007. Soybean varieties breeding on specific of agroecology in Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 205-228. In Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/03/dele_9.darman-1.pdf

Astuti M., Meliala A., Dalais F.S., Wahlqvistet M.L. 2000. Tempe, a nutritious and healthy food from Indonesia. Asia Pacific J Clin Nutr (2000) 9(4): 322–325.

Brata I.G.C.S. and Yasa I.G.W.M. 2015. Degree of import disclosure and degree of soybean commodities in Indonesia. Journal of Economic Development. The University of Udayana, Bali. Vol. 4 No. 8. Pages: 873-897. ISSN: 2303-0178

Badan Stardarisasi Indonesia [BSN]. 2012. Tempeh: Indonesian gift to the world. Jakarta. In Bahasa Indonesia. Link: http://www.bsn.go.id/uploads/download/Booklet_tempe-printed21.pdf

Chaerani, Hidayatun N., Utami D.W. 2011. Genetic Diversity of 50 Soybean Accessions Based on Ten Microsatellite Markers. AgroBiogen Journal 7(2):96-105. In Bahasa Indonesia. Link: http://ejurnal.litbang.pertanian.go.id/index.php/ja/article/viewFile/3775/3124

Friedman M. and Brandon D.L. 2001. Nutritional and Health Benefits of Soy Proteins. J. Agric. Food Chem., 2001, 49 (3), pp 1069–1086. DOI: 10.1021/jf0009246

Ginting and Tastra. 2007. The quality standard of soybeans seeds ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 444-463. In Bahasa Indonesia

IAARD. 2017. Description of soybean varieties released in 1918-2016. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/09/kedelai.pdf

Krisnawati A. and Adie M.M. 2015. Selection of soybean genotypes by seed size and its prospects for industrial raw material in Indonesia. Procedia Food Science 3 (2015) 355 – 363. DOI: 10.1016/j.profoo.2015.01.039

Kristanto H., Arsyad D.M., Purwantoro. 2013. Acidic-dry land soybean characteristic. Cash crop Journal. Indonesian Agency for Agricultural Research and Development. No. 25-2013: 1–10. In Bahasa Indonesia

Mejaya M.J. 2010. Support of germplasm in the establishment of superior soybean varieties. Secondary Food Bulletin. The Indonesian Legume and Tuber Crops Research Institute. Vol. 19. Page:14-18. In Bahasa Indonesia. DOI: http://dx.doi.org/10.21082/bul%20palawija.v0n19.2010.p13-18

Ministry of Agriculture Republic of Indonesia-MoA. 2015. Strategic plan on the 2015-2019 period. In Bahasa Indonesia. Link: http://www1.pertanian.go.id/file/RENSTRA_2015-2019.pdf

Mulyani A., Rachman A., Dairah A., 2009. The spread of acidic-soil: potential and availability for agricultural development in Rock-phosphate: utilization of rock-phosphate as phosphate nutrient source. Pgs: 25-46. In Bahasa Indonesia

Mulyani A., Sukarman, Hidayat A. 2009. Prospect of soybean extensification in Indonesia. Journal of Land Resources Vol. 3 No. 1. ISSN 1907-0799. In Bahasa Indonesia

Nainggolan K. and Rachmat M. 2014. Self-sufficiency prospect of soybean in Indonesia. Journal PANGAN Vol. 23 No. 1. Pages: 83-92. In Bahasa Indonesia

Rachman A, Subiksa IGM, Wahyunto. 2007. Soybean planting area development to sub-optimal land ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg.185-203. In Bahasa Indonesia

Rochayati and Dariah. 2012. Acidic dry-land development: opportunities and challenges ***in*** Dry-land agriculture prospect in supporting food security. Indonesian Agency for Agricultural Research and Development (IAARD). Jakarta. pg. 187-206. In Bahasa Indonesia

Saliem H.P. and Nuryanti S. 2011. The global economic perspective of soybean and cassava to support food self-sufficient. National seminar on the result of a variety of beans and tubers. Malang. Indonesia. in Bahasa Indonesia Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2012/09/01_SET_Handewi-1.pdf

Schilling R. 2000. The soybean commodity and seed multiplication system in Indonesia. Mission report and proposals. The Center for International Cooperation in Agronomic Research for Development (CIRAD, France). Link: https://agritrop.cirad.fr/475487/1/ID475487.pdf

Sidharta M. 2008. Soyfoods in Indonesia ***in*** The world of soy. University of Illinois Press. Urbana and Chicago. pg. 195-207. ISBN: 9780252033414

Statistic Indonesia [BPS]. 2014. Production of soybean by province. Link: www.bps.go.id/linkTableDinamis/view/id/871

Subandi and Wijanarko A,. 2013. The influence of liming technique on soybean growth and the yield on acidic dry-land. Journal of Penelitian pertanian tanaman pangan. Vol. 32 No. 3: 171-178. In Bahasa Indonesia

Subowo G. 2010. Strategy to use organic matter efficiently to enhance soil fertility and productivity. Journal of land resource. Vol. 4 No. 1: 13-25. In Bahasa Indonesia

Sudaryanto and Swastika. 2007. The Economic of soybean in Indonesia in ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 1-27. In Bahasa Indonesia

Suhartina, Purwantoro, Novita Nugrahaeni, Abdullah Taufiq. 2014. Yield stability of drought tolerance soybean genotypes. Journal of crop farming research. IAARD. Vol. 33 No. 1: 54-60. In Bahasa Indonesia

Sumarno and Adie M.M. 2010. The development strategies of soybean production towards sustainable food self-sufficiency. Journal of Iptek Tanaman Pangan. Vol. 5 no. 1: 49-63. In Bahasa Indonesia

Trakoonyingcharoen P., Kheoruenromne I., Suddhiprakarn A., Gilkes R.J., 2005. Phosphate sorption by Thai red oxisols and red Ultisols. Soil science. Vol 170 No. 9: 716-725

Whalen J.K., Chang C., Clayton G.W., Carefoot J.P., 2000. Cattle manure amendments can increase the pH of acid soils. Soil Sci. Soc. Am. J. 64:962–966

Widowati S. 2013. Soybeans processing technique ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 491-521. In Bahasa Indonesia

Yun J.H., Kwon I.K., Lohakare J.D., Choi J. Y., Yong J. S., Zheng J., Cho W. T., Chae B. J. 2005. Comparative efficacy of plant and animal protein sources on the growth performance, nutrient digestibility, morphology and caecal microbiology of early-weaned Pigs. Asian-Aust. J. Anim. Sci. 2005. Vol 18, No. 9: 1285-1293

CHAPTER 2. SCREENING SOYBEAN LINES FOR TOLERANCE TO ACIDIC SOIL

Abstract

Soybean is the third major crop in Indonesia after rice and corn. The soybean production increases more slowly than the demand within the country. The opportunity to increase soybean production exists by planting soybean in the land available outside of the Java island, on acidic Ultisol soils. However, the number of soybean accessions that are tolerant to acidic soils is limited and these accessions do not have desirable seed traits to meet the market demands. The objective of the present study was to test the adaptability of selected soybean germplasm to acidic soils under greenhouse conditions. A total of 706 soybean accessions originating from the USA, China, and Brazil, were screened to select 20 best performing genotypes from each country through two phases of greenhouse trials. In Phase 1, the 20 best performing soybean genotypes from each of the three countries were selected at pH 5.0 using plant height and number of days taken for each line to reach the V2 stage as the selection criteria. In phase 2, these 60 soybean genotypes were subjected to three low pH regimes; 4.5, 5.0 and 5,5 to select the best performing 20 genotypes in acidic soils using plants height and root length 55 days after planting as the selection criteria. Of the 60 genotypes, the 20 selected lines from USA and the 20 selected lines from China reached the V2 stage in 12 - 24 days after planting while the 20 selected lines from Brazil took slightly longer to reach V2 stage with 16 - 30 days after planting. In the second screening, 20 best performing lines out of the previous 60 were selected based on their performance on acidic soils with a pH of 4.5. Aluminum (Al) toxicity could hinder plant growth in low pH soils. Given that Al toxicity is a major concern in Indonesian low pH soils, further studies are needed to evaluate the performance under aluminum (Al) toxicity.

Introduction

Soybean is the third strategic commodity after rice and maize in Indonesia. Soybean has been listed by the Indonesian government as one of the top national priority-crops in the food self-sufficiency programs for decades (Ministry of Agriculture Republic of Indonesia, MoA, 2015). The demand for soybean and two other commodities is increasing every year due to the importance of rice as the primary carbohydrate source, corn being the main component for the food and feed industry, and soybean as the most valuable protein source for humans and livestock. While both rice and corn have shown success in increasing yield due to plant breeding efforts, soybean production increases more slowly compared to the demand (Sudaryanto and Swastika, 2007; Supadi, 2010).

The limited availability of fertile land and superior varieties has been identified as reasons for low production of soybean in Indonesia. For decades, the main area for crop production in the country was the Java Island contributing to more than 60% of the total food production of - mainly rice and soybean (Widiatmaka et al., 2016; Syuaib, 2016). However, in order to succeed in rice self-sufficiency, land allocation in Java was prioritized for rice. Therefore, increasing soybean production areas in the Java Island was no longer possible and the government needs to consider increasing soybean production in non-Java areas, which are particularly acidic dry-land areas. The total acidic dry-land area in Indonesia, as explained by Mulyani et al. (2009), is more than 102 million ha or a total of 69.46% of dry-land spread throughout the eight larger islands. Ultisols dominate the acidic dry-land (40.77%) that is available for soybean development programs in Indonesia.

While the Ultisols soil have the potential to serve as cropland, it has several problems such as acidity, low content of soil organic matter, and low Phosphorus (P) availability

(Trakoonyingcharoen et al., 2005). In Indonesia, Ultisols soil have a pH ranging between 4.27 - 5.30, available, Al between 0.94 - 6.95 me/100 g, and available soil P (Bray) between 3.80 - 36.70 ppm (Rochayati and Dariah, 2012). According to Lyamuremye et al. (1996), the soil fertility problems associated with low soil pH, can be overcome by applying lime to the soil.

The value of liming to correct soil acidity to enhance agricultural productivity is well documented. The importance of liming, according to Pagani (2011), is to increase soil pH regardless of their initial pH, with the range of increasing up to 2.50 units of pH for the first four years after application. The significant role of liming in fixing low pH problem is also well-known by the Indonesian government; and therefore, it has been applied to expand soybean planting areas from 1983 – 1987. The results were seen years later with an increase in soybean yield reaching over 1.5 tons/ha (Sumarno and Adie, 2010).

Indonesian agriculture is dominated by small-holder resource-poor farmers most of whom do not have the capabilities to lime the soil to fix soil fertility constraints, despite understanding its importance. Farmers will not be able to afford and apply the lime due to limitations in capital. In this situation, providing farmers with superior varieties that can withstand acidic soils will be an excellent and long-term strategy for improving soybean production on acidic-soil.

Plant breeding is a sustainable and long-term solution to help farmers and the government increase soybean production. Providing superior varieties adapted to acidic soils is more affordable for farmers than recommendations on liming and other types of conditioning the land (Adie and Krisnawati, 2016). Therefore, since 1995, Indonesia has changed the goals of the soybean breeding program from developing high yielding varieties with broad adaptability to improving soybean varieties that are tolerant to acidic dry-lands (Arsyad et al., 2013; IAARD, 2017). Varieties resulting from this program reported to have good tolerance to acidic soils but did not meet market preference of large seed sizes. For many years, the soybean breeding program in Indonesia depended on a limited number of accessions that are tolerant to acidic soils for use as parents. The Indonesian Center for Agricultural Biotechnology and Genetic Resource Research and Development (ICABIOGRD) has only 12 accessions out of more than 900 accessions that were reported to have tolerance to acidic soils (Chaerani et al., 2011). One of the most effective ways of enhancing a breeding program is to access new germplasm resources through plant introductions from other sources (Arsyad et al., 2013; Ibrahim et al., 2017).

Considering the interest in increasing soybean production by growing the crop in acidic soils, improving the soybean breeding program in Indonesia could consider the following steps in the plant breeding process. These steps include determining objectives (1), accessing genetic variation (2), developing and selecting progeny (3) and disseminating varieties (4) (Bernardo, 2010). In the current study, our goal was to access germplasm from countries that successfully produce soybean in Ultisols under low pH conditions and conduct an initial evaluation of this germplasm under the conditions found in Indonesia, hence meeting the second step in the plant breeding process.

Being the country of origin for soybean, China has the most significant collection of soybean germplasm with > 40,000 accessions, followed by the USA with > 18,000 accessions, and Brazil with > 10,000 accessions (Carter et al., 2003). These three countries also have soybeans production regions that have Ultisols with acidic conditions similar to Indonesia. Furthermore, the USA and Brazil are the largest soybean producers in the world and is home to excellent soybean breeding programs. As such, Indonesia can benefit from obtaining soybean germplasm from these countries to develop an adapted germplasm. Therefore, as the first step in the current study, we obtained soybean germplasm from the above three countries that were available in the National Soybean Research Center of the U.S. Department of Agriculture (USDA). Prior to requesting the germplasm, we superimposed the world soil map along with the world pH map to identify the regions in these countries that successfully produce soybeans in acidic Ultisols. We then subjected the 706 germplasm accessions obtained from the USDA soybean germplasm repository to greenhouse testing to select a subset of germplasm accessions for further testing.

The first screening test was designed to select a subset of 60 soybean accessions of the 706 obtained from USDA-NSRC depending on their performance on acidic soil during its vegetative stages. This selection phase was not only intended to narrow down the number of lines for further experimentation as we strived to identify the best performing soybean germplasm on acidic soils, but also to have an understanding of which of the lines would be useful for enhancing the diversity of soybean germplasm available in Indonesia. As pointed out by Rao and Hodgkin (2002), ecological and geographical factors play a role in the extent and distribution of genetic diversity of plant species. Therefore, an understanding of the available diversity within the soybean lines grown in acidic soils would assist us in determining which of the lines would be the most useful for breeding purposes. Therefore, the goal of this experiment was to select 20 best performing lines from each of the three countries of origin during the vegetative stages.

Materials and Methods

Plant materials

The plant material used in this study consisted of 706 soybean accessions obtained from the National Soybean Research Center of the United States Department of Agriculture (USDA-NSRC) in Urbana, Illinois. Among the lines were 91 originating from the USA, 407 lines from China, and 208 lines from Brazil, the three countries with the most significant number of soybean collections and planting area on acidic soils (Carter et al., 2003). A list of the soybean accessions with information on their origin is given in Tables 2.5 (USA), 2.6 (China) and 2.7 (Brazil).

Greenhouse screening experiments for determining tolerance to acidic soils

Selecting 20 best performing soybean genotypes each from the three regions USA, China and Brazil at pH 5.0

In order to obtain 20 best performing lines from each of the three regions, all of the 706 lines were planted on a screening medium with a pH of 5.0 as this represents the average pH level of Indonesian acidic soils. We conducted the experiment in the greenhouse given that naturally acidic soils that are comparable with that of Indonesia are not available in Michigan.

We used Peat moss as the standard planting medium for greenhouse experiments at Michigan State University (MSU) as it is a pure acidic soil. However, this soil has a very low pH level around 3.5 and had to be raised to 5.0 using Sodium hydroxide (NaOH) as a strong base to bring the pH levels comparable to that of Indonesian acidic soils. To determine the amount of NaOH needed to achieve a pH of 5.0, we used a titration method (Whitney, 1998) which consists of four steps: adding distilled water to peat moss sample, measuring the initial pH level of sample, making a 0.1 M NaOH solution, and titrating droplets of NaOH solution to peat moss sample until reaching the desired pH level.

Adding distilled water to the peat moss sample is intended to dissolve soluble contents in the soil sample in order to measure the initial pH of the soil and to prepare the sample for the next titration steps. For this step, we added 28 ml of distilled water to approximately seven grams of dry peat moss in a small cup and stirred gently until soluble content of the soils dissolved in the water. The mixture was covered and left for 2 hours to allow time for all contents to dissolve before the actual pH of the peat moss solution was measured using a pH meter. The method was replicated three times to prepare three samples.

For the next step, we prepared a 0.1 M NaOH solution by dissolving 4 grams of solid NaOH in 1,000 ml distilled water using Erlenmeyer or volumetric flask. In the titration step, 0.1M NaOH was added to the peat moss sample one drop at a time with a burette, until its pH was brought to 5.0 using a pH meter. The number of drops of NaOH needed to make the pH of the peat moss solution to 5.0 was used to calculate the volume of NaOH needed to prepare the soil medium for the greenhouse experiment.

We used the titration results as a basis to raise the pH level of the peat moss to 5.0 in sufficient quantities being used for the screening test. Given that we required 706 pots filled with 22 grams of dry peat moss for the experiment, we needed 15,510 grams of peat moss. To prepare the medium, we mixed 55,224 ml of distilled water with the peat moss (considering 78 ml distilled water is added to each pot), and let the mixture stand in a closed box for about 5 - 6 hours to allow the material to be mixed. Next, 28,804 ml of 0.1 M NaOH solution was added to the prepared peat moss and the mixture was left to stand for about 12-24 hours. As a final step, the pH of the prepared medium was measured to ensure that the pH level is 5.0 before filling the media into the pots.

We planted three soybean seeds in each pot at 2.5 cm below the surface and allowed seeds to germinate and grow until V2, the vegetative phase previously identified. No chemical treatments were given to the soil since we were interested in observing the plant's adaptation to specific pH conditions. However, we watered every pot daily using the same amount of distilled water. The distilled water was used in place of tap water to maintain soil pH level around 5.0. Daily observations were made to evaluate plant growth during the vegetative (V) phases.

The variables observed in this experiment were plant height and the number of days taken for each plant to reach vegetative stages from emergence (VE) to the stage where we could observe at least two unrolled trifoliate leaves (V2). Plant height was measured at 35 days after planting as well as at the V2 stage. Plant height is an important variable to be measured in understanding the effect of H^+ toxicity which begins to show in five days after planting (Kidd and Proctor, 2001; Adie and Krisnawati, 2016). The growth stage V2 is an important stage in plant growth that provides information regarding the plant's response to acidic planting medium. In this stage, soybean roots have been well developed to support the development of root nodules and absorption of nutrients for plant growth (Lersten and Carlson, 2004; Pedersen and Licht, 2014). Given that nodular formation and active nitrogen fixation begins at the V2 stage in soybean, we considered V2 as critical for the plants to establish itself in acidic soils. Guidelines for soybean vegetative phases is based on Pedersen and Licht (2014).

The data collected on plant height was tabulated using Microsoft Excel. We then sorted the data from the highest to lowest for each variable to simplify the genotypic selection. SAS 9.4 was used to analyze the data and generate an analysis of variance (ANOVA) table followed by multiple comparisons if the result showed a significant difference at $P \leq 0.05$. In this experiment, we selected as many as 60 genotypes to represent the three countries of origin for the soybean accessions and will be used for future experimentation.

Selecting a total of 20 best performing soybean genotypes using three low pH regimes

The second screening test was used to select 20 soybean lines out of the previous 60 selected (20 from each of the countries USA, China and Brazil) that perform better on varying low pH levels. Thus, we used two factors for this study; the selected soybean genotypes (from the first screening), and the varying pH levels. The 60 selected soybean genotypes from the preliminary trial were treated with a commercial inoculant of *Rhizobium* bacteria prior to planting to assist nodule formation on soybean roots. The dose of inoculant was 0.4 gram per 100 grams of soybean seeds (USDA, 2015). Eighteen seeds of each of the genotypes were mixed with the inoculant in a small cup and planted directly on to the appropriate soil medium 5 to 10 minutes after mixing.

For the second factor, the variation of soil pH level, we considered three pH levels: 4.5, 5.0 and 5.5. As in the first screening experiment, peat moss with an initial pH of 3.5 was selected as the preferred growing medium. Therefore, as described in the first screening experiment, the soil was treated with NaOH to achieve the desired pH level. The amount of NaOH needed to adjust the desired pH level was calculated using the same titration procedure (Whitney, 1998) and the process for mixing the distilled water and NaOH to prepare the medium for the greenhouse experiment remained unchanged. A total of 36,000 grams of peat moss and 69,000 ml of 0.1 M NaOH solution were needed to make as much as 360 pots of growth medium.

We planted three seeds in each pot at 2.5 cm below the surface and allowed seeds to germinate and grow until V2, the vegetative phase previously identified. No chemical treatments were provided to the seedlings except the seed inoculant with *Rhizobium* bacteria as we were particularly interested in evaluating the ability of each genotype to form nodules under naturally acidic field soil conditions. Plants were watered once or twice a day using tap water provided in the greenhouse depending on the condition of the soil surface moisture as a means of keeping the plants alive.

Plant growth was monitored every three days to evaluate their performance in terms of plant height, and the vegetative stage reached. Observation of vegetative phases was determined in reference to Pedersen and Licht (2014). We also counted the number of root nodules on each genotype at the end of the research about 55 days after planting. Data were subjected to analysis of variance using SAS 9.4, and a test of means was used as a comparison tool to decide on the 20 best performing genotypes if the ANOVA test results showed a significant F-value ($P \leq 0.05$).

Results and Discussion

More than 90% of the selected lines had yellow color seed-coat (Table 2.1) which is a trait in high demand in the Indonesian market as the raw material for processed food and feed. Moreover, the selected lines also showed a wide range of maturity groups (MGs) and seed sizes. Therefore, the initial results shed promise for using the selected lines for potential release in Indonesia if they perform well in future field trials or for use as parents for improving current soybean varieties in the country.

Selecting 20 best performing soybean genotypes each from the three regions USA, China and Brazil at pH 5.0

When requesting the germplasm from USDA-NSRC, one of our criteria was that the germplasm be developed in or grown in regions that represent acidic Ultisols in the three countries Brazil, China and USA. The list of soybean accessions from the three regions shown in Table 2.5, 2.6, and 2.7. We assumed that such selection criteria would provide germplasm that could best perform under the land currently available to expand soybean cultivation in Indonesia. However, of the 706 plants, 36 accessions from USA, 276 accessions from China and 53 accessions from Brazil failed to survive to a stage where we could obtain measurements for plant height and/or did not reach V2 stage when planted in the acidic peat moss medium. As such, these accessions were excluded from any further experimentation.

Significant differences of plant height were found among the 706 lines at $P < 0.0001$ (Table 2.8). The significant result from the analysis of variances justified selection of 60 lines through comparison of means, which was conducted for each group of lines so that the 20 best lines from each country of origin could be selected. Plant height could be determined by genetic factors and environmental factors including the plant's adaptability to a low pH medium. Several investigations have reported the effect of low pH in reducing the plant growth rate (Board, 1991; Caires et al., 2008; Joris et al., 2013). Given our interest in selecting soybean genotypes that favorably respond to acidic soils, we considered plant height to be one of the indicators. Plant height is also used as one of the main indicators in evaluating soybean adaptability on acidic soil in Indonesia (Adie and Krisnawati, 2016).

USA accessions

The results obtained from comparing the average plant height for the accessions from the USA is shown in Table 2.10 and Figure 2.1. As many as 55 lines (60%) grew successfully until 35 days after planting, while the rest of the lines did not survive. The ability of these lines to grow showed an initial tolerance to low pH soil. The 55 lines were of three seed-size categories, when compared to the seed-size standards used in Indonesia (Ginting and Tastra, 2013); small seeded (≤ 10.0 grams per 100 seeds), medium seeded (10.1 - ≤13.0 grams per 100 seeds), and large seeded (> 13.0 grams per 100 seeds). The maturity groups (MGs) of the accessions also showed a wide range between MG-I to MG-VIII.

Among the 55 surviving lines, line number PI556727 had the highest plant height and was significantly different from 38 other lines from USA (Table 2.10). One hundred seeds of these accessions weighed 15.61 grams, hence were binned in the large-seeded category. Moreover, these accessions along with another eight accessions were grouped into MG-VIII, which is the most suitable category for the Indonesian climate. Number of plant stands that reached a V2 stage speaks to the ability of the selected lines to survive on an acidic growing medium.

The number of the days taken by the 20 selected accessions from the USA to reach V2 is shown in Table 2.2. Ten of the accessions including PI556727 reached 100% plant stand in 17 to 24 days after planting meaning these lines showed tolerance to acidic soil conditions. This variable also allowed us to select accessions that are fast maturing. For example, accession PI594922 exhibits the shortest life span followed by PI556564. Early maturing accessions are of particular interest to Indonesian climate and planting season where soybean is generally planted at the end of the rainy season after rice or corn (Handayani et al., 2018).

Based on the comparison of means of plant height and the days for the plants to reach V2 stage 35 days after planting, the 20 selected lines from USA that show a higher value and plant stand are PI556727, PI556744, PI556537, PI556612, PI615694, PI556536, PI576154, PI590932, PI583367, PI548987, PI603953, PI556515, PI553047, PI584506, PI615695, PI556564, PI548986, PI556481, PI556584, PI594922.

Chinese accessions

The comparison of means for the 407 lines obtained from China and tested in the low pH medium is shown in Table 2.11 and Figure 2.2. Of these only 131 lines (32%) survived until 35 days after planting. Accession number PI567652 reached the highest value of plant height and significantly differed from the other 17 lines from China. This line together with another 130 lines showed some tolerance to low pH soil by surviving for 35 days after planting.

The seed weight of the 131 surviving lines varied from 6.64 grams to 32.09 grams per 100 seeds which provides us with opportunities to select large seeded accessions of interest to Indonesia as 59 of the lines (45%) had a seed weight of ≥ 15.0 grams per 100 seeds and dominated by yellow seed-coat. The maturity groups for all surviving lines ranged from MG-IV to MG-VII.

The number of days it took for the accessions from China to reach the V2 stage is shown in Table 2.4. Only six lines reached 100% plant stand at V2 stage, while other lines were less than 70%. According to this result, the accessions obtained from the USA had a higher plant stand than the Chinese accessions. However, all of these six lines reached the V2 stage at the same time of 20 days after planting which can be considered as promising lines due to the short season available for soybean in Indonesia (Arsyad et al., 2013), especially those lines with the larger seeds. The other lines reached the V2 stage between 15 to 24 days with a maximum plant stand of 66.6%.

Based on the comparison of means for plant height and the days taken for plants to reach the V2 stage at 35 days after planting, the 20 selected lines that show a highest values are PI567620B, PI594568B, PI567643, PI567652, PI587714A, PI603637A, PI567379A, PI567410C, PI567413, PI567611, PI567614C, PI567646A, PI567684B, PI567779A, PI587572B, PI587614, PI587692B, PI587768, PI594643, and PI603706B.

Brazilian accessions

For the 208 accessions obtained from Brazil the comparison of means are shown in Table 2.12 and Figure 2.3. With 155 accessions surviving (74.5%), Brazil provided the highest number of accessions performing under acidic soil conditions. Accession PI 675656 was the tallest among the 208 lines and was significantly different from 61 of the surviving lines obtained from Brazil. This line along with the other 154 lines showed some tolerance to low pH by surviving in acidic medium for 35 days after planting.

The seed weight of all the 155 lines that survived, varied from 7.88 grams to 23.58 grams per 100 seeds. Of these, 76 lines (49%) had a seed weight ≥ 15.0 gram per 100 seeds. Of the germplasm obtained from USDA-NSRC, the number of large-seeded accessions was highest in those obtained from Brazil. Moreover, the yellow seeds also dominated the surviving lines obtained from Brazil increasing the opportunity to obtain lines with large seeds and yellow coat for improving the soybean breeding program in Indonesia. The maturity groups for all surviving lines ranged from MG-VI to MG-X. However, only a portion of the lines that survived could reach the V2 stage.

Table 2.4 shows the number of the days it took for the 20 accessions selected from the group obtained from Brazil to reach the V2 stage. Of these 20 lines, only seven lines reached 100% of plant stand and reached the V2 stage at 18 – 30 days after planting. These seven lines along with the rest of the 13 lines selected needed more days to reach the V2 stage, compared to the accessions obtained from USA and China. However, the accessions obtained from Brazil had the highest number of lines with large seeds size, and given that Brazil's location is comparable to Indonesia, we hope these lines would be better adapted to Indonesian climate.

Based on the comparison of means for plant height and the days needed to reach the V2 stage, the 20 selected lines from Brazil are PI628842, PI628929, PI628885, PI628962, PI675671, PI628873, PI628835, PI628848C, PI628894, PI628828, PI628812, PI628965, PI628925, PI675661, PI628809, PI675669, PI628869, PI628871, PI628952, and PI628880.

Selecting a total of 20 best performing soybean genotypes using three low pH regimes

We used all of the 60 lines selected in the previous experiment for this study. This study was specifically designed to determine the 20 best performing lines in three different pH levels. There were significant differences among the main effect of lines and pH levels to plant height (Table 2.9). Such differences would indicate the tolerance of each accession at different acidity levels of the growing media. Results showed significant differences between lines for the three pH levels, as well as for the interaction between lines and pH levels. Therefore, a multiple comparison was needed to select 20 lines from the 60 considered in the study.

We intended to find 20 best performing accessions out of the 706 obtained from the USDA-NSRC based on their performance on various low pH levels. In order to narrow down the number of accessions from 60 to 20, we wanted to select accessions that were able to perform better in two of the three pH levels used in the second study. The results from the means comparison of plant height variable are shown in Table 2.13. Of the 60 accessions, 44 lines survived in the medium with pH 4.5. Of these 44 lines, accession PI628871 showed the highest value for plant height and was significantly different from the other 40 lines that survived at pH 4.5 (Figure 2.4). The accession PI567611 showed the highest value for plant height among the lines that were tested at pH 5.0 (Figure 2.5), and line number PI628925 showed the highest value for plant height at pH 5.5 (Figure 2.6). However, different results were found for the root length variable (Table 2.14). The highest value for root length at each pH level were seen in PI556727, PI628871, and PI556537 for pH 4.5, 5.0, and 5.5 respectively.

Means of root length of 44 survived accessions are shown in Table 2.14 and Figure 2.7. Root length of 44 survived plants at pH 4.5 were longer than surviving lines at both pH 5.0 and 5.5. Among all lines that survived at pH 4.5, PI556727 had better root growth and had the longest root length. In the medium with pH 5.0, among the 22 lines that survived, PI628871 was the accession with the highest root length. According to the data, several accessions were able to survive at all three pH levels including the lines PI556727, PI628871, and PI567611.

In this study, we noted that the lines planted on growing medium with pH 4.5 performed better than lines planted on medium with slightly higher pH levels of 5.0 and 5.5. We believe this observation supports the explanation provided by Peterson (1982), Robson (1989) and Havlin et al. (2014) where a positive correlation between lower pH and the availability of manganese (Mn^{2+}) was observed especially at pH < 5.0. The availability of Mn^{2+} for uptake by plants would increase the rate of photosynthesis and hence, plant growth.

Based on the results of mean comparisons, the 20 lines selected are PI628871, PI628962, PI567611, PI556744, PI556727, PI615695, PI628925, PI567779A, PI556537, PI628842, PI594922, PI556515, PI590932, PI628929, PI628880, PI567410C, PI567643, PI556612, PI675661, and PI556564. These lines performed better on either all the three pH levels or two of the three pH levels tested.

APPENDIX

Table 2.1. Summary of the seed characteristics including seed weight, maturity group, and percent yellow seed coat of 706 lines from USA, China, and Brazil

Country of origin	Number of lines	% lines with yellow seed coat	Maturity group (range)	Range of 100 seed weight (g)
USA	91	100	I – VIII	5.83 – 20.89
China	407	94	IV – VII	6.06 – 32.09
Brazil	208	98	V - X	7.88 – 41.33

Table 2.2. Seed coat color, seed weight, and days taken by 20 selected USA lines to reach V2 stage

No	PI	MG	Seed coat color	Weight of 100 seeds (gr)	Days to reach V2 stage		
					33.3%	66.6%	100.0%
1	PI594922	V	yellow	15.56	12	15	17
2	PI548987	V	yellow	14.53	13	15	20
3	PI548986	VI	yellow	12.98	14	17	20
4	PI556564	VI	yellow	13.83	12	15	20
5	PI556727	VIII	yellow	15.61	13	17	20
6	PI584506	VII	yellow	12.10	13	17	20
7	PI615694 *	VII	yellow	14.15	13	17	20
8	PI615695	VII	yellow	7.38	13	17	20
9	PI556536	VII	yellow	16.96	14	17	24
10	PI556584	VII	yellow	12.32	15	20	24
11	PI556481	VII	yellow	10.68	15	20	-
12	PI556515	VIII	yellow	14.89	13	17	-
13	PI556537	VIII	yellow	14.12	14	17	-
14	PI556744	V	yellow	17.58	13	17	-
15	PI576154	VI	yellow	11.36	13	17	-
16	PI590932	IV	yellow	17.31	13	20	-
17	PI556612	VI	yellow	12.90	15	20	-
18	PI603953 *	VIII	yellow	11.38	15	20	-
19	PI553047	VII	yellow	8.94	17	24	-
20	PI583367	VII	yellow	8.62	20	24	-

Table 2.3. Seed coat color, seed weight, and days taken by 20 selected Chinese lines to reach V2 stage

No	PI	MG	Seed coat color	Weight of 100 seeds (gr)	Days to reach V2 stage		
					33.3%	66.6%	100.0%
1	PI567611	IV	yellow	10.53	12	15	20
2	PI594568B	V	yellow	15.00	13	17	20
3	PI567643	IV	yellow	16.72	14	17	20
4	PI567652	IV	yellow	9.42	14	17	20
5	PI587714A	V	yellow	11.72	14	17	20
6	PI603637A	V	yellow	12.66	14	17	20
7	PI567379A	V	yellow	16.35	13	17	-
8	PI567410C	VII	yellow	13.91	12	15	-
9	PI567413	V	yellow	6.64	20	24	-
10	PI567620B	IV	yellow	10.60	14	20	-
11	PI567614C	IV	yellow	11.72	13	20	-
12	PI567646A	IV	yellow	16.22	13	20	-
13	PI567684B	IV	yellow	10.34	17	20	-
14	PI567779A	IV	yellow	16.33	15	20	-
15	PI587572B	VI	yellow	15.42	17	23	-
16	PI587614	VI	yellow	13.44	15	20	-
17	PI587692B	VII	yellow	21.38	12	15	-
18	PI587768	VI	yellow	13.38	14	20	-
19	PI594643	V	yellow	8.64	17	20	-
20	PI603706B	IV	yellow	13.29	15	20	-

Table 2.4. Seed coat color, seed weight, and days taken by 20 selected Brazilian lines to reach V2 stage

No	PI	MG	Seed coat color	Weight of 100 seeds (g)	Days to reach V2 stage		
					33.3%	66.6%	100.0%
1	PI628842	VIII	yellow	14.75	-	16	18
2	PI628929	IX	yellow	18.92	-	18	24
3	PI625695	VII	yellow	13.46	18	20	24
4	PI628962	VII	yellow	14.07	-	20	24
5	PI675671	VIII	yellow	23.17	-	20	30
6	PI628873	VI	yellow	13.28	18	24	30
7	PI628835	VII	yellow	14.47	18	25	30
8	PI628848C	VII	yellow	14.08	18	24	-
9	PI628894	VIII	yellow	13.01	18	27	-
10	PI628828	VI	yellow	15.05	18	27	-
11	PI628812	VI	yellow	13.45	20	24	-
12	PI628965	VII	yellow	13.52	20	24	-
13	PI628925	VIII	yellow	14.51	20	24	-
14	PI675661	X	yellow	15.24	20	24	-
15	PI628809	VI	yellow	16.20	20	27	-
16	PI675669	X	yellow	14.72	22	27	-
17	PI628869	VI	yellow	15.71	24	27	-
18	PI628871	VI	yellow	14.21	24	30	-
19	PI628952	VI	yellow	12.72	-	24	-
20	PI628880	V	yellow	13.91	-	27	-

Table 2.5. List of 91 soybean lines of the USA accessions

No.	PI Number	Cultivar	MG	State	Sub-collection	Year	Seed Weight (grams/100 seeds)
1	PI561211	3172	I	N. Carolina	Private	1994	18.53
2	PI561212	3202	II	N. Carolina	Private	1994	16.81
3	PI556741	COKER 393	III	S. Carolina	Private	1984	17.13
4	PI559379	3311	III	N. Carolina	Private	1991	12.40
5	PI515961	Pennyrile	IV	Kentucky	Modern	1987	20.89
6	PI576440	Calhoun	IV	Kentucky	Modern	1993	16.89
7	PI590931	CF492	IV	Kentucky	Modern	1995	14.99
8	PI590932	CF461	IV	Kentucky	Modern	1995	17.31
9	PI611112	7499	IV	Kentucky	Modern	2000	15.03
10	PI548987	Dare	V	N. Carolina	Modern	1965	14.53
11	PI572239	Holladay	V	N. Carolina	Modern	1993	13.93
12	PI594922	Graham	V	N. Carolina	Modern	1996	15.56
13	PI596414	Clifford	V	N. Carolina	Modern	1997	16.28
14	PI556506	McNair 500	V	N. Carolina	Private	1976	15.23
15	PI556697	TERRA-VIG 505	V	S. Carolina	Private	1983	13.36
16	PI556742	COKER 355	V	S. Carolina	Private	1984	14.62
17	PI556743	COKER 485	V	S. Carolina	Private	1984	18.32
18	PI556744	COKER 425	V	S. Carolina	Private	1984	17.58
19	PI596540	Camp-lx2	V	Kentucky	Modern	1996	10.43
20	PI508266	Young	VI	N. Carolina	Modern	1984	12.63
21	PI511813	Twiggs	VI	Georgia	Modern	1987	14.35
22	PI542712	Bryan	VI	Georgia	Modern	1990	12.00
23	PI548835	3615	VI	N. Carolina	Private	1991	15.07
24	PI548985	Kershaw	VI	S. Carolina	Modern	1982	12.87
25	PI548986	Brim	VI	N. Carolina	Modern	1990	12.98
26	PI548988	Pickett	VI	N. Carolina	Modern	1965	13.33
27	PI556480	McNair 600	VI	N. Carolina	Private	1974	12.52
28	PI556504	LANCER	VI	S. Carolina	Private	1976	16.36
29	PI556514	COKER 136	VI	S. Carolina	Private	1973	17.41
30	PI556564	COKER 156	VI	S. Carolina	Private	1980	13.83
31	PI556612	TERRA-VIG 606	VI	S. Carolina	Private	1981	12.90
32	PI556716	GK-67	VI	Georgia	Private	1983	15.94
33	PI556827	COKER 686	VI	S. Carolina	Private	1987	13.45
34	PI576154	Doles	VI	Georgia	Modern	1993	11.36
35	PI592756	Dillon	VI	S. Carolina	Modern	1994	16.75
36	PI597389	Prolina	VI	N. Carolina	Modern	1997	11.80
37	PI599333	Musen	VI	S. Carolina	Modern	1997	10.77
38	PI602597	Boggs	VI	Georgia	Modern	1998	10.29
39	PI614702	Soyola	VI	N. Carolina	Modern	2000	11.94
40	PI617045	NC-Roy	VI	N. Carolina	Modern	2001	12.91

Table 2.5. Cont'd

No.	PI Number	Cultivar	MG	State	Subcollection	Year	Seed Weight (grams/100 seeds)
41	PI619615	N6201	VI	N. Carolina	Modern	2002	19.71
42	PI642732	Nitrasoy	VI	N. Carolina	Modern	2006	12.37
43	PI522236	Thomas	VII	Georgia	Modern	1988	14.15
44	PI531068	Stonewall	VII	Alabama	Modern	1988	13.96
45	PI536009	Colquitt	VII	Georgia	Modern	1989	12.94
46	PI548657	Jackson	VII	N. Carolina	Modern	1953	14.11
47	PI548989	Ransom	VII	N. Carolina	Modern	1970	16.02
48	PI553041	Duocrop	VII	Georgia	Modern	1981	9.70
49	PI553042	Wright	VII	Georgia	Modern	1979	10.21
50	PI553046	Gasoy 17	VII	Georgia	Modern	1977	8.36
51	PI553047	Gordon	VII	Georgia	Modern	1984	8.94
52	PI555453	Hagood	VII	S. Carolina	Modern	1990	10.79
53	PI556481	McNair 800	VII	N. Carolina	Private	1974	10.68
54	PI556516	TERRA-VIG 708	VII	S. Carolina	Private	1977	14.81
55	PI556536	COKER 237	VII	S. Carolina	Private	1978	16.96
56	PI556545	Brooks	VII	Georgia	Private	1978	13.00
57	PI556583	McNair 710	VII	N. Carolina	Private	1980	15.69
58	PI556584	McNair 770	VII	N. Carolina	Private	1980	12.32
59	PI556623	COKER 317	VII	S. Carolina	Private	1982	11.17
60	PI556825	COKER 627	VII	S. Carolina	Private	1986	13.44
61	PI556847	6727	VII	S. Carolina	Private	1987	12.13
62	PI572238	Haskell	VII	Georgia	Modern	1993	15.08
63	PI583367	Pearl	VII	N. Carolina	Modern	1994	6.82
64	PI584506	Carver	VII	Alabama	Modern	1994	12.10
65	PI595645	Benning	VII	Georgia	Modern	1996	12.91
66	PI615694	N7001	VII	N. Carolina	Modern	2001	14.15
67	PI615695	N7103	VII	N. Carolina	Modern	2001	7.38
68	PI617041	Santee	VII	S. Carolina	Modern	2001	14.67
69	PI619616	N7101	VII	N. Carolina	Modern	2002	7.22
70	PI619617	N7102	VII	N. Carolina	Modern	2002	8.31
71	PI641156	NC-Raleigh	VII	N. Carolina	Modern	2005	13.64
72	PI647085	N7002	VII	N. Carolina	Modern	2007	12.87
73	PI661157	N7003CN	VII	N. Carolina	Modern	2011	17.59
74	PI508267	Johnston	VIII	N. Carolina	Modern	1983	14.27
75	PI536637	Perrin	VIII	S. Carolina	Modern	1988	19.68
76	PI548697	Majos	VIII	S. Carolina	Private	1990	13.40
77	PI548698	Yelnanda	VIII	S. Carolina	Private	1990	15.45
78	PI553045	Cook	VIII	Georgia	Modern	1991	18.47
79	PI556467	Coker Hampton 266A	VIII	S. Carolina	Private	1971	13.95
80	PI556515	COKER 338	VIII	S. Carolina	Private	1976	14.89

Table 2.5. Cont'd

No.	PI Number	Cultivar	MG	State	Subcollection	Year	Seed Weight (grams/100 seeds)
81	PI556537	COKER 488	VIII	S. Carolina	Private	1978	14.12
82	PI556696	COKER 368	VIII	S. Carolina	Private	1983	11.30
83	PI556727	COLLIER	VIII	Georgia	Private	1984	15.61
84	PI556848	6738	VIII	S. Carolina	Private	1987	13.07
85	PI568236	Maxcy	VIII	S. Carolina	Modern	1992	14.53
86	PI603953	Motte	VIII	S. Carolina	Modern	1998	11.38
87	PI608033	Kuell	VIII	Alabama	Modern	1999	12.43
88	PI612157	Prichard	VIII	Georgia	Modern	2000	10.22
89	PI614156	Hampton	VIII	S. Carolina	Modern	1962	16.03
90	PI647086	N8001	VIII	N. Carolina	Modern	2007	19.66
91	PI654355	N8101	VIII	N. Carolina	Modern	2008	5.83

Table 2.6. List of 407 lines of the Chinese accessions

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
1	PI103080	White Soybean	IV	Henan	10.37
2	PI071444		IV	Jiangsu	15.89
3	PI071463		IV	Jiangsu	18.72
4	PI072227	Siu wong tau	IV	Hubei	16.11
5	PI446893	Wan No. 100-1	IV	Anhui	15.73
6	PI532455B	Dan yang bai hua dou	IV	Jiangsu	13.20
7	PI567381A	Bai ke huang	IV	Shaanxi	12.42
8	PI567611	Ba yue zha	IV	Henan	10.60
9	PI567612	Bo ai er zi bai dou	IV	Henan	11.46
10	PI567614C	Chang yuan xiao tian e dan	IV	Henan	11.72
11	PI567614D	Chang yuan xiao tian e dan	IV	Henan	12.69
12	PI567615	Chen liu niu mao huang	IV	Henan	16.47
13	PI567620B	Guang shan tian e dan	IV	Henan	10.53
14	PI567623	Ji yuan shui bai dou	IV	Henan	14.48
15	PI567626	Jian ding da bai dou	IV	Henan	14.98
16	PI567627B	Kai feng xiao zi tie jiao huang	IV	Henan	8.40
17	PI567630B	Luan chuan ba yue zha bai dou	IV	Henan	13.86
18	PI567631	Luan chuan bai neng dou	IV	Henan	13.99
19	PI567638	Min quan wan dou yuan	IV	Henan	22.14
20	PI567639	Min quan yuan dan li	IV	Henan	14.25
21	PI567643	Nei huang niu mao huang	IV	Henan	16.72
22	PI567646A	Pu yang tie jiao huang	IV	Henan	16.22
23	PI567646B	Pu yang tie jiao huang	IV	Henan	20.73
24	PI567650A	Ru nan huang mao dou	IV	Henan	12.46
25	PI567650C	Ru nan huang mao dou	IV	Henan	14.02
26	PI567652	Shang cai qi yue ban	IV	Henan	9.24
27	PI567654	Shang qiu bai hua cao	IV	Henan	8.05
28	PI567655	Shang qiu tie jiao huang	IV	Henan	14.75
29	PI567658	Tang yin bai hua cao huang dou	IV	Henan	21.65
30	PI567660A	Tong xu xiao zi huang	IV	Henan	12.01
31	PI567660B	Tong xu xiao zi huang	IV	Henan	13.64
32	PI567661A	Wei shi hong mao huang dou	IV	Henan	11.49
33	PI567667A	Xia yi zi hua jiao	IV	Henan	16.22
34	PI567667B	Xia yi zi hua jiao	IV	Henan	22.21
35	PI567669	Xin an huang dou	IV	Henan	13.93
36	PI567673B	Yu cheng da zi tie jiao huang	IV	Henan	9.81
37	PI567674	Yu cheng xiao tie jiao huang	IV	Henan	8.83
38	PI567676A	Yu xian da zi huang	IV	Henan	18.20
39	PI567677	Yu xian huang dou	IV	Henan	12.74
40	PI567684A	Zheng zhou zao shu xiao zi huang	IV	Henan	10.80

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
41	PI567684B	Zheng zhou zao shu xiao zi huang	IV	Henan	10.34
42	PI567687	Fu yang 4	IV	Anhui	9.31
43	PI567698B	Fu yang 17	IV	Anhui	17.54
44	PI567701	Fu yang 20	IV	Anhui	14.95
45	PI567704	Fu yang 23	IV	Anhui	10.08
46	PI567707	Fu yang 26	IV	Anhui	12.35
47	PI567713B	Fu yang 36	IV	Anhui	19.21
48	PI567713D	Fu yang 36	IV	Anhui	19.78
49	PI567713E	Fu yang 36	IV	Anhui	22.27
50	PI567726	Fu yang 50	IV	Anhui	7.97
51	PI567739A	Feng xian sun lou mei guo qing	IV	Jiangsu	15.28
52	PI567739B	Feng xian sun lou mei guo qing	IV	Jiangsu	13.59
53	PI567743	Gan yu zhe wang da hong mao chun dou	IV	Jiangsu	16.02
54	PI567745	Pei xian cheng guan tian e dan	IV	Jiangsu	12.18
55	PI567747	Pei xian da bai pi jia	IV	Jiangsu	13.69
56	PI567750	Pei xian da ping ding huang	IV	Jiangsu	22.86
57	PI567751A	Pei xian hong mao you	IV	Jiangsu	17.64
58	PI567751B	Pei xian hong mao you	IV	Jiangsu	18.37
59	PI567753C	Pei xian liu yue xian	IV	Jiangsu	17.91
60	PI567755B	Pei xian ping ding huang yi	IV	Jiangsu	15.63
61	PI567757	Pei xian tie jiao huang	IV	Jiangsu	14.45
62	PI567758	Pei xian tu shan da ping ding huang	IV	Jiangsu	14.94
63	PI567760	Pei xian xiao bai pi	IV	Jiangsu	21.05
64	PI567762A	Pei xian xiao huang ke	IV	Jiangsu	14.40
65	PI567765D	Sui ning da si li yi	IV	Jiangsu	14.64
66	PI567767B	Tong shan da bai pi	IV	Jiangsu	19.24
67	PI567771C	Tong shan da wu bai jian ke	IV	Jiangsu	16.75
68	PI567771D	Tong shan da wu bai jian ke	IV	Jiangsu	12.97
69	PI567772	Tong shan hong mao you	IV	Jiangsu	10.72
70	PI567775B	Tong shan niu mao huang	IV	Jiangsu	14.47
71	PI567777	Tong shan wan dou yuan	IV	Jiangsu	11.73
72	PI567779A	Tong shan xiao hong mao	IV	Jiangsu	16.33
73	PI567780B	Tong shan zheng ji dou	IV	Jiangsu	10.32
74	PI578490	He nan zao feng No. 1	IV	Henan	10.24
75	PI587620B	Wu jiang ba yue niu mao huang	IV	Jiangsu	12.57
76	PI592949	Yu dou No. 8	IV	Henan	17.58
77	PI594393	Shui niu pi	IV	Anhui	14.68
78	PI603498A	Lao shu pi	IV	Shaanxi	17.75
79	PI594398B	87-32	IV	Anhui	16.69
80	PI594399C	85-23-9	IV	Anhui	16.03

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
81	PI594406	25-1	IV	Anhui	22.14
82	PI594409A	86-8-39	IV	Anhui	15.61
83	PI594410	Liu yue zha	IV	Anhui	21.02
84	PI594413	Ba yue bai	IV	Anhui	18.57
85	PI594586A	Bao jing niu mao huang jia	IV	Hunan	14.10
86	PI594647A	Wu zui zao dou No. 3	IV	Guizhou	12.29
87	PI594647B	Wu zui zao dou No. 3	IV	Guizhou	8.68
88	PI594664	E shui zao No. 2	IV	Guizhou	14.93
89	PI594682B	Liu yue ba	IV	Guizhou	11.87
90	PI602500A	Tong shan tian er dan	IV	Jiangsu	19.84
91	PI602501	Tong shan tian er dan	IV	Jiangsu	14.48
92	PI602992	Qin yang shui dou	IV	Henan	13.83
93	PI594398A	87-32	IV	Anhui	12.27
94	PI603498B	Lao shu pi	IV	Shaanxi	15.09
95	PI603502C	Da hei dou	IV	Shaanxi	14.05
96	PI603505	Da dou	IV	Shaanxi	7.12
97	PI603511A	Wan dou huang	IV	Shaanxi	12.98
98	PI603511B	Wan dou huang	IV	Shaanxi	14.71
99	PI603527A	Hei liao dou	IV	Shaanxi	5.93
100	PI603531A	Zao jiao hu mian dou zi	IV	Shaanxi	13.13
101	PI603636	Chi huang dou No. 2	IV	Hubei	-
102	PI603673G	Dong hai bai ta me jia cao	IV	Jiangsu	18.22
103	PI603678B	Feng xian xiao huang dou	IV	Jiangsu	10.88
104	PI603691	Su qian hong mao zi	IV	Jiangsu	15.09
105	PI603706B	Huang dou	IV	Jiangxi	13.29
106	PI103079	Shang tsai	V	Henan	8.82
107	PI171430		V	Henan	12.45
108	PI179825	Paoting	V	Hubei	20.64
109	PI464933	Su xie No. 1	V	Jiangsu	16.15
110	PI561378	Guanyun da hei dun	V	Jiangsu	22.77
111	PI567379A	Bai gun dou	V	Shaanxi	16.35
112	PI567383	Da ke huang dou	V	Shaanxi	20.17
113	PI567396C	Lao shu pi	V	Shaanxi	14.31
114	PI567396D	Lao shu pi	V	Shaanxi	17.86
115	PI567413	Yi wo feng	V	Shaanxi	6.64
116	PI567629B	Lu yi xiao zi huang	V	Henan	14.00
117	PI567634	Mi yang niu mao huang	V	Henan	13.23
118	PI567650D	Ru nan huang mao dou	V	Henan	14.76
119	PI567657	Tang he huang dou	V	Henan	14.05
120	PI567736	Dong hai bai ta me jia cao	V	Jiangsu	19.82

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight grams/100 seeds
121	PI567755C	Pei xian ping ding huang yi	V	Jiangsu	18.26
122	PI567764	Sui ning da qing dou yi	V	Jiangsu	27.65
123	PI567766	Sui ning jian ding chun da qing dou	V	Jiangsu	25.49
124	PI567779C	Tong shan xiao hong mao	V	Jiangsu	17.67
125	PI578488A	Feng xian sui dao huang	V	Jiangsu	20.85
126	PI578491A	Hua xian da lu dou	V	Henan	29.91
127	PI587577A	Wu jiang wu yue niu mao huang	V	Jiangsu	14.59
128	PI587577B	Wu jiang wu yue niu mao huang	V	Jiangsu	13.13
129	PI587577C	Wu jiang wu yue niu mao huang	V	Jiangsu	13.66
130	PI587577D	Wu jiang wu yue niu mao huang	V	Jiangsu	17.84
131	PI587577E	Wu jiang wu yue niu mao huang	V	Jiangsu	19.50
132	PI587577F	Wu jiang wu yue niu mao huang	V	Jiangsu	10.62
133	PI587577G	Wu jiang wu yue niu mao huang	V	Jiangsu	21.28
134	PI587585A	Kan jiang qiu dao huang jia	V	Jiangsu	16.37
135	PI587585C	Kan jiang qiu dao huang jia	V	Jiangsu	16.42
136	PI587585D	Kan jiang qiu dao huang jia	V	Jiangsu	17.92
137	PI587588B	Tai xing niu mao huang yi	V	Jiangsu	14.85
138	PI587589	Tai xing guo yi No. 1	V	Jiangsu	10.91
139	PI587598A	Ru gao xiao mang dou er	V	Jiangsu	17.70
140	PI587600C	Ru gao xiao huang dou	V	Jiangsu	17.63
141	PI587606B	Nan tong huang you guo zi	V	Jiangsu	12.78
142	PI587612A	Ru dong ba yue bai jia	V	Jiangsu	16.98
143	PI587608B	Hai men jie jie si	V	Jiangsu	18.73
144	PI587619	Yi xing zao huang dou	V	Jiangsu	19.61
145	PI587639	Dan tu he dou	V	Jiangsu	21.78
146	PI587642A	Ru dong zao jia hong	V	Jiangsu	21.90
147	PI587643A	Nan tong hong pi xiang zi dou	V	Jiangsu	24.99
148	PI587643B	Nan tong hong pi xiang zi dou	V	Jiangsu	27.32
149	PI587645	Nan tong jiang you dou	V	Jiangsu	22.81
150	PI587646	Nan tong zong se dou	V	Jiangsu	22.53
151	PI587647B	Nan tong zhuang yang dou	V	Jiangsu	22.00
152	PI587648	Nan tong niu kou hong	V	Jiangsu	21.04
153	PI587649	Hai men po pi feng jia	V	Jiangsu	20.66
154	PI587650	Hai men hong huang dou jia	V	Jiangsu	23.87
155	PI587651	Hai men hong huang dou yi	V	Jiangsu	21.37
156	PI587667	Dau huang dou	V	Anhui	20.19
157	PI587696	Mi feng qiu	V	Anhui	13.76
158	PI587712A	E dou No. 1	V	Hubei	13.92
159	PI587713	You 70-23	V	Hubei	15.13
160	PI587714A	Jing 802	V	Hubei	11.72

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
161	PI587714B	Jing 802	V	Hubei	9.54
162	PI587716C	Tain men da zi huang	V	Hubei	17.83
163	PI587722	Gu cheng yi shu hou	V	Hubei	12.32
164	PI587728	Ji mu dou dan zhu	V	Hubei	10.78
165	PI587734	Song zi yang huang dou	V	Hubei	12.96
166	PI587752	Xian ning dong huang dou jia	V	Hubei	16.39
167	PI587753B	Xian ning dong huang dou yi	V	Hubei	14.27
168	PI587773	Tian men xiao gan dou	V	Hubei	6.06
169	PI587788A	Nan zhang hei huang dou	V	Hubei	17.15
170	PI587805	Tong shan san ji huang pi dou	V	Hubei	6.93
171	PI587814A	Ba yue dou	V	Hubei	15.92
172	PI587814B	Ba yue dou	V	Hubei	17.84
173	PI587820A	En shi ji dan huang	V	Hubei	17.89
174	PI587820B	En shi ji dan huang	V	Hubei	11.60
175	PI587836	Tong shan qi yue huang	V	Hubei	15.15
176	PI587846A	An lu hong huang dou No. 2	V	Hubei	17.72
177	PI587848	Wu chang hei dong dou	V	Hubei	26.39
178	PI592914	1138-2	V	Jiangsu	18.90
179	PI594392	Wu he qi tou huang	V	Anhui	11.39
180	PI594397B	87-74	V	Anhui	19.81
181	PI594400	87-10	V	Anhui	17.83
182	PI594418A	Ye xi xiao li huang	V	Anhui	12.48
183	PI594418C	Ye xi xiao li huang	V	Anhui	12.47
184	PI594421	Da du huang dou	V	Anhui	20.64
185	PI594428	Bai hua qing	V	Anhui	22.83
186	PI594430D	Guang qian qing dou	V	Anhui	12.95
187	PI594431	Chang pu qing dou	V	Anhui	12.47
188	PI594432	Zheng nong wan qing dou	V	Anhui	14.91
189	PI594568A	Ba yue huang	V	Jiangxi	16.94
190	PI594568B	Ba yue huang	V	Jiangxi	15.00
191	PI594579	Zhong he tian cheng dou	V	Hunan	14.97
192	PI594595	Ba yue da huang dou jia	V	Hunan	19.22
193	PI594602	Bao jing cha huang dou	V	Hunan	19.08
194	PI594605B	Qi yue dou	V	Guizhou	14.26
195	PI594623	Da hei dou	V	Guizhou	18.12
196	PI594627A	Xia kou bai shui dou No. 1	V	Guizhou	10.60
197	PI594643	Ba yue huang No. 4	V	Guizhou	8.64
198	PI594653	Mi dou No. 2	V	Guizhou	10.38
199	PI594656	Liu yue dou No. 2	V	Guizhou	8.31
200	PI594657	Liu yue dou No. 3	V	Guizhou	6.91

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
201	PI594659A	Liu yue ba No. 1	V	Guizhou	11.54
202	PI594660C	Liu yue dou No. 1	V	Guizhou	9.73
203	PI594660D	Liu yue dou No. 1	V	Guizhou	10.40
204	PI594665	Liu yue mang No. 3	V	Guizhou	9.50
205	PI594667	Jiang kou huang dou No. 4	V	Guizhou	13.73
206	PI594671	Liu yue mang No. 2	V	Guizhou	11.46
207	PI594675	Huang dou No. 1	V	Guizhou	12.55
208	PI594677	Huang dou No. 7	V	Guizhou	10.51
209	PI594678	Huang dou No. 1	V	Guizhou	9.91
210	PI594679	Huang dou No. 3	V	Guizhou	14.04
211	PI594680	Huang dou No. 2	V	Guizhou	8.80
212	PI594681	Huang dou	V	Guizhou	9.23
213	PI594683A	Liu yue ba No. 10	V	Guizhou	6.48
214	PI594683B	Liu yue ba No. 10	V	Guizhou	9.94
215	PI594698	Huang dou 13	V	Guizhou	12.22
216	PI594700A	Qing huang za dou No. 7	V	Guizhou	12.63
217	PI594702	Liu yue bao No. 6	V	Guizhou	12.93
218	PI594704	Qing pi dou No. 2	V	Guizhou	10.97
219	PI594705	Qing pi dou No. 3	V	Guizhou	10.84
220	PI594706	Qing pi dou	V	Guizhou	13.02
221	PI594711A	Qing huang za dou No. 3	V	Guizhou	12.07
222	PI594711B	Qing huang za dou No. 3	V	Guizhou	10.87
223	PI594719	Bai zhi dou	V	Guangxi	8.67
224	PI594776	Bai ri dou	V	Yunnan	23.44
225	PI594792B	Xiao lu dou	V	Yunnan	20.31
226	PI594806	Gao jiao huang dou	V	Yunnan	18.79
227	PI594829	Lu dou	V	Yunnan	17.23
228	PI594858A	Huang pi dou zi	V	Yunnan	9.17
229	PI594858B	Huang pi dou zi	V	Yunnan	10.94
230	PI594864	Yang yan dou	V	Yunnan	24.12
231	PI597470	Nan nong 73-935	V	Jiangsu	13.84
232	PI597473	82-24	V	Hubei	12.07
233	PI599508		V	Yunnan	21.44
234	PI603178		V	Yunnan	15.94
235	PI603507	Bai dou	V	Shaanxi	17.72
236	PI603508	Bai hei dou	V	Shaanxi	8.00
237	PI603530C	An hui dou	V	Shaanxi	25.29
238	PI603609	Pu qi huang se dou	V	Hubei	9.28
239	PI603616	69-4	V	Hubei	14.86
240	PI603624	Liu yue bao	V	Hubei	13.39

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
241	PI603635	Zao niu mao huang	V	Hubei	16.15
242	PI603637A	Qing pi cao huang dou	V	Hubei	12.66
243	PI603638	Lu pi dou	V	Hubei	16.67
244	PI603677A	Sui ning huang xu da dou	V	Jiangsu	29.39
245	PI603677B	Sui ning huang xu da dou	V	Jiangsu	32.09
246	PI603681A	Pei xian xiao bai pi	V	Jiangsu	23.32
247	PI603681B	Pei xian xiao bai pi	V	Jiangsu	22.31
248	PI561379B	Sudoi No. 1	VI	Jiangsu	19.25
249	PI587550B	Nan jing da dai dou yi	VI	Jiangsu	13.42
250	PI587550C	Nan jing da dai dou yi	VI	Jiangsu	16.59
251	PI587557B	Li shui zhong zi huang do yi	VI	Jiangsu	19.27
252	PI587558A	Ju rong ziao zi huang	VI	Jiangsu	12.26
253	PI587563B	Dan yang huang xiang dou yi	VI	Jiangsu	18.54
254	PI587564A	Dan yang san san er	VI	Jiangsu	19.22
255	PI587564B	Dan yang san san er	VI	Jiangsu	10.07
256	PI587570A	Li yang dan yang zao No. 1	VI	Jiangsu	20.64
257	PI587570B	Li yang dan yang zao No. 1	VI	Jiangsu	18.32
258	PI587571	Li yang zao shi ri	VI	Jiangsu	21.93
259	PI587572A	Yi xing zhong ji huang dou yi	VI	Jiangsu	14.34
260	PI587572B	Yi xing zhong ji huang dou yi	VI	Jiangsu	15.42
261	PI587577I	Wu jiang wu yue niu mao huang	VI	Jiangsu	14.79
262	PI587581	Tai cang huang mao dou jia	VI	Jiangsu	22.51
263	PI587583B	Jiang pu huang da dou yi	VI	Jiangsu	18.17
264	PI587584	Yi zheng da li huang dou	VI	Jiangsu	16.78
265	PI587595B	Bao ying deng xi feng ding	VI	Jiangsu	20.85
266	PI587595C	Bao ying deng xi feng ding	VI	Jiangsu	16.91
267	PI587596A	Hai an wu zui dou jia No. 2	VI	Jiangsu	18.75
268	PI587597B	Hai an ci yu dou No. 1	VI	Jiangsu	10.76
269	PI587601A	Ru gao ba yue bai jia	VI	Jiangsu	17.77
270	PI587601B	Ru gao ba yue bai jia	VI	Jiangsu	19.53
271	PI587601C	Ru gao ba yue bai jia	VI	Jiangsu	13.92
272	PI587603A	Nan tong ai jiao huang	VI	Jiangsu	14.47
273	PI587603C	Nan tong ai jiao huang	VI	Jiangsu	16.76
274	PI587603D	Nan tong ai jiao huang	VI	Jiangsu	12.09
275	PI587606C	Nan tong huang you guo zi	VI	Jiangsu	9.35
276	PI587608C	Hai men jie jie si	VI	Jiangsu	19.19
277	PI587612D	Ru dong ba yue bai jia	VI	Jiangsu	14.36
278	PI587614	Ru dong xiao huang ke	VI	Jiangsu	13.44
279	PI587618A	Li yang ba yue huang yi	VI	Jiangsu	15.72
280	PI587627A	Hai men guan qing dou	VI	Jiangsu	20.36

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
281	PI587638	Ru dong hei wan huang dou	VI	Jiangsu	23.08
282	PI587659A	Qing dou zi	VI	Anhui	19.05
283	PI587659B	Qing dou zi	VI	Anhui	19.73
284	PI587664A	Shan zi bai	VI	Anhui	16.32
285	PI587664B	Shan zi bai	VI	Anhui	11.52
286	PI587666	Er dao zao	VI	Anhui	18.83
287	PI587668B	Hui mei dou	VI	Anhui	17.63
288	PI587669	Zan zi bai	VI	Anhui	16.54
289	PI587670A	Liu yue bao	VI	Anhui	12.21
290	PI587673	Ke ban jin	VI	Anhui	15.71
291	PI587676	Qing ke dou	VI	Anhui	18.02
292	PI587679	Da li dou	VI	Anhui	15.51
293	PI587683	Hua mi yan	VI	Anhui	19.00
294	PI587684A	Ai jiao huang	VI	Anhui	17.55
295	PI587684B	Ai jiao huang	VI	Anhui	16.71
296	PI587686A	Xi li huang No. 1	VI	Anhui	20.26
297	PI587686B	Xi li huang No. 1	VI	Anhui	20.32
298	PI587689	Xiao li huang	VI	Anhui	15.63
299	PI587693	Yu shan dou	VI	Anhui	24.53
300	PI587697	Da qing dou	VI	Anhui	20.57
301	PI587698A	Qing pi	VI	Anhui	10.36
302	PI587702	Qing pi dou	VI	Anhui	18.59
303	PI587704	Qing pi dou	VI	Anhui	22.40
304	PI587705B	Qing pi dou	VI	Anhui	14.38
305	PI587719C	Xi shui xiao dou	VI	Hubei	7.77
306	PI587721A	Gu cheng huang dou	VI	Hubei	8.84
307	PI587721B	Gu cheng huang dou	VI	Hubei	10.27
308	PI587721C	Gu cheng huang dou	VI	Hubei	10.61
309	PI587723A	Gu cheng mian yang wei	VI	Hubei	9.05
310	PI587727	Song zi ci yi zi	VI	Hubei	12.25
311	PI587732	Ying shan ji mu wo	VI	Hubei	10.96
312	PI587733	Da wu ai jiao huang	VI	Hubei	13.89
313	PI587736A	Jing zhou dong huang dou	VI	Hubei	11.32
314	PI587736B	Jing zhou dong huang dou	VI	Hubei	9.96
315	PI587737	Da wu huang se dou	VI	Hubei	10.17
316	PI587738	Jing huang 22	VI	Hubei	12.46
317	PI587740	Jing huang No. 7	VI	Hubei	13.89
318	PI587742A	An lu hong huang dou	VI	Hubei	12.96
319	PI587742C	An lu hong huang dou	VI	Hubei	15.48
320	PI587743	An lu niu pi huang dou	VI	Hubei	18.96

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
321	PI587742B	An lu hong huang dou	VI	Hubei	8.86
322	PI587749	Jing shan niu mao huang	VI	Hubei	13.39
323	PI587755	Yi chang ba yue huang	VI	Hubei	17.83
324	PI587757B	Han chuan wu lu bai	VI	Hubei	14.83
325	PI587761	Ying shan tian e dan	VI	Hubei	17.20
326	PI587764	Han chuan wu lu bai	VI	Hubei	13.83
327	PI587766	Jing 398	VI	Hubei	16.64
328	PI587768	Tong shan da huang dou	VI	Hubei	13.38
329	PI587769	Wu chang zhu po dou	VI	Hubei	12.78
330	PI587774	Xiao gan dou	VI	Hubei	14.77
331	PI587788B	Nan zhang hei huang dou	VI	Hubei	12.42
332	PI587797	Yang xin hei da dou	VI	Hubei	8.89
333	PI587800	Ying shan da li huang	VI	Hubei	17.94
334	PI587806B	Wu ming 24 yi	VI	Hubei	18.52
335	PI587813	Yi duo yun	VI	Hubei	16.32
336	PI587814C	Ba yue dou	VI	Hubei	19.92
337	PI587814G	Ba yue dou	VI	Hubei	14.63
338	PI587814F	Ba yue dou	VI	Hubei	15.57
339	PI587815B	Hong mao za dou	VI	Hubei	17.84
340	PI587817	Wu lu bai	VI	Hubei	16.02
341	PI587823	Jing shan qing da dou	VI	Hubei	18.38
342	PI587825B	E huang 13	VI	Hubei	11.76
343	PI587826	Da wu qing pi dou No. 2	VI	Hubei	15.95
344	PI587835	Huang dou	VI	Hubei	11.95
345	PI587839A	Han chuan fen qing huang dou	VI	Hubei	17.08
346	PI587839B	Han chuan fen qing huang dou	VI	Hubei	15.95
347	PI587839C	Han chuan fen qing huang dou	VI	Hubei	15.55
348	PI587841A	Shan zi bai	VI	Hubei	7.17
349	PI587841B	Shan zi bai	VI	Hubei	11.21
350	PI587844A	Tong cheng hei se dou	VI	Hubei	18.68
351	PI587844B	Tong cheng hei se dou	VI	Hubei	17.32
352	PI587846B	An lu hong huang dou No. 2	VI	Hubei	16.18
353	PI587847	Tong shan niu gan dou	VI	Hubei	15.24
354	PI594418E	Ye xi xiao li huang	VI	Anhui	10.72
355	PI603517A	Lao shu pi	VI	Shaanxi	16.58
356	PI603522	Gao gan qing	VI	Shaanxi	19.54
357	PI603539A	Huang dou	VI	Shaanxi	11.82
358	PI603539B	Huang dou	VI	Shaanxi	12.81
359	PI603539C	Huang dou	VI	Shaanxi	14.96
360	PI603611B	Wu feng shai lu qing	VI	Hubei	18.44
361	PI603617	65-391	VI	Hubei	11.40
362	PI603618	Tian e dan No. 2	VI	Hubei	10.92
363	PI603702A	73-2	VI	Jiangsu	15.31
364	PI603702B	73-2	VI	Jiangsu	13.49

Table 2.6. Cont'd

No.	PI Number	Cultivar	MG	State	Seed Weight (grams/100 seeds)
365	PI071564	-	VII	Jiangsu	13.52
366	PI171446	-	VII	Jiangsu	13.22
367	PI518722	Nan nong 493-1	VII	Jiangsu	15.08
368	PI567391	Jiang se huang dou	VII	Shaanxi	21.83
369	PI567410B	(Yang huang dou)	VII	Shaanxi	13.91
370	PI567410C	(Yang huang dou)	VII	Shaanxi	15.53
371	PI587557A	Li shui zhong zi huang do yi	VII	Jiangsu	12.80
372	PI587563A	Dan yang huang xiang dou yi	VII	Jiangsu	16.04
373	PI587563C	(Dan yang huang xiang dou yi)	VII	Jiangsu	19.04
374	PI587565A	Dan yang da zi xi dou jia	VII	Jiangsu	16.75
375	PI587567B	(Li yang su huang dou yi)	VII	Jiangsu	28.92
376	PI587573A	Yi xing zhong zi dou yi	VII	Jiangsu	13.74
377	PI587573B	(Yi xing zhong zi dou yi)	VII	Jiangsu	15.63
378	PI587574A	Wu jin bai hua dou	VII	Jiangsu	20.80
379	PI587583D	(Jiang pu huang da dou yi)	VII	Jiangsu	18.49
380	PI587603B	(Nan tong ai jiao huang)	VII	Jiangsu	13.61
381	PI587622B	(Liu he lu dou No. 2)	VII	Jiangsu	17.35
382	PI587654	Tai xing ma que dou	VII	Jiangsu	19.83
383	PI587662B	(Mi feng qiu)	VII	Anhui	13.60
384	PI587680	Gao jiao huang	VII	Anhui	16.75
385	PI587682B	(Da li huang No. 1)	VII	Anhui	18.31
386	PI587687E	(Xiao li dou No. 1)	VII	Anhui	16.49
387	PI587691	Hou zi mao	VII	Anhui	16.94
388	PI587692B	(Pi wai qing)	VII	Anhui	21.38
389	PI587695	Dong huang dou	VII	Anhui	25.16
390	PI587699	Qing dou	VII	Anhui	18.73
391	PI587701	Qing dou	VII	Anhui	21.19
392	PI587731	Yun meng hua ye dou	VII	Hubei	13.97
393	PI587759	Song zi ba yue cha	VII	Hubei	17.04
394	PI587760	Dang yang xiao li dou	VII	Hubei	19.36
395	PI587762	Wu ming 22	VII	Hubei	15.58
396	PI587763	Jing huang 36	VII	Hubei	15.03
397	PI587767A	Yun meng bai mao huang dou	VII	Hubei	14.97
398	PI587790B	(Mian yang huang feng wo)	VII	Hubei	17.21
399	PI587791	Mian yang ya dong bai	VII	Hubei	18.47
400	PI587815A	Hong mao za dou	VII	Hubei	17.10
401	PI587829	E huang No. 9	VII	Hubei	8.93
402	PI587831	Yun an qing huang dou	VII	Hubei	7.65
403	PI587833	Jing men shu hou zi	VII	Hubei	13.97
404	PI587834	Yun an qing pi dou	VII	Hubei	7.47
405	PI587838	Mian yang ji mu dun	VII	Hubei	17.21
406	PI587843		VII	Hubei	19.70
407	PI587844C	(Tong cheng hei se dou)	VII	Hubei	18.08

Table 2.7. List of 208 soybean lines of the Brazilian accessions

No.	PI Number	Cultivar	MG	Sub-collection	Seed Weight (grams/100 seeds)
1	PI 628799	BR-2 (Vagem clara)	V	12S-2118	10.32
2	PI 628821	FT-Cometa	V	12S-2119	13.59
3	PI 628854	IAS-2	V	12S-2120	16.39
4	PI 628878	Pampeira	V	12S-2121	15.28
5	PI 628879	Parana	V	12S-2122	15.12
6	PI 628880	Paranagoiana	V	12S-2123	13.91
7	PI 628910	BR-23	V	12S-2124	17.44
8	PI 628964	Tropical OT	V	12S-2125	13.81
9	PI 417503	Pioneira	VI	09S-3838	15.27
10	PI 628801	BR-4	VI	12S-2262	17.41
11	PI 628802	BR-5	VI	12S-2263	15.66
12	PI 628803	BR-7	VI	12S-2264	14.27
13	PI 628804	BR-8 (Pelotas)	VI	12S-2265	13.12
14	PI 628807	BR-13 (Maravilha)	VI	12S-2266	16.05
15	PI 628809	BR-16	VI	12S-2267	16.20
16	PI 628812	MG/BR-46 (Conquista)	VI	12S-2268	13.45
17	PI 628814	Campos Gerais	VI	12S-2269	14.13
18	PI 628816	CEP 12 (Cambara)	VI	12S-2270	14.32
19	PI 628817	CEP 16 (Timbo)	VI	12S-2271	15.20
20	PI 628819	Coker 136	VI	12S-2272	15.28
21	PI 628820	Decada	VI	12S-2273	13.55
22	PI 628828	FT-9 (Inae)	VI	12S-2274	15.05
23	PI 628831	FT-13 (Alianca)	VI	12S-2275	14.74
24	PI 628837	FT-20 (Jao)	VI	12S-2276	15.33
25	PI 628839	FT-Eureka	VI	12S-2277	11.30
26	PI 628840	FT-Guaira	VI	12S-2278	17.88
27	PI 628841	FT-Manaca	VI	12S-2279	16.24
28	PI 628846	IAC-11	VI	12S-2280	11.13
29	PI 628852	Ipagro-21	VI	12S-2281	17.41
30	PI 628856	IAS-5	VI	12S-2281	13.86
31	PI 628858	Invicta	VI	12S-2283	15.17
32	PI 628860	Ivora	VI	12S-2284	14.65
33	PI 628862	Lancer	VI	12S-2285	16.13
34	PI 628867	Ocepar-3 (Primavera)	VI	12S-2286	18.82
35	PI 628868	Ocepar-4 (Iguacu)	VI	12S-2287	16.87
36	PI 628869	Ocepar-5 (Piquiri)	VI	12S-2288	15.71
37	PI 628871	Ocepar-8	VI	12S-2289	14.21
38	PI 628872	Ocepar-9=SS1	VI	12S-2290	14.59
39	PI 628873	Ocepar-10	VI	12S-2291	13.28
40	PI 628874	Ocepar-11	VI	12S-2292	14.95

Table. 2.7. Cont'd

No.	PI Number	Cultivar	MG	Sub-collection	Seed Weight (grams/100 seeds)
41	PI 628876	Ocepar-14	VI	12S-2293	11.57
42	PI 628877	Ocepar-18	VI	12S-2294	15.11
43	PI 628881	Paranaiba	VI	12S-2295	14.81
44	PI 628882	Perola	VI	12S-2296	14.30
45	PI 628883	Planalto	VI	12S-2297	16.66
46	PI 628884	Prata	VI	12S-2298	12.38
47	PI 628892	Sertaneja	VI	12S-2299	16.63
48	PI 628900	IPB-90-77	VI	12S-2300	15.47
49	PI 628901	IPB 204-77	VI	12S-2301	13.95
50	PI 628909	MG BR-22 (Garimpo)	VI	12S-2302	13.77
51	PI 628911	BR-24	VI	12S-2303	16.98
52	PI 628912	BR-29 (Londrina)	VI	12S-2304	14.57
53	PI 628917	BR-37	VI	12S-2305	12.56
54	PI 628920	CEP-20 (Guajuvira)	VI	12S-2308	12.67
55	PI 628923	Embrapa-1 (IAS-5 RC)	VI	12S-2309	15.57
56	PI 628924	Embrapa-4 (BR-4 RC)	VI	12S-2310	20.64
57	PI 628926	Emgopa-302	VI	12S-2311	14.39
58	PI 628931	FT-1	VI	12S-2312	12.17
59	PI 628949	Ipagro-20	VI	12S-2313	14.52
60	PI 628952	Ocepar-17	VI	12S-2314	12.72
61	PI 628953	Ocepar-20	VI	12S-2315	17.08
62	PI 417496	3802	VII	04S-1544	13.24
63	PI 417497	3837	VII	04S-1545	14.21
64	PI 518756	Centenaria	VII	04S-1673	8.39
65	PI 628806	BR-12	VII	12S-2419	17.13
66	PI 628815	CEP 10	VII	12S-2420	15.25
67	PI 628829	FT-10 (Princesa)	VII	12S-2421	13.87
68	PI 628830	FT-12 (Nissei)	VII	12S-2422	12.42
69	PI 628835	FT-17 (Bandeirantes)	VII	12S-2423	14.47
70	PI 628836	FT-18 (Xavante)	VII	12S-2424	17.49
71	PI 628838	FT-Abyara	VII	12S-2425	13.52
72	PI 628844	IAC-5	VII	12S-2426	12.79
73	PI 628845	IAC-10	VII	12S-2427	11.66
74	PI 628847	IAC-12	VII	12S-2428	10.50
75	PI 628848 A	IAC-13	VII	12S-2429	15.33
76	PI 628848 B	(IAC-13)	VII	12S-2430	11.98
77	PI 628848 C	(IAC-13)	VII	12S-2431	14.08
78	PI 628849	IAC-14	VII	12S-2432	13.88
79	PI 628850	IAC-100	VII	04S-144	8.56
80	PI 628851	IAC-Foscarin 31	VII	12S-2434	14.64

Table 2.7. Cont'd

No.	PI Number	Cultivar	MG	Sub-collection	Seed Weight (grams/100 seeds)
81	PI 628853	IAS-1	VII	12S-2435	16.24
82	PI 628855	IAS-4	VII	12S-2438	13.51
83	PI 628865	Missoes	VII	10S-2052	15.64
84	PI 628866	Ocepar-2 (lapo)	VII	12S-2440	15.07
85	PI 628870	Ocepar-6	VII	12S-2441	14.43
86	PI 628875	Ocepar-13	VII	12S-2442	13.76
87	PI 628885	RS-5 (Esmeralda)	VII	12S-2443	13.46
88	PI 628886	RS-6 (Guassupi)	VII	12S-2444	15.96
89	PI 628887	RS-7 (Jacui)	VII	12S-2445	19.90
90	PI 628888	Sant' Ana	VII	12S-2446	17.21
91	PI 628890	Sao Carlos	VII	12S-2447	15.12
92	PI 628893	Sulina	VII	12S-2448	18.46
93	PI 628898	Uniao	VII	12S-2449	14.77
94	PI 628908	MS BR-21 (Buriti)	VII	12S-2450	13.79
95	PI 628913	BR-30	VII	12S-2451	13.87
96	PI 628914	BA BR-13	VII	08S-1316	8.88
97	PI 628915	MS BR-34 (Empaer 10)	VII	10S-6586	9.12
98	PI 628916	BR-36	VII	08S-1317	12.86
99	PI 628918	BR-38	VII	12S-2455	13.53
100	PI 628928	Emgopa-304 (Campeira)	VII	12S-2456	13.32
101	PI 628932	FT-2	VII	12S-2457	13.71
102	PI 628936	FT-Estrela	VII	12S-2458	12.81
103	PI 628938	FT-Canarana	VII	12S-2459	9.81
104	PI 628945	IAC-7	VII	09S-5358	11.91
105	PI 628948	IAC-17	VII	12S-2461	14.97
106	PI 628962	Vila Rica	VII	12S-2462	14.07
107	PI 628963	La Suprema	VII	08S-1319	8.55
108	PI 628965	UFVITM-1	VII	12S-2464	13.52
109	PI 663948	Embrapa-48*	VII	12S-3023	13.24
110	PI 203398	Abura	VIII	14S-1742	13.58
111	PI 417500	Escura A	VIII	04S-1906	14.78
112	PI 417501	Kedelle Stb 26	VIII	04S-1907	7.88
113	PI 417502	L356	VIII	07S-2477	14.67
114	PI 417504	S44/55	VIII	04S-1908	11.01
115	PI 628800	BR-3	VIII	12S-2581	17.79
116	PI 628805	BR-9 (Savana)	VIII	12S-2582	11.24
117	PI 628808	BR-14 (Modelo)	VIII	12S-2583	14.82
118	PI 628810	BR-27 (Cariri)	VIII	08S-1359	14.34
119	PI 628811	MT/BR-45 (Paiaguas)	VIII	12S-2585	12.96
120	PI 628813	MG/BR-48 (Garimpo RCH)	VIII	12S-2586	15.04
121	PI 628822	FT-3	VIII	12S-2587	14.12
122	PI 628824	FT-5 (Formosa)	VIII	12S-2588	15.15
123	PI 628825	FT-6 (Veneza)	VIII	12S-2589	15.22

Table 2.7. Cont'd

No.	PI Number	Cultivar	MG	Sub-collection	Seed Weight (grams/100 seeds)
124	PI 628826	FT-7 (Taroba)	VIII	12S-2590	16.01
125	PI 628834	FT-16	VIII	12S-2591	13.60
126	PI 628842	IAC-1	VIII	12S-2592	14.75
127	PI 628843	IAC-4	VIII	12S-2593	15.01
128	PI 628857	Industrial	VIII	12S-2594	15.45
129	PI 628859	Ivai	VIII	12S-2595	14.71
130	PI 628864	Mineira	VIII	12S-2596	14.08
131	PI 628891	Sao-Luiz	VIII	12S-2597	14.79
132	PI 628894	Tiaraju	VIII	12S-2598	13.01
133	PI 628895	UFV-2	VIII	09S-5356	12.05
134	PI 628897	UFV-4	VIII	12S-2600	13.67
135	PI 628899	Vicoja	VIII	12S-2601	13.07
136	PI 628902	BR-1	VIII	12S-2602	9.19
137	PI 628906	MS BR-19 (Pequi)	VIII	12S-2603	15.05
138	PI 628919	MT/BR-50 (Parecis)	VIII	12S-2604	17.09
139	PI 628922	Dourados	VIII	14S-564	12.96
140	PI 628925	Embrapa-20 (Doko RC)	VIII	12S-2605	14.51
141	PI 628927	Emgopa-303	VIII	12S-2606	13.06
142	PI 628930	FT-Cristalina	VIII	12S-2607	11.33
143	PI 628935	FT-Seriema	VIII	12S-2608	11.13
144	PI 628937	FT-Jatoba	VIII	12S-2609	15.07
145	PI 628939	FT-Bahia	VIII	12S-2610	11.33
146	PI 628940	FT-Cristal	VIII	12S-2611	12.31
147	PI 628941	FT-Iracema	VIII	12S-2612	11.65
148	PI 628944	IAC-6	VIII	13S-1210	12.59
149	PI 628947	IAC-9	VIII	09S-5360	11.40
150	PI 628950	IAS-2 (Delta)	VIII	12S-2617	11.32
151	PI 628951	Numbaira	VIII	12S-2618	14.52
152	PI 628954	Timbira	VIII	12S-2619	10.98
153	PI 628958	UFV-7 (Juparana)	VIII	09S-5362	12.10
154	PI 628960	UFV-9 (Sucupira)	VIII	12S-2621	11.52
155	PI 628961	UFV-Araguira	VIII	12S-2622	13.44
156	PI 628966	BR-6 (Nova Bragg)	VIII	12S-2623	15.13
157	PI 644103	BRS Tiana	VIII	10S-2096	12.45
158	PI 675650	BRS 283	VIII	16CR-2	17.76
159	PI 675651	BRS 284	VIII	16CR-3	15.56
160	PI 675665	BRSMG 752S	VIII	16CR-17	18.31
161	PI 675671	BRSMG 753 C	VIII	16CR-23	23.17
162	PI 183485	Abura	IX	06CR-1015	18.68
163	PI 341252	Amerelo Giganti	IX	14CR-1029	23.34
164	PI 417498	Alianca Preta	IX	06CR-1300	41.33
165	PI 417499	Aratiba	IX	06CR-1302	13.13
166	PI 417505	S67/62	IX	06CR-1304	13.63

Table 2.7. Cont'd

No.	PI Number	Cultivar	MG	Sub-collection	Seed Weight (grams/100 seeds)
167	PI 430901		IX	11CR-2222	13.41
168	PI 483251	Cristalina	IX	03CR-339	20.58
169	PI 483252	Doko	IX	05CR-367	22.25
170	PI 483253	Tropical	IX	16CR-439	18.12
171	PI 628797	Andrews	IX	05CR-606	21.38
172	PI 628823	FT-4	IX	11CR-2444	25.48
173	PI 628827	FT-8 (Araucaria)	IX	11CR-2446	23.69
174	PI 628832	FT-14 (Piracema)	IX	11CR-2448	22.95
175	PI 628833	FT-15	IX	11CR-2451	23.58
176	PI 628861	J-200	IX	06S-3131	13.17
177	PI 628863	LC 72-749	IX	06CR-1718	21.42
178	PI 628889	Santa Rosa	IX	14CR-1216	17.45
179	PI 628896	UFV-3	IX	06CR-1720	19.39
180	PI 628903	BR-15 (Mato Grosso)	IX	05CR-612	18.22
181	PI 628904	MS BR-17 (Sao Gabriel)	IX	14CR-1219	18.30
182	PI 628905	MS BR-18 (Guavira)	IX	14CE-1220	21.82
183	PI 628907	MS BR-20 (Ipe)	IX	07CR-227	16.81
184	PI 628929	Emgopa-305 (Caraiba)	IX	14CR-1222	18.92
185	PI 628933	FT-11 (Alvorada)	IX	08CR-2072	21.55
186	PI 628934	FT-19 (Macacha)	IX	06CR-1660	19.16
187	PI 628942	FT-Maracaju	IX	12S-2613	14.93
188	PI 628943	IAC-2	IX	06CR-1626	21.81
189	PI 628946	IAC-8	IX	14CR-1226	16.46
190	PI 628957	UFV-5	IX	06CR-1630	22.06
191	PI 628959	UFV-8 (Monte Rico)	IX	05CR-620	22.92
192	PI 675667	BRS 7980	IX	16CR-19	16.26
193	PI 675668	BRS 326	IX	16CR-20	18.30
194	PI 675652	BRS Barreiras	X	16CR-4	11.50
195	PI 675653	BRS Camauba	X	16CR-5	18.66
196	PI 675654	BRSGO Chapadoes	X	16CR-6	15.75
197	PI 675655	BRS Corisco	X	16CR-7	17.95
198	PI 675656	BRS Jiripoca	X	16CR-8	19.37
199	PI 675657	BRSGO Luziana	X		-
200	PI 675659	BRSMT Pintado	X	16CR-11	20.75
201	PI 675660	BRS Sambaiba	X	16CR-12	14.40
202	PI 675661	BRS Tracaja	X	16CR-13	15.24
203	PI 675662	BRSMG 68 (Vencedora)	X	16CR-14	21.36
204	PI 675663	BRSGO 8360	X	16CR-15	-
205	PI 675664	BRS 313	X	16CR-16	16.97
206	PI 675666	BRS 361	X	16CR-18	17.84
207	PI 675669	BRS Perola	X	16CR-21	14.72
208	PI 675670	BRSGO 8660	X	16CR-22	18.44

Table 2.8. Analysis of variance for plant height for the 706 lines using PROC ANOVA procedure (SAS 9.4)

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Lines	705	55007.92	78.03	12.42	<.0001
Error	706	4433.59	6.28		
Corrected Total	1411	59441.51			

Table 2.9. Analysis of variance for plant height for 60 soybean lines tested on three different pH regimes using PROC MIXED procedure (SAS 9.4)

Source	DF	Sum of square	Mean square	F value	Pr>F
Lines	59	9066.91	153.68	62.07	<0.0001
pH	2	2301.43	1150.71	464.80	<0.0001
Lines*pH	118	4821.41	40.86	16.50	<0.0001
Error	180	445.63	445.63		
Corrected Total	359	16635.37	16635.37		

Table 2.10. Comparison of means for plant height for 55 surviving lines within the USA accessions used to select the best 20 out of 91 lines

Lines		Plant Height (cm)		
		I	II	Mean
1	PI556727	25.90	24.20	25.05 a **
2	PI556744	23.00	25.00	24.00 ab
3	PI556537	22.10	25.00	23.55 abc
4	PI556612	22.00	24.50	23.25 abc
5	PI615694	19.70	19.30	19.50 abc
6	PI556536	19.00	18.00	18.50 abc
7	PI576154	18.60	18.20	18.40 abc
8	PI590932	18.40	18.00	18.20 abc
9	PI583367	15.20	20.60	17.90 abc
10	PI548987	17.50	18.20	17.85 abc
11	PI603953	15.80	19.40	17.60 abc
12	PI556515	17.00	18.00	17.50 abc
13	PI553047	16.30	18.60	17.45 abc
14	PI584506	21.20	13.50	17.35 abc
15	PI615695	17.20	17.40	17.30 abc
16	PI556564	17.90	16.50	17.20 abc
17	PI548986	16.00	18.30	17.15 abc
18	PI556481	19.50	14.80	17.15 abc
19	PI556584	22.70	11.40	17.05 abc
20	PI594922	22.70	11.30	17.00 abc
21	PI617041	16.10	17.80	16.95 abc
22	PI561211	17.60	14.40	16.00 abc
23	PI559379	13.60	18.20	15.90 abc
24	PI647085	20.70	10.40	15.55 abc
25	PI556825	20.00	10.20	15.10 abc
26	PI556847	9.65	19.30	14.48 abc
27	PI597389	19.60	9.70	14.65 abc
28	PI548835	15.30	13.60	14.45 abc
29	PI548985	10.40	18.10	14.25 abc
30	PI642732	10.60	17.90	14.25 abc
31	PI596540	13.60	14.30	13.95 abc
32	PI556848	18.40	9.10	13.75 abc
33	PI654355	18.30	9.20	13.75 abc
34	PI614702	17.80	9.00	13.40 abc
35	PI596414	17.20	8.70	12.95 abc
36	PI619615	16.90	8.40	12.65 abc
37	PI548698	10.50	14.50	12.50 abc
38	PI556480	16.70	8.30	12.50 abc
39	PI556506	16.20	8.10	12.15 abc
40	PI508267	11.90	12.10	12.00 abc
41	PI590931	10.70	12.70	11.70 abc
42	PI556742	15.00	7.60	11.30 abc
43	PI553041	14.60	7.40	11.00 abc
44	PI555453	14.70	7.30	11.00 abc
45	PI576440	14.60	7.20	10.90 abc
46	PI536009	12.20	7.50	9.85 abc
47	PI556545	12.70	6.30	9.50 abc
48	PI572239	12.40	6.40	9.40 abc
49	PI508266	4.30	14.30	9.30 abc
50	PI511813	12.20	6.10	9.15 abc
51	PI556741	12.00	6.00	9.00 abc
52	PI548988	11.70	5.80	8.75 abc
53	PI553042	4.00	10.50	7.25 abc
54	PI531068	8.30	4.20	6.25 bc
55	PI641156	6.50	3.20	4.85 c

*** Means within columns followed by the same letter are not significantly different (LSD, P<0.05)*

Table 2.11. Comparison of means for plant height for 131 surviving lines within the Chinese accessions used to select the best 20 out of 407 lines

Lines	Plant Height (cm)					Lines	Plant Height (cm)					Lines	Plant Height (cm)			
	I	II	Mean				I	II	Mean				I	II	Mean	
PI567652	30.4	26.5	28.45	a**		PI567650D	14.0	11.6	12.80	abc		PI594602	7.9	9.5	8.70	abc
PI567684B	20.7	29.8	25.25	ab		PI567623	7.0	18.2	12.60	abc		PI594659A	7.6	9.7	8.65	abc
PI567611	18.8	27.5	23.15	abc		PI567638	8.0	17.0	12.50	abc		PI587683	11.5	5.8	8.63	abc
PI587572B	21.8	19.3	20.55	abc		PI587761	16.6	8.3	12.45	abc		PI603691	11.3	5.6	8.48	abc
PI567413	11.3	28.6	19.95	abc		PI587577A	16.5	8.2	12.38	abc		PI587606B	8.2	8.6	8.40	abc
PI587614	23.1	16.3	19.70	abc		PI587693	16.5	8.2	12.38	abc		PI587743	11.2	5.6	8.40	abc
PI594568B	17.0	21.8	19.40	abc		PI587712A	12.0	12.4	12.20	abc		PI587769	8.0	8.7	8.35	abc
PI567620B	19.2	19.5	19.35	abc		PI587800	9.2	15.1	12.15	abc		PI594595	11.1	5.6	8.33	abc
PI603637A	18.1	19.0	18.55	abc		PI594864	11.0	13.3	12.15	abc		PI587763	10.8	5.4	8.10	bc
PI587692B	16.5	20.2	18.35	abc		PI603677B	10.3	14.0	12.15	abc		PI587764	6.5	9.4	7.95	bc
PI587714A	16.4	19.5	17.95	abc		PI594660C	10.4	13.8	12.10	abc		PI594647B	9.8	4.9	7.35	bc
PI567614C	17.8	18.0	17.90	abc		PI594627A	10.1	14.0	12.05	abc		PI567780B	9.5	4.8	7.13	bc
PI567379A	17.5	18.1	17.80	abc		PI594665	12.0	12.1	12.05	abc		PI594806	8.9	4.5	6.68	bc
PI587768	14.5	21.0	17.75	abc		PI567650A	16.0	8.0	12.00	abc		PI594682B	8.6	4.3	6.45	bc
PI567410C	14.6	20.8	17.70	abc		PI567396D	10.2	13.3	11.75	abc		PI587766	5.50	7.20	6.35	bc
PI567643	17.8	17.3	17.55	abc		PI567757	15.6	7.8	11.70	abc		PI567676A	8.20	4.10	6.15	bc
PI603706B	22.4	11.2	16.80	abc		PI594679	11.2	12.1	11.65	abc		PI587622B	8.00	4.00	6.00	bc
PI567646A	12.0	20.6	16.30	abc		PI171430	15.5	7.7	11.63	abc		PI587620B	7.20	3.60	5.40	bc
PI567779A	15.3	17.2	16.25	abc		PI567698B	15.4	7.7	11.55	abc		PI603678B	7.20	3.60	5.40	bc
PI594643	15.7	17.4	16.55	abc		PI594431	15.4	7.7	11.55	abc		PI587606C	7.10	3.55	5.33	bc
PI587701	21.3	10.6	15.98	abc		PI594671	10.6	12.5	11.55	abc		PI567736	7.40	3.70	5.55	bc
PI567627B	20.4	10.2	15.30	abc		PI567612	11.5	11.5	11.50	abc		PI567630B	6.00	3.00	4.50	c
PI567684A	15.0	15.6	15.30	abc		PI179825	15.3	7.6	11.48	abc		PI567750	5.70	2.85	4.28	c
PI594667	13.1	17.2	15.15	abc		PI587571	7.4	15.4	11.40	abc		PI587618A	6.00	0.00	3.00	c
PI587684B	13.4	16.8	15.10	abc		PI587603D	9.2	13.6	11.40	abc		PI587666	6.00	0.00	3.00	c
PI567745	13.1	16.7	14.90	abc		PI594657	10.7	11.9	11.30	abc						
PI072227	11.5	18.0	14.75	abc		PI587696	8.6	13.5	11.05	abc						
PI587728	10.7	18.4	14.55	abc		PI594623	14.5	7.2	10.88	abc						
PI603681B	12.0	17.1	14.55	abc		PI603702A	14.5	7.2	10.88	abc						
PI567660B	12.0	17.0	14.50	abc		PI587760	14.4	7.3	10.80	abc						
PI567650C	22.5	6.3	14.40	abc		PI587619	8.5	12.5	10.50	abc						
PI446893	13.3	15.0	14.15	abc		PI587684A	13.5	6.7	10.13	abc						
PI567614D	18.8	9.4	14.10	abc		PI567772	11.1	9.0	10.05	abc						
PI594653	14.0	14.2	14.10	abc		PI603638	13.4	6.7	10.05	abc						
PI594432	13.5	14.6	14.05	abc		PI587659B	12.9	6.4	9.68	abc						
PI603681A	13.6	14.5	14.05	abc		PI567410B	12.8	6.4	9.60	abc						
PI603673G	18.4	9.2	13.80	abc		PI567391	12.6	6.3	9.45	abc						
PI567743	13.3	14.2	13.75	abc		PI587757B	9.2	9.5	9.35	abc						
PI567615	18.2	9.1	13.65	abc		PI587774	9.2	9.4	9.30	abc						
PI587689	18.2	9.1	13.65	abc		PI587573A	12.3	6.2	9.23	abc						
PI594681	18.2	9.1	13.65	abc		PI587813	9.2	9.2	9.20	abc						
PI103079	18.0	9.0	13.50	abc		PI567381A	12.2	6.1	9.15	abc						
PI587713	17.7	8.8	13.28	abc		PI587608B	12.1	6.1	9.08	abc						
PI567396C	11.2	15.3	13.25	abc		PI603677A	12.1	6.0	9.08	abc						
PI594680	12.2	14.3	13.25	abc		PI587767A	8.3	9.8	9.05	abc						
PI567777	17.5	8.7	13.13	abc		PI587577B	12.0	6.0	9.00	abc						
PI594430D	17.5	8.7	13.13	abc		PI594660D	5.4	12.6	9.00	abc						
PI567755B	9.0	17.0	13.00	abc		PI594647A	12.0	6.0	9.00	abc						
PI567677	15.3	10.5	12.90	abc		PI532455B	11.8	6.0	8.85	abc						
PI567753C	17.2	8.6	12.90	abc		PI587695	7.3	10.4	8.85	abc						
PI561378	8.7	17.0	12.85	abc		PI587734	7.8	9.8	8.80	abc						
PI587714B	10.1	15.6	12.85	abc		PI594656	8.5	9.0	8.75	abc						
PI594678	12.5	13.2	12.85	abc		PI587603C	11.6	5.8	8.70	abc						

*** Means within columns followed by the same letter are not significantly different (LSD, P<0.05)*

Table 2.12. Comparison of means for plant height for 155 surviving lines within the Brazilian accessions used to select the best 20 out of 208 lines

Lines	Plant Height (cm)				Lines	Plant Height (cm)				Lines	Plant Height (cm)			
	I	II	Mean			I	II	Mean			I	II	Mean	
PI 675656	17.00	15.40	16.20	a**	PI 628841	13.20	6.60	9.90	abc	PI 628865	7.10	7.00	7.05	abc
PI 675669	16.10	13.00	14.55	ab	PI 628927	13.20	6.60	9.90	abc	PI 628930	7.60	6.30	6.95	abc
PI 628828	14.20	14.00	14.10	ab	PI 628817	12.50	7.10	9.80	abc	PI 628914	9.20	4.60	6.90	abc
PI 628873	14.10	13.70	13.90	abc	PI 628858	10.10	9.50	9.80	abc	PI 628963	7.80	6.00	6.90	abc
PI 628842	14.50	13.00	13.75	abc	PI 628808	10.50	9.10	9.80	abc	PI 628954	7.70	6.10	6.90	abc
PI 675671	13.80	13.60	13.70	abc	PI 628874	10.50	9.00	9.75	abc	PI 628928	9.10	4.55	6.83	abc
PI 675659	17.60	9.50	13.55	abc	PI 628922	12.50	7.00	9.75	abc	PI 628904	8.00	5.60	6.80	abc
PI 628869	13.80	13.20	13.50	abc	PI 417499	13.10	6.40	9.75	abc	PI 628855	9.20	4.30	6.75	abc
PI 628965	13.50	13.10	13.30	abc	PI 628877	10.40	9.00	9.70	abc	PI 628813	9.00	4.50	6.75	abc
PI 628962	13.50	12.60	13.05	abc	PI 628826	12.60	6.80	9.70	abc	PI 628843	7.50	6.00	6.75	abc
PI 675667	15.50	10.40	12.95	abc	PI 675650	10.40	9.00	9.70	abc	PI 628934	8.90	4.45	6.68	abc
PI 628929	13.10	12.60	12.85	abc	PI 628863	12.20	7.10	9.65	abc	PI 628964	8.50	4.50	6.50	abc
PI 628880	13.30	12.30	12.80	abc	PI 628824	11.00	8.20	9.60	abc	PI 628961	8.60	4.30	6.45	abc
PI 628870	12.80	12.80	12.80	abc	PI 628901	12.50	6.50	9.50	abc	PI 628943	11.6	1.30	6.45	abc
PI 675654	15.00	10.60	12.80	abc	PI 628957	9.70	9.20	9.45	abc	PI 628878	8.50	4.25	6.38	abc
PI 628871	15.20	10.30	12.75	abc	PI 628825	9.50	9.10	9.30	abc	PI 203398	8.40	4.20	6.30	abc
PI 628910	13.30	12.10	12.70	abc	PI 675668	10.00	8.50	9.25	abc	PI 628941	6.40	6.20	6.30	abc
PI 628894	13.10	12.30	12.70	abc	PI 628932	12.30	6.15	9.23	abc	PI 628945	7.00	5.40	6.20	abc
PI 628860	12.70	12.60	12.65	abc	PI 628915	10.20	8.20	9.20	abc	PI 628950	8.40	4.00	6.20	abc
PI 675661	12.80	12.50	12.65	abc	PI 628834	9.10	9.10	9.10	abc	PI 628840	8.20	4.10	6.15	abc
PI 628812	13.50	11.70	12.60	abc	PI 628890	9.60	8.50	9.05	abc	PI 628906	7.50	4.70	6.10	abc
PI 628839	13.10	12.10	12.60	abc	PI 628942	9.50	8.60	9.05	abc	PI 675660	8.00	4.00	6.00	abc
PI 628809	12.50	12.20	12.35	abc	PI 628883	12.00	6.00	9.00	abc	PI 628908	7.70	3.85	5.78	abc
PI 628862	12.10	12.10	12.10	abc	PI 628887	9.40	8.50	8.95	abc	PI 644103	7.50	3.75	5.63	abc
PI 628872	14.50	9.60	12.05	abc	PI 628916	9.80	8.10	8.95	abc	PI 628884	6.30	4.70	5.50	abc
PI 341252	13.50	10.50	12.00	abc	PI 675664	11.80	5.90	8.85	abc	PI 628889	5.50	5.50	5.50	abc
PI 628960	12.40	11.30	11.85	abc	PI 628816	9.20	8.30	8.75	abc	PI 628820	7.30	3.65	5.48	abc
PI 628811	14.50	9.10	11.80	abc	PI 628837	10.00	7.20	8.60	abc	PI 628902	7.30	3.65	5.48	abc
PI 628831	14.50	9.00	11.75	abc	PI 628909	11.10	6.00	8.55	abc	PI 628799	7.20	3.60	5.40	abc
PI 628885	12.30	10.70	11.50	abc	PI 628937	9.60	7.40	8.50	abc	PI 628800	7.20	3.60	5.40	abc
PI 675662	11.90	11.00	11.45	abc	PI 628867	10.40	6.50	8.45	abc	PI 628900	7.10	3.55	5.33	abc
PI 628876	15.60	7.20	11.40	abc	PI 628936	9.40	7.50	8.45	abc	PI 628948	7.00	3.50	5.25	abc
PI 628895	12.60	10.10	11.35	abc	PI 628864	9.50	7.30	8.40	abc	PI 417505	7.00	3.50	5.25	abc
PI 628905	13.30	9.40	11.35	abc	PI 628951	9.80	7.00	8.40	abc	PI 628907	6.70	3.35	5.03	abc
PI 628947	13.00	9.60	11.30	abc	PI 628859	9.50	7.20	8.35	abc	PI 628935	5.80	4.10	4.95	abc
PI 628944	12.70	9.70	11.20	abc	PI 628886	9.20	7.10	8.15	abc	PI 628856	6.40	3.20	4.80	abc
PI 628892	13.30	9.10	11.20	abc	PI 628966	9.20	7.10	8.15	abc	PI 628832	6.40	3.20	4.80	abc
PI 628946	13.20	9.10	11.15	abc	PI 483253	11.20	5.10	8.15	abc	PI 675653	6.30	3.15	4.73	abc
PI 628852	13.00	9.10	11.05	abc	PI 628939	10.90	5.30	8.10	abc	PI 628896	6.10	3.05	4.58	abc
PI 628918	13.50	8.30	10.90	abc	PI 483251	10.80	5.40	8.10	abc	PI 675652	4.70	4.30	4.50	abc
PI 628868	11.70	9.80	10.75	abc	PI 628807	8.60	7.50	8.05	abc	PI 483252	6.00	3.00	4.50	abc
PI 628803	13.10	8.00	10.55	abc	PI 628940	9.00	7.00	8.00	abc	PI 628833	5.70	2.85	4.28	bc
PI 628933	10.70	10.40	10.55	abc	PI 675655	10.60	5.30	7.95	abc	PI 417504	4.70	2.35	3.53	bc
PI 628897	12.00	9.00	10.50	abc	PI 628879	8.70	7.10	7.90	abc	PI 628881	3.50	3.10	3.30	bc
PI 628925	12.10	8.90	10.50	abc	PI 628913	9.40	6.40	7.90	abc	PI 628882	4.30	2.15	3.23	bc
PI 675663	12.20	8.60	10.40	abc	PI 628822	11.40	4.10	7.75	abc	PI 417501	4.30	2.15	3.23	bc
PI 628866	13.80	6.90	10.35	abc	PI 628814	10.30	5.15	7.73	abc	PI 675651	4.30	2.15	3.23	bc
PI 663948	11.00	9.70	10.35	abc	PI 628893	7.80	7.60	7.70	abc	PI 628853	5.00	0.00	2.50	c
PI 628846	14.10	6.30	10.20	abc	PI 628875	7.60	7.60	7.60	abc	PI 628797	3.20	1.60	2.40	c
PI 628854	10.10	9.90	10.00	abc	PI 628802	9.60	4.80	7.20	abc					
PI 417502	10.20	9.70	9.95	abc	PI 628857	8.00	7.40	7.70	abc					
PI 675666	12.30	7.60	9.95	abc	PI 675665	8.60	5.90	7.25	abc					
PI 628819	13.20	6.60	9.90	abc	PI 628899	7.20	7.00	7.10	abc					

*** Means within columns followed by the same letter are not significantly different (LSD, P<0.05)*

Table 2.13. Comparison of means for plant height for 60 lines grown on three pH regimes

Lines		Plant Height (cm)					
		pH 4.5		pH 5.0		pH 5.5	
1	PI628871	22.10	a **	12.80	bc	10.60	a
2	PI628962	21.40	a	13.50	b	12.80	a
3	PI567611	20.60	ab	19.50	a	0.00	
4	PI556744	20.30	ab	0.00		12.50	a
5	PI556727	20.10	ab	9.40	de	9.40	bc
6	PI615695	18.20	b	11.70	bc	11.90	a
7	PI628925	18.00	b	9.70	de	13.60	a
8	PI567779A	16.90	c	9.90	cde	10.10	b
9	PI556537	16.60	c	9.10	de	12.50	a
10	PI628842	15.00	cd	10.80	bcd	9.90	b
11	PI594922	14.60	cd	9.40	de	12.90	a
12	PI556515	13.30	def	9.10	de	9.10	bc
13	PI590932	12.20	efg	10.10	cde	11.90	a
14	PI628929	12.00	efg	8.90	de	8.70	bc
15	PI628880	11.90	efg	11.20	bcd	10.10	b
16	PI567410C	11.10	fghi	10.90	bcd	9.40	bc
17	PI567643	10.80	fghi	8.30	de	10.20	b
18	PI556612	9.70	ghij	7.10	e	8.50	bc
19	PI675661	7.90	jk	13.20	b	11.00	a
20	PI556564	0.00		10.10	cde	10.60	a
21	PI628828	21.60	a	0.00		0.00	
22	PI628848C	21.10	ab	0.00		0.00	
23	PI628894	20.90	ab	0.00		0.00	
24	PI628812	20.70	ab	0.00		0.00	
25	PI628809	20.60	ab	0.00		0.00	
26	PI628880	20.10	ab	7.50	e	7.60	bc
27	PI587768	15.90	cd	0.00		0.00	
28	PI576154	12.40	efg	0.00		0.00	
29	PI567614C	11.30	fgh	0.00		0.00	
30	PI587614	11.10	fghi	0.00		0.00	
31	PI556536	9.50	ghij	0.00		0.00	
32	PI628885	9.00	ijk	0.00		0.00	
33	PI556481	8.80	hij	0.00		0.00	
34	PI594643	8.30	ijk	0.00		0.00	
35	PI584506	8.20	ijk	0.00		0.00	
36	PI628952	8.10	ijk	0.00		0.00	
37	PI567413	7.90	jkl	0.00		0.00	
38	PI675669	7.10	jkl	0.00		0.00	
39	PI587714A	6.60	jkl	9.40	de	0.00	
40	PI567652	5.50	kl	0.00		0.00	
41	PI583367	4.90	l	0.00		0.00	
48	PI567620B	0.00		9.30	de	0.00	
44	PI615694 *	0.00		0.00		6.80	c
45	PI556584	0.00		0.00		10.00	b

*** Means within columns followed by the same letter are not significantly different (LSD, P<0.05)*

Table 2.14. Comparison of means for root length for 60 lines grown on three pH regimes

Lines		Root Length (cm)		
		pH 4.5	pH 5.0	pH 5.5
1	PI556727	8.05 a **	2.15 c	2.05 ab
2	PI567611	7.43 ab	3.33 b	0.00
3	PI615695	6.90 abc	2.10 c	1.98 ab
4	PI556744	6.30 bc	0.00	2.50 ab
5	PI628962	5.88 d	2.68 bc	2.35 ab
6	PI567779A	5.50 de	2.40 bc	2.30 ab
7	PI628925	5.18 defg	2.33 bc	2.65 a
8	PI628929	4.58 d-i	2.10 c	2.00 ab
9	PI567410C	4.43 e-k	2.10 c	2.05 ab
10	PI594922	4.38 e-k	2.00 c	1.98 ab
11	PI556537	4.35 e-l	1.80 c	2.80 a
12	PI628842	4.25 e-l	2.33 bc	1.98 ab
13	PI556515	4.18 f-l	2.08 c	2.23 ab
14	PI628871	4.10 f-l	3.80 a	1.98 ab
15	PI567643	3.63 g-m	2.48 bc	2.20 ab
16	PI590932	3.60 h-m	2.00 c	1.70 ab
17	PI628880	3.30 i-m	2.30 bc	2.00 ab
18	PI556612	3.15 k-n	1.85 c	2.30 ab
19	PI675661	1.70 N	2.65 bc	1.98 ab
20	PI556564	0.00	2.85 bc	2.65 a
21	PI628828	6.80 abc	0.00	0.00
22	PI628848C	5.90 cd	0.00	0.00
23	PI628809	5.35 def	0.00	0.00
24	PI628812	4.85 d-h	0.00	0.00
25	PI628894	4.53 e-j	0.00	0.00
26	PI567614C	4.35 e-l	0.00	0.00
27	PI628880	4.00 g-l	1.88 c	1.70 ab
28	PI567413	3.43 i-m	0.00	0.00
29	PI675669	3.23 j-m	0.00	0.00
30	PI628885	3.18 k-n	0.00	0.00
31	PI628952	2.80 lmn	0.00	0.00
32	PI583367	2.75 lmn	0.00	0.00
33	PI584506	2.60 mn	0.00	0.00
34	PI576154	2.53 mn	0.00	0.00
35	PI556481	2.43 mn	0.00	0.00
36	PI587768	2.40 mn	0.00	0.00
37	PI556536	2.38 mn	0.00	0.00
38	PI587714A	2.35 mn	1.93 c	0.00
39	PI587614	2.33 mn	0.00	0.00
40	PI594643	2.33 mn	0.00	0.00
41	PI567652	2.05 n	0.00	0.00
42	PI567620B	0.00	1.85 c	0.00
43	PI615694 *	0.00	0.00	1.28 b
44	PI556584	0.00	0.00	1.73 ab

*** Means within columns followed by the same letter are not significantly different (LSD, P<0.05)*

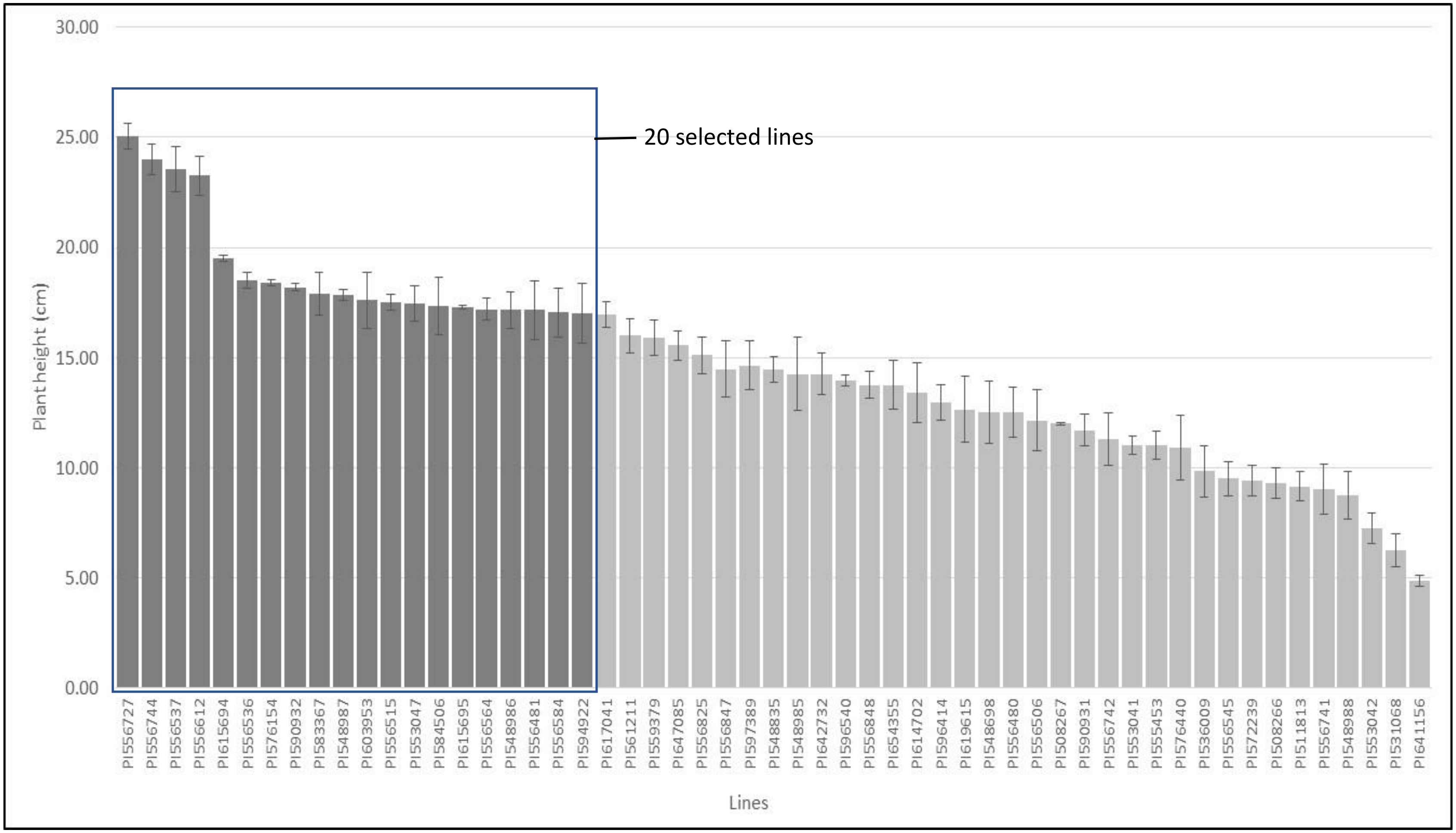


Figure 2.1. Means of plant height in 55 surviving lines (60.4% of a total 91 lines) within the USA accessions at 35 days after planting

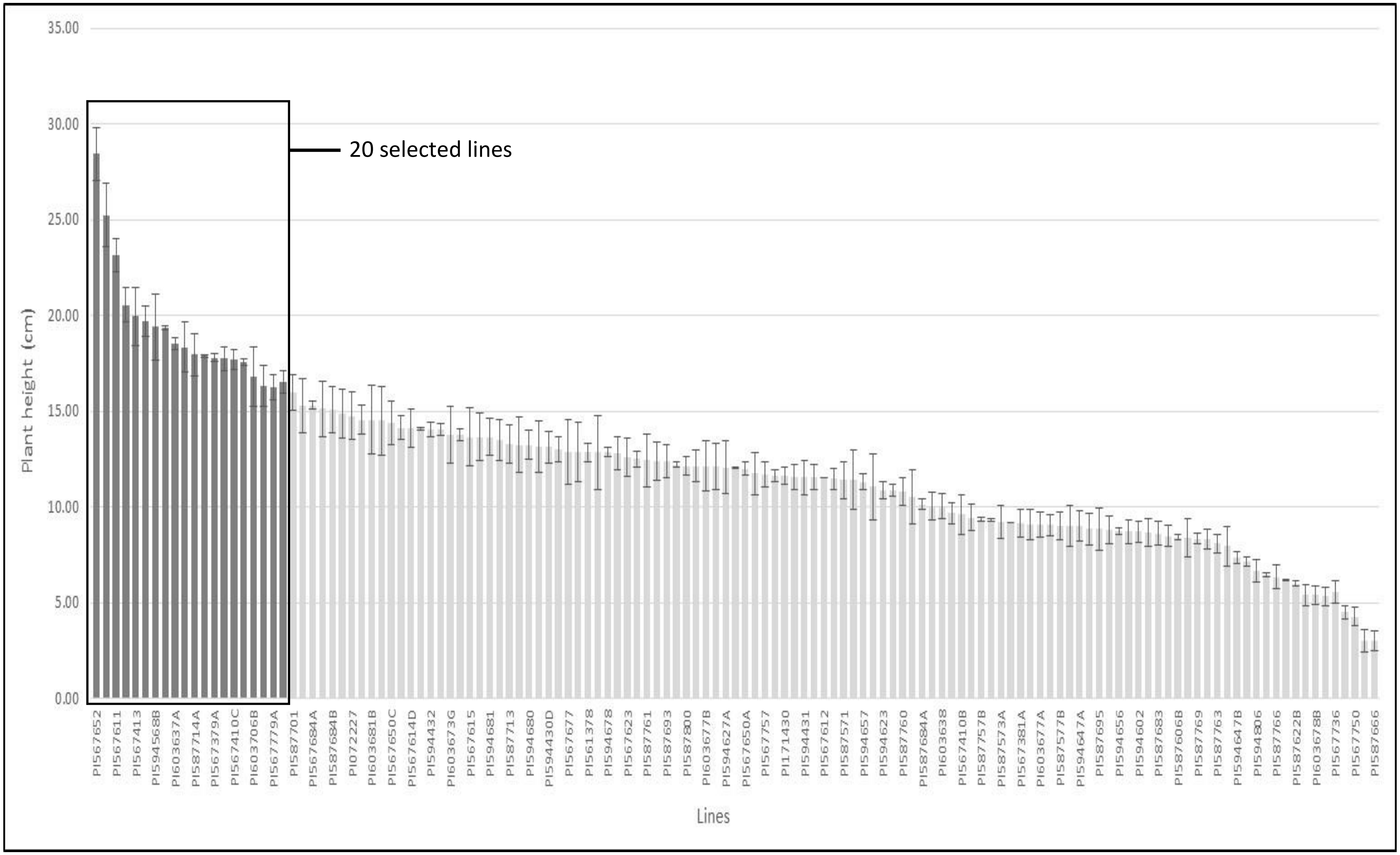


Figure 2.2. Means of plant height in 131 surviving lines (32.2% of total 407 lines) within Chinese accessions at 35 days after planting

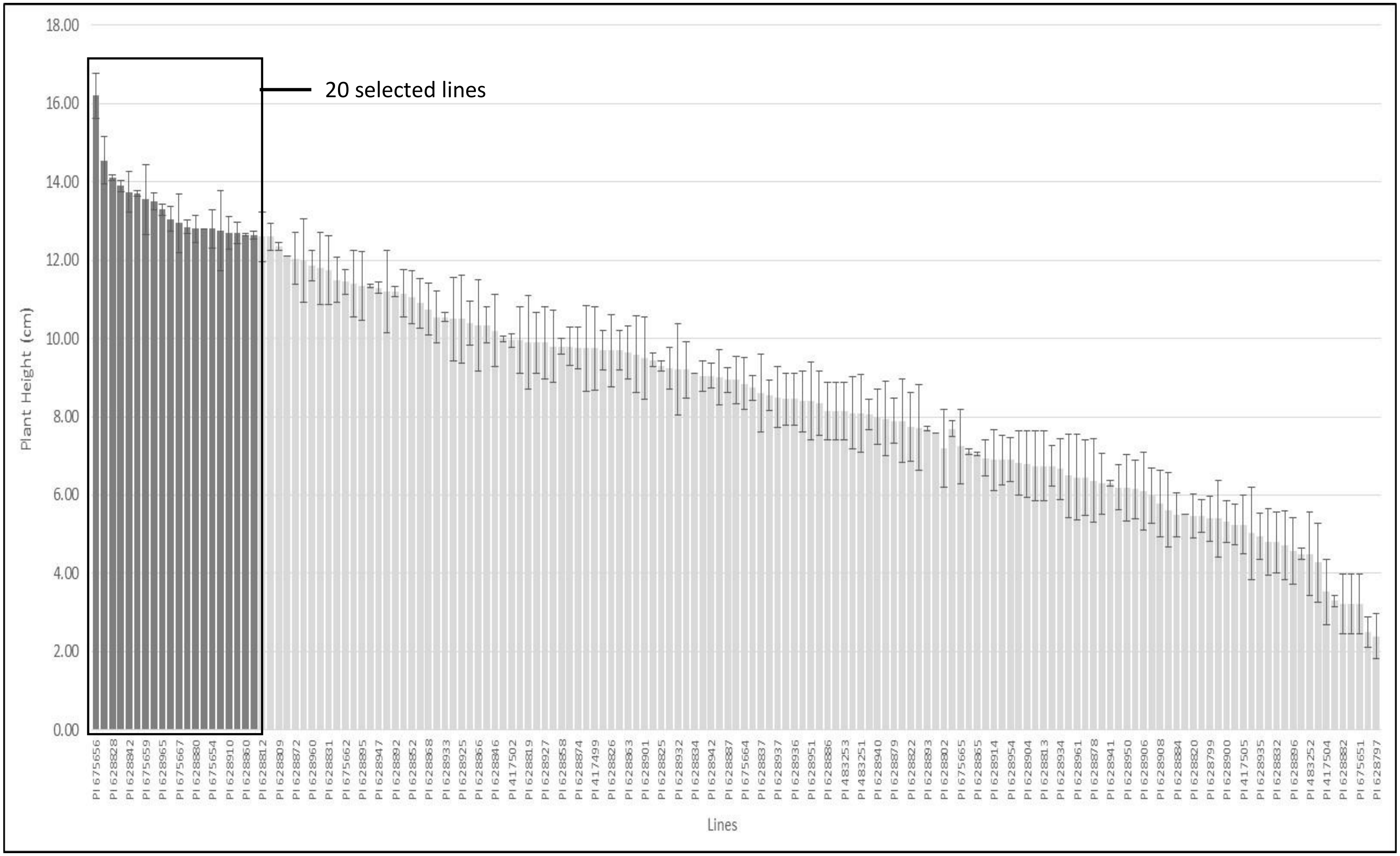


Figure 2.3. Means of plant height in 155 surviving lines (74.5% of total 208 lines) within Brazilian accessions at 35 days after planting

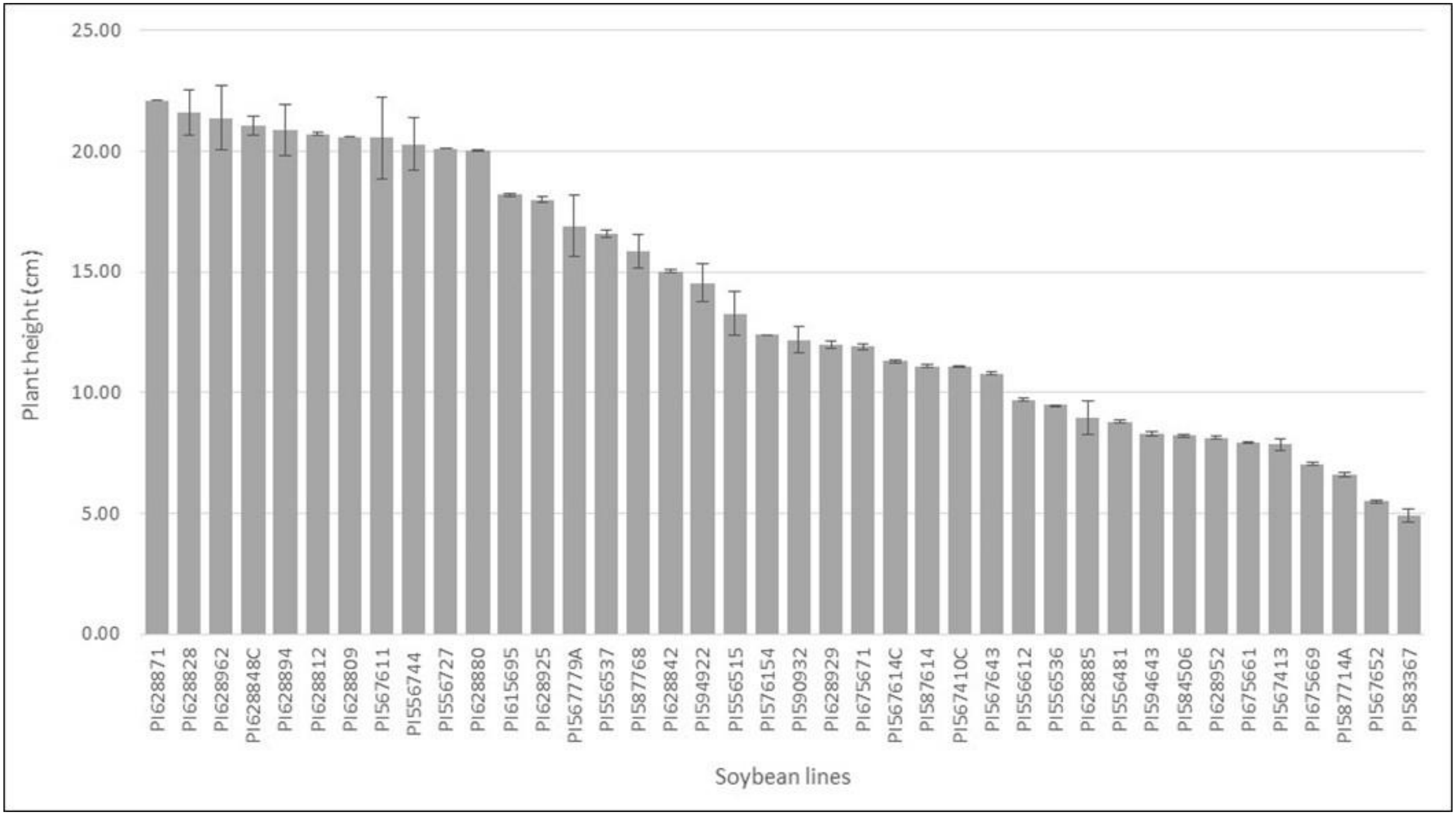


Figure 2.4. Means of plant height in 39 surviving lines (65% of total 60 lines) grown on **pH 4.5** at 35 days after planting (the second selection phase)

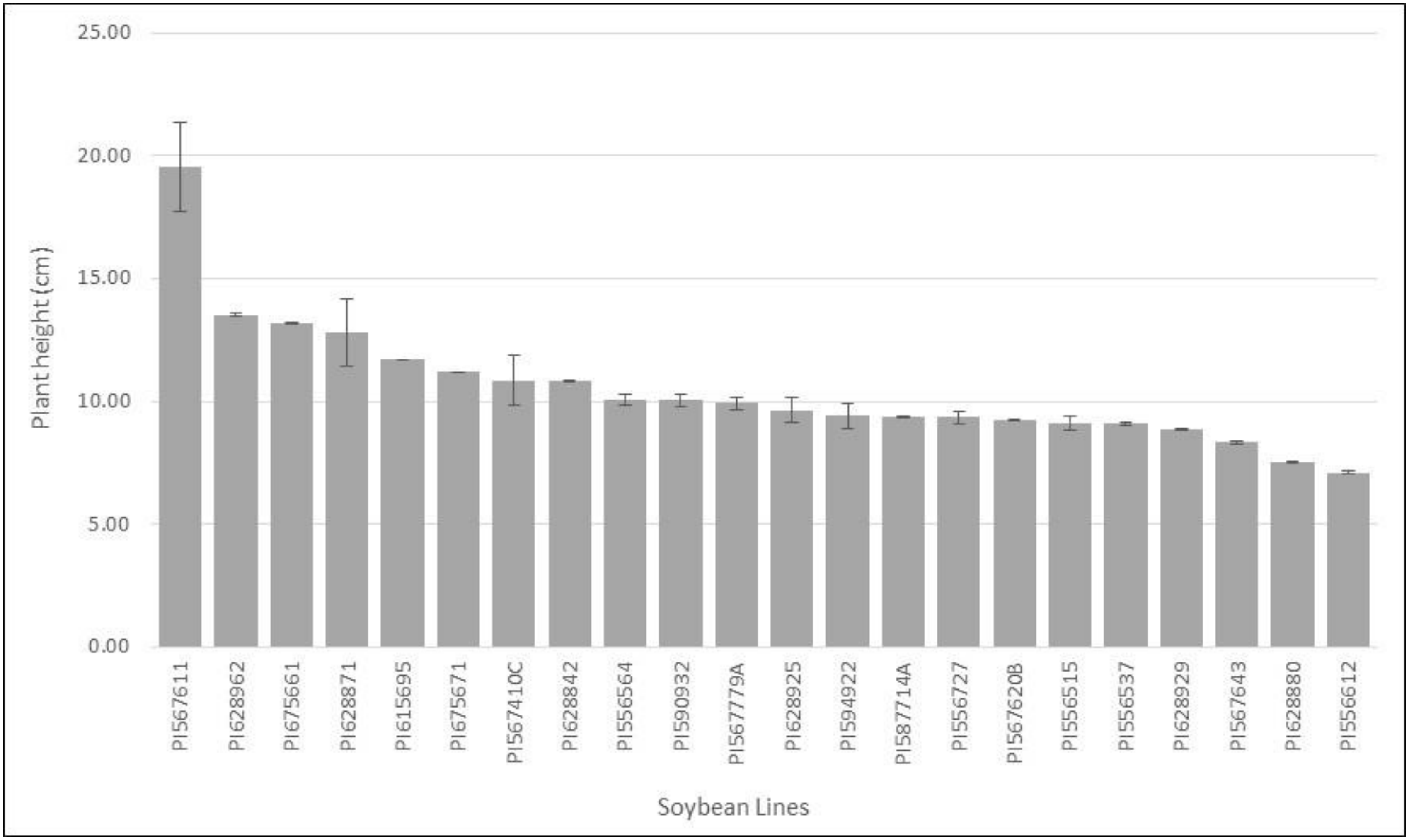


Figure 2.5. Means of plant height in 22 surviving lines (37% of total 60 lines) grown on **pH 5.0** at 35 days after planting (the second selection phase)

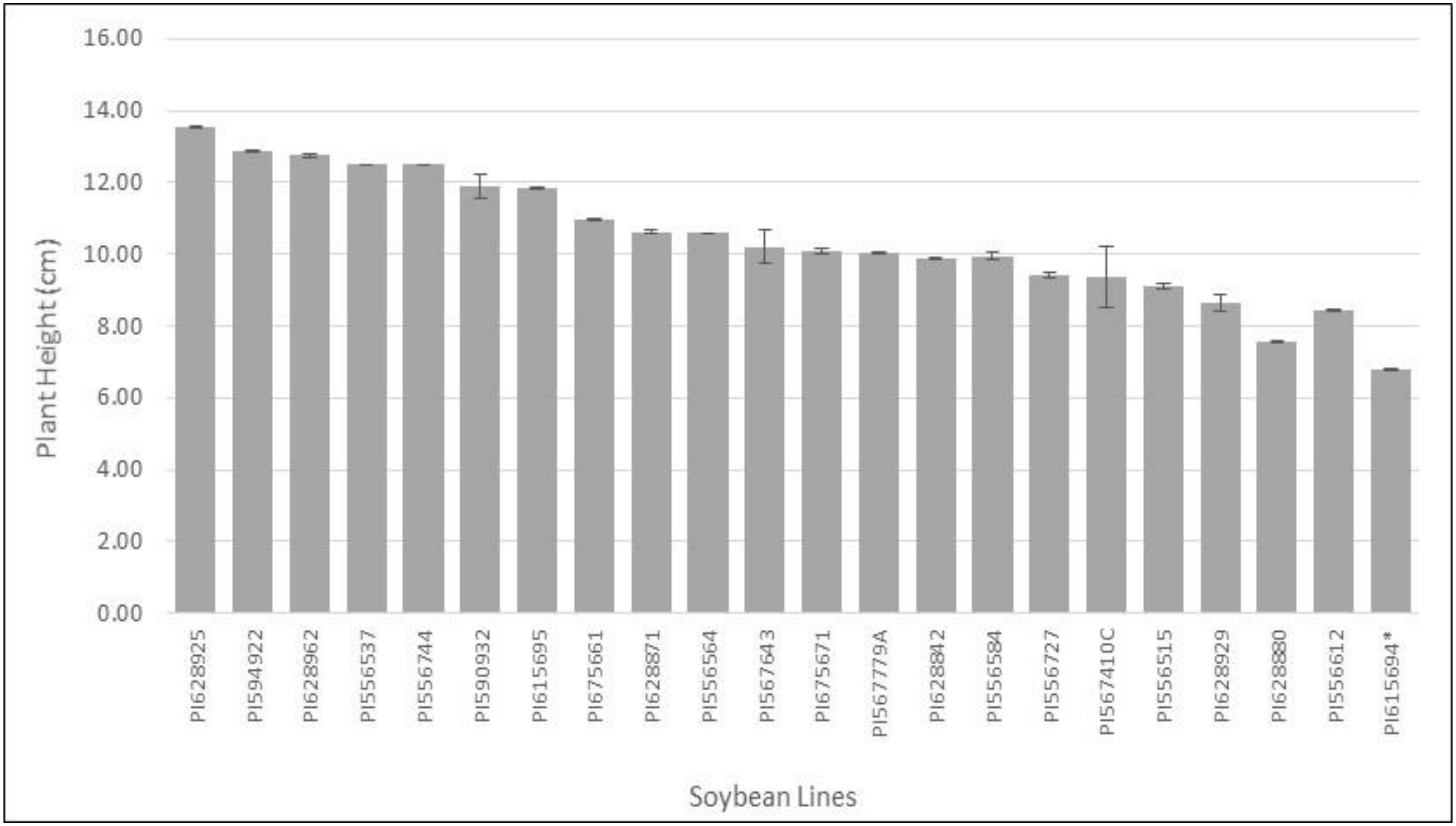


Figure 2.6. Means of plant height in 22 surviving lines (37% of total 60 lines) grown on **pH 5.5** at 35 days after planting (the second selection phase)

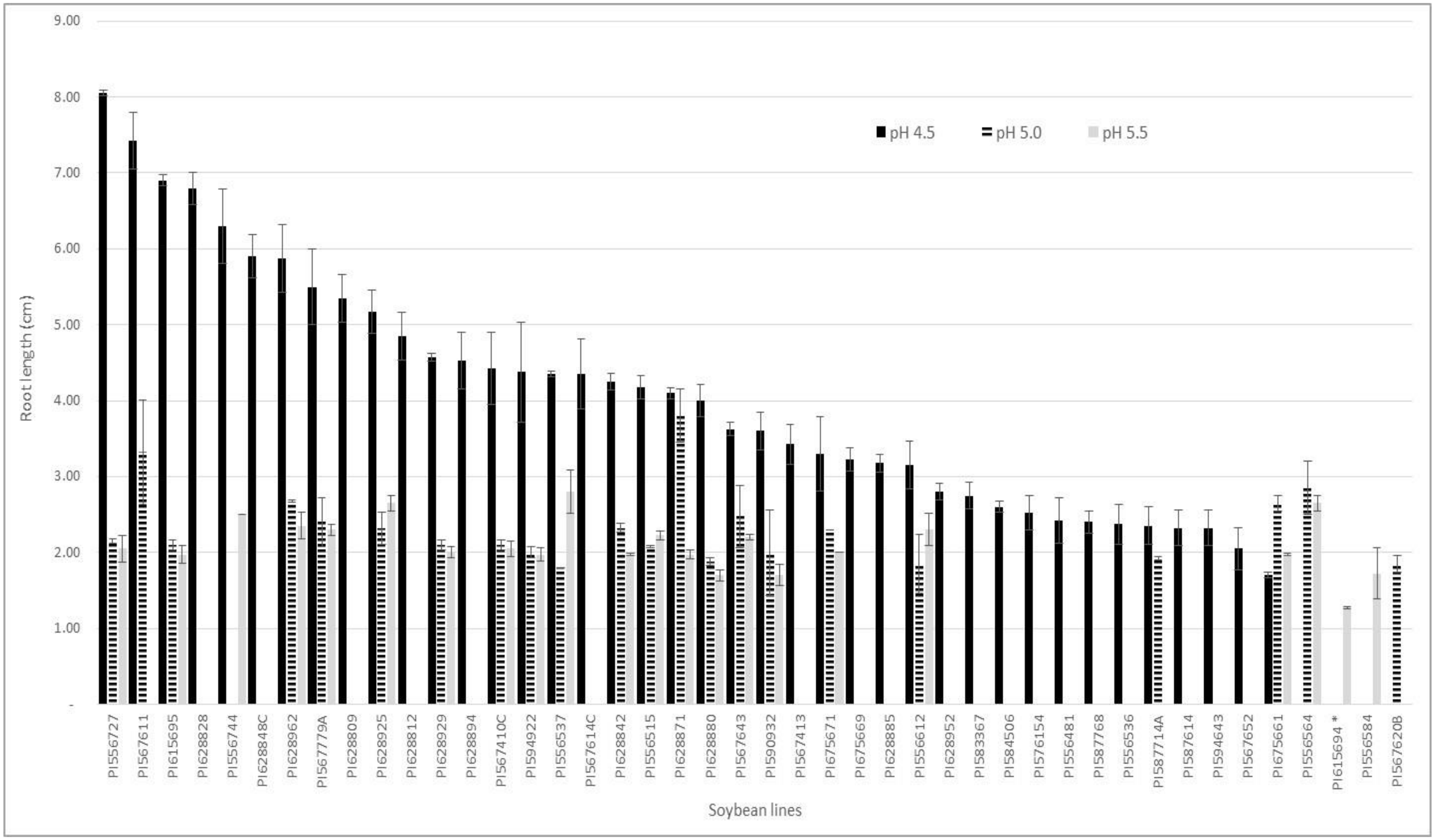


Figure 2.7. Means of root length in 44 surviving lines at pH 4.5, 5.0, and 5.5 (the second selection phase)

REFERENCES

REFERENCES

Adie M.M. and Krisnawati A. 2016. Identification of soybean genotypes adaptive and productive to acid soil agro-ecosystem. Biodiversitas: Vol. 17, No. 2. Pages: 565-570. ISSN: 1412-033X. DOI: 10.13057/biodiv/d17022

Arsyad D.M., Adie M.M., Kuswantoro H. 2013. Soybean varieties breeding on specific of agroecology in Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 205-228. In Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/03/dele_9.darman-1.pdf

Bernardo R. 2010. Essentials of Plant Breeding. ISBN 978-0-9720724-1-0 Published July 2010

Board, J E. 1991. Response of determinate soybean cultivars to low pH soils. Louisiana State University Agricultural Experiment Station Reports. 349. Link: http://digitalcommons.lsu.edu/agexp/349

Caires E.F., Garbuio F.J., Churka S., Barth G., Correa J.C.L. 2008. Effects of soil acidity amelioration by surface liming on no-till corn, soybean, and wheat root growth and yield. Europ. J. Agronomy 28 (2008) 57–64. doi:10.1016/j.eja.2007.05.002

Carter, T.E., Nelson, R.L., Sneller, C.H., Cui, Z. 2003. Genetic diversity in soybean ***in*** Soybeans: improvement, production, and uses. Third edition. American Society of Agronomy, inc., Crop Science Society of America, inc., Soil Science Society of America, inc. 2004. ISBN: 978-0-89118-154-5

Chaerani, Hidayatun N., Utami D.W. 2011. Genetic Diversity of 50 Soybean Accessions Based on Ten Microsatellite Markers. AgroBiogen Journal 7(2):96-105. Link: http://ejurnal.litbang.pertanian.go.id/index.php/ja/article/viewFile/3775/3124

Ginting and Tastra. 2013. Quality standard of soybeans seed ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 444-463. Link: http://balitkabi.litbang.pertanian.go.id/publikasi/monograf/kedelai-teknik-produksi-dan-pengembangan/[in Bahasa Indonesia]

Handayani L., Rauf A., Rahmawaty, Supriana T. 2018. The strategy of sustainable soybean development to increase soybean needs in North Sumatera. International Conference on Agriculture, Environment, and Food Security. IOP Conf. Series: Earth and Environmental Science 122 (2018) 012018. doi :10.1088/1755-1315/122/1/012018

Havlin J.L., Tisdale S.L., Nelson W.L., Beaton J.D. 2014. Soil fertility and fertilizers: an ntroduction to nutrient management. Eight editions. Pearson education Inc. Upper Saddle River, N.J: Prentice Hall. 503 p. ISBN: 978-81-203-4868-4

IAARD. 2017. Description of soybean varieties released in 1918-2016. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/09/kedelai.pdf

Ibrahim S.E., Han W.Y., Baek I.Y., Cho G.R. 2017. Evaluating soybean germplasm for agronomic performance under irrigated cropping environment in Sudan. The Jpurnal of Korean Sicoety of International Agriculture. Vil. 29(4). Pages: 415~420. ISSN 2287-8165. https://doi.org/10.12719/KSIA.2017.29.4.415

Joris H.A.W., Caires E.F., Bini A.R., Scharr D.A., Haliski A. 2013. Effects of soil acidity and water stress on corn and soybean performance under a no-till system. Plant Soil (2013) 365:409–424. DOI 10.1007/s11104-012-1413-2

Kidd P.S. and Proctor J. 2001. Why plants grow poorly on very acid soils: are ecologists missing the obvious? Journal of Experimental Botany. Vol. 52. No. 357. Page: 791-799.

Lersten N.R. and Carlson J.B. 2004. Vegetative morphology in Soybeans: improvement, production, and uses. Agronomy Np. 16. Third Edition. Page 15-57. ISBN: 0-89118-154-7

Lyamuremye, F., Dick, R. P., Baham, J. 1996. Organic amendments and phosphorus dynamics ***in*** phosphorus chemistry and sorption. Soil Science 161(7):426-435.

Ministry of Agriculture Republic of Indonesia. 2015. Strategic plan on 2015-2019 period. Link: http://www1.pertanian.go.id/file/RENSTRA_2015-2019.pdf

Mulyani A., Rachman A., Dairah A. 2009. The spread of acidic-soil: potential and availability for agricultural development in Rock-phosphate: utilization of rock-phosphate as phosphate nutrient source. Pgs: 25-46.

Pagani A. 2011. Soil pH and lime management for corn and soybean. Dissertation. Iowa State University. Ames, Iowa

Pedersen P., and Licht M. 2014. Soybean growth and development. Extension and outreach of Iowa State University. PM 1945. Reviewed July 2014.28 p. Link: www.extension.iastate.edu

Peterson J.C. 1982. Effects of pH upon nutrient availability in a commercial soilless root medium utilized for floral crop production. Ornamental Plants- -1982: a summary of research. Research circular 268. Ohio Agricultural Research and Development Center. Wooster, Ohio.

Rao V.R. and Hodgkin T. 2002. Genetic diversity and conservation and utilization of plant genetic resources. Plant Cell, Tissue and Organ Culture 68: 1–19, 2002.

Robson A.D. 1989. Soil acidity and plant growth. Harcourt Brace Javanovich Publishers. Academic Press Australia. 30-52 Smidmore St. Marrickville, NSW. ISBN: 0-12-433312-5

Rochayati and Dariah. 2012. Acidic dry-land development: opportunities and challenges ***in*** Dry-land agriculture prospect in supporting food security. Indonesian Agency for Agricultural Research and Development (IAARD). Jakarta. pg. 187-206

Sudaryanto and Swastika. 2007. The Economic of soybean in Indonesia in ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 1-27

Sumarno and Adie M.M. 2010. The development strategies of soybean production towards sustainable of food self-sufficiency. Journal of Iptek Tanaman Pangan. Vol. 5 no. 1: 49-63. [in Bahasa Indonesia]

Supadi. 2010. Impact of the sustained soybean import on food security. Journal of agriculture policy analysis. Vol 7, No. 1: 87-102

Syuaib, M.F. 2016. Sustainable agriculture in Indonesia: Facts and challenges to keep growing in harmony with environment. AgricEngInt. Vol. 18, No. 2. CIGR Journal Open access at http://www.cigrjournal.org

Trakoonyingcharoen P., Kheoruenromne I., Suddhiprakarn A., Gilkes R.J. 2005. Phosphate sorption by Thai red Oxixols and red Ultisols. Soil science. Vol 170 No. 9: 716-725.

USDA, 2015. Legume seed inoculation. Plant materials technical notes number: TX-PM-15-01. United States Department of Agriculture-Natural Resource Conservation Service. Link: http://nrcs.usda.gov/internet/FSE PLANTMATERIALS/publications/etpmctn12525.pdf

Whitney A.D. 1998. Soil Salinity. Recommended Chemical Soil Test Procedures for the North Central Region. North Central Regional Research Publication No. 221 (Revised). Link: https://www.canr.msu.edu/uploads/234/68557/Rec_Chem_Soil_Test_Proce55c.pdf

Widiatmaka, Ambarwulan W., Setiawan Y., Walter C. 2016. Assessing the suitability and availability of land for agriculture in Tuban Regency, East Java, Indonesia. Applied and Environmental Soil Science Volume 2016, Article ID 7302148, 13 pages. http://dx.doi.org/10.1155/2016/7302148

CHAPTER 3. EVALUATION OF A SELECTED SET OF SOYBEAN LINES FOR TOLERANCE TO ALUMINUM TOXICITY

Abstract

Efforts to increase soybean production in Indonesia have not been successful due to two main factors: limited availability of high-yielding varieties, and limited availability of suitable land to increase soybean production due to the best available land being used for rice and corn. The land available for expanding soybean production in Indonesia has acidic Ultisols soils. Plants grown in acidic soils often face aluminum toxicity as Al^{3+} becomes readily available for uptake when pH is low. In the previous study, we had selected 20 germplasm accessions that performed well on Peat moss, an acidic growth medium. However, Peat moss does not contain aluminum (Al), hence, we were unable to test the response of the 20 selected lines to aluminum toxicity. To address this limitation, we conducted a greenhouse study where the previously selected 20 soybean lines were subjected to two levels of Al; 0.0% and 5% Al (by weight). Root length, number of root nodules, and plant height were taken as the dependent variables 35 days after planting, as the criteria for determining germplasm that best tolerates Al toxicity. The data collected were analyzed using ANOVA and LSD. All 20 selected lines survived and grew well at the 5% Al treatment. The measured variables were significantly different at $P < 0.0001$. Plant height and root length of the 20 lines were higher in the medium with 5% Al compared to the control with 0.0% aluminum. Of the 20 lines tested, PI628871 accession had the longest root length and PI567643 accession had the highest plant height. When comparing the initial and final pH levels of the growth medium, we observed a positive effect of adding Al to the growth medium as it increased the pH of the medium from an initial pH of 4.30 to a final pH of 5.23 - 5.34. The results indicated that all of the previously selected 20 lines would be tolerant to soils

with low pH and Al^{3+} levels up to 5% by weight and could perform well under Indonesian acidic soils.

Introduction

The availability of soybean as an important and affordable protein source for people of Indonesia has placed soybean as the third most important food crop. In order to meet food needs through domestic production, the Indonesian government has implemented various programs from plant breeding to soil fertility improvement for decades (Sumarno and Adie, 2010). However, these efforts failed to significantly increase soybean production in the country due to two main factors: limitation in the availability of high-yielding varieties, and limited land availability for soybean farming due to the competition of land-used for other remunerative crops such as rice and corn.

Increasing soybean yield through cultivar development is widely used by many countries. High-yielding soybean varieties have contributed to a 30% to 50% increase in production (Specht et al., 1999; Surahman et al., 2012; Burton and Miranda, 2013). As such, plant breeding is critical for increasing food production in many countries including Indonesia. In Indonesia, while there is a great need to develop soybean varieties that perform well under different agro-ecologies (Arsyad et al., 2013), the major bottleneck for developing new varieties has been the limited access to germplasm resources. The soybean breeding programs in Indonesia was only able to release a total of nine varieties from 1918 - 1980 and this was achieved by crosses made between just two sources of soybean lines originating from Taiwan together with limited local accessions (IAARD, 2017). Introduction of soybean germplasm accessions to Indonesia from other countries and regions around the world that successfully grow soybeans could assist in enhancing the efficiency of the breeding program in the country.

In the early 1980s, the soybean breeding program in Indonesia underwent restructuring with an objective of enhancing the efficiency of breeding activities. To aid this effort, the government provided support to obtain soybean accessions from Thailand, the Philippines, Columbia, Nigeria, Taiwan, and USA. Furthermore, there was an expansion of the areas allocated to growing soybean, and programs were introduced to focus on improving soil fertility through calcification and fertilization (Sumarno and Adie, 2010; Arsyad, 2013; IAARD, 2017). As a result, by 2016, the Ministry of Agriculture of the Republic of Indonesia was able to release 85 soybean varieties. However, many of the newly released varieties did not meet the market demand for large-seeds. Moreover, the new land area that was allocated to soybean development contained acidic soils, which was not favorable for the newly developed varieties that were developed and tested under different conditions. Therefore, our objective is to complement the Indonesian government's efforts by selecting better adapted soybean germplasm that are tolerant to acidic soils so that they can be used in the newly allocated land to increase production.

Indonesia has a total of 102.8 million ha of low pH/acid soils – this is as much as 69.46% of total dry-land that is available for crop production. These acid soils are dominated by Ultisols, Oxisols, and Inceptisols which have a pH of 5.30 in some areas, however, many regions have pH 4.00 or lower (Nurlaeny et al., 1996; Mulyani et al., 2009; Rochayati and Dariah, 2012; Martinsen et al., 2015; Cornelissen et al., 2018). Given this pH range, these soils are considered to be infertile with low soil organic matter (SOM) content and hence, low water holding capacity, making the soil susceptible to erosion (Yulnafatmawita et al., 2014).

Ultisols and other acid soils are not suitable for many crops like soybean because they contain low levels of nutrients and are prone to high metal toxicity (Bojorquez-Quintal et al., 2017; Santore et al., 2018). As a highly weathered soil, Ultisols often face a deficit of certain vital nutrients such as phosphorous (P), Magnesium (Mg), and Calcium (Ca) (Fageria et al., 1988). While nutrient deficiencies may cause yield reduction, it can often be addressed through the application of appropriate fertilizer as needed. However, metal toxicity such as Aluminum (Al) toxicity is an issue that is more difficult to address in Ultisols. There is a strong correlation between pH and the solubility of Al in soils (Santore et al., 2018); thus, soil pH can be used as an appropriate variable to discover the exchangeable Al (Havlin et al., 2014). Aluminum is soluble in low pH; especially when pH drops to less than 5.5 and will precipitate as the soil pH increases above that level (Santore et al., 2018). The toxicity of Al to the plant occurs when the soil pH level is between 3.0 – 5.0 where Al^{3+}, the most toxic form of Al, is released into the soil (Panda et al., 2009; Alleoni et al., 2010; Sposito, 2016).

Aluminum could interfere plant growth in acidic soils (Panda et al., 2009; Bojórquez-Quintal et al., 2017; Rahman et al., 2018). Acidic soil in Indonesia consists of 48% - 89% of saturated Al with a range of 0.1 - > 4.0 cmol/kg available for plants to absorb (Subardja, 2007). The existence of Al as a toxic metal in the soil has become a central issue in crop production and is a significant barrier that affects plant growth and yield (Foy and Fleming, 1978; Alleoni et al., 2010; Krstic and Djalovic, 2012; Rengel et al., 2015; Rahman et al., 2018). The first target of Al toxicity on a plant is the root. Aluminum will hamper root growth and induce the plant to be having short and thick roots which reduce the plant's ability to take up water and nutrients from the soil solution (Board and Caldwell, 1991; Alleoni et al., 2010; Liang et al., 2013).

Peat moss, a widely used growing medium for greenhouse studies, is an excellent medium to select germplasm tolerant to Al toxicity in acidic soils. The pH of the peat moss growth medium ranges between 3.0 – 6.0 (Mofidpoor, 2007) and it consists of low nutrients (Will and Faust, 2010). There are also several advantages to using peat moss as a growth medium including its' high-water holding capacity and the cation exchange capacity (CEC). These two factors alone would ensure that the medium provides adequate moisture around the plant roots. Peat moss also consists of few pathogens and weed seeds compared to other media used for growing plants (Mofidpoor, 2007; Will and Faust, 2010; Robbins, 2018). Both cellulose and lignin are responsible for the structure of peat moss (Coupal and Lalancette, 1976).

The characteristics of the peat moss growing medium are ideal for use in experiments related to evaluating nutrient deficiencies or the effects of metal toxicity in plants. However, peat moss does not contain aluminum, which is needed in this study for evaluating the response of selected soybean lines to acidic soils where Al^{3+} becomes readily available. Therefore, it is necessary to add aluminum to the medium in specific amounts as needed for the experiments to determine the response of selected lines. We had previously selected 20 soybean lines that are tolerant to acidic soils out of 706 lines obtained from USA, China and Brazil (detailed in Chapter 2). Provided we are selecting soybean accessions obtained from the USDA-NSRC based on their ability to withstand the acidic soils available to expand production in Indonesia; it is critical that we also observe how tolerant our selected lines are to Al toxicity. Therefore, the purpose of this study was to evaluate the 20 selected lines for tolerance to aluminum toxicity so that the best performing genotypes would have better adaptation to naturally acidic Indonesian soils. This study would thus provide useful information on how each selected line responds to a certain level of Al before they are used in field evaluations in Indonesia.

Materials and Methods

We used a completely randomized experimental design (CRD) with two replications in this greenhouse study to evaluate the response of the 20 selected soybean lines to aluminum (Al) toxicity. The total number of the experimental units was 80, obtained from 20 soybean lines x 2 Al levels x 2 replications. All units were placed randomly on one bench in the greenhouse at Michigan State University.

Plant material

The plant material selected for the study are the 20 soybean accessions (out of the original 706 accessions obtained from USDA-NSRC) that best performed in a medium of Peat moss at pH levels of 4.5 to 5.5 (detailed in Chapter 2). The lines included in the experiment were: PI628871, PI628962, PI567611, PI556744, PI556727, PI615695, PI628925, PI567779A, PI556537, PI628842, PI594922, PI556515, PI590932, PI628929, PI628880, PI567410C, PI567643, PI556612, PI675661, and PI556564**.**

Potting media

In this experiment, we wanted to determine the effect of added aluminum on the growth of soybean lines at 5% level (by weight) in comparison to how the lines perform under 0% aluminum (the control). For the growth media with 0% Al, we used the Peat moss media without the addition of any Al - a treatment designed to show only the effect of low pH on plant growth. We selected to test the effect of Al on plant growth at 5% level because we assume that as much as 4% of Al would be bound to CEC sites and another 1% of Al to be bioavailable to the plants. To prepare the growth medium, we added a readily soluble form of Al to the media two days after raising the pH of the peat moss media.

Given that Peat moss has a much lower initial pH level of 3.5 than desirable for our growth medium, as an initial step, we first raised the pH level of the growing medium to a pH of 4.5 by adding sodium hydroxide (NaOH) as described in Chapter 2. Sodium hydroxide was allowed to mix with the Peat moss media for two days after mixing to allow it to raise the pH to the desired level of 4.5. The pH of the media was measured using a digital pH meter available at the Michigan State University Soil Laboratory.

Adding Al to the media was done after ensuring the growing medium had the desired pH level of 4.5. The source of Al used in this study was Aluminum hydroxide ($Al(OH)_3$), in powder form, which was added to the medium following the treatment of 5% of the medium by weight. The peat moss weight for each pot was 100 grams; hence, the amount of aluminum hydroxide added to each pot was five ± 0.05 grams. The number of experimental units with Al treatment was 40 pots. Therefore, the total amount of aluminum hydroxide needed in this study was 200 grams ± 2.0 grams. In order to have an even mixture, the media was stirred gently in a small box and left for a full day before being used as a planting medium for the experiment.

Planting

Before planting the selected soybean lines in the prepared soil medium, we used a seed treatment of *Bradyrhizobium japonicum* (Wrigth et al., 2013) as an inoculant. This treatment was done 15-20 minutes before planting the seed. The amount of inoculant used was 0.4 grams per 100 grams of soybean seeds (USDA, 2015) mixed with a small amount of water to ensure the attachment of the inoculant to the surface of the seeds. This seed treatment is used by soybean farmers in Indonesia.

Since it is critical to ensure the medium has sufficient moisture to support seed germination, we added an adequate amount of distilled water to the growth medium until it was moist but not too wet. Moisture was also crucial for the aluminum ions to be available for uptake by plants. We used distilled water in this study to ensure the pH level is maintained at a desirable level and would not affect the treatment.

All seeds of the 20 selected soybean lines were planted a day after the mixing of $Al(OH)_3$ to the growth medium at 2.5 cm below the surface. Planting was done after all seeds were treated with the inoculant with three seeds per pot. Other than the seed inoculant and aluminum, no fertilizer or treatments were given to the plants. The plants were watered daily using distilled water to maintain soil moisture.

Variables and data analysis

We determined the effect of aluminum on plant growth by measuring plant root and shoot growth (Delhaize and Ryan, 1995; Bloom and Erich, 1996; Rout G. et al. 2001; Yang et al., 2013). We measured root length and number of root nodules of each plant at the end of the study or 35 days after planting, along with the plant height, which was measured every seven days. We used the Proc GLM procedure (SAS, 2012) to analyze the observed data and the Fisher's Protected Least Significant Differences (LSD) at a 5% significance level to test the significant differences among treatments based on the results of the analysis of variance (ANOVA).

Results and Discussion

We found significant differences among lines and aluminum levels using the analysis of variance test at $P < 0.0001$ (Table 3.1). These differences indicate that each line has a different ability to grow and adapt to the given growing medium and aluminum treatment. The interaction between lines and aluminum treatments was also found to be significantly different. Therefore, we conducted a multiple comparisons test using LSD method to determine differences between treatments.

The results of the LSD test for root length is presented in Table 3.2. The root length of 20 selected lines grown in the medium with 0% aluminum ranged from 5.88 cm to 11.70 cm, with PI567779A having the longest root length and significantly different from five other lines. All of the lines were able to grow at the given pH level of 4.5 with different lengths of roots. However, the root length of all the 20 selected lines increased significantly between 23.3% to 218.4% when treated with 5% Al. The highest increase in root length was in PI675661, with a 218% increase compared to the control. The roots of this line grew even longer than PI567779A, which had the longest roots at 0% Al, and the increase was only 38.5% after treatment with 5% aluminum. Based on root length, line number PI628871 had the longest root length when treated with 5% aluminum, and it was significantly different from nine other lines with the same treatment.

The plant height of all the 20 tested lines is presented in Table 3.3 and Al influence on changes in plant height from day 7 to day 35 can be seen in Figure 3.1. At 0% of Al, plant height ranged from 9.75 cm to 19.08 cm, with line number PI675661 as the shortest plant and PI556537 being the tallest and significantly different from six lines. However, 18 out of 20 lines had an increased plant height on the medium supplemented with 5% Al, with an increase ranging from 8.7% to 130.8%. In the 5% Al treatment, plant height of PI567643 was the highest with 33.67 cm and was significantly different with 18 other lines in this study. Accession PI675661 had the highest increase in height at 130.8% when compared to its height in 0% Al. Figure 3.1 shows the difference in plant height in the 0% and 5% Al treatments starting at 14 days after planting for all strains except lines PI567410C and PI625695.

The number of root nodules observed for the 20 selected lines is presented in Table 3.4. The results show a positive correlation with the 5%b Al treatment. In the control pots with 0% of Al, the number of root nodules in the lines ranged from 1.0 to 11.75 with the PI567410C having the highest number of root nodules. Furthermore, results show that all lines were able to form root nodules after being inoculated with *Rhizobium*. The number of root nodules for 17 lines increased significantly between 24.1% to 600.0% when grown on medium supplemented with 5% Al. However, there were three lines, PI567410C, PI628962, and PI628871, which showed a negative correlation when treated with 5% Al. In these three lines, the number of root nodules deceased between 23.4%, 14.6%, and 8.7% respectively.

The three variables measured in this study, root length, plant height, and the number of root nodules formed, show that all the 20 soybean lines perform well on soils with low pH of 4.5 and up to 5% aluminum. All lines were able to grow well and form root nodules in the low pH growth medium without the addition of any nutrients. Given that we conducted this experiment using lines especially selected to perform well in low pH soils, it is not surprising to find all lines performing well under these conditions.

Tolerance of soybeans to acidic soils and aluminum toxicity depends on the genotype, physiological age, and the environment (Liao et al., 2006; Bojórquez-Quintal et al., 2017). Genetic factors could influence the differences seen in root growth and plant height. These differences would be useful to increase the genetic diversity of the soybean accessions in Indonesia and be used for further improving soybean varieties.

We were able to observe a positive effect of adding Al to the growth medium by comparing the initial and final pH levels for the control with 0% Al and treatment with 5% Al. The pH of the growing medium at the beginning and end of the experiment in pots with 0% Al remained about the same and only ranged from 4.27 to 4.44; however, in the medium with 5% Al treatment, pH level increased about 1.0 or from an initial pH of 4.30 to a final pH level of 5.23 – 5.34. We believe this change was favorable to the plants (Table 3.5). Aluminum treatment to the peat moss in this study provided a better environment for soybeans to grow. Peat moss is a medium with a high CEC (Mofidpoor, 2007). Perhaps this characteristic allowed ionic exchange in soil solution due to the strong absorption level of Al and helped increase the pH of the medium.

Perhaps the amount of Al given to the medium we tested was not high enough to cause a toxic effect to the soybean plants. In low concentrations, the presence of Al will be beneficial to the plant and will stimulate root growth (Osaki et al., 1997; Bojórquez-Quintal et al., 2017). The results observed in this study seem to support this observation.

Similarly, in the case of the number of root nodules formed, 17 out of the 20 lines showed a positive increase when treated with 5% Al. The number of root nodules of soybean were highly correlated with the level of pH of the growth medium (Foy, 1992). When the pH level of the medium increased, it stimulated plant root growth and improved the opportunity for the rhizobium to interact with the roots and form more nodules. Given that the pH level in the medium with 5% Al was higher compared to the control but was not over a pH level of 6.0, it supports the observations made by Rice et al. (1977) that soil pH influenced the number of root nodules on alfalfa in the pH under 6.0 and had a slight or no effect when the pH level increased to or higher than 6.0.

We assumed that the positive effect of Al in a low concentration could be different if the plants were exposed to Al for a more extended period. In this study, we were unable to expand our experiment further due to the unavailability of greenhouse facilities on campus. However, given that the naturally occurring acidic soils in Indonesia fall in the range tested in our experiment, we believe the 20 lines used in this experiment to perform favorably under Indonesian soils.

APPENDIX

Table 3.1. Analysis of variance for plant height

Source	DF	Sum of square	Mean square	F value	Pr>F
Lines	19	658.15	34.64	5.88	<0.0001
Al level	1	1342.26	1342.26	227.86	<0.0001
Lines*Al level	19	270.29	14.23	2.41	0.0094
Error	40	235.63	5.89		
Corrected Total	79	2506.33			

Table 3.2. LSD means separation for root length

Accession	Root length (cm)	
	Al 5%	Al 0%
PI628871	20.48 a **	8.03 a-e
PI556744	19.30 ab	10.05 abcd
PI625695	18.88 abc	10.35 abcd
PI556727	18.73 abcd	10.85 abc
PI590932	17.95 a-e	7.95 a-e
PI628880	17.85 a-e	7.50 a-e
PI675661	17.75 a-e	5.58 e
PI628842	17.23 a-e	6.80 de
PI628929	16.98 a-e	11.33 ab
PI556537	16.68 a-e	10.20 abcd
PI556612	16.55 a-e	6.58 de
PI556564	16.20 bcde	8.50 a-e
PI567779A	16.20 bcde	11.70 a
PI567611	15.90 bcde	6.90 cde
PI567643	15.83 bcde	7.23 bcde
PI628962	15.73 bcde	8.28 a-e
PI556515	15.25 bcde	8.85 a-e
PI628925	14.90 cde	8.90 a-e
PI567410C	14.53 de	5.88 de
PI594922	14.03 e	11.38 a

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 3.3. LSD means separation for plant height

Accession	Plant height (cm)	
	Al 5%	Al 0%
PI567643	33.67 a **	15.42 a-e **
PI567779A	28.40 ab	18.97 a
PI556727	27.43 bc	18.40 ab
PI556744	27.38 bcd	18.35 ab
PI628929	25.63 bcde	15.06 a-e
PI594922	24.62 b-f	18.30 ab
PI556612	24.42 b-f	18.93 a
PI556537	24.22 b-f	19.08 a
PI628925	23.40 b-g	14.90 a-e
PI556515	22.63 c-g	16.95 abc
PI556564	22.53 c-g	16.14 abcd
PI675661	22.51 c-g	9.75 f
PI567611	22.03 defg	13.57 a-f
PI628842	21.98 efg	9.95 ef
PI628871	21.48 efg	10.68 def
PI590932	20.83 efg	12.28 cdef
PI628880	20.47 efg	11.85 cdef
PI567410C	19.95 fg	18.35 ab
PI625695	18.67 fg	16.12 abcd
PI628962	17.12 g	12.48 b-f

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 3.4. LSD means separation for number of root nodules

Accession	Root nodules number (unit)	
	Al 5%	Al 0%
PI556612	18.75 a **	9.75 abc
PI556727	14.25 ab	4.75 abc
PI556537	13.50 ab	2.00 bc
PI594922	13.25 ab	2.75 bc
PI567779A	13.00 ab	3.50 abc
PI628925	12.50 ab	7.25 abc
PI625695	10.50 ab	2.50 bc
PI567643	10.25 b	5.50 abc
PI556744	9.00 b	7.25 abc
PI567410C	9.00 b	11.75 a
PI628842	9.00 b	2.50 bc
PI628962	8.75 b	10.25 ab
PI556515	8.50 b	6.00 abc
PI556564	8.25 b	4.25 abc
PI567611	8.00 b	2.25 bc
PI628929	7.25 b	5.50 abc
PI675661	7.00 b	1.00 c
PI590932	6.75 b	4.00 abc
PI628880	6.75 b	4.75 abc
PI628871	5.25 b	5.75 abc

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 3.5. pH of the medium pre- and post- study

Growth Medium samples	Initial pH	Final pH	
		0% Al	5% Al
1	4.30	4.30	5.34
2	4.40	4.44	5.26
3	4.32	4.27	5.23
4	4.34	4.34	5.28
5	4.30	4.29	5.30

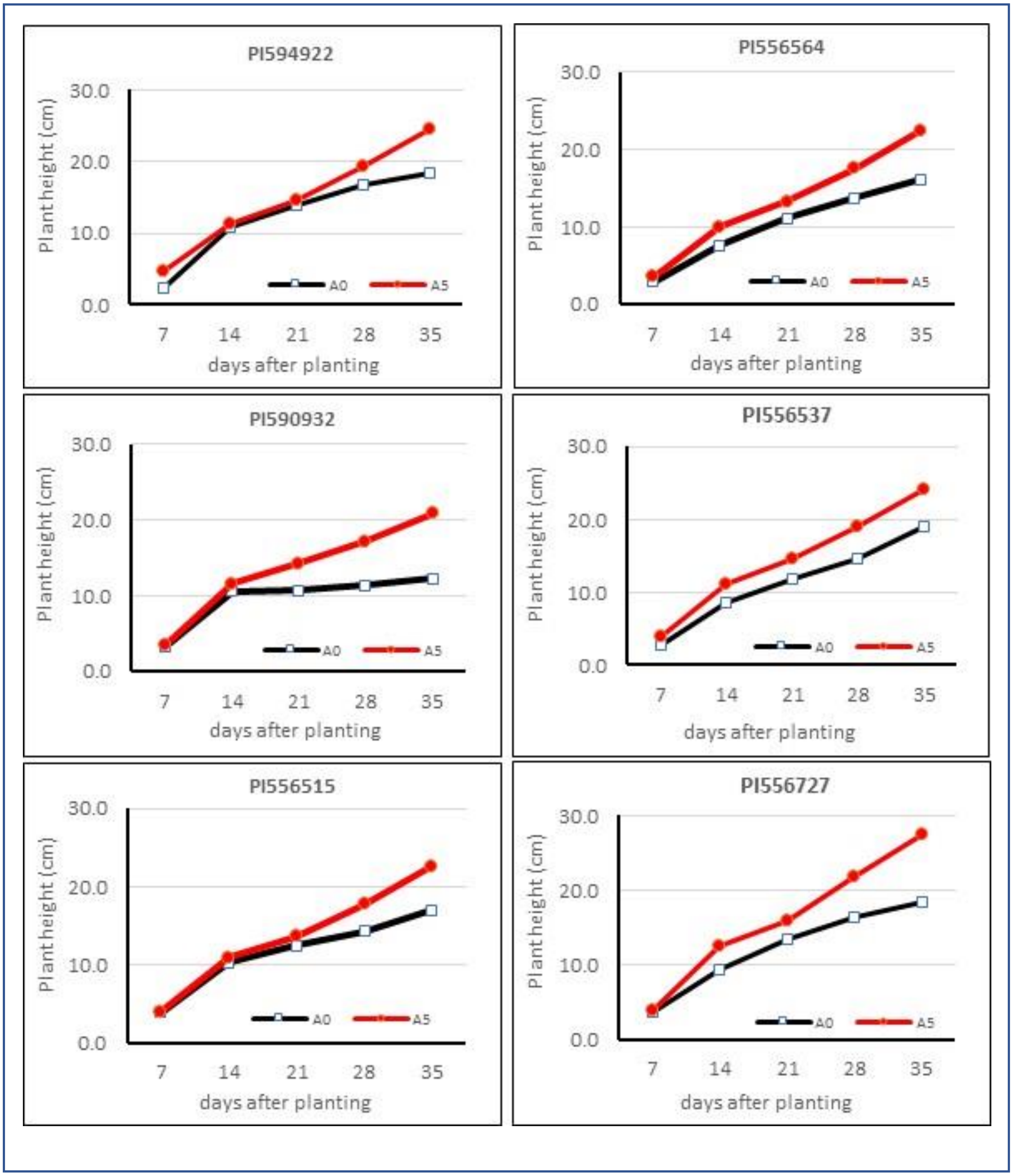


Figure 3.1. Means of plant height in 20 soybean lines from day 7 to day 35 after planting (A0: 0% aluminum, A5: 5% aluminum treatments)

Figure 3.1. (Cont'd)

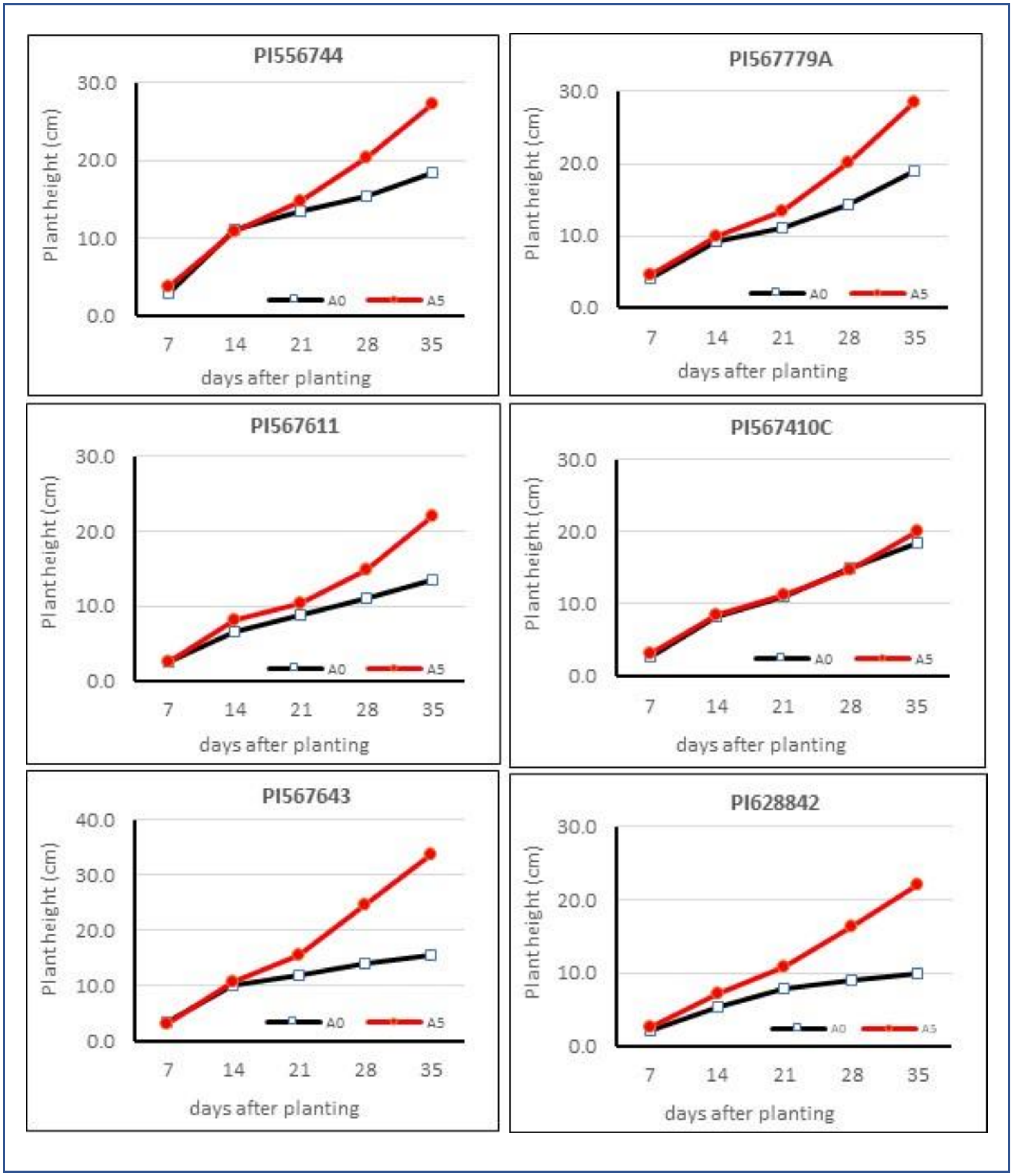
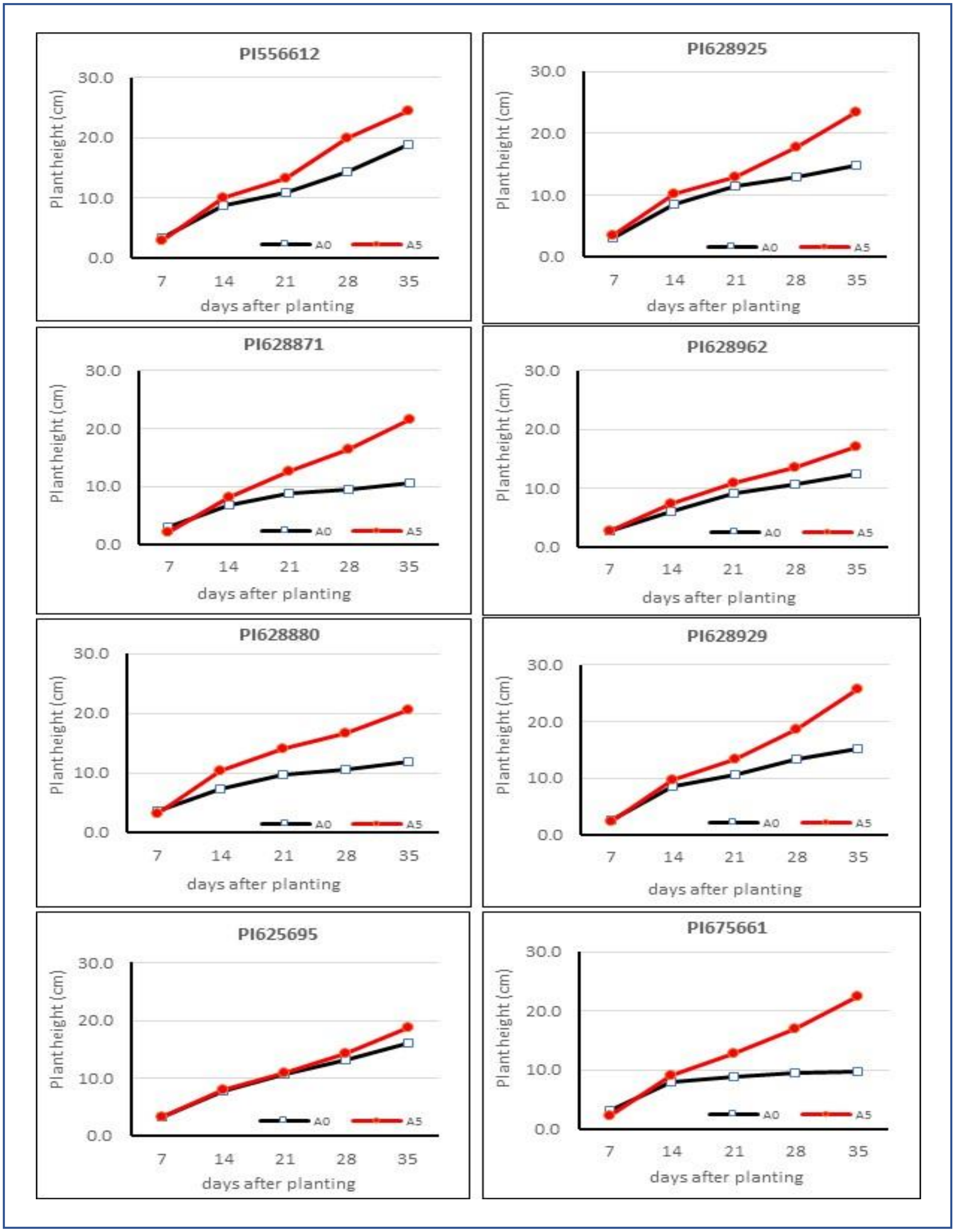


Figure 3.1. (Cont'd)



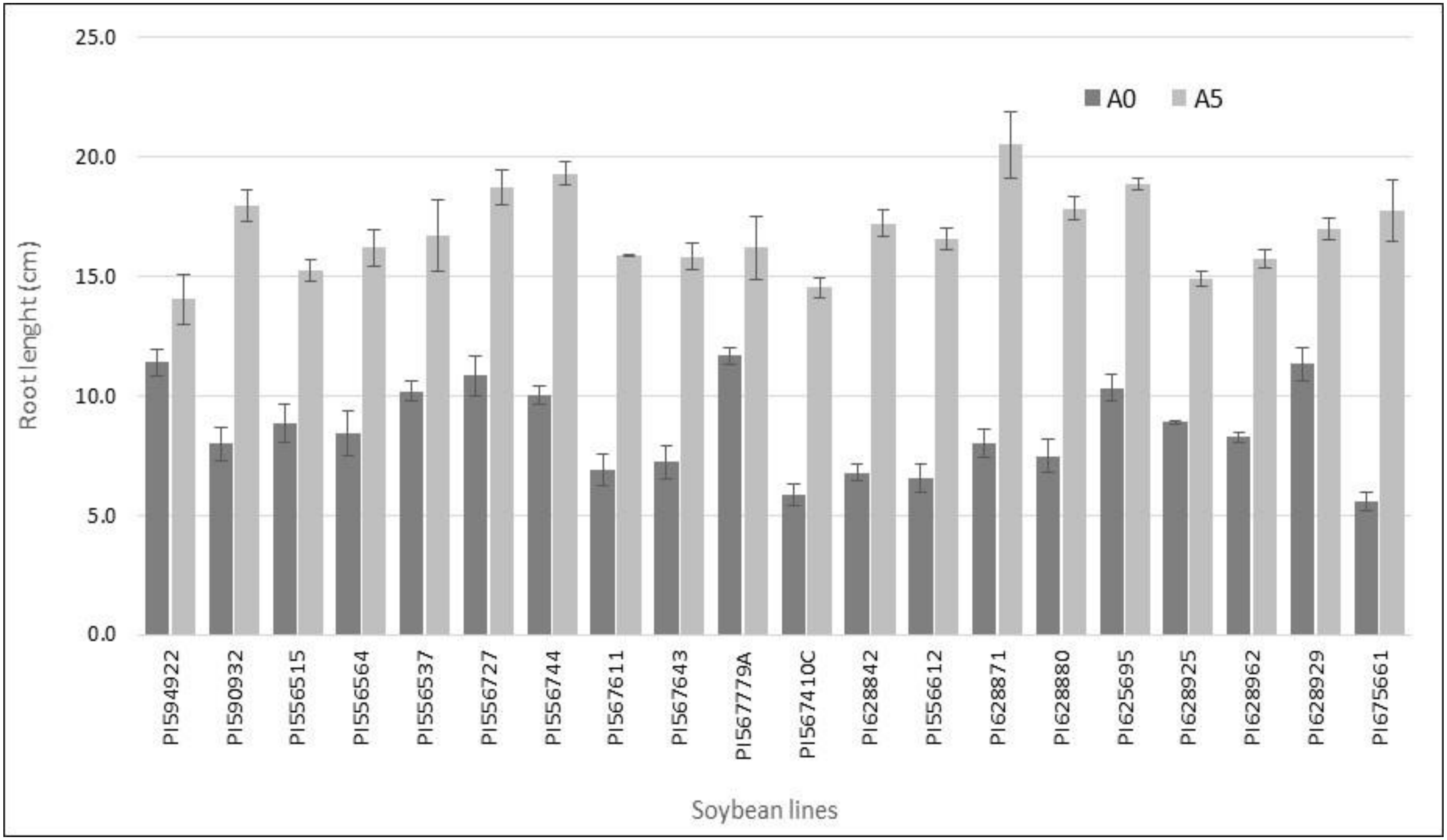


Figure 3.2. Means of root length in 20 soybean lines (at 35 days after planting)

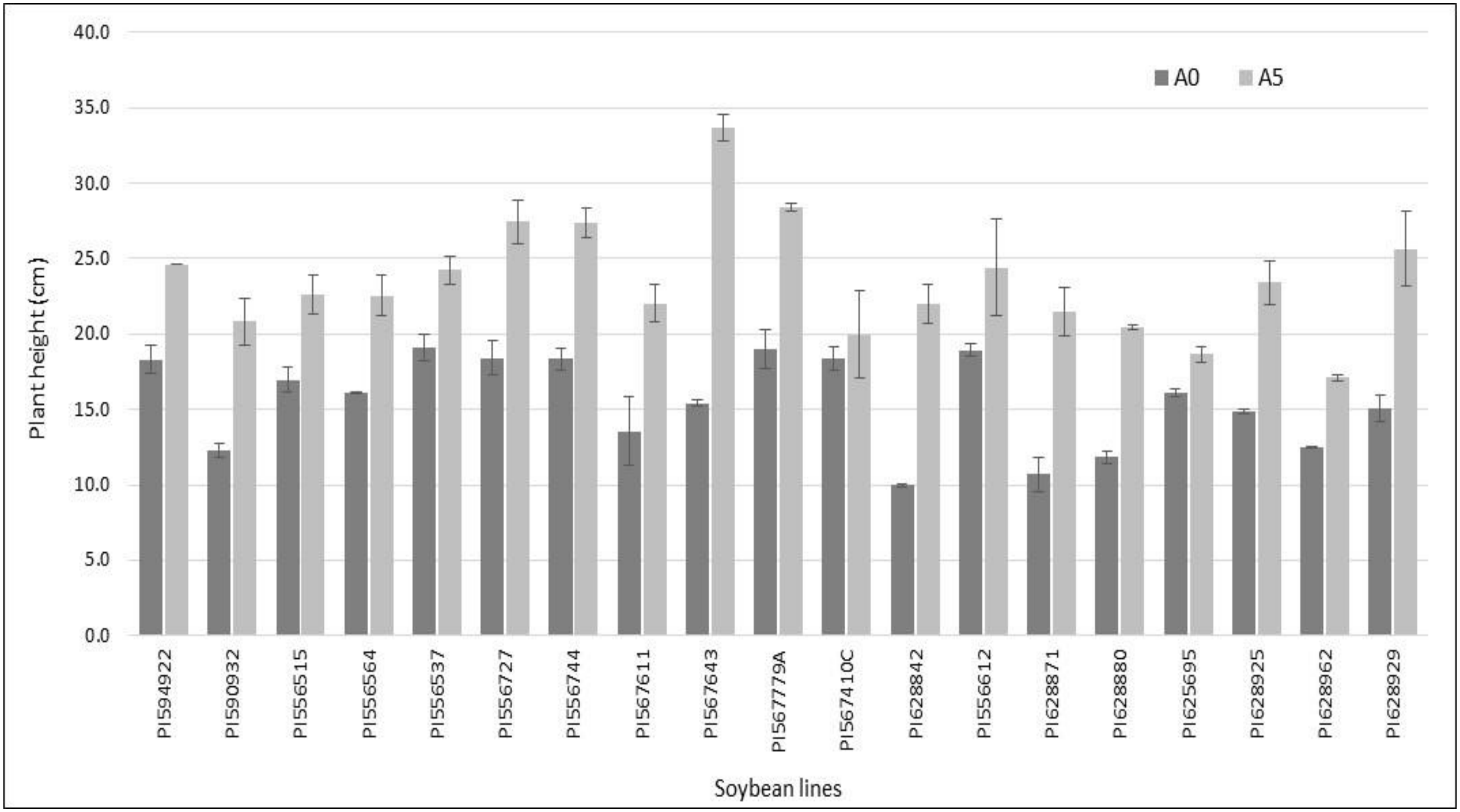


Figure 3.3. Means of plant height in 20 soybean lines (at 35 days after planting)

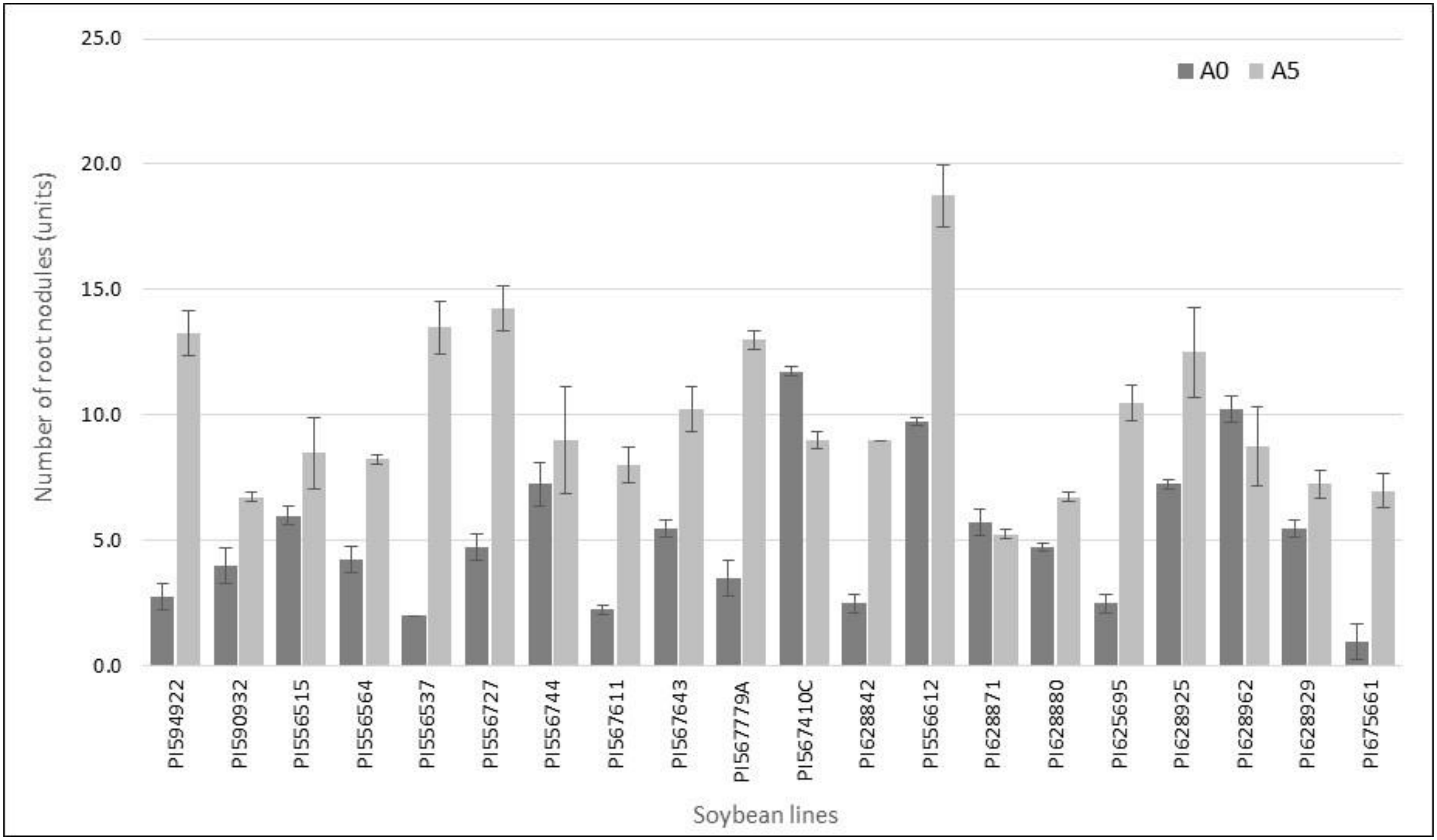


Figure 3.4. Means of number of root nodules in 20 soybean lines (at 35 days after planting)

REFERENCES

REFERENCES

Alleoni L.R., Cambri M.A., Caires E.F., Garbuio F.J., 2010. Acidity and aluminum speciation as affected by surface liming in tropical no-till soils. Nutrient management and soil and plant analysis. Soil Sci. Soc. Am. Journal 74:1010-1017. Doi: 09.0254/ssaj2009.0254

Arsyad D.M, Adie M.M., Kuswantoro H., 2013. Assembling of soybean superior varieties for specific agroecology in soybean – production and development techniques. Indonesian Agency for Agricultural Research and Development. In Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/03/dele_9.darman-1.pdf

Bloom P.R. and Erich M.S., 1996. The quantitation of aqueous aluminum in the environmental chemistry of aluminum. Second edition. Chapter 1:1-38. Lewis Publisher. ISBN: 1-56670-030-2.

Board, J E. and Caldwell A.G., 1991. Response of determinate soybean cultivars to low pH soils. LSU Agricultural Experiment Station Reports: 349. Link: http://digitalcommons.lsu.edu/agexp/349

Bojórquez-Quintal E., Escalante-Magaña C., Echevarría-Machado I., Martínez-Estévez M., 2017. Aluminum, a friend or foe of higher plants in acid soils. Front. Plant Sci. 8:1767. doi: 10.3389/fpls.2017.01767

Burton J. and Miranda L., 2013. Soybean improvement: achievements and challenges. Ratar.Povrt. 50:2 (2013) 44-51. doi:10.5937/ratpov50-4158

Cornelissen G., Jubaedah, Nurida N.L., Hale S.E., Martinsen V., Silvani L., Mulder J., 2018. Fading positive effect of biochar on crop yield and soil acidity during five growth seasons in an Indonesian Ultisol. Science of The Total Environment Volume 634:561-568. https://doi.org/10.1016/j.scitotenv.2018.03.380

Coupal B. and Lalancette J.M., 1976. The treatment of waste waters with peat moss. Water Research Vol. 10: 1071-1076. Pergamon Press. https://doi.org/10.1016/0043-1354(76)90038-5

Delhaize E. and Ryan P.R., 1995. Aluminum Toxicity and Tolerance in Plants. Plant Physiol. Vol.107: 31 5-321.

Fageria N.K., Ballgar V.C., Wright R.J., 1988. Aluminum toxicity in crop plants. Journal of Plant Nutrition, 11:3, 303-319. DOI: 10.1080/01904168809363804 online source: https://doi.org/10.1080/01904168809363804

Foy C.D. and Fleming A.L., 1978. The physiology of plant tolerance to excess available aluminum and manganese in acid soils.

Foy C.D., 1992. Soil chemical factors limiting plant root growth. Advance in soil science Vol. 19. Springer-Verlag New York Inc. Link: https://link.springer.com/content/pdf/10.1007/978-1-4612-2894-3_5.pdf

Havlin J.L., Tisdale S.L., Nelson W.L., Beaton J.D., 2014. Soil fertility and fertilization: an introduction to nutrient management. Eight editions. Published by Pearson Education, Inc. Upper Saddle River, New Jersey, USA. ISBN: 978-81-203-4868-4

IAARD, 2017. Description of soybean varieties (1918-2016). Published by the Indonesian Legume and Tuber Research Institute, Malang. In Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/09/kedelai.pdf

Krstic D. and Djalovic I., 2012. Aluminum in acid soils: chemistry, toxicity and impact on maize plants in food production – approaches, challenges, and tasks. ISBN: 978-953-307-887-8. DOI: 10.5772/1870.

Liao H., Wan H., Shaff J., Wang X., Yan X., Kochian L.V., 2006. Phosphorous and aluminum interaction in soybean in relation to aluminum tolerance. Exudation of specific organic acids from different regions of the intact root system. Plant physiology. Vol. 141: 674-684. Link: www.plantphysiol.org/cgi/doi/10.1104/pp.105.076497

Liang C., Piñeros M.A., Tian J., Yao Z., Sun L., Liu J., Shaff J., Coluccio A., Kochian L.V., Liao H., 2013. Low pH, aluminum, and phosphorus coordinately regulate malate exudation through GmALMT1 to improve soybean adaptation to acid soils. Plant Physiology, Vol. 161: 1347–1361. Link: www.plantphysiol.org/cgi/doi/10.1104/pp.112.208934

Martinsen V., Alling V., Nurida N.L., Mulder J., Hale S.E., Ritz C., Rutherford D.W., Heikens A., Breedveld G.D., Cornelissen G., 2015. pH effects of the addition of three biochars to acidic Indonesian mineral soils. Soil Science and Plant Nutrition, 61:5, 821-834, DOI:10.1080/00380768.2015.1052985 online source: https://doi.org/10.1080/00380768.2015.1052985

Mofidpoor M., 2007. Quality of peat moss as a component of growing media. Thesis. The University of British Columbia. Link: https://open.library.ubc.ca/cIRcle/collections/ubctheses/831/items/1.0100713

Mossor-Pietraszewska T., 2001. Effect of aluminum on plant growth and metabolism. Acta Biochimica Polonica. Vol. 48 No.3: 673-686.

Mulyani A., Rachman A., Dairah A., 2009. The spread of acidic-soil: potential and availability for agricultural development in Rock-phosphate: utilization of rock-phosphate as phosphate nutrient source. Pgs: 25-46. Link: http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/buku/fosfatalam/anny_mulyani.pdf

Nurlaeny N., Marschner H., George E., 1996. Effects of liming and mycorrhizal colonization on soil phosphate depletion and phosphate uptake by maize (Zea mays L.) and soybean (Glycine max L.) grown in two tropical acid soils. Plant and Soil (1996) 181: 275-285. Kluwer Academic Publishers. https://doi.org/10.1007/BF00012062

Osaki M., Watanabe T., Tadano T., 1997. Beneficial effect of aluminum on growth of plants adapted to low pH soils. Soil Science and Plant Nutrition, 43:3, 551-563, DOI: 10.1080/00380768.1997.10414782. online source: https://doi.org/10.1080/00380768.1997.10414782

Panda S.K., Baluska F., Matsumoto H. 2009. Al stress signaling in plants. Plant signaling and behavior 4:7 592-597

Rengel Z., Bose J., Chen Q., Tripathi B.N., 2015. Magnesium alleviates plant toxicity of aluminum and heavy metals. Crops and Pasture Science, 66:1298-1307. http://dx.doi.org/10.1071/CP15284

Rahman M.A., Lee S-H., Ji H.C., Kabir A.H., Jones C.S., Lee K-W., 2018. Importance of mineral nutrition for mitigating aluminum toxicity in plants on acidic soils: current status and opportunities. International Journal of Molecular Sciences 19, 3073. Doi: 10.3390/ijms19103073

Rice W.A., Penney D.C., Nyborg M., 1977. Effects of soil acidity on rhizobia numbers, nodulation, and nitrogen fixation by alfalfa and red clover. Can. J. Soil Sci. 57: 197-203. Link: https://www.nrcresearchpress.com/doi/pdf/10.4141/cjss77-024

Robbins J.A., 2018. Growing Media for Container Production in a Greenhouse or Nursery. FSA6097-PD-8-2018RV. The University of Arkansas System Division of Agriculture in little rock. Link: https://www.uaex.edu/publications/PDF/FSA-6097.pdf

Rochayati and Dariah. 2012. Acidic dry-land development: opportunities and challenges ***in*** Dry-land agriculture prospect in supporting food security. Indonesian Agency for Agricultural Research and Development (IAARD). Jakarta. pg. 187-206

Rout G., Samantaray S., Das P., 2001. Aluminium toxicity in plants: a review. Agronomie, EDP Sciences, 21 (1): 3-21. DOI: 10.1051/agro:2001105.

Santore R.C., Ryan A.C., Kroglund F., Rodriguez P.H., Stubblefield W.A., Cardwell A.S., Adams W.J., Nordheim E., 2018. Development and aaplication of a biotic ligand model for predicting the chronic toxicity of dissolved and precipitated aluminum to aquatic organisms. Environment Toxicology and Chemistry. Vol. 37 No. 1: 70-79. Wiley online library. DOI: 10.1002/etc.4020

SAS, 2012. SAS Institute Inc., version 9.4 Enhanced logging facilities, Cary, NC, USA.

Situmorang A.R.F., MUBARIK N.R., Triadiati. 2009. the use of acid-aluminium tolerant Bradyrhizobium japonicum inoculant for soybean grown on acid soils. HAYATI Journal of Biosciences. Vol. 16 No. 4. Pages: 157-160. ISSN: 1978-3019

Sposito G., 2016. The chemistry of soil. Third edition. Oxford University Press. New York. ISBN: 978-01-906-3088-1

Specht J.E., Hume D.J., Kumudini S.V., 1999. Soybean yield potential – a genetic and physiological perspective. Crop Science Vol. 39 No. 6: 1560-1570. DOI: 10.2135/cropsci1999.3961560x.

Subardja D. 2007. Characteristics and management of acid soils derived from volcanic rocks for extensification of maize in Sukabumi Regency, West Java. Journal of Soil and Climate. N0. 25/2007. In Bahasa Indonesia. Link: https://media.neliti.com/media/publications/134702-ID-none.pdf

Sumarno and Adie M.M. 2010. The development strategies of soybean production towards sustainable of food self-sufficiency. Journal of Iptek Tanaman Pangan. Vol. 5 no. 1: 49-63. In Bahasa Indonesia.

Surahman A., Hendriadi A., Kartiwa B., Sulistyo A., Mulyandari R.S.H., 2012. Achievement of soybean self-sufficiency in 2014 using system dynamics approaches. Policy on self-sufficiency and sustainable self-sufficiency of five main crops through dynamic system approaches. Indonesian Agency for Agricultural Research and Development. In Bahasa Indonesia. Link: https://www.litbang.pertanian.go.id/buku/aplikasi-system-modelling/

USDA, 2015. Legume seed inoculation. Plant materials technical notes number: TX-PM-15-01. United States Department of Agriculture-Natural Resource Conservation Service. Link: http://nrcs.usda.gov/internet/FSE PLANTMATERIALS/publications/etpmctn12525.pdf

Will E. and Faust J.E., 2010. PB1618-Growing Media for Greenhouse Production. The University of Tennessee Agricultural Extension Service. Link: http://trace.tennessee.edu/utk_agexcomhort/28

Wright, David, Lenssen, Andrew W. 2013. Inoculant Use on Soybean Seed. Agriculture and Environment Extension Publications. 192. Link: http://lib.dr.iastate.edu/extension_ag_pubs/192

Yang L.T., Qi Y.P., Jiang H.X., Chen L.S., 2013. Roles of organic acid anion secretion in aluminium tolerance of higher plants: a review article. BioMed Research International. Hindawi Publishing Corporation. Vol. 2013. http://dx.doi.org/10.1155/2013/173682

Yulnafatmawita, Detafiano D., Afner P., Adrinal, 2014. Dynamics of physical properties of Ultisol under corn cultivation in wet tropical area. International Journal on Advanced Science Engineering Information Technology. Vol.4 (2014) No. 5. ISSN: 2088-5334

CHAPTER 4. EVALUATION OF TWENTY SOYBEAN LINES FROM USA, CHINA, AND BRAZIL FOR TOLERANCE TO ACIDIC SOILS IN INDONESIA

Abstract

In Indonesia, the industry prefers large seeded soybean varieties. However, given the land available for soybean production in Indonesia has acidic soils, any large seeded varieties developed must also be tolerant to acidic soils. While some soybean varieties currently available in Indonesia show tolerance to acidic soils, their seeds are categorized as small to medium sized. Since it is easier to improve the seed size trait through breeding, in our attempts at developing better soybean varieties for Indonesia, we focused on adaptability to acidic soils and tolerance to aluminum toxicity as the primary breeding objective. Hence, in the present study we evaluated a previously selected set of 20 soybean lines under Indonesian acidic soils for their tolerance to acidic soil and aluminum toxicity. The study was conducted for two planting seasons, in 2017 and 2018, in two locations, Tanah Laut and Banjarbaru Regency. To select the best performing out of the 20 lines under current farmer practices, a split-split plot design with three factors was used with lime as the main plot, organic fertilizer as the subplot, and soybean genotypes as the sub-subplot. Two farmer preferred varieties, ANJASMORO and DERING, were used as standard check varieties to evaluate performance. Plant height, root length, number of root nodules, number of pods, and yield were used to evaluate the performance of the 20 lines. All data were analyzed using ANOVA and LSD. Of the 20 lines tested, the best four genotypes with the highest yields were PI675661 with 3.08 tons/ha (for farmers who applied lime, but did not apply organic fertilizer), PI628880 with 2.46 tons/ha and PI628929 with 2.41 tons/ha (both: for farmers who did not apply lime, but applied only organic fertilizer), PI628880 with 2.03 tons/ha (for farmers who did not apply lime or organic fertilizer), and PI628871 with 2.32 tons/ha and

PI628929 with 2.28 tons/ha (both: for farmers who applied a combination of lime and organic fertilizer). In the 2018 season, the yield reported was the highest in PI628925 with 2.38 tons/ha (for farmers who applied a combination of lime and organic fertilizer), and PI675661 with 2.17 tons/ha and PI628929 with 2.03 tons/ha (both: for farmers who did not apply lime, but applied only organic fertilizer). The yields of these lines in both seasons were higher than the two standard check varieties. The two lines PI675661 and PI628929 can be considered as the promising lines with superior traits: number of pods, yield, and larger seed size.

Introduction

People in Indonesia have grown soybean since the 16th century (Hartman et al., 2011). In Indonesia, soybeans have been mainly used as a processed food since the 17th century (Sidharta, 2008). Therefore, soybean is considered to be a part of the Indonesian food culture and is used in daily diets. About 88% of soybean from the national production is used to make tempeh and tofu, the two most preferred high protein processed food products, while another 10% is used for soy milk and soy-based snacks (Saliem and Nuryanti, 2011). As many as 81,000 household units and industries are involved producing tempeh and tofu, providing significant employment opportunities to locals (The National Standardization Agency Republic of Indonesia - BSN, 2012).

In addition to the dry grains, there is a demand for soybean meal, used as an essential ingredient and protein source in animal feed. With the increase in the livestock industry in Indonesia, this demand is expected to increase (Sudaryanto and Swastika, 2007; Bantacut, 2017). Given that more than 95% of soybean grain is processed into food products, the demand for soybean meal is met through imports.

The Ministry of Agriculture, Republic of Indonesia (2015) reported that the national demand for soybean reached 2.235 million tons of dry grain in 2014, a 5.67% increase from 2013. However, Indonesia can only produce about 955,000 tons which is 42.7% of the demand; hence, as demands increases, more imports are required. While efforts were underway to increase soybean production since the 1980s, due to the lack of varieties that met market demand and limited availability of land for soybean production, expected targets could not be reached.

The most important qualities of soybean required for tempeh and tofu industries are the large seed size, yellow seed-coat color, and the amount of grain that can be shelled and processed into products (personal communication with tempeh and tofu industries in South Kalimantan Province in 2018). Appearance of both tempeh and tofu are attractive to consumers when they are made with yellow seeds (Krisnawati and Adie, 2015). However, soybean cultivars currently available are categorized as having small and medium sized seeds, which do not meet the market demand as farmers have difficulty in shelling the grain.

With an interest in achieving self-sufficiency in rice, the most favorable agricultural land in the Java island was allocated to rice. This meant that the available land for increasing soybean production has to be in non-Java areas with acidic dry-lands. These dry-land areas are dominated by Ultisols representing 40.77% (Mulyani et al. 2009). While Ultisols have the potential to be used for agriculture, acidity (pH 4.27 – 5.30), low soil organic matter content, high saturated Aluminum (Al) levels, and high level of fixed Phosphorus (P) that plants cannot absorb (Rochayati and Dariah, 2012; Yulnafatmawita et al., 2014) limit their productive capacity.

The total acidic dry land in Indonesia is more than 100 million hectares (ha) and is mainly located on the islands outside of the Java island. For the past 30 years, lower soil acidity was known to be the main factor obstructing agriculture production in these areas and liming is recommended before planting. Besides liming, the Indonesian government has also recommended the use of organic fertilizer to improve soil fertility. Some farmers use liming to manage soil fertility issues brought forward by low pH. However, most smallholder resource poor farmers often do not have the capital to lime the soils, hence farmer-adoption of liming application has been low. Therefore, the government is considering the development of soybean varieties that can withstand acidic soils without great yield penalties as a means of assisting farmers to increase their economic gains by planting soybean in the acidic marginal lands.

The soybean breeding program in Indonesia started in 1918, but this program was only focused on developing high yielding varieties with broader adaptability. Focus on specific characteristics such as adaptation to soil type only began in the 1990s. As the result, the Indonesian Agency for Agricultural Research and Development (IAARD) was able to release three varieties; ANJASMORO, TANGGAMUS and DEMAS, with tolerance to acidic soils. However, the seed size of these three varieties does not meet the market demand that requires larger seed sizes of > 13 g/100 seeds (Kristanto et al., 2013). Thus, developing large seeded, early maturing and high yielding soybean varieties that perform well on acidic soils, are critically needed for Indonesia in order to meet the industry and consumer demands (Arsyad et al., 2013).

One of the main limitations in Indonesia's soybean breeding program is the lack of germplasm with the favorable characteristics mentioned above. To bridge this gap, we focused on adaptive breeding. In this study, over 700 germplasm accessions obtained from the US, China and Brazil were first screened for their tolerance to acidic soils (Chapter 2) and aluminum toxicity (Chapter 3) and then were field tested in naturally acidic Ultisols soils in Indonesia to evaluate their agronomic performance for two seasons in 2017 and 2018. Provided Indonesia cannot rely on the Java island for increasing soybean production (Rachman, et al., 2007; Rochayati and Dariah, 2012; Susanti and Waryanto, 2017), the field testing was conducted in the Kalimantan region of the large island, dominated by acidic Ultisols.

In this study, we were particularly interested in testing soybean varieties that have tolerance to acidic soils, large seed size and the preferred yellow seed coat color in comparison to the currently used varieties in the country. As such, this study is an important part of the government's efforts in providing large seeded soybean varieties for the farmers. Therefore, our objectives were: to evaluate the 20 previously selected lines for tolerance to acidic soils in Indonesia and to select promising lines that can be grown by farmers and/or for use as parents in the soybean breeding program in Indonesia.

Materials and Methods

Location and experimental design

The field research was conducted in two different seasons and sites. In the 2017 planting season, the study took place in Tanah Laut region as one of the agriculture centers in the South Kalimantan province. This area is located on $03^{0}64'$ – 03°99' of south latitude and 114,642° – 114,872° of east longitude. In the 2018 season, the study was conducted in Banjarbaru region which is located on 03°27' - 03°29' of south latitude and 114°45' - 114°45' of east longitude. This experiment used a split-split plot design with three factors including lime as the main plot, organic fertilizer as the sub plot, and soybean genotypes as the sub-sub plot. Lay out of these plots arrangement in the field is shown in Figure 4.1.

Treatments

Two levels of lime were used as the main plots, which were 0.0 tons/ha and 5.0 tons/ha. Two levels of organic fertilizer were also used as the sub plots, which consisted of 0.0 tons/ha and 10.0 tons/ha. All units were arranged randomly in the field. The number of soybean lines used in the 2017 and 2018 seasons were the same, which were 20 lines previously selected (further described in Chapters 2 and 3) as the sub-sub plot, but the number of local varieties used as controls were different. In the 2017 season, five local varieties; ANJASMORO, ARGOMULYO, BURANGRANG, DEMAS, and DERING, were used as standard check varieties whereas in the 2018 season, due to limited availability of seed, we could only use 2 of these local varieties, ANJASMORO and DERING as standard check varieties. However, only two of the same local varieties will be used in data analysis for both seasons. ANJASMORO is a popular soybean variety widely planted in Indonesia for its' larger seed size and higher yield compared to other varieties, and DERING is a variety which performs well when planted in the dry season.

The individual experimental plot size was 1.6 x 1.0 m^2 for the 2017 planting season and 1.0 x 0.8 m^2 for the 2018 season. Each plot was separated by a small drainage channel of 0.2 m in depth and 0.3 m in width. The distance between main plots was 1.0 m. The total number of experimental units was 200 in the 2017 season and 176 in the 2018 season. The differences of plot size between the 2017 and 2018 season was because the availability of land for research on both locations was different. The planting population per hectare for both seasons were the same with each plant being planted using 0.4 m x 0.15 m row space. Planting depth was 2.5 cm with 2 seeds per planting hole.

Soil test

Soil tests were conducted prior to planting date and after the study. The purpose of soil sampling was to determine the pH level, organic matter content, N, P, and K, total cation exchange capacity and the Al saturation level. The soil sampling was carried out using a soil drill in a composite manner with five sample points per site, each time sampling was carried out. The soil samples was taken at a depth of 20 cm (Ackerson, 2018). After the experiment, the soil samples were collected in accordance with organic matter treatments. All soil samples were sent to the Indonesian Swampland Agriculture Research Institute (ISARI) for analysis. ISARI is the IAARD's national reference laboratory in the Kalimantan area located in Banjarbaru that conducts soil, plant, fertilizer, and water testing.

Maintenance

The plants were fertilized using commercial chemical fertilizers with the following dosage: 11.5 kg/ha nitrogen, 52 kg/ha P_2O_5, and 60 kg/ha K_2O. These dosages are based on government recommendations for soybean planted on acidic dry land. All fertilizers were applied once at the time of planting (Yusuf and Harnowo, 2012). In this study, we applied only a half dosage of all fertilizer as recommended by IAARD to get the benefit from Rhizobium and organic fertilizer application. Watering and pesticide applications were done on a need basis.

Observations and data analysis

We observed variables at vegetative and reproductive stages. As such, measurements were taken at five points in the 2017 season and 3 points in the 2018 season. The main variables considered were plant height, root length, number of rood nodules, number of pods, and yield.

Data was subjected to analysis of variance using PROC MIXED in SAS (SAS, 2012). Fisher's Protected Least Significant Differences (LSD) at a 5% significance level was used to test the significant differences among treatments based on the significant results obtained from the analysis of variances (ANOVA) test.

Participatory selections with local farmers

Research locations in Both Tanah Laut and Banjarbaru Regency were within the area of the South Kalimantan Assessment Institute for Agricultural Technology (AIAT) research stations. These two locations have become centers for dissemination of agricultural technologies to farmers and officers in the South Kalimantan Province. Therefore, while we had our own selection criteria, we used this opportunity to invite farmers and extension officers to evaluate and choose their preferred lines based on their own selection criteria. This participatory approach was important to us to gather useful information from groups that promote and/or use promising line(s) released from research efforts.

Results and Discussion

The soil test results are shown in Table 4.1. The soil analyses provided by IAARD (Eviati and Sulaeman, 2009) indicate both Tanah Laut and Banjarbaru soils are very acidic with pH levels < 4.0. Soil carbon stocks of both locations are categorized to be very low (<1.00%) with low nitrogen content (<0.20%). Therefore, the C/N ratio of both locations were low. Cation exchange capacity (CEC) of soil in Banjarbaru site was higher than Tanah Laut site which also had a higher level of phosphorous. These results indicated that the soils in both locations have low nutrient content not suitable to support crops. However, the aluminum content was also low and at a level that can be tolerated by crops (Osaki et al., 1997; Bojórquez-Quintal et al., 2017).

Line performance in the 2017 planting season

There were significant differences among the lines at $P < 0.0003$ and significant interaction of lime and organic fertilizer application at $P<0.0096$ (Table 4.4). This result indicated each line has different abilities for producing seed influenced by both environment and genetic factors. Other than the genetic factors, environmental factors such as low soil pH level (Table 4.1), lower precipitation (Table 4.2), diseases, and practical difficulties had an effect on the yield. Application of lime and organic fertilizer improved soil quality and supported plant growth to obtain a higher yield. Moreover, the 20 tested lines were also genetically different from some aspects such as the maturity group (Table 4.3) and number of pods produced (Table 4.7).

Calcification treatment of 5 tons/ha dolomite increased soil pH to about 1.0 point from 3.66 to 4.77, and the combination treatments of lime and organic fertilizer application further increased soil pH by 1.6 points from 3.66 to 5.26 (Table 4.1). Application of lime is widely used to increase soil pH and to provide calcium (Ca) and magnesium (Mg) to the growing medium to benefit plant growth (Gillman et al., 1998; Pagani, 2011). Soil pH can also be increased by applying organic fertilizer to the medium (Whalen et al., 2000). We observed this as the application of organic fertilizer as a sub plot resulted in the higher yield.

In the first treatment, which is application of 5.0 tons/ha of lime as the main plot and 10.0 tons/ha of organic fertilizer as the sub plot, the highest yield was obtained by DERING (local standard check variety), PI628871, and PI628929. The yield of these three-soybean accessions/lines were >0.5 tons higher than ANJASMORO (the first local standard check variety), the widely planted variety in Indonesia, and the other tested lines (Table 4.5). Moreover, the PI628871 and PI628929 had a larger seed size compared to DERING, which can fulfill the market demand for seed size, especially with PI628929 that had 18.92 gram/100 seeds and categorized as large seeded in Indonesia (Table 4.3).

The second treatment, the application of 5.0 tons/ha lime as the main plot and 0.0 tons/ha organic fertilizer as the sub plot, lines PI675661 and PI628929 gave the highest yield. Line PI675661 produced 3.08 tons/ha was not only the highest yield obtained in the second treatment but also the highest among all tested lines in all treatments. In this second treatment, although the yield of PI675661 does not differ from the two local standard check varieties, the difference in yield exceeded by > 1.0 tons/ha. The other line, PI628929, yielded 2.26 tons/ha which was 0.5 tons higher than the local standard check variety, ANJASMORO (Table 4.5). Line PI675661 had a similar seed size and seed coat color to that of the local variety ANJASMORO, while PI628929, had larger seeds and fell in the large seeded category with the preferred yellow seed color (Table 4.3). As such, these two lines can be considered as promising lines to improve soybean production in acidic soils.

For the third treatment, the application of 0.0 tons/ha lime as the main plot and 10.0 tons/ha organic fertilizer as the sub plot, lines PI628880 and PI628929 gave the highest yields. The yield of these two lines were 0.1 to 0.2 tons higher than local ANJASMORO and DERING varieties currently grown. Line number PI628929 had seed sizes larger than both ANJASMORO and DERING. Seeds of PI628880 were larger than DERING but were smaller than ANJASMORO. The third treatment is the treatment preferred by farmers because they can afford to obtain organic fertilizer but are often not able to purchase lime. Therefore, PI628929 shows promise to be used as a variety for planting in acidic soils.

The fourth treatment, the application of 0.0 tons/ha lime as the main plot and 0.0 tons/ha organic fertilizer as the sub plot, generated PI628880 and PI628962 as the lines with the highest yield. Line number PI628880 yielded 2.03 tons/ha which was 0.7 tons higher than both ANJASMORO and DERING local varieties, while PI628962 produced 1.72 tons/ha which was 0.5 higher than ANJASMORO and DERING. However, the seed size of both PI628880 and PI628962 lines were slightly smaller than ANJASMORO and hence would not be suitable to cater the market demands.

As for number of pods, line number PI675661 generated more pods than ANJASMORO and DERING for the first and second treatments (Table 4.7). Since number of pods is one important component in soybean production, PI675661 has met another criterion to be a promising line beside the seed size and seed color. However, the third and fourth treatments show that both ANJASMORO and DERING perform better than PI675661. In the fourth treatment, there was an interesting result where PI628925 produced the highest number of pods exceeding ANJASMORO and DERING. Interestingly, PI628925 was selected by farmers as a preferred line considering plant height and maintaining the crop in the field and because PI628925 has a seed size similar to ANJASMORO. Therefore, PI628925 could become a promising line especially if it can be bred to improve seed size and pod number.

The results obtained from the four treatments can be summarized based on farmer preferences. Lines PI628929 and PI675661 were considered as promising lines on acidic soils for farmers who could afford to add lime and organic fertilizer to improve soil fertility before planting. Line PI628880 could be considered in the soybean improvement programs for farmers with limited capital.

The higher yields obtained by the lines mentioned above indicate applying organic fertilizer prior to planting provide better growing conditions for soybean, mainly on acidic soil. In this treatment, adding organic fertilizer even with no lime application helped increase the soil organic carbon to a higher level than other treatments (Table 4.1). Adding organic fertilizer to acidic soil would not only increase soil organic matter (SOM) content (McCauley et al., 2017), but also could reduce aluminum (Al) activity in the soil (Lyamuremye et al., 1996). The existence of Al in small amounts in the soil will stimulate plant root growth and increase the plant's ability to take up soil nutrients (Bojorquez-Quintal et al., 2017).

The advantage of adding manure to increase soil quality specifically for acidic soil is beneficial for farmers in developing countries like Indonesia. Low crop productivity induced by low soil nutrient content and Al toxicity has changed farmers' decision from planting soybean to other remunerative crops like rice. The common recommendation provided by government to reduce soil acidity is by applying lime to the soil. However, smallholder farmers cannot afford to purchase lime and tend to avoid the recommendation (Uguru et al., 2012). Therefore, the results of this study can be used to recommend the use of organic fertilizer for soybean production in acidic soils.

Line performance in the 2018 planting season

Significant differences were found among organic fertilizer applications, and lines as factors and the interaction between all factors, the 3-way-interactions, to the yield. These results indicated that combining lime and organic fertilizer application to the soil was the best treatment to obtain the highest yield. One of the positive effects of applying the combination treatment in this study was an increase in soil pH by 1.24 points from 3.88 to 5.12 (Table 4.1). Increase in soil pH levels helped to increase the yield.

In the first treatment, which was application of lime at 5.0 tons/ha as the main plot and 10.0 tons/ha of organic fertilizer as the sub plot, line number PI628925 obtained the highest yield with 2.38 tons/ha which was 0.4 tons higher than the local standard check varieties ANJASMORO, and more than 1.0 tons higher than DERING (Table 4.9). In the second treatment, the application of 5.0 tons/ha lime as the main plot and 0.0 tons/ha organic fertilizer as the sub plot, lines PI675661 gave the highest yield with 1.95 tons/ha which was 0.2 tons higher than ANJASMORO and 0.8 tons higher than DERING.

In the third treatment, the application of lime at 0.0 tons/ha as the main plot and application of organic matter at 10.0 tons/ha as the sub plot, line PI675661 gave the highest yield followed by PI628929 with the second highest yield. The yield of line PI675661 was 2.17 tons/ha which was 0.7 tons higher than the local variety ANJASMORO and more than 1.0 tons higher than DERING. The yield of line PI628929 yield was 2.03 tons/ha which was higher than both ANJASMORO and DERING. In the fourth treatment, when lime was applied at 0.0 tons/ha as the main plot and organic matter was applied at 0.0 tons/ha as the sub plot, lines PI556744 and P628871 had the highest yields with 1.47 tons/ha and 1.43 tons/ha respectively. These yields were 0.3 tons higher than the local variety ANJASMORO and 0.5 tons higher than DERING. Line PI556744 also had a bigger seed size than ANJASMORO and was categorized as large-seeded.

In terms number of pods, line number PI628880 generated more pods than both ANJASMORO and DERING for the first and third treatments, treatments that used organic fertilizer, while line number PI675661 produced the highest number of pods for the second and fourth treatments, treatments without organic fertilizer applications (Table 4.11). If number of pods are to be considered as a production variable, PI628880 and PI675661 would be the two promising lines that can be suggested for acidic soils. However, the yield of all tested lines and local varieties in the 2018 planting season were lower than the 2017 planting season (Figure 4.2) due to a number of reasons.

Some challenges influenced soybean yield in the 2018 study to be lower than that of the 2017 study due to climate, disease, and practical difficulties. The 2018 study began in the mid of May which was the end of the rainy season in the district of Banjarbaru. Furthermore, the rainfall was much lower in 2018 than that of 2017 season (Table 4.2). In order to maintain live and growing plants, all plots had to be watered two times daily when there was no rain during the day or the previous day. Pest infestations also contributed to the lower yields in 2018. During the 2018 study, there were no other crops around the field planted by farmers due to it being a dry season. Therefore, we observed higher pest infestations in 2018 than in 2017. Among the pests found in the field were: true white grubs, armyworms, grasshoppers, stink bugs (green), and stem borers. Combined with manual control, we had to spray pesticides three times during the growing season to protect the plants.

We were able to make some important observations from these two seasons of field studies. Liming applications can increase soil pH as much as 1.0 point or more and is a good recommendation for farmers who are not resource constrained, to increase soybean production. Furthermore, higher yields can be achieved by combining the applications of both lime and organic fertilizer. Applying lime will also reduce the negative effects of aluminum and increase crop yields (Kamprath, 1984). However, for farmers who have limited capital, the application of organic fertilizer to acidic soils can be considered as the best option to improve soybean production. By doing so, farmers could benefit by increasing soil pH and the soil organic carbon

(SOC). In addition, application of manure also increases the availability of phosphorous and reduce effects from aluminum toxicity (Babou et al. 2007).

The soil organic carbon is an important indicator of soil health (Wiesmeier at al. 2019). The content of SOC in the experimental fields was very low and needed enhancement through amendments such as application of cattle manure. Indonesia has high precipitation during the rainy season, from October to March, and has high temperatures during the dry season, from May to September/October. These seasonal differences influence SOC content in the soil (Wiesmeier at al. 2019). Applying organic fertilizer also enhances water holding capacity of the soil which is important for farmers who cultivate dry-acidic land (Haynes and Naidu, 1998).

In summary, through our research efforts, we have identified several soybean lines out of the initial set of over 700 tested, that farmers could use to improve soybean production in acidic soils in Indonesia. We are also able to recommend soybean lines based on preferred farmer practices and seasonal weather patterns. The 20 lines that are able to withstand acidic soils can also be added to the IAARD’s soybean breeding program to facilitate the development of better varieties and to improve the seed size of local varieties.

APPENDIX

Table 4.1. Soil test results from two locations in 2017 and 2018 growing seasons

Location/site	pH*	C-Org (%)	N (%)	C/N (%)	CEC (cmol/kg)	P (Bray 1, ppm)	Al (cmol/kg)
Tanah Laut							
Before study	3.66	0.95	0.15	6.42	15.03	19.26	2.48
After study							
- Treatment #1:** w/o lime and w/o organic fertilizer	3.97	0.97	0.20	4.8		25.90	1.08
- Treatment #2: w/o lime + w/ organic fertilizer	4.00	1.09	0.12	9.05		29.48	1.66
- Treatment #3: w/ lime + w/ organic fertilizer	5.26	1.08	0.10	10.44		26.65	0.00
- Treatment #4: w/ lime + w/o organic fertilizer	4.77	0.96	0.16	5.82		23.79	0.00
Banjarbaru							
Before study	3.88	0.93	0.18	5.17	21.95	52.91	0.00
After study							
- Treatment #1: w/o lime and w/o organic fertilizer	3.90	0.78	0.08	9.74		84.20	0.00
- Treatment #2: w/o lime + w/ organic fertilizer	3.98	0.73	0.08	9.43		6.99	0.00
- Treatment #3: w/ lime + w/ organic fertilizer	5.12	0.84	0.09	9.13		119.15	0.00
- Treatment #4: w/ lime + w/o organic fertilizer	4.79	0.72	0.06	11.93		187.97	0.00

**Soil was tested in the IAARD's soil, plant, fertilizer, and water testing laboratory*
(Tanah Laut is location for 2017 season and Banjabaru is location for 2018 season)
*** w/ = with; w/o = without*

Table 4.2. Monthly rainfall during the field research in 2017 and 2018 growing seasons

Location	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nop	Dec	Total
2017													
Tanah Laut	509	248	215	287	295	179	127	134	81	145	431	398	3,049
2018													
Banjar baru	391	313	370	174	75	112	77	78	107	107	227	205	2,236

Table 4.3. PI number, seed weight, and maturity group of soybean lines and local varieties used in 2017 and 2018 growing seasons

PI Number	Weight of 100 seeds (g)	MG / Origin
PI594922	15.56	V / USA
PI590932	17.31	VI / USA
PI556515	14.89	VIII / USA
PI556564	16.96	VII / USA
PI556537	14.12	VIII / USA
PI556727	15.61	VIII / USA
PI556744	17.58	V / USA
PI567611	10.53	IV / China
PI567643	16.72	IV / China
PI567779A	16.33	IV / China
PI567410C	13.91	VII / China
PI628842	14.75	VIII / China
PI556612	11.72	V / China
PI628871	14.21	VI / Brazil
PI628880	13.91	V / Brazil
PI625695	13.46	VII / Brazil
PI628925	14.51	VIII / Brazil
PI628962	14.07	VII / Brazil
PI628929	18.92	IX / Brazil
PI675661	15.24	X / Brazil
ANJASMORO	15.30	Local / Indonesia
DERING	10.70	Local / Indonesia

Table 4.4. Analysis of variance for yield variable in the 2017 growing season

Source of var.	DF	Sum of Square	Mean Square	F-value	Pr > F
Lime	1	0.1700	0.1700	1.04	0.4941
Organic fertilizer	1	0.0529	0.0529	0.15	0.6952
Lines	21	20.5005	0.9762	2.85	0.0003
Lime*Organic Fertilizer	1	2.3994	2.3994	7.02	0.0096
Lime*Lines	21	5.7235	0.2725	0.80	0.7157
Organic Fertilizer*Lines	21	7.2673	0.3461	1.01	0.4583
Lime*Organic Fertilizer*Lines	21	4.7230	0.2249	0.66	0.8618
Block	1	0.3645	0.3645	2.22	0.3760
Block*Lime	1	0.1638	0.1638	0.48	0.4907
Residual	86	29.4071	0.3419		

Table 4.5. Comparison of means for yield in the 2017 growing season

Lines	Yield (t/ha)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
DERING	**2.37** a**	2.03 ab	2.31 abc	1.29 b-f
P628871	**2.32 a**	1.98 ab	1.79 abcd	1.65 abc
PI628929	2.28 a	**2.26** ab	2.41 ab	1.31 bcde
PI590932	1.84 ab	1.90 ab	1.19 bcde	1.48 bcde
PI628880	1.83 ab	1.98 ab	**2.46** a	**2.03** a
PI567643	1.71 ab	1.07 b	1.63 abcd	1.38 bcde
PI567779A	1.54 ab	0.98 b	1.11 cde	0.64 h
PI628962	1.49 ab	1.87 ab	2.02 abcd	1.72 ab
PI628842	1.43 ab	1.72 ab	1.71 abcd	1.29 b-f
PI567611	1.42 ab	1.05 b	1.07 cde	0.77 fgh
PI556727	1.33 ab	1.72 ab	1.13cde	0.74 gh
PI556744	1.22 ab	1.48 b	1.25 a-e	1.17 c-g
ANJASMORO	1.20 ab	1.61 ab	2.26 abc	1.36 bcde
PI625695	1.19 ab	1.24 b	0.97 de	1.04 efgh
PI567410C	1.18 ab	1.23 b	1.48 a-e	1.28 b-f
PI594922	1.11 ab	0.97 b	1.16 bcde	1.20 b-g
PI628925	1.10 ab	1.63 ab	1.49 a-e	1.60 abcd
PI556515	1.08 ab	0.78 b	1.73 abcd	1.17 c-g
PI675661	0.87 b	**3.08** a	1.75 abcd	1.27 b-f
PI556564	0.86 b	1.45 b	1.65 abcd	1.38 bcde
PI556537	0.79 b	1.39 b	1.60 abcd	1.67 abc
PI556612	0.53 b	1.65 ab	0.30 e	1.11 d-h

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 4.6. Comparison of means for plant height in the 2017 growing season

Lines	Plant height (cm)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
DERING	**78.50** a**	70.00 a	70.00 ab	63.30 a
PI628880	67.70 ab	54.20 bc	66.80 b	53.50 b
ANJASMORO	61.20 bc	58.00 b	76.50 a	57.95 ab
PI675661	58.20 bc	**76.80** a	**83.30** a	**64.80** a
PI628929	54.60 bc	50.60 bcd	45.90 d	44.00 c
PI567779A	53.65 c	45.75 cde	56.15 c	42.25 c
PI567611	50.70 c	41.35 def	32.30 e	33.20 defg
PI567410C	40.70 cd	48.90 bcd	48.40 cd	39.40 cd
PI567643	36.70 de	36.95 efg	45.90 d	37.05 cde
PI590932	34.20 def	34.95 fgh	33.28 e	31.45 d-h
PI628925	33.63 def	38.05 efg	32.60 e	36.70 cdef
PI628871	33.20 def	35.10 fgh	42.00 d	31.45 d-h
PI594922	24.10 ef	24.40 ij	23.30 fg	22.20 i
PI556515	29.10 ef	24.90 hij	28.10 efg	26.20 ghi
PI556727	28.95 ef	30.55 ghi	27.01 efg	21.40 i
PI628962	27.20ef	26.60 hij	27.50 efg	25.80 ghi
PI556744	26.30 ef	29.98 ghi	27.70 efg	22.65 hi
PI556612	26.00 ef	31.10 ghi	24.90 efg	27.70 fghi
PI556537	25.30 ef	29.40 ghi	31.20 ef	28.50 e-i
PI625695	24.50 ef	18.55 i	20.60 g	23.70 hi
PI556564	24.20 ef	23.80 ij	25.80 efg	23.10 hi
PI628842	20.80 f	22.60 ij	22.20 g	21.40 i

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 4.7. Comparison of means for pod number in the 2017 growing season

Lines	Pods number (unit)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
PI675661	**118.30** a**	**62.70** a	54.40 b-f	37.50 a-f
ANJASMORO	102.30 ab	42.10 a-f	59.70 b-f	37.70 a-e
PI628880	101.70 ab	62.70 a	73.20 bc	47.10 ab
DERING	94.60 abc	60.10 ab	**125.60** a	37.90 a-e
PI567611	90.90 abcd	55.60 abcd	61.10 bcde	40.20 a-e
PI567410C	74.50 bcde	53.10 abcd	69.40 bcd	39.70 a-e
PI567779A	70.60 b-f	45.00 a-e	71.60 bc	26.60 ghi
PI628929	67.70 c-g	57.40 abc	57.80 b-f	42.60 abcd
PI590932	65.80 c-g	57.20 abc	46.50 b-f	36.30 c-g
PI628871	63.70 c-g	50.70 a-e	61.60 bcde	37.70 a-e
PI628842	63.00 c-g	44.40 a-e	63.00 bcde	41.40 a-e
PI628925	59.50 defg	55.20 abcd	74.60 b	**47.80** a
PI556612	58.50 defg	43.70 a-e	29.60 f	32.60 d-i
PI625695	55.80 efg	39.30 a-f	36.60 ef	43.80 abc
PI628962	54.70 efg	39.90 a-f	56.80 b-f	36.70 c-g
PI556744	51.30 efg	30.00 cdef	41.20 def	27.30 fghi
PI567643	48.40 efg	24.20 ef	44.10 cdef	35.40 c-h
PI556564	40.70 fg	36.30 a-f	39.20 ef	31.30 e-i
PI594922	40.20 fg	27.90 def	41.10 cdef	33.30 d-i
PI556727	40.50 fg	32.30 b-f	44.10 cdef	25.20 hi
PI556537	38.10 g	31.70 cdef	50.60 b-f	37.20 b-f
PI556515	37.20 g	15.10 f	45.10 b-f	24.70 i

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 4.8. Analysis of variance for yield in the 2018 growing season

Source of var.	DF	Sum of Square	Mean Square	F-value	Pr > F
Lime	1	0.5841	0.5841	1.71	0.3206
Organic fertilizer	1	4.0289	4.0289	37.91	<0.0001
Lines	21	19.4695	0.9271	8.72	<0.0001
Lime*Org Fertilizer	1	3.3948	3.3948	31.94	<0.0001
Lime*Lines	21	5.4923	0.2615	2.46	0.0008
Org Fertilizer*Lines	21	6.2674	0.2984	2.81	0.0001
Lime*Org Fertilizer*Lines	21	8.7224	0.4154	3.91	<0.0001

Table 4.9 Comparison of means for yield in the 2018 growing season

Lines	**Yield (t/ha)**			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
PI628925	**2.38 a****	1.66 ab	1.20 ef	0.99 bcd
ANJASMORO	1.80 ab	1.70 ab	1.40 b-f	1.15 a
PI567779A	1.78 ab	0.42 f	1.29 cdef	0.45 gh
PI594922	1.58 bc	1.14 def	1.25 def	0.86 bcde
PI556727	1.57 bc	1.01 f	1.97 abc	1.05 abc
PI556744	1.50 bc	0.93 f	1.09 efg	**1.47 a**
PI567410C	1.38 bcd	1.19 cdef	1.04 efg	0.50 fgh
PI628962	1.36 bcd	1.15 def	1.17 ef	0.98 bcd
PI567643	1.28 bcd	1.15 def	1.96 abcd	0.82 cdef
PI590932	1.26 bcd	1.42 bcde	2.00 abc	1.09 ab
PI628871	1.24 bcd	1.50 bcd	1.14 efg	**1.43 a**
DERING	1.22 bcd	1.10 def	1.16 efg	0.95 bcde
PI628929	1.16 bcd	1.58 abc	**2.03** ab	0.98 bcd
PI625695	1.07 cde	1.14 def	0.82 fg	0.80 cdef
PI556564	1.04 cde	1.00 f	1.13 efg	0.64 efgh
PI567611	1.03 cde	1.09 def	1.42 bcdef	0.42 h
PI675661	1.02 cde	**1.95 a**	**2.17 a**	0.98 bcd
PI556612	0.98 cde	0.85 f	1.19 ef	1.00 bcd
PI628842	0.96 cde	1.22 cdef	1.06 efg	0.76 defg
PI628880	0.74 de	1.46 bcde	1.69 abcde	0.90 bcde
PI556515	0.51 e	0.40 f	0.44 g	0.43 h
PI556537	0.49 e	1.07 ef	0.92 fg	0.38 h

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 4.10. Comparison of means for pod number in the 2018 growing season

Lines	Pods number (unit/plant)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
PI628880	**178.67** a**	111.33 a	**213.67** a	143.67 ab
PI675661	171.00 a	**113**.00 a	129.00 b	**158.00** a
ANJASMORO	112.00 b	91.33 ab	85.67 cd	48.00 cd
PI628929	94.67 bc	68.67 abcd	86.00 cd	116.00 bc
PI567410C	93.00 bc	35.00 cd	57.67 defg	43.67 cd
DERING	91.33 bcd	69.67 abcd	101.00 bc	47.67 cd
PI628925	85.67 bcde	87.00 abc	72.33 cdef	70.33 c
PI567611	68.67 cdef	41.33 bcd	52.00 defg	50.67 cd
PI625695	65.33 defg	24.33 d	43.33 efg	40.00 cd
PI567643	62.67 efgh	33.00 cd	75.00 cde	28.33 d
PI556612	60.00 efgh	78.67 abc	60.67 defg	40.67 cd
PI556537	59.33 efgh	38.67 cd	36.67 fg	42.00 cd
PI628842	59.00 efgh	46.67 bcd	43.33 efg	42.67 cd
PI590932	57.67 fgh	38.33 cd	57.67 defg	51.67 cd
PI628962	55.67 fghi	39.00 cd	32.33 g	45.00 cd
PI567779A	54.67 fghij	26.33 d	52.33 defg	37.33 cd
PI628871	43.67 fghij	38.33 cd	65.00 cdefg	43.00 cd
PI556564	40.67 ghij	31.33 cd	34.33 g	33.67 cd
PI556744	40.33 ghij	30.00 cd	39.00 efg	46.00 cd
PI594922	38.00 hij	37.00 cd	43.67 efg	33.33 cd
PI556515	28.67 ij	29.67 cd	34.33 g	15.00 d
PI556727	28.00 j	28.33 cd	54.67 defg	40.00 cd

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Table 4.11. Comparison of means for root length in the 2018 growing season

Lines	Root length (cm)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
PI628880	**24.78** a**	23.06 abc	25.28 a	**25.89** a
PI675661	24.68 ab	23.20 ab	**25.82** a	22.73 abc
PI628929	24.54 ab	**26.30** a	23.30 ab	23.79 ab
ANJASMORO	23.59 abc	20.89 abcd	23.29 ab	18.72 cde
PI628871	22.99 abcd	19.07 bcde	22.42 abc	19.07 cde
PI590932	22.24 a-e	16.33 defg	18.48 b-f	18.24 cde
PI628925	21.63 a-f	20.80 bcd	22.18 abc	19.37 bcde
DERING	21.20 a-f	17.58 cdef	25.27 a	18.08 cde
PI625695	20.46 a-f	16.77 defg	18.43 cdef	15.02 ef
PI628962	20.29 a-f	17.41 defg	17.79 cdef	17.34 def
PI567410C	20.20 a-f	15.52 defg	14.79 ef	15.74 ef
PI556612	19.98 b-f	17.84 b-f	19.22 bcde	14.79 ef
PI567779A	19.78 cdef	14.91 efg	17.17 def	18.30 cde
PI628842	19.33 cdef	16.26 defg	14.99 def	17.58 de
PI556744	19.29 cdef	16.37 defg	19.61 bcd	19.41 bcde
PI567643	19.07 cdef	19.36 bcde	18.31 cdef	15.28 ef
PI556727	18.77 def	14.80 efg	18.42 cdef	21.08 bcd
PI594922	18.47 def	17.81 b-f	18.74 bcde	18.26 cde
PI556515	17.92 ef	13.57 fg	13.82 f	12.80 f
PI556564	17.76 ef	12.03 defg	15.78 def	14.90 ef
PI567611	17.38 f	16.94 defg	18.56 b-f	16.78 def
PI556537	16.89 f	17.12 defg	16.17 def	17.52 de

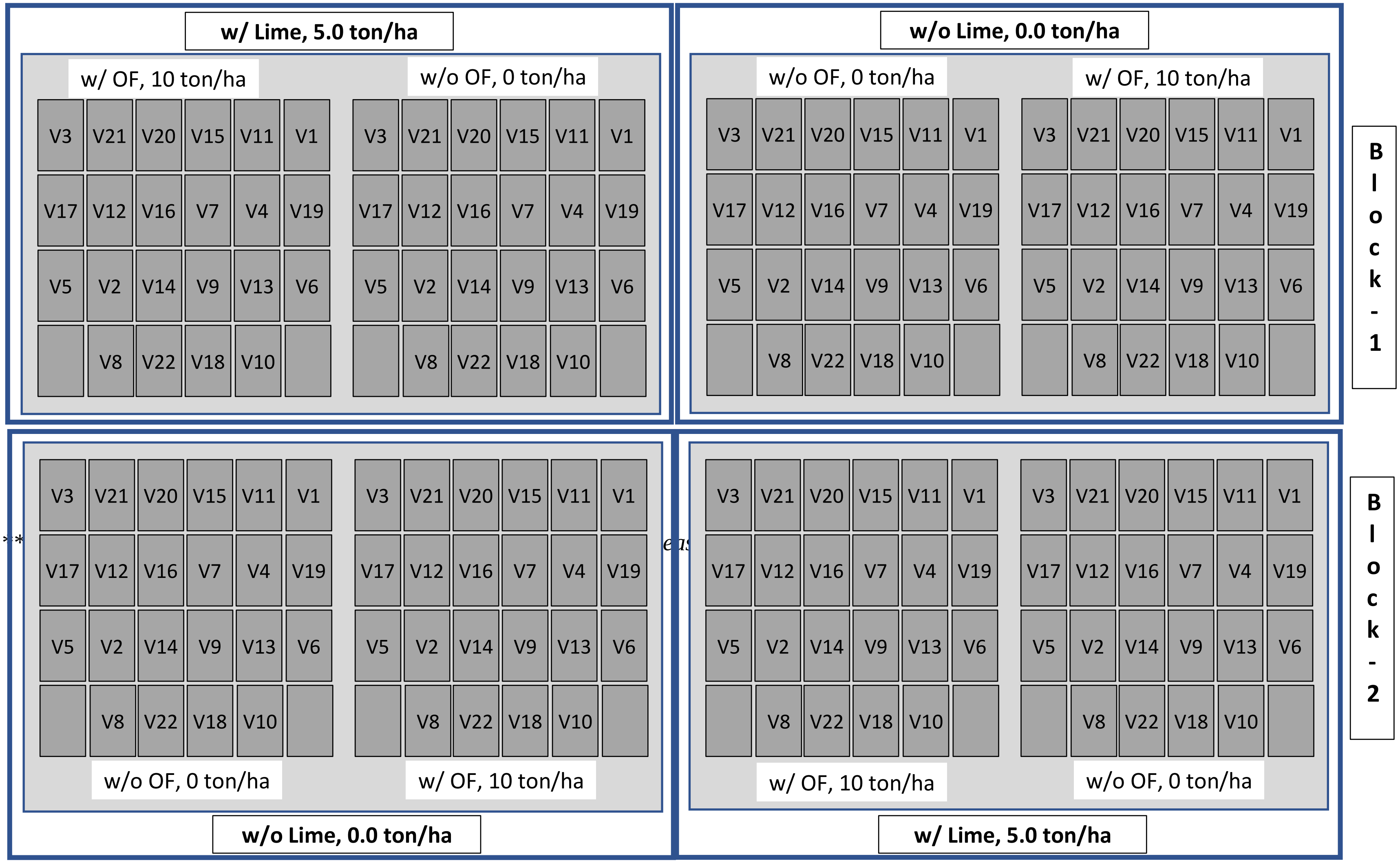
*** means within columns followed by the same letter are not significantly different (P<0.05)*

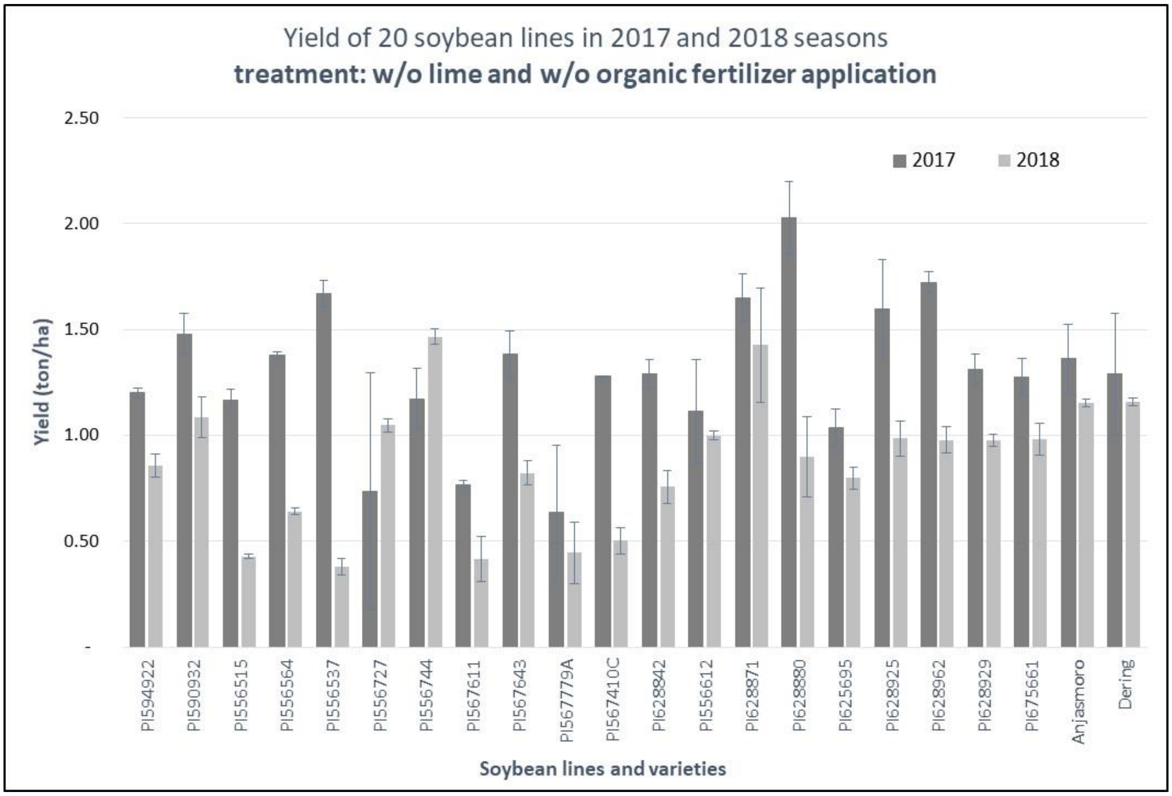
Table 4.12. Comparison of means for plant height in the 2018 growing season

Lines	Plant height (cm)			
	W/ Lime		W/O Lime	
	W/ Organic Fertilizer	W/O Organic Fertilizer	W/ Organic Fertilizer	W/O Organic Fertilizer
PI628880	84.50 a**	87.67 a	93.00 a	82.00 a
PI675661	74.94 ab	68.39 b	90.33 a	76.67 ab
PI628925	74.33 abc	68.50 b	72.11 b	70.78 b
PI628929	71.78 abcd	69.11 b	87.11 a	75.72 b
PI590932	70.00 a-e	41.33 ef	54.83 cd	38.00 efg
PI556744	69.67 a-e	49.22 de	49.11 de	47.89 cde
PI567643	60.89 a-f	46.00 def	55.44 cd	47.83 cde
PI567611	58.78 a-g	42.11 ef	50.67 cde	43.33 cde
PI567779A	57.67 b-g	40.33 efg	56.22 cd	47.67 cde
PI628871	56.44 b-g	63.94 bc	63.11 bc	53.44 c
PI556727	55.11 b-g	50.89 cde	53.94 cd	50.44 cd
PI628842	54.83 b-g	43.33 def	43.56 de	36.67 efg
PI556612	53.67 b-g	37.33 efg	48.44 de	37.89 efg
ANJASMORO	53.17 b-g	56.39 bcd	54.39 cd	39.78 def
PI567410C	50.78 b-g	42.39 ef	49.11 de	42.61 cdef
PI594922	48.67 c-g	41.94 ef	45.22 de	42.00 cdef
PI556515	47.78 defg	34.89 fg	42.58 de	30.92 fg
PI628962	47.67 defg	43.94 def	50.00 cde	47.22 cde
PI556537	45.44 efg	38.11 efg	45.33 de	43.89 cde
DERING	39.67 fg	57.00 bcd	46.33 de	49.78 cd
PI625695	35.50 fg	38.94 efg	38.67 ef	31.00 fg
PI556564	33.56 g	26.56 g	28.78 f	27.11 g

*** means within columns followed by the same letter are not significantly different (P<0.05)*

Figure 4.1. Layout of main plots, sub plots, and sub-sub plots in the field research





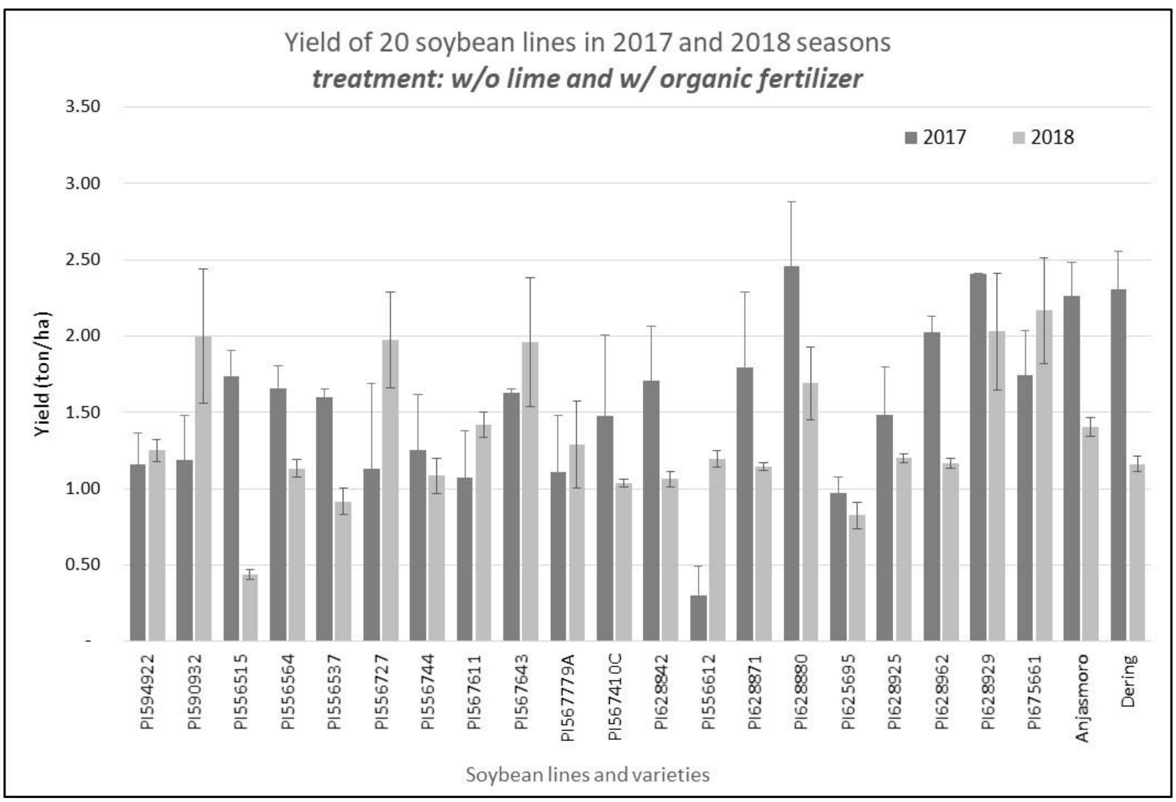
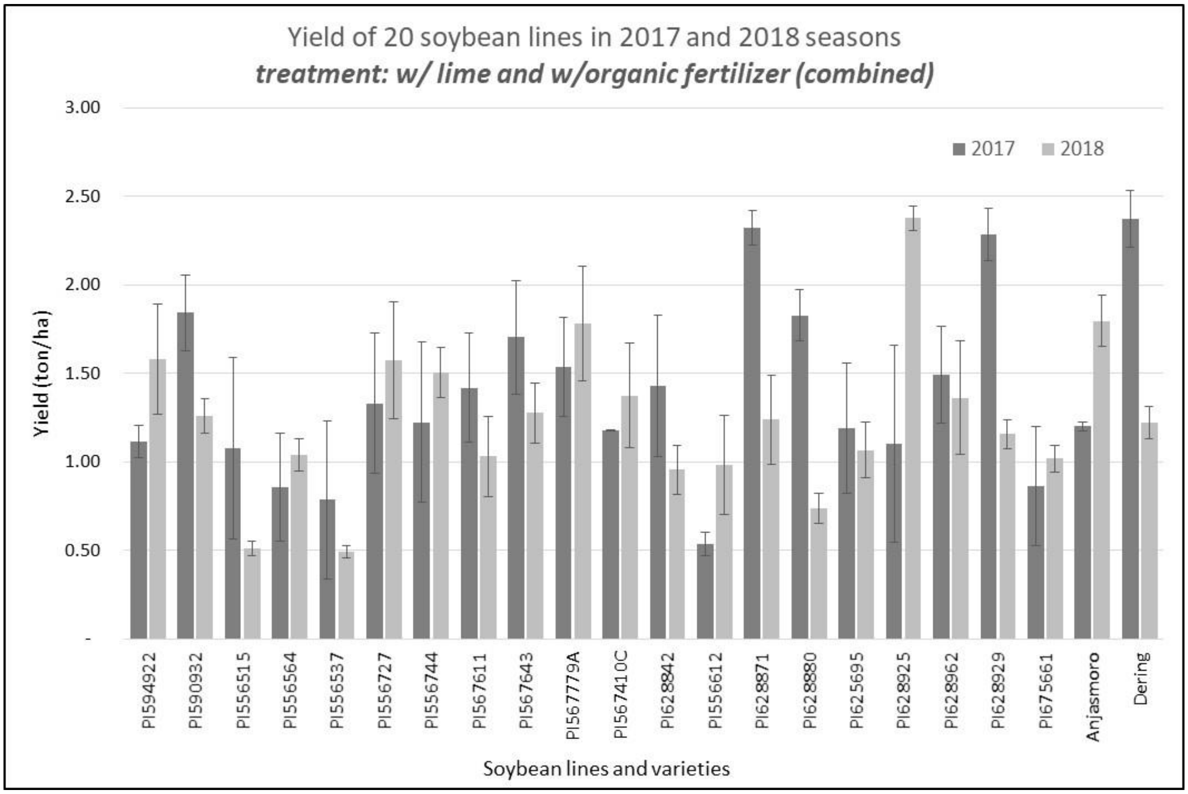
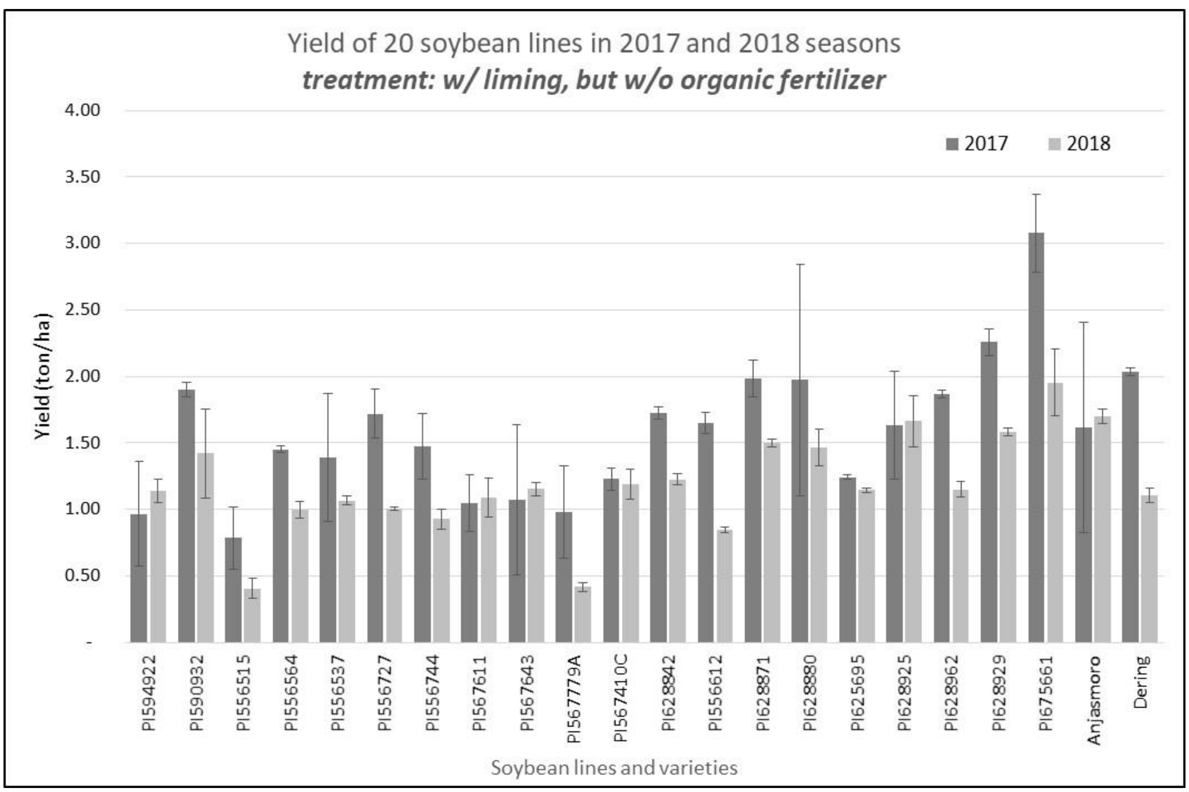


Figure 4.2. Means of yield in the 20 selected lines and 2 local varieties for both 2017 and 2018 growing seasons

Figure 4.2. Cont'd





REFERENCES

REFERENCES

Arsyad D.M., Adie M.M., Kuswantoro H. 2013. Soybean varieties breeding on specific of agroecology in Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 205-228. In Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2016/03/dele_9.darman-1.pdf

Ackerson J.P., 2018. Soil Sampling Guidelines. Purdue University Extension. Bulletin number AY-368-W. Link: https://www.extension.purdue.edu/extmedia/AY/AY-368-w.pdf

Babou O.J., Shiow-Long Tsai, Zeng Y Hseu. 2007. Relationship between compost pH buffer capacity and P content on P availability in a virgin Ultisol. Soil Science Vol. 172 No. 1: 68-85

Badan Stardarisasi Indonesia [BSN]. 2012. Tempeh: Indonesian gift to the world. Jakarta. In Bahasa Indonesia. Online source: http://www.bsn.go.id/uploads/download/Booklet_tempe-printed21.pdf

Bantacut T. 2017. Soybeans development for food sovereignty, industrial, and economy. Journal of Food. Vol. 26 No. 1. pages: 81 - 96

Bojórquez-Quintal E., Escalante-Magaña C., Echevarría-Machado I., Martínez-Estévez M., 2017. Aluminum, a friend or foe of higher plants in acid soils. Front. Plant Sci. 8:1767. doi: 10.3389/fpls.2017.01767

Eviati and Sulaeman, 2009. Technical instructions on soil chemical, plant, water, and fertilizers analysis. Second edition. Published by the Indonesian Soil Research Institute of the Indonesian Agency for Agricultural Research and Development. Bogor. ISBN 978-602-8039-21-5. In Bahasa Indonesia. Accessed May 10th, 2019. Link: http://balittanah.litbang.pertanian.go.id/ind/dokumentasi/juknis/juknis_kimia2.pdf

Gillman J.H., Dirr M.A., Braman S.K., 1998. Effects of dolomitic lime on growth and nutrient uptake of Buddleia davidii 'Royal Red' grown in pine bark. J. Environ. Hort. 16(2):1l1-1I3.

Hartman G.L., West E.D., Herman T.K., 2011. Crops that feed the World 2. Soybean—worldwide production, use, and constraints caused by pathogens and pests. Food Sec. (2011) 3:5–17 DOI:10.1007/s12571-010-0108-x. Link: https://naldc.nal.usda.gov/download/48661/PDF

Haynes, R.J. and Naidu, R. 1998. Influence of lime, fertilizer and manure application on soil organic matter content and soil physical conditions: A review. Nutrient Cycling in Agroecosystem: 51, 123-137

Kamprath E.J., 1984. Crop Response to Lime on Soils in the Tropics. ASA-CSSA-SSSA, 677 South Segoe Road, Madison, WI 53711, USA. Soil Acidity and Liming-Agronomy Monograph no. 12 (2nd Edition).

Krisnawati A. and Adie M.M. 2015. Selection of soybean genotypes by seed size and its prospects for industrial raw material in Indonesia. Procedia Food Science 3. Pages: 355 – 363. doi: 10.1016/j.profoo.2015.01.039

Kristanto H., Arsyad D.M., Purwantoro. 2013. Acidic-dry land soybean characteristic. Cash crop Journal. Indonesian Agency for Agricultural Research and Development. No. 25-2013: 1–10. In Bahasa Indonesia

Lyamuremye, F., Dick, R. P., Baham, J. 1996. Organic amendments and phosphorus dynamics ***in*** phosphorus chemistry and sorption. Soil Science 161(7):426-435

McCauley A., Jones C., Olson-Rutz K., 2017. Soil pH and organic matter. Nutrient management module No. 8 (4449-8). Montana State University Extension. Link: http://landresources.montana.edu/nm/documents/NM8.pdf

Ministry of Agriculture Republic of Indonesia. 2015. Strategic plan on 2015-2019 period. Link: http://www1.pertanian.go.id/file/RENSTRA_2015-2019.pdf

Mulyani A., Rachman A., Dairah A., 2009. The spread of acidic-soil: potential and availability for agricultural development in Rock-phosphate: utilization of rock-phosphate as phosphate nutrient source. Pgs: 25-46. In Bahasa Indonesia

Osaki M., Watanabe T., Tadano T., 1997. Beneficial effect of aluminum on growth of plants adapted to low pH soils. Soil Science and Plant Nutrition, 43:3, 551-563, DOI: 10.1080/00380768.1997.10414782. Link: https://doi.org/10.1080/00380768.1997.10414782

Pagani A. 2011. Soil pH and lime management for corn and soybean. Dissertation. Iowa State University. Ames, Iowa

Rochayati and Dariah. 2012. Acidic dry-land development: opportunities and challenges ***in*** Dry-land agriculture prospect in supporting food security. Indonesian Agency for Agricultural Research and Development (IAARD). Jakarta. pg. 187-206. Link: http://www.litbang.pertanian.go.id/buku/Lahan-Kering-Ketahan/BAB-III-6.pdf

Rachman A, Subiksa IGM, Wahyunto. 2007. Soybean planting area development to sub-optimal land ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg.185-203

Saliem H.P. and Nuryanti S. 2011. The global economic perspective of soybean and cassava to support food self-sufficient. National seminar on the result of a variety of beans and tubers. Malang. Indonesia. in Bahasa Indonesia. Link: http://balitkabi.litbang.pertanian.go.id/wp-content/uploads/2012/09/01_SET_Handewi-1.pdf

SAS, 2012. SAS Institute Inc., version 9.4 Enhanced logging facilities, Cary, NC, USA.

Sidharta, Myra. 2008. Soyfoods in Indonesia ***in*** the world of soy. University of Illinois Press. Urbana and Chicago. pg. 195-207. ISBN: 9780252033414

Sudaryanto and Swastika. 2007. The Economic of soybean in Indonesia in ***in*** Soybean: production and development. Indonesian Agency for Agricultural Research and Development. pg. 1-27. In Bahasa Indonesia

Susanti and Waryanto. 2017. Statistic of agriculture 2017. Published by Center for Agricultural Data and Information System Ministry of Agriculture Republic of Indonesia ISBN : 979-8958-65-9

Uguru M.I, Oyiga B.C., Jandong E.A. 2012. Responses of some soybean genotypes to different soil pH regimes in two planting seasons. The African Journal of Plant Science and Biotechnology. Vol 6(1). Pages: 26-37.

Whalen J.K., Chang C., Clayton G.W., Carefoot J.P., 2000. Cattle manure amendments can increase the pH of acid soils. Soil Sci. Soc. Am. J. 64:962–966. Link: https://dl.sciencesocieties.org/publications/sssaj/pdfs/64/3/962

Wiesmeier M., Urbanski L., Hobley E., Lang B., Lützow M., Marin-Spiotta E., Wesemael B., Rabot E., Ließ M., Garcia-Franco N., Wollschläger U., Vogel H-J., Kögel-Knabner I., 2019. Soil organic carbon storage as a key function of soils - A review of drivers and indicators at various scales. Geoderma Vol. 333. Pages 149-162. https://doi.org/10.1016/j.geoderma.2018.07.026

Yulnafatmawita, Detafiano D., Afner P., Adrinal, 2014. Dynamics of physical properties of Ultisol under corn cultivation in wet tropical area. International Journal on Advanced Science Engineering Information Technology. Vol.4 (2014) No. 5. ISSN: 2088-5334.

Yusuf A. and Harnowo D., 2012. Soybean technology supports tntegrated plant management. Published by the North Sumatera Assessment Institute for Agricultural Technology. Link: http://sumut.litbang.pertanian.go.id/ind/images/DokumenPdf/Brosur/SLPTT%20kedelai,%20brosur%20buku.pdf

CHAPTER 5. CONCLUSIONS AND FUTURE DIRECTIONS

Conclusions

This present study was intended to support the Indonesian soybean breeding program by broadening the number of accessions that are tolerant to acidic soils and has larger seed size to increase production areas and meet the market demands. Initially we screened 706 soybean accessions originating from the USA, China, and Brazil in a medium with pH 5.0 and selected 60 best performing accessions based on plant height and number of days taken to reach V2 stage. Of the 60 genotypes, the 20 selected lines from USA and the 20 selected lines from China reached the V2 stage in 12 - 24 days after planting while the 20 selected lines from Brazil took slightly longer to reach the V2 stage with 16 - 30 days after planting. In the second phase of the present study, 20 best performing lines out of the previous 60 were selected based on their performance on acidic soils under three pH levels of 4.5, 5.0, and 5.5. The 20 selected accessions with better performance on either two or all three of the pH levels based on plant height and root length are PI628871, PI628962, PI567611, PI556744, PI556727, PI615695, PI628925, PI567779A, PI556537, PI628842, PI594922, PI556515, PI590932, PI628929, PI628880, PI567410C, PI567643, PI556612, PI675661, and PI556564.

The next phase of the present study was conducted to evaluate the responses of the 20 selected soybean lines obtained in the previous study to aluminum (Al) toxicity, which is a major limiting factor for soybean production in Indonesia in areas with low pH. We found that plant height and root length of the 20 lines were higher in the medium with 5% Al compared to the control with 0.0% aluminum. Of the 20 lines tested, PI628871 accession had the longest root length and PI567643 accession had the highest plant height. When comparing the initial and final pH levels of the growth medium, we observed a positive effect of adding Al to the growth medium as it increased the pH of the medium from 4.30 to 5.28. Moreover, we assumed the amount of Al given to the medium was not high enough to cause a toxic effect to the soybean plants. As reported by some researchers, the presence of Al in low concentrations would be beneficial to the plant by stimulating the root growth. The results also indicated that the 20 selected lines would be tolerant to soils with low pH and Al^{3+} levels up to 5% (by weight) and thus, could perform well under Indonesian acidic soils.

With the results obtained from the greenhouse experiments at Michigan State University, the 20 selected lines were then tested in low pH Ultisols soils in Indonesia for two growing seasons in 2017 and 2018. Given that depending on the resources farmers often lime the soil and/or add organic matter to improve the quality of low pH soils before planting soybeans, our experiments tested the 20 selected lines in four conditions; 1) without the addition of lime or organic matter, 2) addition of lime but no organic matter, 3) addition of organic matter but no lime, and 4) addition of both lime and organic matter. The experiment was conducted as a split-split plot design with three factors including lime as the main plot, organic matter as the sub plot and the 20 soybean lines as the sub-sub plot. The Table 5.1 summarizes the best performing lines under the four conditions tested.

Future Directions

Identifying some promising soybean lines that would perform well in acidic soils using the present study was the first step we embarked on to support the government’s efforts of increasing soybean production in Indonesia. The recent information from IAARD indicated that other scientists also have been working to improve characteristics of existing soybean varieties with regards to tolerance to soil acidity and seed size. Therefore, the present research contributes to enriching the diversity of soybean lines tolerant to acidic soils in Indonesia. In addition, the fact that farmers were interested in some of the 20 accessions we tested in the field shows promise that these lines may have value for adoption as new varieties.

A flowchart in Figure 5.1 provides a comprehensive overview of the future directions that can be laid out. The boxes with light shading are part of the national efforts in increasing soybean production. The boxes with dark shading show the work that has been completed during the present study. The white boxes outline the future directions. The two promising lines obtained from this study, PI675661 and PI628929, can be submitted for release through the Ministry of Agriculture (MoA) of Republic of Indonesia's variety release-procedure. While following this procedure, PI628925, another promising line, would be improved through breeding to increase pod number and seed size. In doing this work, we would work together with a soybean breeder from the Indonesian Legume and Tuber Research Institute. In addition, we would identify farmers who would be interested in further testing the promising lines in their fields with acidic soils to increase soybean production and use the produce to develop soy-based foods. To do this, we would work with local government, farmers, and soybean-based food industries.

APPENDIX

Table 5.1. The best performing soybean lines in both 2017 and 2018 growing seasons

Season	**Line***	**Yield (tones/ha)**	**Farmers practiced**		**Remarks**
			Liming	**Organic fertilization**	
2017	PI675661	3.08	Yes	No	Higher no. of pods, higher yield, larger seed size
	PI628880	2.46	No	Yes	Higher yield, seed size larger than DERING,
		2.03	No	No	Higher yield, seed size larger than DERING,
	PI628871	2.32	Yes	Yes	Higher yield, seed size larger than DERING
	PI628929	2.28	Yes	No	Higher no. of pods, higher yield, larger seed size
2018	PI628925	2.38	Yes	Yes	Farmers prefer the plant height (40-50 cm), few pods compared to PI75661 and PI628929
	PI675661	2.17	No	Yes	Larger seed size than locals, higher no of pods

** All lines mentioned here reported the yield more than the control varieties tested.*

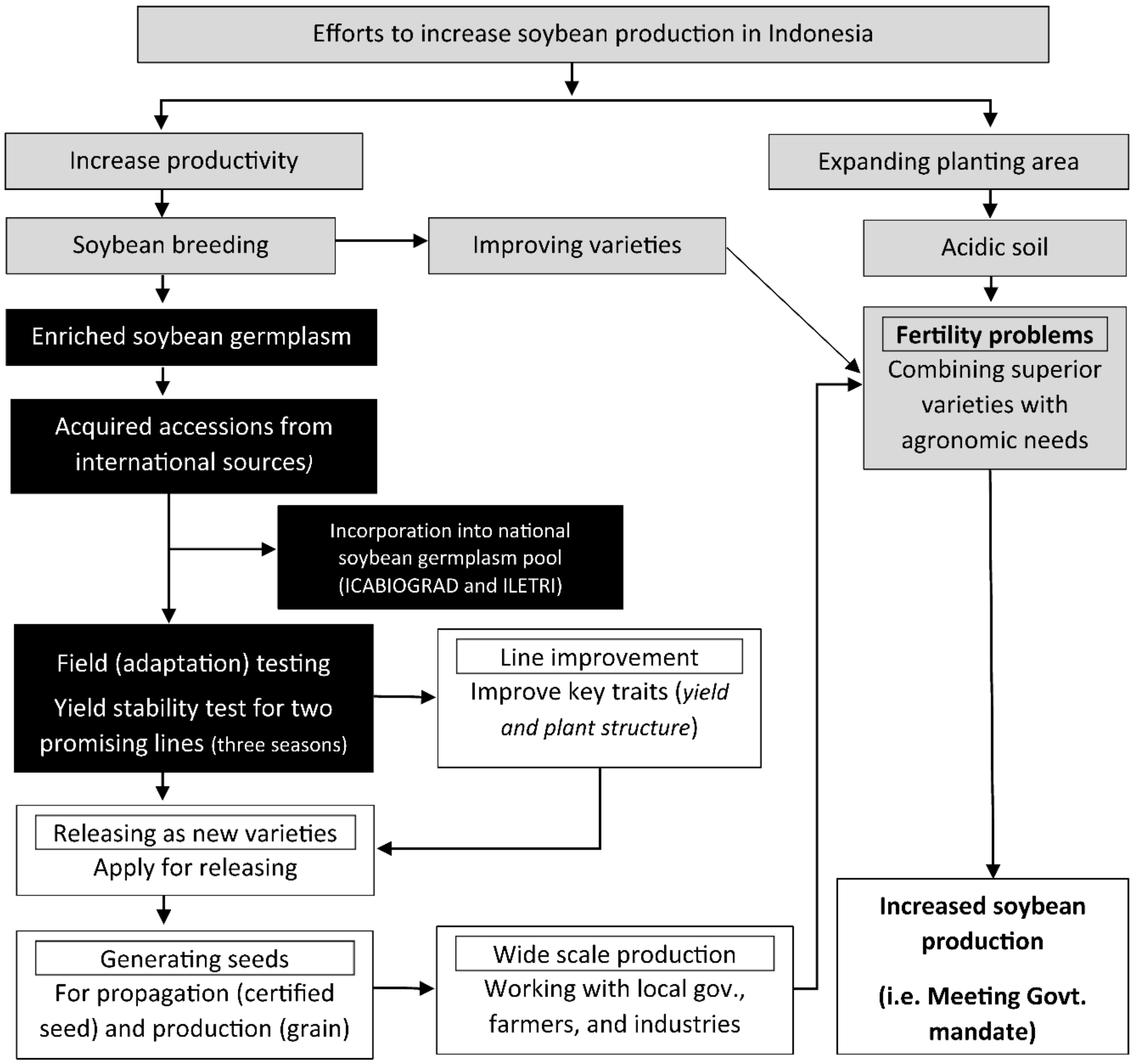


Figure 5.1. Future directions of the present study. The white boxes indicate the future directions with respect to the government work (grey boxes) and accomplishments of the present study (black boxes).