Genetic analysis of quantitative traits in soybean (*Glycine max* L. Merril) under low and high phosphorus conditions

By

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Abstract

Soybean is emerging as a very important food, market and oil crop in Ethiopia. However, its productivity in Western Ethiopia is constrained by several production constraints, of which soil acidity is one of the most important ones. On acidic soils the availability of several plant nutrients is limited; among which phosphorus is the least available. Thus, development of high yielding and low P tolerant soybean varieties need to be among the top priorities in areas with such problematic soils. Therefore, the objectives of the study were to: 1) conduct a Participatory Rural Appraisal (PRA) study to assess farmers' perception on various soil fertility, soybean consumption and marketing issues, 2) evaluate soybean genotypes under low and high P regimes, and 3) conduct genetic analysis of soybean performance under low and high P conditions. The PRA was conducted to assess farmers' perception on various soil fertility, soybean consumptions and market issues. A total of 186 soybean producing farmers across three locations of Western Ethiopia were interviewed using a semi-structured questionnaire. Results from the study indicated that the use of soybean for crop rotation and soil fertility improvement was more important to the farmers than household consumption and marketing of the crop. The study also revealed poor demand for soybean compared to other crops on the local market. The majority of respondent farmers' recognized that soil fertility has been declining over time and obtaining inorganic fertilizers on time was difficult; mainly due to high price of fertilizer. Though farmers' cooperative was identified as the major supplier of fertilizer, farmers rated the quality of its service in supplying fertilizer as poor. With deteriorating soil fertility and limited capacity to use inorganic fertilizers, farmers are producing soybean under low soil fertility conditions. Thus, breeding programs need to develop varieties that perform well under low fertility soil.

Screening soybean genotypes for response to different P regimes was performed in a field experiment using a split plot design, where the main plots were three levels of applied P (0, 100 and 200 kg ha^{-1} P), and the sub plots were 36

soybean genotypes (G) planted across three locations (L) with two replications. The extent of genetic variation of the 36 soybean genotypes was assessed under low (0 kg ha^{-1}) and high P (100 kg ha^{-1}) conditions. The analysis of variance revealed significant differences among genotypes for all the traits, except pod number at low P; while all the traits, except root volume, pod number, and number of seeds per pod showed significant differences at high P. Plant fresh weight, root fresh weight and root volume exhibited high genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) under both P conditions. Both principal component and cluster analyses revealed variation in the population. The 100-seed weight, plant height, roots and plant fresh weight combined high heritability and genetic advance estimates indicating that the inheritance of such traits is controlled by additive gene action under both P conditions. In general, the study revealed high genetic variation in the population, which can be exploited to improve performance under both high and low P conditions.

The analysis of variance revealed significant genotype X phosphorus (GXP) interaction for number of nodules and total nodule weight at Jimma, and Assossa, and for root weight and root volume at Mettu. Though the GXP and GXPXL interactions showed non-significant difference for across locations analysis, the genotypes displayed significant difference for root fresh weight, root volume, tap root length, and weight of effective nodule. Genotypes: Pr-142 (26), AGS-3-1, SCS-1, AGS 234, and H 3 were identified among the best for root and nodulation characteristics.

Yield and yield related traits were also assessed separately in the screening program. The results revealed significant GXP interactions for grain yield only at one site; while the genotypes exhibited highly significant differences for most of the traits in all the sites. G and GXL interaction were significantly different for most the traits. Essex 1, IAC 11, and AGS-3-1 were the best performing genotypes at high P; while genotypes IAC 11, AA 7138, G 9945 and AGS-7-1 displayed tolerance to low P. Genotypes AA-7138, PR-142 (26) and H3 exhibited stable performance across the three P levels. These genotypes have paramount significance in breeding soybean for low P tolerance and stable performance in varying P conditions for resource poor subsistence farmers.

The genetic control mechanism for the major quantitative traits for performance under high and low P condition was studied in a nine parent half diallel cross. The results revealed that the GCA effects were highly significant for grain yield, pod length, days to maturity and plant height under low-P conditions. GCA effects were highly significant for grain yield, 100-seed weight, days to maturity, plant height, pod number, and pod length under high P. GCA effects were also significant for number of seeds per pod under high P condition. In addition, the relative contribution of GCA was higher than SCA under both P conditions, except for 100-seed weight at low P. Variety Hardee-1 was the best general combiner for most of the quantitative traits under both P conditions, indicating that it can be used in breeding programs to improve soybean for better genetic response to low and high P.

Declaration

I, Abush Tesfaye Abebe, declare that

1. The research reported in this thesis, except where otherwise indicated, is my original research.
2. This thesis has not been submitted for any degree or examination at any other university.
3. This thesis does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from other persons.
4. This thesis does not contain other persons' writing, unless specifically acknowledged as being sourced from other researchers. Where other written sources have been quoted, then:
    a. Their words have been re-written but the general information attributed to them has been referenced
    b. Where their exact words have been used, then their writing has been placed in italics and inside quotation marks, and referenced.
5. This thesis does not contain text, graphics or tables copied and pasted from the Internet, unless specifically acknowledged, and the source being detailed in the thesis and in the references sections.

Signed

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Abush Tesfaye Abebe

As the candidate's supervisors, we agree to the submission of this thesis:

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Prof. Mwangi Githiri (Supervisor)

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Prof. John Derera (Co-Supervisor)

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Dedication

I dedicate this piece of work to my lovely family, Zebenay Zerihun, Blen Dereje, Yonatan Dereje, Rediet Dereje and Fasil Tesfaye.

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Introduction to thesis

Taxonomy and distribution

The soybean species consists of two-sub genera. The subgenus Glycine is perennial, and comprises about 18 species; while Soja is an annual soybean (Hymowitz, 2004). The sub genus Soja is also classified in to two species i.e., *Glycine soja* which is a wild soybean, and *Glycine max* L., which is the cultivated soybean (Hymowitz, 2004).

Soybean (*Glycine max* L. Meril) is a leguminous crop that originated in the eastern half of Northern China. It spread to several other countries developing landraces, and forming secondary gene center in Japan, Indonesia, Philippines, Vietnam, Thailand, Malaysia, Myanmar, Nepal, and North India (Hymowitz, 2004). It was introduced to Europe in the 17th century, and reached in the United States in 1765 (Hymowitz, 2004).

Production status

Soybean is one of the world's most important pulse crops with an annual worldwide production of 223,184,884 tons in 2009 (FAO STAT, 2011). It is the leading oil seed crop and contributed about 35% of the world's vegetable oil production in 2001 (Wilcox, 2004; Berma and Specht, 2004).). It is also the world's primary livestock feed supplement (Berma and Specht, 2004). In 2000/2001, the leading soybean producing countries were USA with 45%, and Brazil with 21% of the world's total production (Wilcox, 2004). In 2009, Nigeria was the leading producer of soybeans in Africa followed by South Africa, Uganda, and Zimbabwe; while Ethiopia was the sixth highest producer (FAOSTAT, 2011).

In Ethiopia, pulses rank second as food crops after cereals, occupying 17.7% of the total cultivated area, and contribute 12% of the total crop production (Central Statistical Authority, 2002). Soybean is one of the most important pulse crops of the country with an annual production of 7,205 tons in 2009 (FAOSTAT, 2011). Subsistence farmers in different parts of the country, who have been engaged in soybean production, are benefiting from the multiple uses of the crop.

Table 1 Soybean production and productivity in the year 2009

Country	Area harvested (ha)	Total production (tons)	Productivity kg ha^{-1}	% Productivity Increase over Ethiopia
World	99,501,101	223,184,884	2243	76.8
Africa	1,345,584	1,681,799	1249.9	Less
USA	30,907,000	91,417,300	2957.8	133.1
Nigeria	591,531	573,863	2170.3	71.1
Ethiopia	5,679	7,205	1268.7	

Source: FAO STAT 2011

Importance of soybean

Soybean is a multipurpose crop. It is useful for the preparation of different kinds of foods, prevention of chronic human diseases, crop rotation, improving soil fertility, and raw material for oil and concentrates food-producing factories. It is one of the most nutritious food crops; its protein has a good balance of the essential amino acids. Approximately, it has 40 to 42% protein, and 20 to 22% oil on a dry seed weight basis (FAO, 1994). The sulphur amino acids viz., methionine, and cystine are in low concentration, while lysine and tryptophan are in high concentration (FAO, 1994). This indicates the possibility of obtaining balanced diet by combining soybean, and cereal foods in the diet, since cereals contain the reverse essential amino acid concentration. Thus, soybean is easily available, cheap, and a rich source of protein for poor farmers, who have less access to animal source protein due to their low purchasing capacity. Due to its nutritional composition, it also helps to prevent human diseases, especially those arising from unbalanced diet.

According to Birt *et al*. (2004), soybean consumption can prevent some chronic human diseases. The authors reported that there is strong evidence to conclude that soybean consumption can prevent heart disease risk factor, and bone sparing. Even though, the available evidence is not conclusive enough, they also noted the availability of reports that associate soybean diet with reduced cancer and diabetes.

As a leguminous crop, soybean is important for crop rotation in areas where cereal sole cropping is a common practice. In Southwestern Ethiopia, where maize is the major staple food crop, and grown in mono crop condition, the importance of soybean for crop rotation is paramount. This is mainly because of the fact that mono crop system causes depleted soil fertility, and unbalanced diet to the maize feeders over time.

Soybean also plays an important role in increasing household income; as it is a source of cash for subsistence farmers. Recently there has been an increase in the demand and market value of soybean due to the fact that the crop is a raw material for oil, margarine, and concentrates food-producing factories; and there has also been an expansion of soybean processing factories in the country. As a result, farmers were motivated by the improved price of the crop. Consequently, their involvement in soybean production increased.

Considering the importance of the crop, and favorable weather to produce it, various agricultural development organizations have been exerting concerted efforts to add soybean into the cropping system of South Western Ethiopia. As a result, soybean production on farmers farm holdings showed considerable increase in the last few years i.e., from nil in 1999-2001 to 15,824.41tonnes in 2010 (Table 2).

Production constraints

Soybean was introduced to Ethiopia in the 1960's (IAR, 1982). Despite this early introduction, it was not easy to achieve wider dissemination and production of soybean; especially among the small scale farmers. The main limitations for this were: lack of knowhow by the local farmers on how to utilize the crop, unavailability of an attractive market for the produce, and lack of a systematic approach for popularizing the crop through training female farmers on how to prepare different meals from soybean. Consequently, the proportion of land in the country on which soybean was grown remained low for several years (Table 2).

In spite of the importance of the crop, and efforts made to enhance its production, the productivity of soybean on farmer's field has been very low i.e., 920-1410 kg ha^{-1} (Table 2) relative to its potential productivity 2000-3500 kg ha^{-1} (Tesfaye, 2007). The low productivity has been attributed to several constraints among which include: (a) lack of application of the right type and amount of fertilizers; (b) bird damage at emergence; (c) poor soil fertility management, and (d) poor crop management practices, such as improper weed management, sub-optimum plant population, and inappropriate planting time. In addition, the lack of improved varieties having desirable traits such as nutrient use efficiency, disease resistance, and high yielding ability magnified the problem.

Table 2 Total area coverage, production, and productivity of soybean in the main cropping season on the farmers farmer holdings in Ethiopia for the period 1999-2006

Production year	No. of holders	Area of coverage (ha)	Total production in quintals	Productivity quintal/ha
1999-2001		NA	NA	NA
2002		1769.47	16205.35	9.2
2003		1027	4,547.00	4.5
2005		2606	8,335.00	3.2
2006	29,923	3327	38,119.00	11.5
2007		7807	84,006.39	10.7
2008		6236	78,989.00	12.7
2010		11261.12	158,244.12	14.1

Source: Central Statistical Authority (CSA), statistical bulletins for the periods 2000-2011, NB: one quintal=100kg

Poor soil fertility management practices i.e., lack of use of commercial fertilizers, and lack of use of improved varieties with high yield and nutrient use efficiency are among the key factors responsible for the low productivity of soybean, especially on soils of low fertility. Besides, most farmers spare fertile soils for the production of cereals, especially maize, while pulses including soybean are grown on marginal soils usually for crop rotation. In addition, farmers sometimes apply below the optimum level, but usually do not apply commercial fertilizers on pulse crops in general, and soybean in particular. The main reasons for low use of commercial fertilizers by subsistence farmers have been poor financial capacity, and fertilizer infrastructure (Vance *et al*., 2003), high price of commercial fertilizers, poorly developed rural transportation and distribution systems particularly during rainy seasons (Mesfin, 1980). Consequently, subsistence farmers grow most crops including soybean under very low levels of soil nutrients.

For a leguminous crop, such as soybean, Nitrogen (N) nutrition is not a serious problem; as the plant has the inherent ability to obtain most of its N requirement from the atmosphere through N fixation by forming a symbiotic relationship with Rhizobium bacteria in the soil. Soybean requires 378 kg ha^{-1} of nitrogen to complete its growth cycle; however, it has the potential to obtain 60 to 70% of its requirement from nitrogen fixation (Abendroth and Elmore, 2000). Nonetheless, this relationship could not occur without inoculating the seed with appropriate strain of Rhizobium bacteria, the optimum amount of “inocula”, and proper method of inoculation.

As the nitrogen requirement of the crop could be improved by nitrogen fixation; however phosphorus (P) nutrition remains the critical limiting factor of productivity. The problem is serious in developing countries where, according to Mesfin (1980) commercial fertilizer use is very low or non-existent. Moreover, the proportion of available P is very low compared to the large P reserve in many soils. Al Abbas and Barber (1964) indicated that total P is often 100 times higher than the fraction of soil P available to crop plants. According to Manske *et al*. (2001), the areas with low phosphorus availability are large in the world.

Availability of P is limited both on soils of highly withered acidic, and calcareous alkaline soils. In alkaline soils, the availability of P is restricted due to the formation of insoluble calcium phosphate, while in acidic soils aluminum toxicity hinders uptake, translocation, and utilization of phosphate by plants (Haynes 1982).

Development of low P tolerant and high P responsive cultivars

The identification and use of phosphorus use-efficient genotypes can greatly solve low P availability problem. To achieve this, breeding programs need to focus on identifying cultivars with best performance that could overcome the extensive nutrient stresses, which cause reduction in productivity (Leonforte, 2000). Manske *et al*. (2001) reported the possibility of solving low P availability through breeding approaches, and recommended selecting under both high and low-P conditions to improve crops for performance under low and high-P conditions.

The possibility of classifying genotypes as phosphorus-efficient (higher yielding than other cultivars under low phosphorus supply), and responsive (higher yielding than other cultivars under high phosphorus supply) was reported by Ortiz-Monasterio *et al*. (2002). Producers in developed countries and resource rich farmers in developing countries could overcome the problem of low phosphorus availability, and gain from increased productivity through the application of phosphorus-based fertilizer, and by the use of responsive genotypes (Ortiz-Monasterio *et al*., 2002). In areas, where the use and availability of fertilizers and manures are limited, Ortiz-Monasterio *et al*. (2002), recommended the use of genotypes, which are efficient at utilizing the low levels of available P in the soil.

Several researchers reported low P tolerant genotypes on various crops, such as Furlani *et al*. (2002) on soybean, Vadez and Drevon (2001) on common bean, and Alam *et al*. (2003) on wheat. Even though, low P tolerant varieties could bring improvement in productivity under soils of low nutrient availability, there was no study done previously to evaluate soybean genotypes for their response and combining ability for varying P regimes, on acidic soils. Consequently, literature on soybean low P tolerance, high P responsiveness and combining ability and gene action for low P tolerance and high P responsiveness on acidic soils is scarcely reported. Thus, undertaking such a study will allow identification of low P tolerant varieties, which along with seed inoculation with Rhizobium bacteria could reduce the amount required and cost of commercial fertilizers. Thus, this enables subsistence farmers to maximize their return from soybean production on soils of low fertility.

Research goal

The overall goal of this research is to contribute for increased productivity of soybean, improved nutritional status, and increased household income of subsistence farmers through the development and subsequent use of high yielding, low P tolerant, and high P responsive soybean varieties in Ethiopia.

Research objectives

The specific objectives of the study were to:

a) understand farmers' perceptions on the existing soil fertility problems and management practices that help make decision on plant breeding intervention in the development of low P tolerant varieties
b) identify low P-tolerant, and high P-responsive soybean genotypes,
c) determine the gene actions involved in soybean performance under low-P and high-P conditions,
d) estimate the magnitude and pattern of genetic diversity in the crop using morphological data under low and high P conditions,

e) estimate combining ability for quantitative traits in soybean under high and low P conditions

Structure of the thesis

The thesis includes eight distinct chapters that align with a number of activities related to the research objectives listed above. The fact that the chapters were prepared as an independent scientific paper, some overlap and repetition of some important and crosscutting information might have occurred between the chapters. Some of the papers have already been published or accepted for publication and are indicated in the thesis.

Table 3 Structure of the thesis

Chapter	Title
-	Introduction to thesis
1	A review of the literature
2	Smallholder Farmers' perceptions and experiences on the importance, consumption and marketing of soybean in Western Ethiopia
3	Subsistence farmers' experiences and perceptions about the soil, and fertilizer use in Western Ethiopia
4	Genotypic variability of soybean for selected quantitative traits under high and low P conditions
5	Response of soybean (Glycine max L.) genotypes to levels of phosphorus and locations for root and nodulation characteristics on acidic soils
6	Response of soybean (*Glycine max* L.) genotypes to phosphorus regimes for yield and related traits
7	Combining ability of soybean genotypes for quantitative traits under low and high phosphorus conditions on acidic soils
8	An overview of the research findings

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CHAPTER 1

A Review of the Literature

1.1 Introduction

1.1.1 Taxonomy and distribution

The soybean species consists of two-sub genera. The subgenus Glycine is perennial, and comprises of about 18 species; while Soja is an annual soybean (Hymowitz, 2004). The sub genus Soja is also classified into two species i.e., *Glycine soja*, the wild soybean, and *Glycine max* L., the cultivated soybean (Hymowitz, 2004).

Soybean (*Glycine max* L. Merrill) is a leguminous crop originated in the eastern half of Northern China (Hymowitz, 2004; Sleper and Poehlman, 2006) at around 2,500 B.C. (Sleper and Poehlman, 2006). It spread to several other countries developing landraces, and forming secondary gene centers in Japan, Indonesia, Philippines, Vietnam, Thailand, Malaysia, Myanmar, Nepal, and North India (Hymowitz, 2004). It was introduced to Europe in the 17th century, and reached the United States in 1765 (Hymowitz, 2004).

1.1.2 Adaptation and production

Soybean is an intermediate altitude crop, which performs well in areas with an altitudinal and annual rainfall range of 1300-1800masl and 900-1300mm, respectively (Hammer and Haraldson, 1975; Belay, 1987; Asfaw *et al*., 2006;). However, it can also be grown at altitudes as low as 500masl, and as high as 1900masl with mean annual rainfall ranging between 550-700mm, and uniform distribution throughout the growing period.

Soybean is a short day plant; however, genotypes vary in their response to day length. If genotypes adapted to longer photoperiod are grown under short day length, this results in early flowering; pod setting on the lower part of the plant, and reduced yield and seed quality. On the other hand, growing genotypes in longer photoperiod than their adaptation, results in extended vegetative growth, and delayed flowering and seed setting. The adaptability of different maturity group soybeans were compared across Ethiopia based on mean yield of 15 years trials, and early and medium maturity groups were relatively better yielding; especially in areas, where the rainfall is moderate (Asfaw *et al*., 2006). However, the long maturing varieties have better adaptation to high rainfall areas, such as western Ethiopia, where the current research was undertaken (Asfaw *et al*., 2006).

The worldwide importance of soybean arises from its high nutritional value i.e., high protein, oil and fat content, and its market value as whole grain, and factory processed food products, such as oil, margarine, and concentrate infant feeds. It is also a crop of worldwide market importance; for instance, 24% of soybean production in the year 2000/2001 entered into world market (Wilcox, 2004). In recent years, USA is the leading exporter of soybean, contributing about 58% of the world's export, followed by Brazil (23%), and Argentina (8%) (Wilcox, 2004). The author also reported that world's largest soybean exporting countries are also the largest producers. According to Wilcox (2004), the main importers of soybean are Europe and Asia. Besides its role as an export commodity, soybean has high agricultural value in crop rotation and nitrogen fixation.

The yield potential of soybean varies from place to place depending on the cultivars used and the prevailing environmental conditions. In general, its productivity has shown an increase of 1% per year in major soybean producing countries (Wilcox, 2004). The author also reported that the plateau of soybean productivity curve has not been reached, indicating the potential for further improvement in the productivity of the crop. World average productivity of soybean in the year 2009 was 2243 kg ha^{-1}, while USA's productivity was 2957.8 kg ha^{-1}. Africa's productivity in the same year was 1249.9 kg ha^{-1}, while the productivity of soybean in Ethiopia was 1268.7 kg ha^{-1} (Table 1).

A yield advance of 71.7% with an annual gain of 2.56% was reported for the period 1956-1984 in the research trials conducted in Ethiopia (Asfaw *et al*., 2006). The authors also reported that the yield gain obtained in recent years was little, which might be due to the low yield potential of genotypes under evaluation, or the erratic rainfall occurring in the country, which might have obscured the actual yield potential of the varieties under production. Thus, there is a very wide gap between the average productivity of the crop on farmer's field in Ethiopia, and the national average productivity in the USA and the productivity reported in the research fields in Ethiopia, which is attributed to several production constraints.

The main production constraints responsible for low productivity of soybean in Ethiopia i.e., 1410.1 kg ha^{-1} national average yield in the year 2010 (Table 2), which is far behind the potential productivity of the crop in the research fields i.e., 2000-3500kg ha^{-1} (Tesfaye, 2007) are: poor soil fertility management practices, soil borne diseases, bird damage at early seedling stage, and low nutrient availability associated with pH of the soil. More importantly, the major soybean producing areas in South Western Ethiopia are characterized by high rainfall and acidic soil, which is also associated with high P fixation, and low P availability. In addition, farmers have limited capacity to purchase and apply commercial fertilizers, which is the principal cause of a very low productivity of soybean in Ethiopia. The potential risk of the depletion and exhaustion of the non-renewable P nutrient from the soil is also a big concern of the future agriculture. Hence, identifying crop varieties, which performs well under P deficient soils and respond to high level of P, is gaining priority in several breeding programs. Thus, this literature review examines the research results and techniques developed to evaluate P use efficiency in soybean and other crops.

1.2 Genetic variability of soybean under low and high P conditions

Determining the extent of genetic variability of soybean genotypes under low and high P condition is an important step in understanding the genetic potential of the crop for further improvement and to design hybridization scheme. Araujo *et al*., (1998) reported the possibility of identifying low P tolerant cultivars, when there is sufficient genetic variation, under low P conditions. Similarly, productivity of the crop could be maximized, and cultivars with high P responsiveness identified, when there is sufficient genetic variability under high P conditions.

Determination of genetic variability has been done in various ways by different researchers; of which the use of multivariate techniques such as, principal component analysis (PCA) and cluster analysis are the most commonly applied techniques on several crops. Even though these techniques were widely used in several other crops, there was no adequate information obtained on the application of the techniques to determine genetic variability of soybean in relation to performance under low and high P conditions on acidic soils. Hence, the application of the techniques and results obtained using these techniques are reviewed based on the research reports on other crops.

Alemu (2001) used cluster analysis based on Mahalanobis D^2 statistics, and categorized 100 barley genotypes into three cluster groups. Tesfaye (2004) reported high genotypic and phenotypic coefficient of variation for plant height and grain yield in the genetic variability study of 64 landrace sorghums of South Western Ethiopia. This indicated the presence of sufficient genetic variability among the landraces for the traits studied. The author also reported that the first three principal components with eigen values greater than unity accounted for more than 79.2% of the total variation. This indicates that the traits, which were mainly explained by the first three principal components, are responsible for the majority of the variability in the genotypes. Korkmaz *et al*. (2007) also reported that shoot dry matter (DM) is the most sensitive indicator of genetic variability under P-deficient conditions.

Johnson *et al*. (2001) assessed the genetic variability of specialty soybean in the two and three parent populations for small seed size $\leq$ 80mg, which are specifically required for producing “natto” in Japan. Consequently, the variation in seed size of 100 F_2 populations derived from each of five sets of three population types, generated from the cross of two small seeded and one normal seeded conventional cultivar, were assessed. The authors reported that the average percentage of lines with a seed size equal to or smaller than one of the parents in a cross was 90% for populations derived from a cross of small seeded x small seeded, 10 % for populations derived from small seeded x normal seed size cultivar, and 20 % for populations derived from three parent cultivars. The authors concluded that there is sufficient genetic variability in the segregating generations to improve for small seed size character. Similarly, Rincon *et al*. (2003) evaluated the variation among six soybean genotypes viz., PI 416937, H2L16, N95-SH-259, PI 407859-2, PI 471938, and young for their ability to absorb water, which was assessed based on root hydraulic conductance in flowing hydroponics condition. The authors reported high genotypic variability for root anatomical traits, which affected water movement through the root system under adequate watering conditions. They also stated that such genetic variations inspire studying the association between root hydraulic conductance and performance of soybean under water stress condition.

Gizlice *et al*. (1993) assessed the genetic diversity of 14 ancestors of soybean that constitute 70% of the North American public soybean genotypes using multivariate technique, and reported the existence of wide genetic diversity for 10 metric characters. These authors also reported that principal component analysis (PCA) decomposed the total variation of the ancestors into four principal components, which explained about 80% of the total variation. However, reports on genetic variability of soybean both under high and low P conditions on acid soils are either limited or unavailable.

1.3 Interaction and response of genotypes to levels of soil P

Genotype x environment interaction is defined by Fox *et al*. (1997) as the differential genotypic expression across environments. In the current study, the procedure used to determine genotype x environment interaction (GxE), which has been used by several researchers (Gauch and Zobel, 1997; Tesfaye, 2001; Tesfaye and Tulu, 2004) will be used to derive the genotype x levels of P (G x P) interaction. In this case, the levels of P across locations will be considered as the environmental component of G x E interaction.

Genotype x levels of P interaction is the change in the relative performance or rank of the genotypes in response to the levels of P in the soil. On the other hand, response of genotypes to levels of P is the differential performance of each of the genotypes under varying levels of P. Determination of response of genotypes to the levels of P will follow the procedures and stability parameters used by the Additive Main Effect and Multiplicative Interaction (AMMI) biplot technique (Crossa, 1990; Tesfaye, 2001; Zobel *et al*., 1998).

The use of low soil fertility tolerant cultivars is important in attaining sustainable farming system, and reducing cost of production and dependence of farmers on commercial fertilizers (Singh *et al*., 2003). The authors reported up to 53% average yield reduction in common bean due to low soil fertility over five cropping seasons. However, crop genotypes differ considerably in their response to varying soil nutrient gradient. According to Ortiz-Monasterio *et al*. (2002), this difference enables us to categorize them into low nutrient tolerant, average responsive, and high nutrient responsive genotypes.

Vadez and Drevon (2001) studied the response of 5000-5500 common bean genotypes (*Phaseolus vulgaris* L.) to low soil fertility, and identified eight landraces and fourteen improved varieties tolerant to low soil fertility. Bonser *et al*. (1996) assessed the influence of P availability on the basal root angle of common bean, and reported that root architectural plasticity might be important in the acquisition of immobile nutrients, such as P. The authors also reported that out of the 16 common bean genotypes examined, six showed a decrease in root orientation in relation to gravity under low P condition, while one showed increased orientation, and nine did not show difference for basal root emergence. The tap root orientation showed decrease with respect to gravity under low P conditions. There was no change in root angle caused by the deficiency of other mineral nutrients, except P (Bonser *et al*., 1996). The effect of low P on root angle is associated with reduced shoot P concentration (Bonser *et al*., 1996). The authors also reported change in basal root angle caused by low P availability in soybean and pea, among other legumes.

Aulakh *et al*. (2003) studied the response of soybean in rotation with wheat to different rates of P under irrigated condition. The authors reported significant response of soybean to up to 80kg ha^{-1} rate of P_2O_5, when no fertilizer was applied to the preceding crop, wheat. On the other hand, when 60kg ha^{-1} of P_2O_5 applied to wheat, the maximum response was obtained for the succeeding soybean at the rate of 60kg ha^{-1} of P_2O_5. In this case, soybean obtained the remaining P from the residual fertilizer, which is left from the previously applied P for the wheat crop. The authors also reported that 60kg ha^{-1} of P_2O_5 is adequate for each soybean and wheat to meet their P requirement on sandy loam soil (Typic ustochrepts). This rate has also increased the fertilizer P use efficiency and recovery, harvest index, and enhanced cost effectiveness; thereby, reducing contamination of ground water by P. Aulakh et al. (2003) reported that mosaic virus resistant soybean varieties i.e., SL 295 and PK 416 showed similar response to the level of P, and produced grain yield of 2.5t ha^{-1}.

Furlani *et al*. (2002) reported significant response of 29 soybean genotypes to the levels of P, in nutrient solution using a multivariate technique. Ogoke *et al*. (2006) reported high response of late maturing soybean cultivars viz. TG x 1670-1F and TG x 923-2 to P, which also produced higher root proliferation at lower rates of applied P, and in areas of low P availability. As this study was conducted in nutrient solution, it cannot represent the actual field conditions, where there are interactions of various soil nutrients and microorganisms with P. Thus, there has been no such a study made on soybean, and on acidic soil, where the level of available soil P is low, and aluminum is believed to be abundant and toxic to plants. Moreover, most of the research results are focusing on tolerance to low soil fertility or low P, and reports on responsiveness for high soil P conditions are scant.

1.4 Combining ability for low P tolerance and Optimum P responsiveness

Selection of parents for crossing, to improve quantitative traits cannot be practiced with confidence based on phenotypic value of inbred parents only (Dabholakar, 1992). This is because of the need to know the heritable proportion of genetic variation i.e., additive genetic variance of the parents, which is transferable from parents to progenies, and allows to estimate the progress that can be achieved on subsequent generation of crosses. Besides, according to Dabohlkar (1992), there is variation in performance of crosses for different combinations of parental lines. Hence, the objective of crossing in crops, such as maize, sorghum, and cotton is to exploit hybrid vigor; while in self-pollinated crops, such as soybean, the crossing objective is to bring important genes together from different parental genotypes, as the required final outcome is a pure line (Dabholakar, 1992).

In addition to the general mean and environmental variance components of the parents, diallel analysis partitions phenotypic value of a cross into two main components i.e., general combining ability (GCA) and specific combining ability (SCA) Griffings (1956). According to Griffings (1956), GCA is the effect of the parents in a cross, which is synonymous to the main effect of a factorial design. On the other hand, SCA is defined as the extra performance over the sum of the GCA effects of the two parents, which is synonymous to the interaction effect of factorial design (Griffings, 1956). The author also indicated that this approach also takes into account the non-allelic interaction. Gravina (2003) defined GCA as the average performance of an inbred parent in a series of hybrid combinations. General combining ability is attributed to the additive gene action. Rojas and Sprague (1952) defined specific combining ability (SCA) as the instances in which certain hybrid combinations are either superior or inferior than would be expected based on the average performance of the inbred parents used in crosses. Specific combining ability is attributed to the effect of dominance.

Combining ability has been studied on various crops for grain yield and other yield related traits. Romanus *et al*. (2007) studied the combining ability of seven cowpea parental inbred lines using diallel mating design without reciprocals for grain yield and eight yield components. The authors reported significant GCA and SCA for most of the traits. These authors also reported that the additive component was important for the eight traits studied, except for pod number, while the non-additive component was not important for grain yield and nodule number. The authors identified two parents IT86D-716, and IT81D-985 as general combiners, and four crosses i.e., IT87D-697-2 X IT86D-716, IT88D-867-11 X IT86D-716, IT93K-624 X IT87D-697-2, and IT87D-697-2 X IT92KD-405-1 as the best specific combiners.

Kimani *et al*. (2007) studied the combining ability of common bean genotypes for low P tolerance at medium and low soil P conditions. The authors reported that GCA and SCA effects were significant at ($P<0.01$) for the five characters studied viz., basal root length, root dry weight, number of nodules per plant, leaf area per plant, and grain yield per hectare, except for SCA of root dry weight at one location. Kimani *et al*. (2007) also reported 12 times higher GCA than SCA, which indicates that additive genetic variance was more important than dominance in the inheritance of low P tolerance.

Combining ability has also been studied on soybean for some important traits. Significant GCA and SCA effects were reported in the combining ability study of seven soybean cultivars with different levels of resistance to frogeye leaf spot disease caused by *Cercospora sojina*, race 04, using diallel mating design without reciprocals (Gravina *et al*., 2003). Three cultivars i.e., Cristalina, Davis, and Uberaba were better parents to be used in breeding soybean for resistance to the disease, as they gave the highest GCA (Gravina *et al*., 2003). The authors also reported that the additive genetic effect was the most important, along with the dominant and epistatic effects.

Several authors used the value of GCA, and SCA in identifying parental lines and specific crosses with superior performance for some useful traits, such as nutrient absorption rates and tolerance to stress environmental conditions, such as P deficiency, and heat tolerance. Krishnawat and Maloo (2004) reported the combining ability of soybean for stress tolerance, and reported that four of the parental lines i.e., PK 327, JS 80-21, JS 79-81, and bragg showed highly significant desirable (positive) GCA effects for germination stress index (GSI), and desirable (negative) GCA effect for heat tolerance. Spehar (1995) studied the genetics of Brazilian tropical adapted soybean genotypes for the uptake of P, K, Ca, Mg, Fe, Al, Mn, Zn, and Cu in a 9x9 diallel mating design. The author reported higher GCA than SCA for all the nutrients, except for copper, manganese, and zinc indicating the importance of additive gene action in the inheritance of these traits. This in-turn implies the possibility of improving the traits through selection. The author also reported that the additive-dominance model was adequate in explaining the genetic difference; as shown by the regression of covariance on variance. The author also noted that heterozygousity for nutrient uptake in the parental varieties might be the cause for the over-dominance. Broad sense heritability (H^2) value was higher than narrow sense heritability (h^2) for acquisition of mineral elements i.e., aluminum, iron, potassium, calcium, and magnesium (Spehar, 1995).

1.5 Research gaps identified in the review of literature

The importance and techniques of determining response of crops to the levels of P, and the interaction of genotype x levels of P; combining ability; heterosis, and inheritance of P use efficiency has been reported by several authors on various crops. However, there was no adequate report on these subjects on soybean, particularly on acidic soil, which indicates the absence of comprehensive study that has been done on the crop for performance under high and low soil P conditions.

Some results related to the current research have been reported on soybean; however, the methodology and the environments used for the study were entirely different. For instance, even though the genetic variability of soybean has been assessed by Gizlice *et al*. (1993), there was no report found on genetic variability study of soybean under high and low P conditions. Similarly, although, Furlani *et al*. (2002) determined the response of soybean genotypes to the levels of P, and genotype x P interaction, however, the study was conducted on nutrient solution, while the current study was undertaken under both pot and field conditions on acidic soils. Even though, combining ability study was reported on soybean, there was no report found on the combining ability of soybean under high and low P conditions. In general, no comprehensive report was found that dealt with the genetic analysis of soybean under low and high P conditions on acidic soil. This shows that the literature review has clearly pointed out the gaps which needed to be addressed by the current research.

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CHAPTER 2

Smallholder Farmers' perceptions and experiences on the importance, consumption and market of soybean in Western Ethiopia

2.1 Abstract

Soybean is a very important leguminous crop in the fight against malnutrition and depletion of soil fertility. The study was conducted to assess farmers' perceptions on the importance of soybeans, their household consumption levels and the local soybean market. A semi-structured questionnaire was administered to 186 randomly selected respondent farmers in three zones. Respondents belonged to 33 farmers associations. Farmers ranked crop rotation as the most important benefit derived from producing soybeans, followed by improvement in soil fertility. Roasted soybean, bread, stew and sauces, and soymilk were some of the most important food types prepared from soybean by respondent farmers. The majority of respondents reported that consuming soybean has no drawback. The greatest proportion of respondents indicated that they never sold soybean before. Among those who sold their soybean, the majority of respondents sold their produce in the local market and at farm gate. The highest proportion of the respondents sold their soybean directly to consumers. The greatest proportion of respondents sold their soybean some 3-6 months after harvest, and the majority of respondents believe that the time of sale of their soybean was not right. Most of the farmers judged the demand of soybean as poor in the local market, when compared to other crops. Enhancing the local consumption, processing and the market price of soybean are some of the most important strategies to enhance soybean production by smallholder farmers. This will bring a range of important benefit to farmers, considering soybeans versatile uses.

Key words: Soybean, malnutrition, soil fertility depletion, local consumption, and market

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2.2 Introduction

Food insecurity and malnutrition are among the urgent challenges that developing countries face these days. The challenges are especially acute in Ethiopia and relatively more serious in the rural than urban areas (Dionco-Adetayo *et al*., 2002; Chanyalew, 2005) mainly because of a low level of understanding of a balanced diet and lack of capacity to purchase animal source proteins. The problem is more severe for underage (below the age of 18) children. Ethiopia has the highest child malnutrition rate in Sub-Saharan Africa (Christiaensen and Alderman, 2001), a figure that manifests itself physically, as the country has one of the highest percentages of abnormally short height (stunted) (Benson, 2005) and under-weight children in the world (Christiaensen and Alderman, 2001). One of the immediate causes of malnutrition is insufficient dietary intake (Benson, 2005). The rural development policy of Ethiopia clearly indicates that one of the causes for the high disease rate in the country is poor feeding habit (Ethiopian Ministry of Information, 2002). The same document also emphasizes the importance of preventive measures rather than curative, for the countries fast and sustainable development.

The major staple food crop of most developing Sub-Saharan African Countries, maize, contains low protein (5.2-13.7 %) (Cortez and Wild-Altamirano, 1972). Furthermore, prevalent continuous mono-cropping of cereals, especially maize and sorghum, reportedly causes depletion of plant nutrients in the soil (Tulu *et al*., 2008). Hence, integrating leguminous crops, such as soybean, in the maize based cropping system of Western Ethiopia and small-scale farmers of other developing countries is critical to nutrition as well as improved soil fertility, amongst other roles.

According to Thoenes (2004), soybean is a strategic crop in the fight against world hunger and malnutrition, especially in developing countries. Soybean provides a nutritious combination of both calorie and protein intake, and supplies the growing demand for vegetable oil and high protein animal feed in developing countries. Soybean, a multipurpose crop, can be prepared as several different kinds of soybean dishes that have been shown to contribute to the prevention of chronic human diseases (Birt *et al*., 2004). When included in crop rotation cycles, soybeans rejuvenate soils depleted by continuous cereal mono-cropping, improving soil fertility (Asfaw *et al*., 2006; Tulu et al., 2008), and serve as raw material for oil and concentrate food-producing factories. Most foods aids that are provided to refugees and displaced people in an emergency situation are required to meet the nutritional requirements, either through fortification or supplementation (FAO, 1995). Soybean is one of the most commonly used crops for fortification. The total amount of soybean fortified food shipped for aid in the year 1993 was 395,775 MT (FAO, 1995).

The previous pre-extension approach, which commonly demonstrated improved varieties and their production practices, failed for soybean popularization in Western Ethiopia, because farmers lack knowledge of how to utilize soybean as well as poor local market conditions. Consequently, a new approach was designed which augmented the pre-extension demonstration with training, and popularization of various meals and how to prepare them from soybean for both rural and urban dwellers of Western Ethiopia (Tulu *et al*., 2008). More than 90 different kinds of meals were demonstrated, and 1168 female farmers were trained in meal preparation (Tulu *et al*., 2008). Milk, Yoghurt, Cheese, Stews, Bread and Injera (Ethiopian traditional thin bread), were among the major meals demonstrated during the popularization. Consequently, the national soybean production has increased from nil in the year 1999-2001, to 3,811,900 kg, in 2006, and 7,898,892 kg in 2008 on small scale farmers' fields.

The rural development policy of Ethiopia gives priority to market oriented crops; especially those preferred by the international market (Ethiopian Ministry of Information, 2002). The country's policy also states that agricultural development policy that is not market-oriented cannot be fast and sustainable. This implies, therefore, that soybean can comply with this policy, because of its international market. The strong soybean international market is due to the crop's diverse uses for human food and animal feed, crushing of soybean for oil, and other concentrate baby meals. United States (44.8 %), Brazil (21.7 %), and Argentina (13.3 %) contributed to 79.8 % of the world soybean production between the period 1994 to 2003 (USDA, 2003). These three countries also exported 90.5 % of the world soybean export with 56.8, 24.1 and 9.5 % respective volume of export. During the same period, the major importers of soybean were European Union (36.9 %) and China (16.2 %). Soybean is exported not only as a grain, but also as processed products, such as soymeal and oil. Soymeal accounts for 60 % of the world's output of vegetable and animal feed, while soyoil accounts for 20 % of the world's vegetable oil production (Thoenes, 2004). The author also reported that small scale processing and local marketing strategies are important to countries that produce soybeans in smaller volumes (insufficient for export) and in a labor intensive farms; while the major exporting countries produce soybean at larger volumes, in mechanized farms.

Even though, soybean was introduced to Ethiopia in the 1950's for the purpose of import substitution (Asfaw *et al*., 2006), production is still insufficient to substitute imports. The country still imports soybean and its products (Ethiopian Revenue and Custom Authority, 2010). According to the Authority, imports reduced from 4,458.4 tons in 2006 to 114.5 tons, and 573.9 tons in 2007 and 2008, respectively. Meanwhile, exports grew significantly during this same period. In 2009, the imports increased by 1044.7% over the 2008 imports, while exports dropped to zero in the same year. This implies that exports are not stabilized and import substitution is not yet achieved.

Besides the export market, the local consumption and domestic market for soybeans are important factors that should drive soybean production in the country. Generating relevant information about farmers experience on the importance, local utilization, and market of soybean is important in designing appropriate strategies to enhance the production and productivity of the crop.

Therefore, the objective of this survey was to examine farmers' perception and experiences about the importance, utilization and local market of soybean in Western Ethiopia, and draw important implication that will help to scale-up soybean, and reduce nutritional and poverty related problems in other developing countries. Moreover, such information is important to improve the marketability and food and oil processing role of the crop in the country.

2.3 Materials and Methods

2.3.1 Description of the study site

The survey was conducted in three zones of Western Ethiopia; namely, Jimma, IIlubabor, and Assosa. The two zones, i.e., Jimma and Mettu, were grouped into a tepid to cool humid mid-highlands category, while Assossa is categorized into a hot to warm sub-humid lowlands category (MoA, 1998). In these zones, maize is the predominant cereal crop. Besides, there is a strong effort to scale-up soybean production and consumption in the zones. Consequently, soybean is emerging as an important legume crop in these zones. These three zones also have high mean annual rainfall ranging from 1316-1835mm (Table 2.3-1).

Table 2.3 1 Agro-ecological characteristics of the study zones

Study sites	*AEZ	Alt. (masl)	Location	Annual mean RF (mm)	Annual mean T^0		Soil type
					Min	Max	
Jimma	H_2	1750	$7^0 46'N\ 36^0 E$	1754	11	26	Reddish brown
Mettu	H_2	1550	$8^0 3'\ N\ 30^0 E$	1835	12	27	Dark red brown
Assosa	SH1	1550	$10^0 0'N 34^0 0'E$	1316	16.8	27.9	Reddish brown

H_{2-} Tepid to cool humid mid highlands, AEZ=Agro ecological zones of Ethiopia SH_1=Hot to warm sub-humid lowlands

2.3.2 Data collection and statistical analysis techniques

A semi-structured questionnaire was administered to a total of 67 respondents in eight farmers associations (PAs) in the Assossa zone, 57 respondents in 12 PAs in Mettu zone; and 62 respondent farmers in 13 PAs in Jimma zone. The PAs and respondent farmers were randomly selected in the major soybean producing areas of each zone. The interviewers in Jimma and Mettu zones were five researchers, with very good command of the local language (Afan Oromo), and selected from different disciplines of Jimma Agricultural Research Center. Similarly, the questionnaire-based interviews around Assossa zone were conducted by five researchers from different disciplines. Data analysis was performed using Statistical Package for Social Sciences (SPSS) software. The relative uses of soybean for the respondents were ranked by calculating the total points i.e., multiplying the rank frequencies by the relative weight of each rank (1^{st} Rank= 5 points, 2^{nd} Rank= 4 points, 3^{rd} Rank= 3 points, 4^{th} Rank = 2 points, and 5^{th} Rank = 1 point).

2.3.3 Socio-economic characteristics of respondent farmers

Of the interviewed farmers, 89.9% were male, and 10.2% were female. The altitude of these farmer's production areas ranged between 1242 and 1989masl (Table 2.3-2). The maximum distance from a respondent's house to all weather roads and market, as well as development agents (DA) center was 12, 36 and 12 kms, respectively. Respondent ages ranged from 20 to 76. The largest family size was 18; while the smallest was three, and seven was the mean family size.

Table 2.3 2 Some socio-economic features of the respondent farmers

Socio-economic feature	N	Minimum	Maximum	Mean	Standard Error
Altitude of the respondents residence	96	1242	1989	1604.8	27.48
Distance from all-weather road	182	0	12	0.9	0.12
Distance from the market	184	0	36	6.8	0.47
Distance from DA center	185	0.01	12	1.4	0.14
Age of head of the household	186	20	76	41.9	0.87
Family size	186	3	18	7.1	0.20

2.4 Results

2.4.1 Farmers' preferences of the different uses of soybean

Farmers ranked the use of soybean in crop rotation as the most important use of this crop (Table 2.4-1). The next most important use of soybean, according to the respondents, was soil fertility improvement, which was closely followed by household consumption. The medicinal use of soybean was the least in the overall rank.

Table 2.4 1 Rank frequencies, total points and overall rank of the various uses of soybean by the respondent farmers

	Rank frequency					Total	Overall
Importance	1	2	3	4	5	points	rank
House hold consumption	22	34	39	38	0	439	3
Income generation	33	41	21	7	1	407	4
Crop rotation	47	36	27	11	0	482	1
Soil fertility improvement	27	34	37	32	2	448	2
Medicinal use	21	19	26	21	1	302	5

2.4.2 Different kinds of meals prepared from soybean alone and in combination with other crops

Roasted soybean and bread were the most commonly prepared and consumed food types made from soybean in the survey areas (Table 2.4-2). Stew and sauces, and soymilk were also important foods prepared from soybean. The proportion of respondent farmers who have prepared '*injera*', the common Ethiopian traditional flatbread, by mixing soybean with other grains was relatively very small. A very small percentage of respondents (4.9 %) did not consume soybean at all.

The various types of meals prepared from soybean included:

- **Bread:** Most respondent farmers of Assossa, Bambasi and Darimu used soybean to prepare bread by mixing soybean with others grains, such as maize and wheat (Table 2.4-2).
- **Injera:** Exceptionally high proportion of respondent farmers prepared 'injera' from soybean at Tiroafeta.
- **Soymilk, soy cheese and soy yoghurt:** Soymilk prepared and consumed by high proportion of the respondent farmers at Chewaka. Relatively high proportion of respondent farmers of Darimu, Kersa, Omonada, Bambasi, Tiroafeta and Assossa were also preparing and consuming soymilk. The preparation and consumption of soy yoghurt was relatively high by Seka and Tiroafeta respondent farmers. The highest proportion of Omonada respondent farmers have prepared and consumed cheese made of soybean.
- **Stews and sauces:** The majority of Seka respondent farmers have previously prepared and consumed stews and sauces from soybean. The preparation and consumption of stews and sauces was relatively higher in all the study sites.
- **Roasted soybeans:** All the respondent farmers of Kersa and Mana have consumed soybean as roasted grain. The proportion of farmers whom

have not consumed soybean was the highest at Bedele, followed by Tiroafeta and Omonada.

Table 2.4-2 Different kinds of foods prepared from soybean by mixing with other grains and consumed at home by the respondent farmers (percentage of total respondents, N=186)

District	N	Bread	Injera	Porriage	Soymilk	Yoghurt	Stew and sauces	Roasted grain	Cheese	Not consumed soybean
Assossa	42	100	0	4.8	30.9	19.0	35.7	73.8	4.8	0
Bambasi	25	92	0	4.0	52.0	16.0	64.0	72.0	4.0	0
Bedele	22	54.5	9.1	13.6	13.6	0	50.0	54.5	0	31.8
Chewaka	21	66.7	4.8	9.5	90.5	14.3	57.1	85.7	4.8	0
Darimu	20	90.0	20.0	20.0	75.0	20.0	65.0	70.0	15.0	0
Kersa	6	66.7	0	16.7	66.7	0	83.3	100.0	16.7	0
Mana	9	77.8	11.1	22.2	0	0	55.6	100.0	0	0
Omonada	13	69.2	0	15.4	53.8	15.4	53.8	76.9	30.8	7.7
Seka	7	85.7	0	0	0	42.9	42.9	85.7	0	0
Tiroafeta	21	71.4	42.9	19.0	42.9	28.6	57.1	76.2	14.3	9.5
Mean		77.4	8.8	12.5	42.5	15.6	56.5	79.5	9.0	4.9

2.4.3 Drawbacks of consuming soybean

The majority of respondent farmers, who have consumed soybean meals before reported that there were no drawbacks in eating such meals. Out of those who reported drawbacks of consuming soybean, the majority reported lack of experience as the most important factor restricting soybean consumption in their house; while the second highest proportion of the respondents reported stomach constipation, and problems when milling (Figure 2.4-1). Difficulty in boiling soybeans was reported as drawback by 16.8 % of respondents.

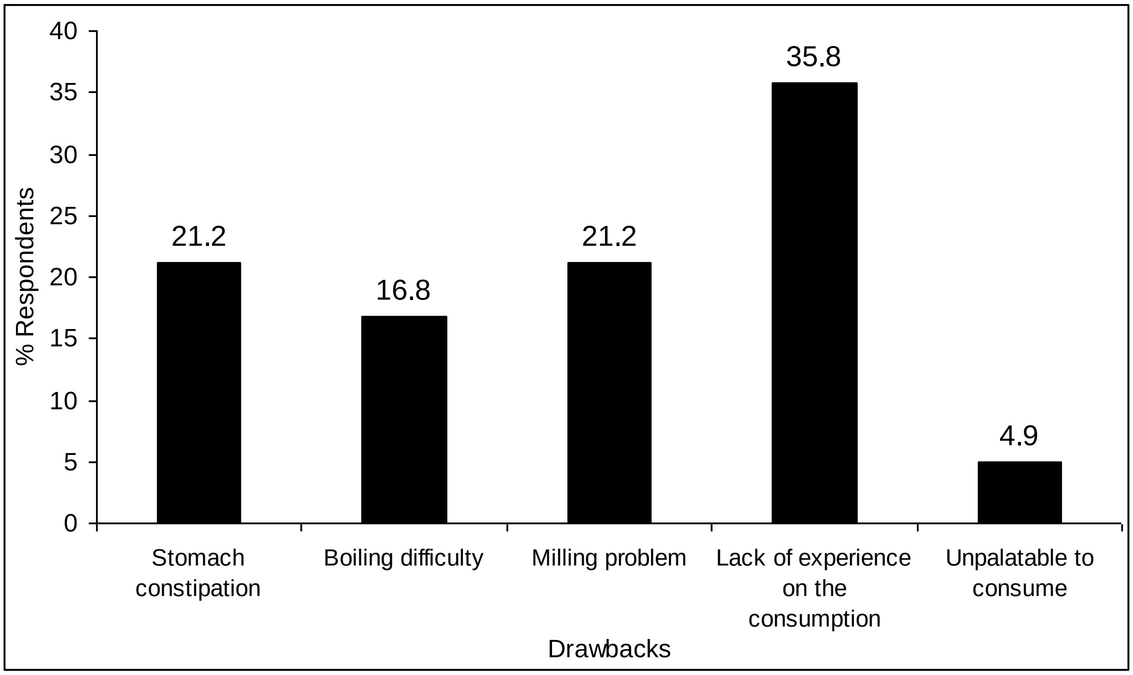

Figure 2.4-1 Draw backs of consuming soybean in the survey areas (% respondent farmers)

2.4.4 Marketing of soybean

The highest proportion of respondent farmers did not sell soybean. Out of the farmers who had sold soybean before, the largest proportion sold in the local market (small markets in the village); while the next highest proportion sold at the farm gate (Figure 2.4-2). Only 14.9% of the respondents were able to sell their soybean in the town market, which is a relatively larger market, located in big towns around their locality.

Among the farmers who had sold soybean previously, the largest proportion sold their soybean directly to consumers (Figure 2.4-3). A nearly equal proportion of respondent farmers sold their soybean to petty traders and cooperatives. The proportion of respondent farmers who sold their soybean to the wholesalers and NGO's were relatively small.

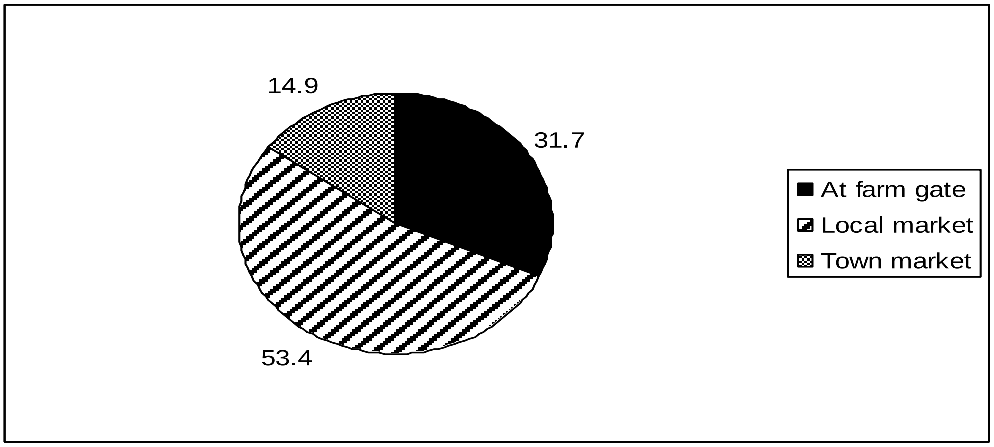

Figure 2.4.2 The places where farmers sold their soybean (% respondents)

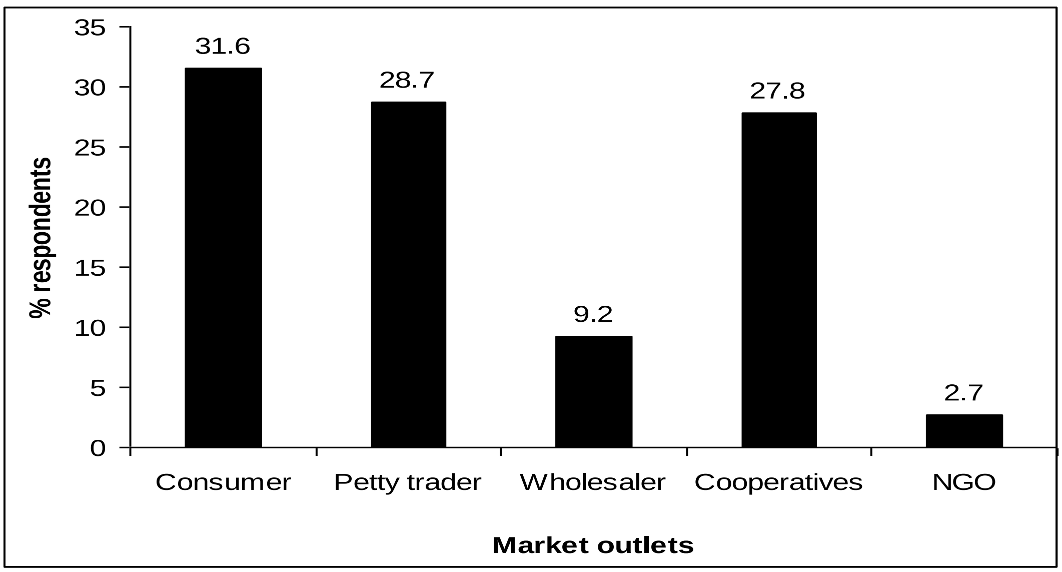

Figure 2.4.3 The different market outlets of soybean for farmers (% respondent farmers)

2.4.5 Timing of soybean sale and farmers judgment on the timing of sale

Among the farmers' who had sold soybean before, the majority sold their grain about 3-6 months after harvest, while the second highest proportion of the respondents sold immediately after harvest (Figure 2.4-4). The proportion of farmers who waited until the end of the season to sell their soybean was only 19.5 %. A very small percentage of respondents indicated no specific time of selling their soybean. However, the majority of respondents believed that the time of sale of their soybean was incorrect (Figure 2.4-5). The next higher proportion of respondents believed that the time of sale of their soybean was correct; meaning optimal timing in terms of price conditions is maintained. Only 11 % of the respondents were unsure whether the time of sale of their soybean was correct or not.

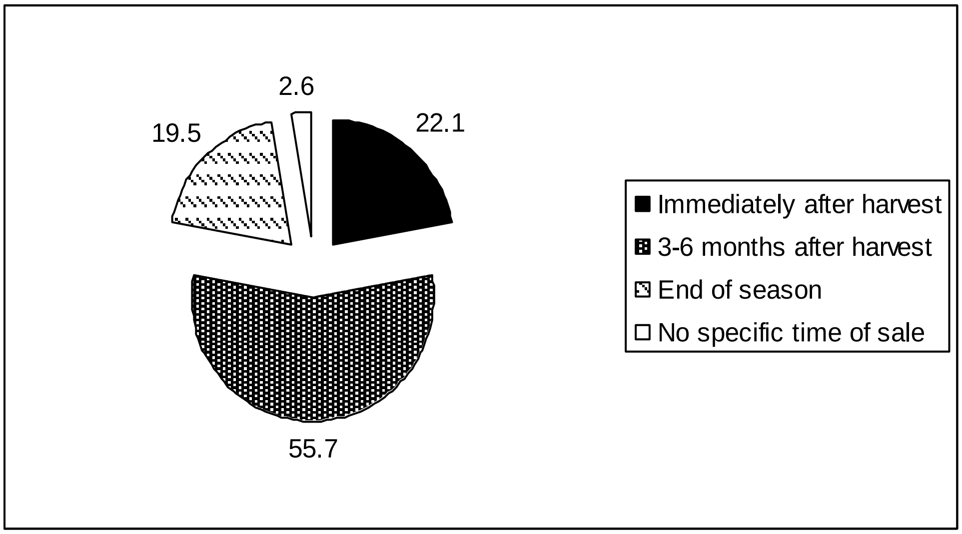

Figure 2.4-4 Response of farmers on the time of sale of soybean (% respondents)

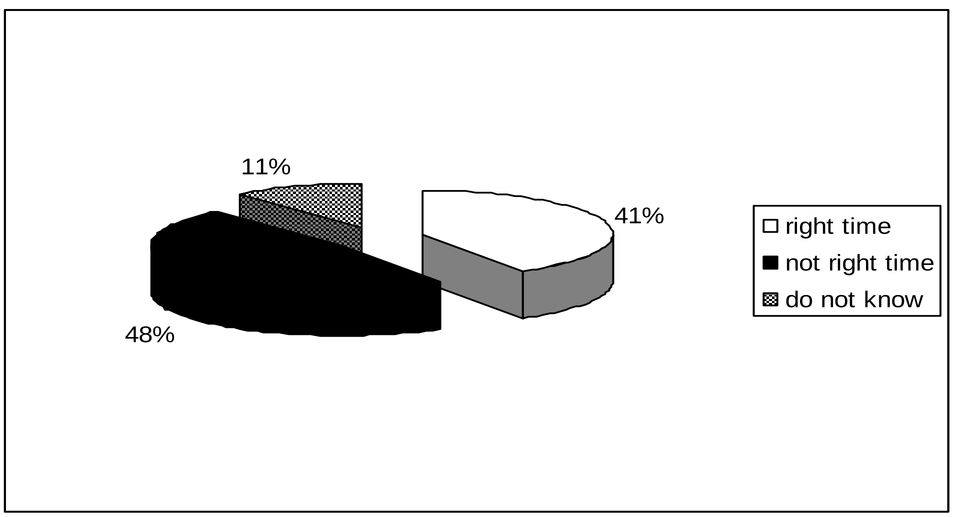

Figure 2.4-5 Farmers' opinion on the appropriateness of the time of sale of soybean (% respondents)

2.4.6 Demand of soybean as compared to other crops and farmers coping strategies for soybean sale failure

The highest proportion of respondent farmers rated the demand of soybean relative to other crops as poor (Table 2.4-3). The next highest proportion of farmers reported that the demand of soybean was better as compared to other crops. A higher proportion of farmers from Assossa, Darimu, Bambasi, Tiroafeta, and Omonada reported that the demand of soybean was poor as compared to other crops. The proportion of farmers who reported better demand of soybean as compared to other crops was higher for Assossa and Chewaka. An exceptionally high proportion of Bedele farmers were unsure about the demand of soybean as compared to other crops.

Under conditions of low price and failure to sell their soybean produce, the majority of respondent farmers used it for home consumption, while the second highest proportion of the respondents waited until the price improved. Only 14.4 % of the respondents sold it at any price (Figure 2.4-6).

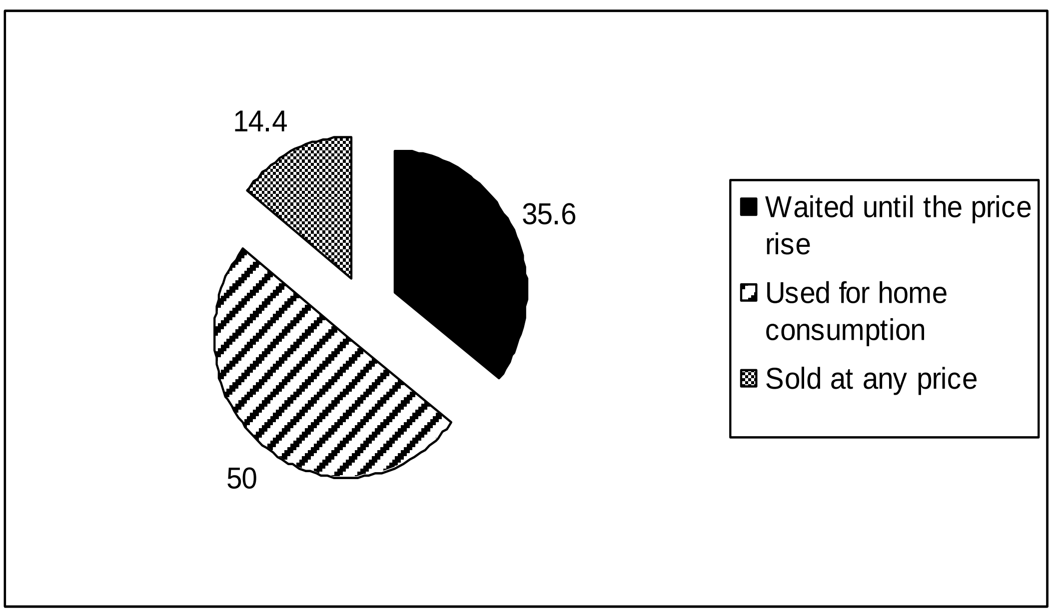

Figure 2.4-6 Farmers' coping strategy when they fail to sell their soybean in the market

Table 2.4 3 Demand and market price of soybean as compared to other crops in each Woreda (Percentage of the total respondents, N=166)

Woredas of the survey	Relative Demand and market price of soybean				
	Better	Poor	Similar	Fluctuates	Don't know
Assossa	7.8	11.4	1.2	3.0	0
Bambasi	4.2	6.0	1.8	3.0	0
Bedele	2.4	4.2	0.6	0	5.4
Chewaka	6.0	4.8	0.6	1.2	0
Darimu	3.0	7.2	1.2	6	0
Kersa	0.6	1.8	0.6	0	0
Mana	3.6	0	0.6	0	0
Omonada	1.8	3.6	0	0	0
Seka	2.4	0.6	0	0	0
Tiroafet	1.8	4.8	0.6	1.2	0
Total	33.7%	44.6%	7.2%	9.0%	5.4%

NB: Woreda is the third level administrative division (next to the federal government, regional government and zonal administration) in Ethiopia managed by local governments

2.5 Discussion

The diverse uses of soybean for smallholder farmers in developing countries have been the most important motive to strongly scale-up soybean production in Western Ethiopia. Farmers commonly prioritize their preferences based on the actual situation and problems they face in the farming practice. The fact that the respondent farmers ranked crop rotation and soil fertility improvement roles of soybean as first and second relative to other uses of soybean indicates that farmers emphasize soil fertility and cropping system problems. This in-turn indicates that the crop rotation and soil fertility improving roles of soybean need to be emphasized more in soybean training and popularization programs. Soil fertility management practices of Western Ethiopia farmers are generally considered poor which is characterized by low use of inorganic fertilizers, lack of proper crop rotation, less use of green and organic manures, which has to be supported by research and development to enhance the use of integrated soil fertility management practices. The reason is that crop rotation plays important in increasing yield, rotation of cereals with nitrogen fixing legumes reduces nitrogen fertilizer requirement significantly, reduces insect and disease developments (Roth, 1996). However, due to the high level of malnutrition problem in Ethiopia (Benson, 2005; Christiaensen and Alderman, 2001), especially in the rural and underage children, the role of soybean in fighting malnutrition should be first on governmental and non-governmental development programs' agendas for scaling-up production of soybean.

Enhancing the local consumption of soybean is one of the most important strategies to improve the local market of soybean, and fight malnutrition problems, which in-turn increases farmers' interest in soybean production. Non-governmental and aid organizations can also play an important role in enhancing the local production and consumption of soybean, which can be an alternative and sustainable way of fighting hunger and mal-nutrition to providing fortified food in developing countries. This can be achieved through strong training and popularization programs on soybean production and preparation techniques of various meals from soybean alone and in mixture with other grains (Tulu *et al*., 2008). The outcomes of such training and awareness creation efforts reflected in the higher proportion of households that prepare and consume soy milk (42.5%), which was unknown to farmers before the training intervention. The fact that high proportion of Bedele farmers (31.8 %) have not consumed soybean at all indicates that similar intervention around Bedele is crucial. Moreover, in areas where a limited number of meals are prepared and consumed and the proportion of respondents that has consumed soybean meals is low, such as Bambasi, Kersa, Seka and Mana (Table 4), further training on the preparation techniques and popularization of the various kinds of meals are necessary. Moreover, a high percentage of respondent farmers (74.4 %), reported that consuming soybean has no drawback, which is a very good opportunity to further scale-up the crop. Some of the drawbacks of consuming soybean, such as lack of experience preparing meals, stomach constipation, milling problems, and problems of boiling soybean, should not be underestimated, and merit attention and resources from researchers, development programs and home economists to reduce the problems.

The local market plays a very important role in stabilizing the market price of soybean, especially if the export market and consumption by large processing companies reduce. The fact that the majority of the respondents (42.9 %) did not sell the soybean they produced indicates that these farmers used their soybean produce mainly for home consumption. Besides, the majority of the buyers of soybean (18.5 %) directly consumed the produce, and the majority of the respondents sold their soybean in the local market (30.5 %) and at farm gate (18.1%), which indicates a strong demand for soybean in the local market.

It should be noted that the majority of the respondents (34.2 %) sold their soybean some 3-6 months after harvest i.e., did not sell immediately after harvest, and 41 % of the respondents believed that they sold their soybean at the right time. However, significant proportion of farmers who lacked adequate soybean market information i.e., farmers who sold their soybean immediately after harvest (13.6 %), who believe that the time of sale of their soybean is not right (41 %), and those who were not sure whether the time to sell their soybean was correct or not (11 %) need to be trained or supported by development programs on how to time their soybean sale during improved price.

Moreover, since soybean production is in-line with the Ethiopian rural development policy for its disease preventive role, especially for diseases that arise from mal-nutrition, and its role as a highly marketable export crop, due attention needs to be given for the scaling-up of soybean production by the Ethiopian government. Besides, good market price is one of the most important incentives for good crop management practice and sustainable production of soybean by smallholder farmers. However, most of the respondent farmers (44.6

%) rated the demand and market price of soybean compared to other crops as poor, while 33.7 % rated as better. This implies that there is much to be done to improve the market price of soybean, so as to integrate soybean in the farming system of Western Ethiopia. Local soybean crushing industries for oil and food, and grain trade organizations, such as Ethiopian Commodity Exchange, and exporters, farmers cooperatives have an important role to play to regulate soybean prices by purchasing soybean directly from farmers in the local market and at farm gate. Moreover, increasing the volume of production is very important to attract export market as importers buy in bulk. Investors will also have comparative advantage to invest in commercial soybean production in Ethiopia, and other developing Sub Saharan African countries than USA and Latin America, mainly due to cheap and abundant labor, availability of uncultivated land, and several free flowing rivers for irrigation, as well as a strategic geographic location with close proximity to major importers, namely the European Union, and Asia.

2.6 Conclusions and research implications

1) Farmers' assessment showed that crop rotation and soil fertility improvement role of soybean was more important than household consumption, market value and medicinal value of the crop. This indicates that farmers' awareness on the role of soybean for crop rotation and soil fertility improvement is high. This may also imply that household consumption and market outlets of the crop are not well developed.

2) The facts that the majority of respondent farmers never sold their soybean before, the major place of sales of soybean were local market and farm-gates, consumers were the major buyers of soybean and that farmers ranked the demand of soybean compared to other crops as poor, indicates that the market and value chains of soybean in Ethiopia is under developed.

3) Future works that enhance the local consumption of soybean and help improve the nutritional problems of the rural community, and especially under-aged children, require due consideration in the rural development policy of the country.

4) Though there has been significant increase in the number of private soybean processing industries, which has contributed to increased demand and market value of soybean; the value chain of the soybean is still weak and market price is inconsistent. Efforts that improve the value chain and stabilize market price should receive due emphasis, and the market link between the producers and processors need to be further strengthened by breaking long chains to maximize farmers benefit from the chain.

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CHAPTER 3

Subsistence farmers' experiences and perceptions about the soil, and fertilizer use in Western Ethiopia

3.1 Abstract

Low crop productivity is a major constraint contributing to food shortage in Ethiopia. Low productivity could be attributed to several factors, which include low soil fertility and low use of soil-fertility enhancing practices. The use of inorganic fertilizers has been suggested as one of the best approaches to address this problem. This study was conducted in Western Ethiopia to assess farmers' perceptions regarding the status of the soil, soil fertility problems and important factors in the use of inorganic fertilizer using semi-structured questionnaires. The results showed that farmers identified reddish brown and black soils as the predominant types of soils in the survey area. Most farmers were aware that soil fertility and the amount of fertilizer used in their farms were declining over the last five decades. The highest proportion of farmers responded to have problems in obtaining fertilizer at the right planting time. In addition, the high cost of fertilizer was identified as one of the most important factors that hindered the use of inorganic fertilizer by farmers. The majority of respondent farmers identified farmers' cooperatives as the major supplier of fertilizer. In general, 23.1, 24.2, and 4.3 % of the respondents rated the quality of service of farmers' cooperatives as better, good and very good, indicating that 51.6 % of the respondents were satisfied; while 36.5% were unsatisfied with the service. As major suppliers, farmers' cooperatives need to improve the quality of their service in supplying fertilizer to farmers.

Key words: Farmers' perception, PRA, Inorganic fertilizer, low soil fertility, acid soils

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3.2 Introduction

High population growth (at the rate of 3.3%), recurrent drought (Deressa and Hassen, 2009), and low productivity of crops, pose a huge challenge to Ethiopian agriculture in meeting the food demand of the country. The wide gap between food production and food demand can be narrowed down through intensive agriculture (Wallace and Knausenberger, 1997). However, intensive agriculture requires the use of high amounts of inputs, such as inorganic fertilizers and pesticides, along with responsive varieties. Despite, the availability of inorganic fertilizers in the market, the level of use of such inorganic fertilizers by subsistence farmers of most Sub-Saharan African (SSA) countries, like Ethiopia is very low, compared to the amount used by developed nations (Wallace and Knausenberger, 1997; Lynch, 2007).

Sub-Saharan Africa uses very low levels of inorganic fertilizers. According to Lynch (2007), average inorganic fertilizer use in North and South America is 100-300 kg ha $^{-1}$, while the use in Africa is 21 kg ha^{-1}, and only 10 kg ha $^{-1}$ is used in SSA. It has been estimated that there has to be at least 18 % annual increase in fertilizer use in SSA in order to boost production to meet the food need of their growing population (Wallace and Knausenberger, 1997). Such a low use of inorganic fertilizer coupled with poor soil fertility is one of the critical food production problems in most developing countries (Lynch, 2007), particularly in Western Ethiopia.

Most of the soils in Western Ethiopia are acidic with pH ranging from 5.5-6.7 (Van Straaten, 2002). According to Wortmann *et al*. (2003), the availability of nutrients in the soil is highly influenced by pH. Soil nutrients, such as nitrogen, potassium, calcium, magnesium, sulfur, zinc, molybdenum and most importantly, phosphorus (P) are deficient on acid soils. The deficiency of P is mainly due to aluminum toxicity, which prevents the uptake and translocation of P by the plant, and aluminum and iron fixes the available P, and converts it into unavailable form (Rao *et al*., 1993). Since, Western Ethiopia receives a high mean annual rainfall of above 1300 mm; there is a high loss of soil fertility, through erosion and leaching. In most cases, cereals are produced in mono-crop condition for several consecutive seasons (Tulu *et al*., 2008), which has contributed a lot to the degradation of the fertility of the soil. Hence, unless efficient soil fertility management practices are designed and implemented, the productivity of such soils will remain poor.

The acidity problem of the soil can partly be improved by the application of lime (Rao *et al*., 1993; Wortmann *et al*., 2003). However, lime application alone without the application of inorganic fertilizers at the right time and rate cannot solve the fertility problem of the soil. On the other hand, the use of inorganic fertilizer has remained very difficult for most subsistence farmers of developing countries, due to high price of fertilizer, which is beyond the purchasing capacity of farmers in the region. Jayne *et al*. (2003) reported that the high price of fertilizer could be attributed to high costs in transaction; transportation, handling and storage; taxes and fees; and excess profit resulting from lack of competition among different fertilizer marketing enterprises.

According to Aklilu (1980), government policy, which includes: agricultural price, credit, taxation and investment policies, has a great influence on the adoption-diffusion of fertilizer. The author opined that three variables i.e., profitability, risk and extension service are the main determinants of adoption-diffusion of fertilizers. Reduction in farm gate price of fertilizer could be achieved through minimizing these different components of farm gate prices, along with policy considerations (Aklilu, 1980). Besides, there are several other reasons, which are believed by farmers as the major bottlenecks that hinder the use of inorganic fertilizer at planting time and in the recommended amount. Hence, assessing these perceptions helps to understand the actual problems that soybean producing farmers are facing, and to design future strategies to enhance the use of fertilizer for soybean production. It also helps to design relevant research approaches, and facilitate researchers-farmers communication (Desbiez *et al*., 2004). Moreover, the level of lack of awareness of farmers on some of the most important agricultural principles and practices can be revealed through such assessments. This will help to design awareness creation programs and trainings to fill the knowledge gap.

Participatory rural appraisal (PRA) techniques have previously been employed to assess farmer's perception on soil quality, soil fertility problems and indigenous soil fertility management practices (Elias, 2002; Desbiez *et al*., 2004; Erkossa *et al*., 2004). Farmers in Caffee Doonsa, a small watershed in the central highlands of Ethiopia, identified and ranked12 types of soils; based on the use (Erkossa *et al*., 2004) and seven types of soils in Kindo Koisha district of southern Ethiopia (Elias, 2002). Desbiez *et al*. (2004) reported that farmers in mid-hills of Nepal identified 62 indicators of soil fertility, which were divided into five major related classes i.e., soil characteristics, crop performance, agricultural management, environmental factors and biology. Crop production was used by farmers as a means to judge the fertility of soil in South West Niger (Osbahra and Allanb, 2003). The Soil Quality Institute of USDA has developed two soil quality assessment tools, which can be used by farmers and field workers (Ditzler and Tugel, 2002).

According to Erkossa *et al*. (2004), farmers identified three soil quality groups in the watershed area viz. Abolse, Kooticha and Carii. Abolse was identified as the best soil followed by Kooticha and Carii, respectively for crop production. The validity of farmers ranking was verified by the highest grain and straw yield of wheat obtained from Abolse soil followed by Kooticha and Carii, respectively (Erkossa *et al*., 2002). According to Elias (2002), farmers classified the soil of Kindo Koisha district into two major groups based on fertility i.e., 'arada', which in the local language means fertile and 'lada', which means infertile or poor soil. Farmers described 'arada' soil as dark, rich and powerful soil; while lada as red, poor, thin and power-less. Elias (2002) emphasized the importance of farmers' involvement in the systematic soil quality assessment.

Through their long experience of agricultural practices, farmers have developed various techniques that can be used to detect the decline in soil fertility. The soil fertility decline indicators used by farmers includes: change in weed biomass and species; changes in soil color, and thickness; reduced growth and color changes of crops and low crop yields in climatically good seasons (Elias, 2002). The author also reported that 94% of the respondent farmers believe in the presence of soil fertility decline in the past several years. Osbahra and Allanb (2003) reported farmers' perception of declining soil fertility by 80% of the respondent farmers. Farmers associated the decline in the fertility of the soil with the addiction of the soil to fertilizer, loss of its fertility, and the soil become sick and power less (Elias, 2002). Although it is difficult to explain what is referred by farmers as to the soil get addicted to fertilizer, and sick, the authors suggested that this might have association with long term use of di-ammonium phosphate (DAP) fertilizer. This in turn might have caused the acidity of the soil, as according to Smaling *et al*. (1992), DAP is a strong acidifying fertilizer. Wortmann *et al*. (2003) reported that all nitrogen, phosphorus, and sulfur fertilizers can cause acidity. The acidity caused by nitrogen fertilizers i.e., anhydrous ammonia, ammonium nitrate, and urea is similar; however, it is higher than ammonium sulfate, DAP and mono ammonium phosphates (MAP).

Despite, the importance of farmer's perception assessment, there was no such study conducted in Western Ethiopia. Thus, recent and adequate information is lacking on farmers perception on the types and status of soils, the trend and constraints of fertilizer use in the region. Therefore, the objective of the study was to assess farmer's perception on the status of the soil, various soil fertility and fertilizer use related factors in Western Ethiopia.

3.3 Materials and Methods

3.3.1 Study sites

The study was conducted in three sites (Jimma, IIlubabor, and Assosa) of Western Ethiopia. Some agro-ecological characteristics of these sites are described in Table 3.3-1. Jimma and Mettu, are categorized as tepid to cool, humid mid highlands, while Assossa is categorized as hot to warm sub-humid lowlands (MoA, 1998). Maize is the dominant cereal crop in all the sites. Besides, tef (Ethiopia's indigenous food crop), sorghum, millet, wheat and barley are the most important crops produced in Western Ethiopia, in the respective order of importance (Efa and Shibru, 2005). Currently, there is strong effort to scale up soybean production and consumption in the survey areas. Consequently, soybean is emerging as an important legume crop in the region. The three sites receive high rainfall. In such high rainfall areas, basic cations usually precipitate, and iron oxides become abundant; resulting in acidic reddish brown soil (Singh and Gilkes, 1992; Shengli *et al*., 2004).

Table 3.3 1 Agro-ecological characteristics of the study zones

Study sites	*AEZ	Altitude (masl)	Location	Annual mean RF (mm)	Annual mean Temperature		Soil type
					Min	Max	
Jimma	H_2	1750	$7^0$46'N 36^0E	1754	11	26	Reddish brown
Mettu	H_2	1550	$8^0$3' N 30^0E	1835	12	27	Dark red brown
Assosa	Hot to warm sub-humid lowlands	1550	$10^0$0'04N, $34^0$0'57E	1316	16.8	27.9	Reddish brown

H_{2-} Tepid to cool humid mid highlands, AEZ=Agro ecological zones of Ethiopia (MoA, 1998)

3.3.2 Data collection and statistical analysis techniques

Semi-structured questionnaire was administered to 67 respondents belonging to eight farmers associations (FAs) in Assossa; 57 respondents from 12 PAs in

Mettu; and 62 respondents from 13 PAs in Jimma. The PAs and respondent farmers were selected randomly in the major soybean producing areas in each site. The questionnaires were administered by five researchers, selected from different disciplines in Jimma Research Center, who have good knowledge of the local language (Afan Oromo), and English. Similarly, the questionnaires around Assossa zone were filled by five researchers from different disciplines. Data analysis was performed using Statistical Package for Social Sciences (SPSS) software. PRA techniques such as rank and rank frequency, and descriptive statistics were used to analyze the data.

3.4 Results

3.4.1 Socio-economic characteristics of the respondent farmers

The proportions of male and female respondent farmers were 89.9% and 10.2%, respectively. The residences of respondent farmers were located at altitudes ranging between 1242 and 1989 masl (Table 3.4-1). The maximum distances of the respondent's house from all-weather roads, market and DA center were 12, 36 and 12 kms, respectively. The maximum age of the respondents was 76, while the minimum was 20. The largest family size was 18, while the smallest was three, and mean family size was seven.

Table 3.4 1 Some socio-economic features of the respondent farmers

Socio-economic features	N	Minimum	Maximum	Mean	Standard error
Altitude of the respondents residence	96	1242	1989	1604.8	27.48
Distance from all-weather road	182	0	12	.9	.12
Distance from the market	184	0	36	6.8	.47
Distance from DA center	185	.01	12.00	1.4	.14
Age of head of the household	186	20	76	41.9	.87
Family size	186	3	18	7.1	.20

3.4.2 Major types of soils in the survey area

Farmers in the survey area reported four major types of soils based on color, (black, reddish brown, brown and gray), and two types based on texture (clay and sandy) (Figure 3.4-1). The most commonly recognized soil types in the study sites were reddish brown (95.6%), followed by black soil, which was identified by 85.8% of the respondents. Based on texture, two types of soils i.e., sandy and clay soils were identified by 10.9 and 6.6 % respondents, respectively.

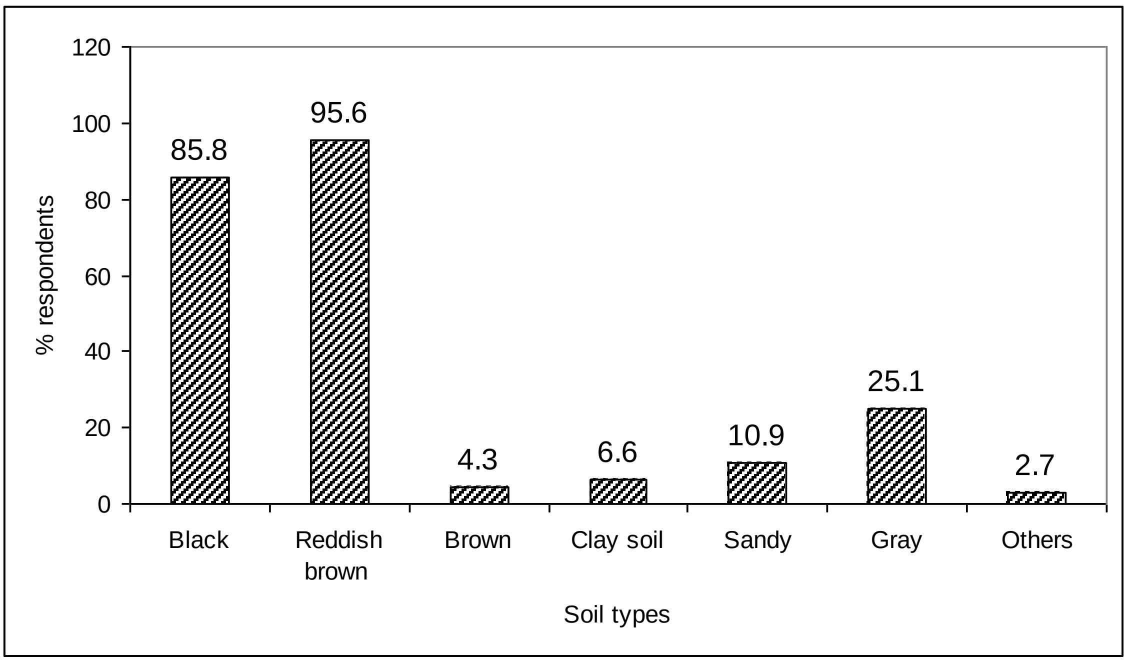

Figure 3.4-1 Types of soils recognized by farmers in the study areas (N=186)

3.4.3 Change in soil fertility over time

Most respondent farmers (87.4%) believed that soil fertility declined in their farming experience (the last 1-5 decades) (Figure 3.4-2). It is only 9.3 % of the farmers who believed that soil fertility increased in the farming experience of respondent farmers. Some of these farmers justified that soil fertility decline or improvement is determined by the way the soil is handled and the soil fertility management system used.

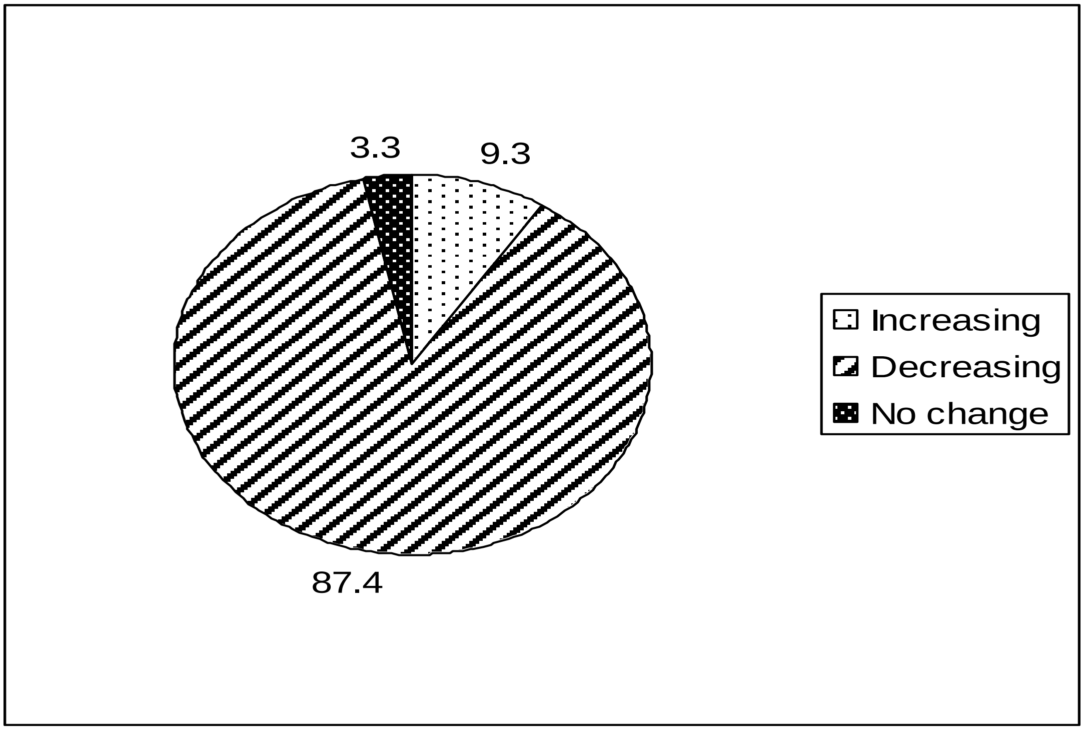

Figure 3.4-2 Farmers perception on the change in the fertility of the soil overtime (N=183)

3.4.4 Indicators used by farmers to detect change in soil fertility

Most farmers (85.9%) use poor crop yield in climatically good season as a means of knowing the decline in soil fertility. The other three i.e., change in soil color and thickness; reduced growth and change in crop color; and shift in weed biomass were also important indicators of change in soil fertility with respective percentage respondents of 67.2, 63.8 and 85.9 (Figure 3.4-3).

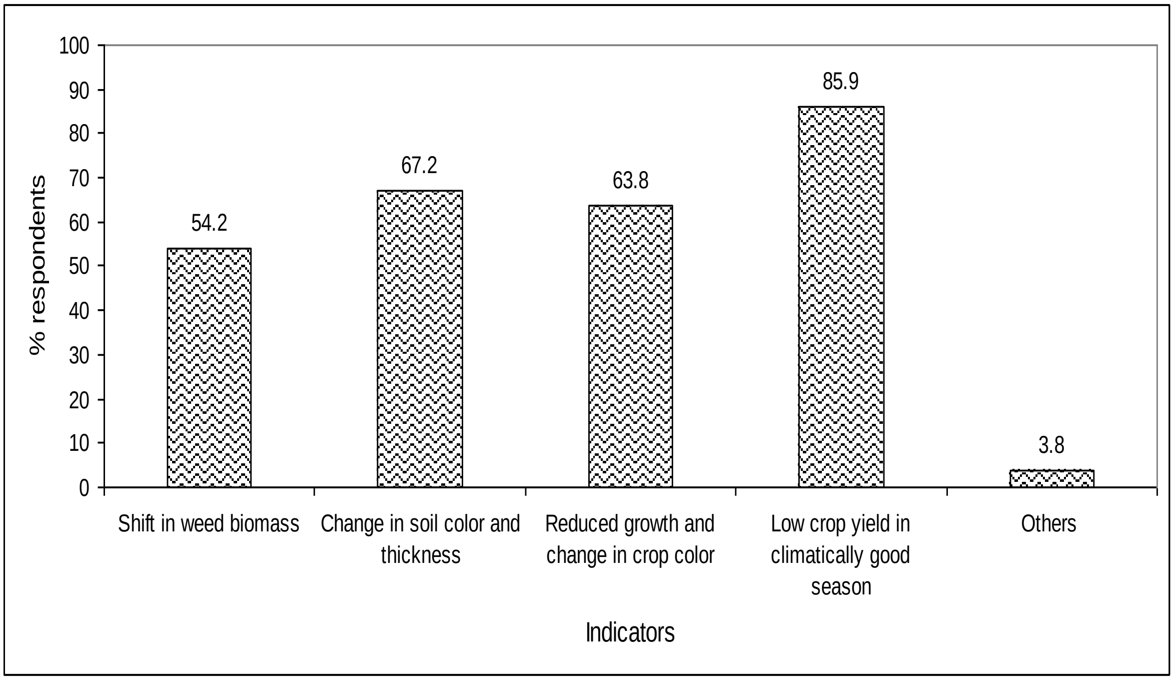

Figure 3.4-3 Indicators used by farmers to detect the change in the fertility of the soil (N=186)

3.4.5 Farmers' perceptions on the major causes of soil fertility decline

Almost all respondent farmers (99.5%) replied that they knew the cause of low soil fertility problem. Farmers ranked soil erosion as the number one cause of low soil fertility problem with 515 points (Table 3.4-2). Long term mono-cropping ranked second (471 points) followed by poor soil fertility management practices (382 points). Dependency of the soil to fertilizer was ranked last with total point of 186.

Table 3.4 2 Farmers rank frequency, total points and rank of the major factors causing low soil fertility problem (N=126)

Factors	Rank frequency					Total points	Rank
	1	2	3	4	5		
Soil erosion	53	39	23	11	3	515	1
Dependency of the soil to fertilizer	6	5	11	18	67	186	5
Long term mono-cropping	40	34	32	18	3	471	2
Producing heavy feeder crops (such as sorghum)	12	21	28	38	14	332	4
Poor soil fertility management practices	18	30	33	28	17	382	3

3.4-6 Problems associated with use of inorganic fertilizers

Majority of the farmers (76.6%) indicated that they could not get inorganic fertilizer at the right planting time. It is only 23.4% who were able to get inorganic fertilizer at the right planting time. Results on the main problems associated with fertilizer access indicated that although, high cost of fertilizer and absence of credit were highly emphasized by Assossa farmers with respective percent respondents of 82.8 and 43.1, the problems were also critical at Jimma and Ilubabor (Table 3.4-3). The untimely availability of fertilizer has got high and nearly the same magnitude across the three locations Jimma, Mettuand Assosa with respective percentage respondents of 65.4, 56.1 and 65.5. Problem in distribution system is uniquely higher at Jimma (38.5%), while lack of purchasing capacity is at Assossa (27.6%).

Table 3.4 3 Problems associated with farmers not obtaining inorganic fertilizer at the right time (% respondents in each location i.e., Jimma, Mettu and Assosa)

Factors	Locations		
	Jimma (N=52)	Mettu (N=57)	Assossa (N=58)
Lack of access for credit	25.0	22.8	43.1
High cost	51.9	61.4	82.8
Timely unavailability	65.4	56.1	65.5
Lack of response	34.6	10.5	17.2
Problem of availability in the required amount	38.5	15.8	32.8
Problem in credit returning system	21.2	1.8	5.2
Obtaining fertilizer at the right planting time is not a problem	21.2	17.5	17.2
In-efficiency of the officers	26.9	19.3	29.3
Supply related problem	17.3	15.8	29.3
Distribution system	38.5	19.3	12.1
Reason unknown	5.8	19.3	17.2
Lack of purchasing capacity	3.8	7.0	27.6
Others	5.8	7.0	3.4

3.4-7 Trend of fertilizer use since 1995

The proportion of farmers who did not apply fertilizer on soybean was 10.7%. Among the farmers who were applying fertilizer on soybean, 53% replied that the amount of fertilizer use in their farm has declined since 1995, where around 32.8% of farmers started using fertilizer (CSA, 1996). Despite, the high cost of fertilizer and problem of availability at the right planting time, a large percentage (39%) of respondents has increased fertilizer use on their farm (Figure 3.4-4). The farmers, who have consistent use of fertilizer, were lowest in proportion, i.e., 8.0 %, respectively.

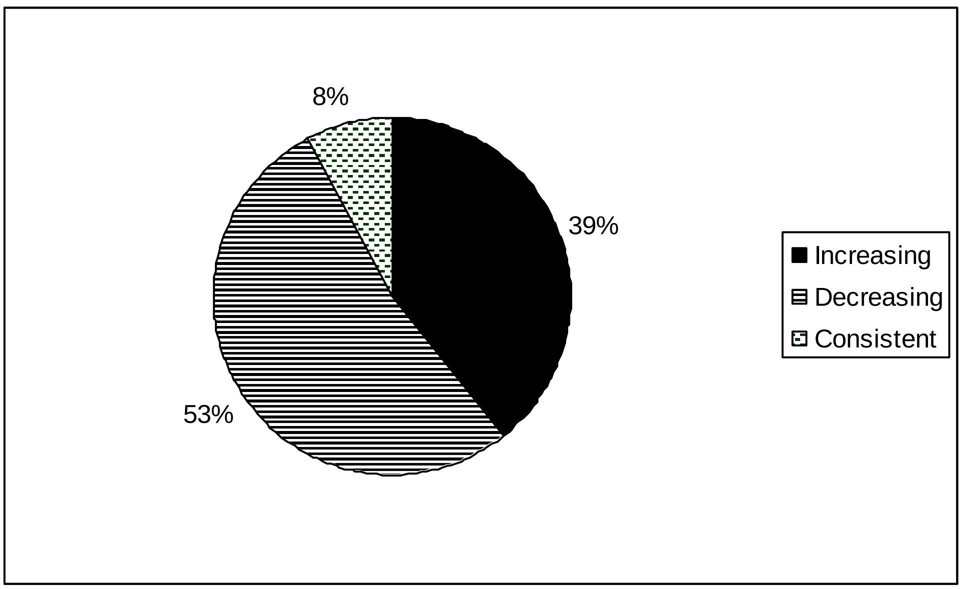

Figure 3.4-4 Trend of inorganic fertilizer use by farmers (percent respondent farmers, N=186)

3.4-8 Farmers' perception on the impact of inorganic fertilizer on the fertility of soil

Assessment was made on what farmers believe is the impact of long term use of inorganic fertilizer on the fertility of the soil. Most of the respondent farmers (66.1%) believed that long term use of inorganic fertilizer reduces the fertility of the soil. It is only 21% of the respondent farmers who believed that use of inorganic fertilizer increases the fertility of the soil, while 11.3% replied no change on the fertility of the soil (Figure 3.4-5).

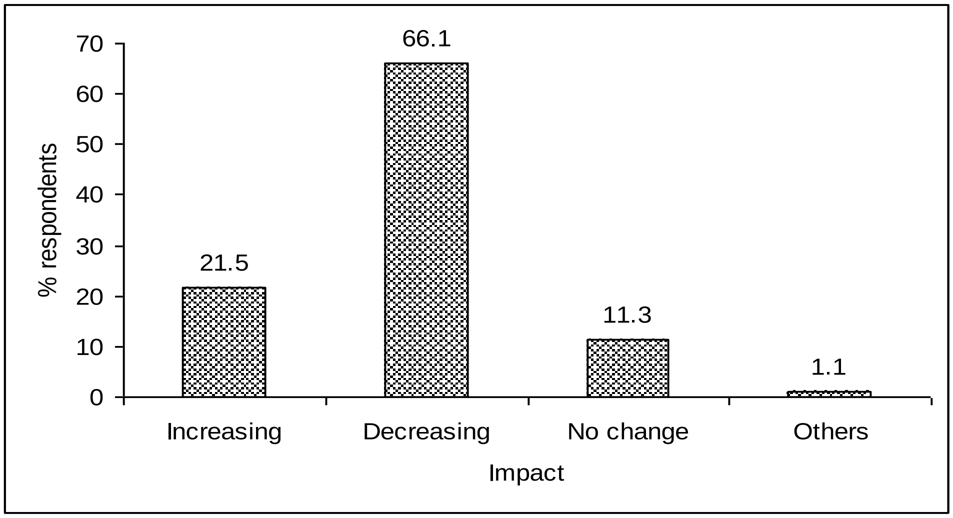

Figure 3.4-5 Farmers' perception on the impact of long-term application of inorganic fertilizer on the fertility of the soil

3.4-9 Sources of inorganic fertilizer

Most of the respondent farmers (69.9%) chose farmers cooperatives as the primary source of inorganic fertilizer (Figure 3.4-6). The Bureau of Agriculture and small private traders were the next important sources of fertilizer, for 20.2% and 18.6% of the respondent farmers, respectively. Most respondent farmers (47%) believe that there is no easy access to inorganic fertilizer. However, among the different sources of fertilizer, farmer's cooperatives and governmental sources were identified as easier sources of inorganic fertilizer by 14.9 and 13.3% respondents, respectively. The proportion of farmers replied that market and small private traders are easier sources of fertilizer, and those replied that there is no problem of access were equal (8.3%) (Figure 3.4-7).

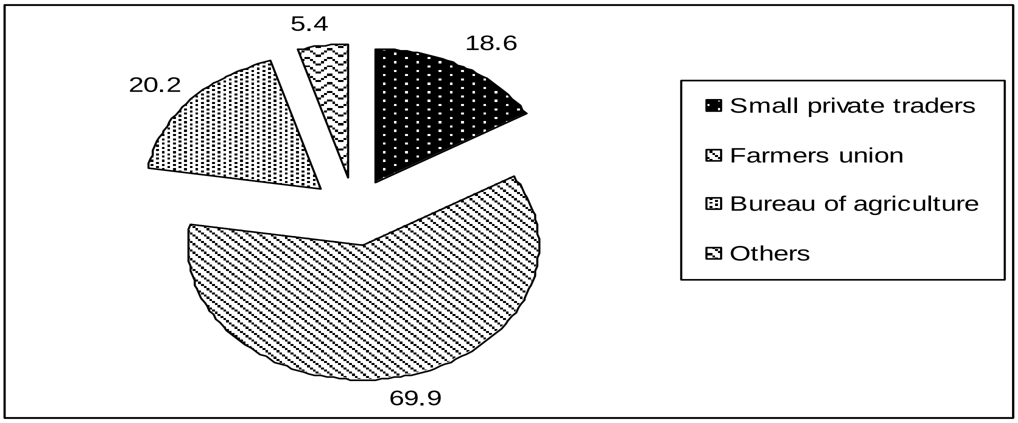

Figure 3.4-6 Major sources of inorganic fertilizer used by farmers (in terms of % respondents) used to obtain their fertilizer

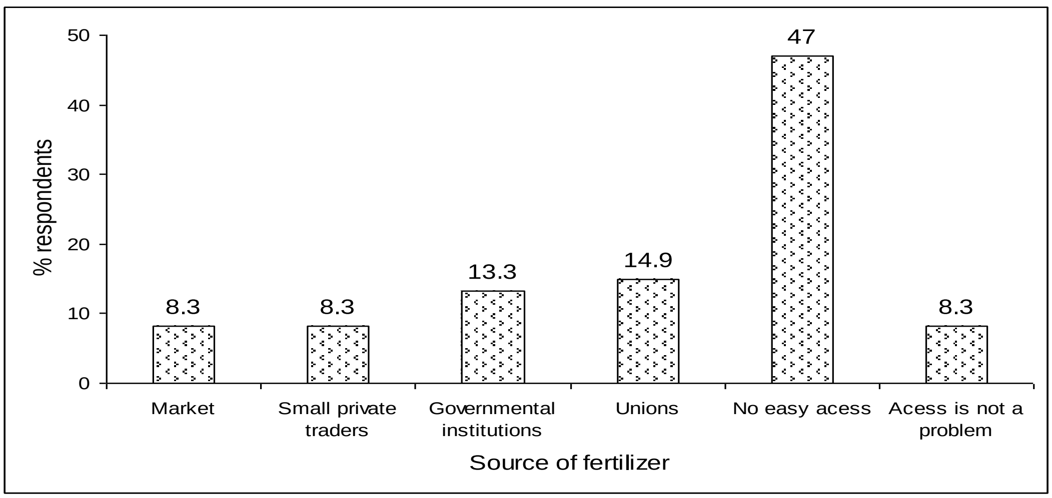

Figure 3.4-7 Sources of fertilizer described by farmers as easy access to inorganic fertilizer (N=183)

3.4.10 Farmers' evaluation of farmer's cooperatives service in supplying fertilizer

Highest percentage of respondent farmers (30.6%) evaluated the quality of service they get from farmers' cooperatives as bad (Figure 3.4-8). The percentage of farmers who rated the quality of service provided by farmer cooperatives as better and good were nearly equal with 23.1 and 24.2% respondents respectively. Those who responded not having cooperatives around them were 9.7%.

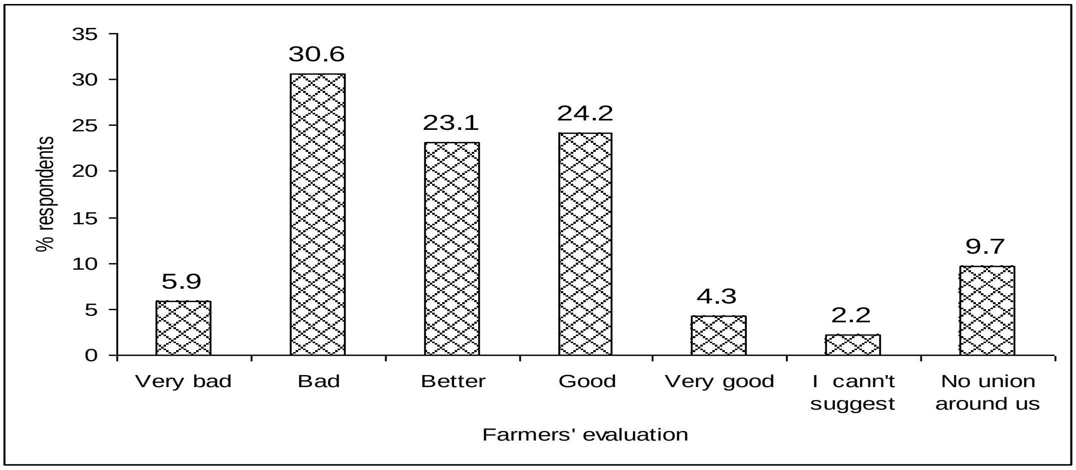

Figure 3.4-8 Farmers' evaluation of the service provided by farmer's cooperatives

3.5 Discussion

Farmers reported different types of soils based on visible criteria, such as soil color and texture. Reddish and reddish brown soil was the most commonly identified type of soil in the study area. Farmers reported that the fertility of reddish brown soil is lower than that of black soil. Other farmers suggested that when the fertility of the soil is exhausted it changes its color from black to reddish brown. The reddish and reddish brown soils of western Ethiopia are nitisols and acrisols, and are characterized by low pH, and poor soil fertility; whereas the black soils in western Ethiopia are cambisols and vertisols that are characterized by good fertility, higher water retention capacity, which is in-line with farmers' opinion. Most farmers reported that soil fertility and the amount of fertilizer used were declining in the last 1-5 decades. Along with those who do not totally apply fertilizer, the farmers, whose fertilizer use is declining might have been discouraged by the various constraints of fertilizer use, of which high cost and timely unavailability of fertilizer are the most important ones. To motivate these farmers use fertilizer at the recommended rate, farm gate price of fertilizer has to be reduced as suggested by Aklilu (1980). The use of user friendly soil fertility testing tools like that reported by Ditzler and Tugel (2002) are very important for use by farmers and field workers, which facilitates frequent monitoring of the change in the fertility of the soil, and to make point recommendation of fertilizer than blanket recommendation, which is a common practice in most developing countries.

Some farmers, on the other hand, replied that the fertility of the soil in their farm is increasing. In a key informant discussion, these farmers justified that the fertility of the soil is dependent on the way the soil is handled and the soil fertility management practices used by farmers. The proportion of farmers, whose fertilizer use increased was relatively high. This increased use of fertilizer might have arisen from the decline in the fertility of the soil over time, which might have in-turn reduced the response from applied fertilizer.

As acidity is the major problem of the soil in SSA countries and Western Ethiopia, which limits the availability of P, acid soil management practices, such as the application of lime is very important (Wortmann *et al*., 2003; Rao *et al*., 1993), which neutralizes the pH and increases the availability of applied P. In addition, to reduce the acidifying effect and dependency of the soil to fertilizer, farmers need to increase the use of other alternative soil fertility management practices, such as crop rotation, the use of compost, biological nitrogen fixation, and control of erosion. Thus, farmers should be encouraged and supported to use such alternative soil fertility management practices by training, research and development programs.

Low crop yield in good season, change in soil color and thickness, reduced growth and change in crop color, and shift in weed biomass were found to be the most important soil fertility decline indicators of farmers in the survey area. These results are in agreement with the report of Elias (2002). Soil erosion followed by long term mono cropping was ranked as the most important cause of low soil fertility problem. Hence, farmers need to be empowered to use soil erosion controlling practices, such as contour ploughing, planting of vetiver grass and other grasses against the slope, and terracing. Besides, training, awareness creation and popularization interventions are required to integrate leguminous crops such as soybean and haricot bean to break the mono-cropping culture in the region.

Most respondent farmers failed to obtain fertilizer at the right planting time. Some of the most important factors, which hindered the use of fertilizer at planting time, were high cost, timely unavailability, absence of credit, and unavailability of fertilizer in the required amount. The problem of lack of credit was exceptionally high at Assosa; hence, credit options should be made available to these farmers. The rest of the problems could be reduced by improving the fertilizer transportation, distribution systems and the efficiency of fertilizer supplying institutions, such as farmers' cooperatives.

Most respondent farmers believed that long term use of inorganic fertilizer reduces the fertility of the soil. These results were in agreement with those of Elias (2002), in which farmers perceived that the soil gets addicted to fertilizer; consequently becoming weak and powerless. The soil acidifying effect of DAP (Smaling *et al*., 1992), and nitrogenous and sulfur fertilizers (Wortman *et al*., 2003) might have caused the decline in the fertility of the soil. DAP is the most commonly used fertilizer as compared to urea and other nitrogenous fertilizers, and thus, it is the main acidity causing inorganic fertilizer in most SSA countries. However, the problem of acidity caused by the application of inorganic fertilizers could be minimized by the application of lime, and the problem is not more critical than not using fertilizer.

To increase food production and meet the growing food demand of developing countries, soil fertility management practices, mainly the use of inorganic fertilizers, needs to be given due attention. The use of inorganic fertilizer could be enhanced through various strategies, of which policy consideration, such as improving the rural transportation and distribution systems of fertilizer, creating conducive fertilizer marketing environment, improving the fertilizer taxation system, improving access to credit and credit returning system, improving the capacity of fertilizer supplying firms are the most important factors.

3.6 Conclusion and implications of research

1) Most farmers' of Western Ethiopia realized that the soil fertility of their farm land had been declining in the last five decades. Therefore, research and extension systems that emphasize sustainable and integrated soil-fertility management practices needs to be implemented.

2) Most respondent farmers' reported that the amount of inorganic fertilizer they have been using has declined in the past five decades, and reported difficulty in obtaining fertilizer at the right planting time. The major problem in the use of fertilizer was high price of fertilizer. Policy measures and improving fertilizer distribution systems that improves the price of fertilizer will have paramount significance in enhancing fertilizer use by farmers.

3) In general, the study revealed that farmers produce soybean under reduced soil fertility and low fertilizer use conditions. Therefore, breeding programs that develop improved varieties that are tolerant to low soil fertility conditions, and efficient in the use of soil nutrients need to be high priority in Western Ethiopia.

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CHAPTER 4

Genotypic variability of soybean for selected quantitative traits under high and low P conditions

4.1 Abstract

Assessment of genetic variability provides a clear understanding of the prevalent genetic potential of the genotypes that could be exploited to improve the crop for low P tolerance for the smallholder sector. Therefore, the objective of the study was to estimate the extent of genetic variability among 36 soybean (*Glycine max* L.) genotypes for selected quantitative traits under low (zero) and high (100kg ha^{-1}) applied P conditions. The genotypes were evaluated on acidic soils at three locations, with two replications each, in Western Ethiopia. Results revealed significant differences among genotypes for all the traits; except for pod number at low P; while all the traits; except root volume, pod number, and number of seeds per pod showed significant differences at high P. Relatively high genetic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were observed for fresh biomass weight, root fresh weight and root volume. The following traits: 100-seed weight, plant height, root and biomass fresh weight exhibited relatively high heritability and genetic advance. The first five principal components (PCs) accounted for more than 85 and 77% of the total variation at low and high P, respectively. The genotypes were fitted into four clusters under both high and low P conditions. Generally, observation of large variation and relatively high heritability indicates that selection would be effective to improve performance of varieties under both conditions that will enable identify highly productive soybean varieties under optimum P and that are tolerant to low P which will have important contribution in the fight against malnutrition and in improving household income.

Keywords: soybean, genetic variability, low P tolerance, genetic parameters, multivariate techniques

4.2 Introduction

Soybean (*Glycine max* L.) is one of the most important leguminous and oil crops with worldwide growing importance; as food and market commodity. The importance of soybean emanates from the high nutritional value of its grain: 40% protein and 20% oil (Gurumu *et al*., 2009), making it an important raw material for food and oil processing industries; in crop rotation, due to its nitrogen fixing capacity that is important in improving soil fertility, and health benefits of its consumption (Tesfaye *et al*., 2010). It is also considered as a strategic crop in fighting the worlds' food shortage and malnutrition problems, and most food aids to displaced and malnourished people are fortified with soybean (Thoenes, 2004).

Despite, the wide range of benefits that soybean has to subsistence farmers of sub-Saharan Africa, its productivity is very low (below 1.5 t ha^{-1}) in many of these countries, compared to more than 2.7 t ha^{-1} productivity obtained elsewhere (FAO, 2013). Several production constraints affecting productivity of the crop have been documented, and among which poor soil fertility that is mainly associated with acidic soils is critical in most developing countries. von Uexkull and Mutert (1995) reported that soil acidity limits crop production on more than 50% of the world's potentially arable land and 12% of the land that is currently under production. Its effect on crop production arises from a combination of several factors, such as toxic levels of iron (Fe), aluminum (Al) and manganese (Mn); low availability of P; and deficiency of K, Ca and Mg (Uexkull and Bosshart, 1982; Kochian *et al*., 2004; Andrade *et al*., 2002). Batjes (1997) reported that the availability of P is limited to plant roots on two third of the world's cultivated soil. Sample *et al*. (1980) and Stevenson and Cole (1999) attributed the low P in most soils to intensive erosion, weathering and P fixation by free Fe and Al oxides.

The application of inorganic P fertilizers is one of the possibilities for addressing the problem of low P availability. However, most farmers of Sub-Saharan African countries have limited capacity to purchase and apply inorganic fertilizers, mainly because of high price, limited availability at the right planting time, and problem of distribution systems (Tesfaye *et al*., 2011). Besides, the non-renewable P reserve is estimated to be exhausted from the soil in the coming few decades (Runge-Metzger, 1995; Vance *et al*., 2003). Treatment of acid soil with lime is another approach in ameliorating acid soils, to reduce the acidity of the soil, and thereby, increasing the availability of applied P. However, due to the large quantities (Rao et al. 1993) of lime required for this purpose, the approach is highly labor intensive and expensive.

Selection and development of crop varieties that can efficiently utilize the soil P and perform well under low soil P conditions are considered as a sustainable and economical approach (Wang *et al*., 2010) to withstand the low P availability problem. The availability of genetic variability in a gene pool is a prerequisite for a breeding program (Aditya *et al*., 2011), and is an important factor in obtaining the expected genetic progress from selection. Further, the effectiveness of selection depends on the availability of heritable differences (Dabholkar, 1992). The existence of a rich genetic variability in soybean that provides a huge potential to improve several economically important attributes was reported by Verma *et al*. (1993).

Aditya *et al*. (2011) emphasized the importance of genetic parameters, such as genotypic coefficient variation (GCV), phenotypic coefficient of variation (PCV), heritability (H^2) and genetic advance (GA) in estimating genetic variability. Negative variance components are expected, when the variance components of the traits are very small in reality, and need to be reported though may not be interpreted (Dudley and Moll, 1969). Jain and Ramgiry (2000) reported high PCV and GCV for seed yield per plant, followed by plant weight, plant height, and moderate coefficient of variability for 100-seed weight, seed per pod, pod bearing nodes and days to flowering in 56 soybean genotypes. These authors also reported high H^2 and GAM for seed yield, plant height and pods per plant. Gohil *et al*. (2006) also reported the highest GCV for number of pods per plant followed by seed yield per plant, and high H^2 estimates for all the attributes studied in 55 diverse soybean genotypes. Plant height, number of clusters per plant, number of pods per plant and seed yield per plant combined high H^2 estimates with high GA, which indicated that these traits are mainly controlled by additive gene action and can be easily improved by selection (Gohil *et al*., 2006). Aditya *et al*. (2011) studied genetic variability in 31 soybean genotypes and reported the highest PCV and GCV of 47.7 and 41%, respectively for seed yield, followed by dry matter weight per plant with 33.9 and 31.1 PCV and GCV, respectively. They also reported highest H^2 (91%) for characters, such as days to 50% flowering, number of primary branches per plant, and 100-seed weight; while two parameters i.e., number of pods and dry matter weight per plant combined high H^2 and GA estimates (Aditya *et al*., 2011).

Previous studies have also reported high genetic variability in soybean for performance under low P conditions for various economically important attributes (Ding and Li, 1998; Tong *et al.*, 1999; Tang *et al*., 2007; XiangWen *et al*., 2008). According to Ma *et al.* (2001) root characteristics, such as root hair length, density, and other root hair parameters significantly affect P acquisition efficiency in plants. Wang *et al*. (2004) also studied the genetic variability of two contrasting genotypes of soybean and 88 F_9-derived recombinant inbred lines on moderately low P availability soil, and reported low heritability for root hair density estimates of basal roots (27.3%), tap roots (31.0%), and total roots (34.0%); while relatively higher genetic variance, which resulted in higher heritability was reported for the average root hair length estimates of basal roots (53.8), tap roots (59.2%), and total roots (61.0%). This indicated that root hair density characteristics are influenced by more environmental factors than average root length estimates. Genotypes that were originally cultivated on acidic soils under low p conditions were reported to be more P efficient than those from high P paddy soils and fluvo aquatic soils (Tong *et al*., 1999). However, Tang *et al*. (2007) attributed genotypic variation in P utilization to early vigor, nodulation, and seed P reserve rather than pH of original cultivation area or root exudation.

Multivariate techniques, such as cluster analysis and principal component analyses have been used to assess the genetic variation of genotypes for P efficiency, as it provides combined effects of several traits for P efficiency (XiangWen *et al*., 2008). Uguru *et al*. (2012) reported the effectiveness of the combination of crop performance and principal component analysis in the identification and characterization of differential genotypic response across diverse environments. Despite the significance of understanding the extent of genetic variability of soybean under varying P regime, there was no previous study undertaken on the genetic variability of soybean population in Ethiopia, under low and high P conditions on acidic soils. Therefore, the present study employed both assessment techniques to objectively compare the genetic variability of 36 soybean genotypes under low and high P conditions on acidic soils.

4.3 Materials and methods

4.3.1 Germplasm

Thirty six soybean genotypes were used in this study and were obtained from various sources: 31 genotypes were obtained from Hawassa and Pawe Research Centers, in Ethiopia. Though they had been introduced into the country in the 1960s from various sources, such as IITA and Intsoy, and no detail information was obtained on their introduction. Of these, four were released varieties viz., Davis, Cocker 240, AGS-7-1, and Clark 63 K. Five of the genotypes i.e., H 16, H 3, H 6, IAC 6, and H 7 were obtained from Mozambique Agricultural Research Institute. They had originally been obtained from Southern China Agricultural University, in a collaborative research on evaluating soybean for P use efficiency on acidic soils with major emphasis on rooting traits.

4.3.2 Experimental sites

The field experiments were conducted at three locations in western Ethiopia, namely Jimma, Mettu, and Assosa. The sites are characterized by strong to moderate acidic soil and low P availability (Table 4.3-1).

4.3.3 Experimental design and management

The genotypes were evaluated in split plot design, where the main plots were two levels of applied P i.e., 0, and 100kg ha^{-1} P, representing low, and high levels, respectively and the sub plots were 36 genetically diverse soybean genotypes. Each experimental unit was replicated twice. The seeds of all genotypes were uniformly dressed with Rhizobium bacteria, and no nitrogen source commercial fertilizer was applied.

There were four rows in each plot, where the middle two rows were harvested for grain yield and 100-seed weight measurement. Planting was done in rows of four meter long and 60 cm wide, and recommended five centimeters spacing was maintained between plants. The distance between two plots was one meter, while 1.5 meter was maintained between blocks. Three times hand weeding was done to create a weed free experimental plot till maturity.

The traits studied included: days to 50% flowering, days to maturity, fresh biomass weight i.e., the average weight of above ground biomass of five freshly harvested plants at late pod filling stage, pod number i.e., the average of the total number of pods counted on each of the five randomly selected plants, pod length that was the average length of five randomly selected pods from five plants, number of seeds per pod i.e., the average number of seeds of five randomly selected pods from five different plants, plant height, 100-seeds weight, and grain yield. In addition, root characteristics, such as root fresh weight, which was the weight of the roots; root volume that is the volume of water displaced from the measuring cylinder by the root, and taproot length, which is the length of the central taproot were measured on randomly selected five plants from each treatment.

4.3.4 Laboratory analysis

Soils from all the experimental sites were analysed for P content before the experiments were conducted. The procedure described by Sahlemedhin and Taye (2000) was used to analyze soil P using Bray II method, N using Kjeldhal method, K using flame photometry, organic carbon (OC) and organic matter (OM) using Walkley and Black method. In addition, the procedures described by Sahlemedhin and Taye (2000) were followed to analyze soil pH and exchangeable acidity, Al and H.

Table 4.3 1 Results of soil analyses conducted on three samples collected from each of the two experimental sites (Assossa and Mettu) before the experiment

No.	Location	K (ppm)	% N	% OC	% OM	P (ppm)	pH (H_2O)	Exchangeable Acidity (meq/ 100g soil	Exchangeable Al (meq/ 100g soil	Exchangeable H (meq/ 100g soil
1	Assossa	10	0.13	2.19	3.77	4.90	4.92	0.24	0	0.24
2	Assossa	5	0.12	2.33	4.02	5.28	5.50	0.24	0	0.24
3	Assossa	5	0.12	2.02	3.48	3.35	4.50	1.68	0.08	1.60
4	Mettu	20	0.28	2.30	3.97	1.80	5.11	1.52	0.8	0.72
5	Mettu	15	0.28	2.62	4.52	2.84	4.86	0.72	0.32	0.40
6	Mettu	20	0.26	2.82	4.87	1.16	4.50	2.48	1.28	1.20
7	Jimma	5	0.14	1.73	2.98	2.96	5.35	0.24	0	0.24
8	Jimma	55	0.13	1.99	3.43	4.77	5.34	0.24	0	0.24
9	Jimma	10	0.14	1.79	3.08	6.96	5.68	0.08	0	0.08

4.3.5 Statistical analysis

Before data were analysed, square root transformation was performed for the count data, such as number of seeds per pod, and pod number, as suggested by

Gomez and Gomez (1984). Analysis of variances for the individual locations was computed using SAS Statistical Software package (SAS Institute, 2008). Test of homogeneity of error variances of the locations was made before combined analysis, and error variances of each location found homogenous. The combined analysis for genotype X location (GXL) interaction was analyzed using SAS software, as two factor experiment for each of the P levels. The genetic variability estimates viz., phenotypic and genotypic variances and coefficient of variations, broad sense heritability, genetic advance were analyzed using Genes, Quantitative Genetics and Experimental Statistics Software (Cruz, 2009).

The formula for phenotypic variance in a single location is:
$\sigma_p^2 = \sigma_g^2 + \sigma_{ge}^2 + \sigma_e^2$, where σ_p^2 =phenotypic variance, σ_g^2=genotypic variance, σ_{ge}^2=variance of genotype X environment interaction, and σ_e^2=environmental variance.

However, the phenotypic variance for combined analysis across location is estimated as per the formula provided by Hallauer and Miranda Filho (1988): $\sigma_{ph}^2=\sigma_g^2 + \sigma_{ge}^2/e + \sigma_e^2/re$
Where: σ_p^2=phenotypic variance, σ_g^2=genotypic variance, σ_{ge}^2=variance of genotype X environment interaction, σ_e^2=environmental variance, r=number of replication and e=number of environments.

The principal component analysis was performed using Genstat 11.1 software (VSN International, 2008); while cluster analysis was performed using SAS Version 9.2 software (SAS Institute, 2008). Cluster mean was calculated by taking the mean value of each trait in each cluster; while cluster mean difference was calculated by subtracting the cluster mean from the grand mean of each trait. Determination of the number of clusters was performed using pseudo F, cubic clustering criterion (CCC) and Pseudo T^2 graphs analyzed by SAS Version 9.2 software (SAS Institute, 2008), based on the procedure described by SAS

Institute (2009). The histograms for the mean of genotypes for grain yield at low and high P were also plotted in Excel.

4.4 Results

4.4.1 Genotype X environment interaction

At the zero applied P the genotypes showed highly significant differences (P<0.01) for all the traits; except for pod number, which showed non-significant differences (Table 4.4-1). At this P level, highly significant genotype X location (GXL) interactions were found for grain yield, days to flowering, and days to maturity. At 100 kg ha^{-1} applied P, the genotypes displayed highly significant differences for grain yield, days to 50% flowering, days to maturity, root biomass, tap root length, pod length, plant height, and weight of hundred seeds; while plant biomass was significant (P<0.05) at 100 kg ha^{-1} applied P. At 200 kg ha^{-1} applied P the G X L interaction was highly significant for grain yield, days to 50% flowering, days to maturity, tap root length, and weight of hundred seeds; while plant height was significant at (P<0.05). Results also indicated significant variation among genotypes for all yield and yield related traits, except for number of seeds per pod, when the analysis was pooled across P levels and sites.

Table 4.4-1 Mean squares for both low and high P environments

Traits	Low P environments		High P environments	
	Genotypes	G XL	Genotypes	GXL
Days to 50% flowering	53.58**	16.347**	40.04**	17.56**
Days to maturity	66.31**	19.16**	87.06**	12.42**
Fresh biomass weight (gm)	8911**	2866	17795*	8360
Root fresh weight (gm)	52.53**	13.03	185.7**	77.1
Root volume (lt)	84.03**	28.92	88.33	42.85
Tap root length (cm)	26.54**	14.15	93.83**	64.70**
Pod number	133.8	75.3	218.0	159.3
Pod length (cm)	0.587**	0.142	0.5141**	0.1281
Number of seeds per pod	0.144**	0.081	0.0855	0.09331
Plant height (cm)	261.77**	60.66	417.09**	52.90*
100-Seeds weight (gm)	21.4**	3.02	23.09**	3.16**
Grain yield (kg ha^{-1})	193860**	158876**	208375**	171302**

* = significant at 5%, and ** = significant at 1 %

4.4.2 Performance of genotypes

There were no much differences in the mean and range values of the accessions between zero and 100 kg ha^{-1} applied P treatments for days to 50% flowering, days to maturity, pod length, and number of seeds per pod (Table 4.4-2). Higher mean grain was observed at high P than low P (Figure 4.4-1 and 4.4-2). Generally, larger means were observed for most traits at 100 kg ha^{-1} applied P compared to zero P. However, there was marginal differences for both mean and range values for 100-seed weight, days to 50% flowering, and days to maturity for the genotypes at 100 kg ha^{-1} and zero applied P.

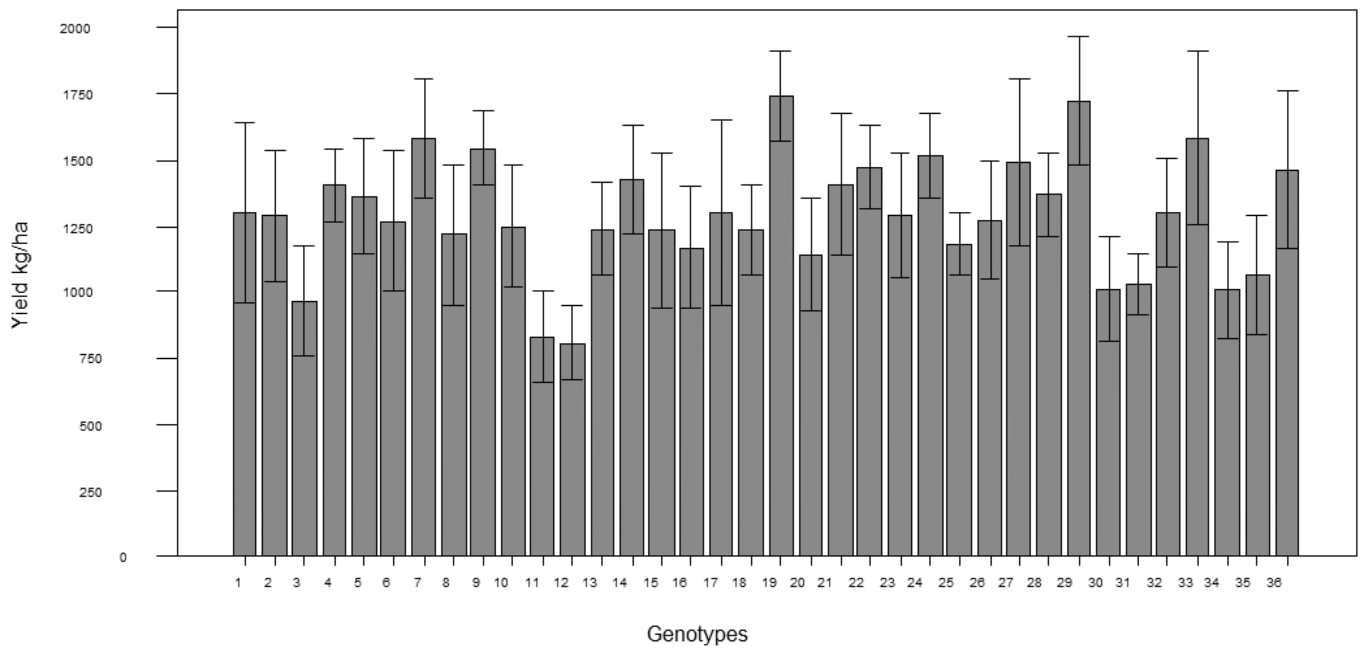

Figure 4.4-1 Mean grain yield of soybean genotypes at low P (numbers and corresponding genotypes are: 1. Davis, 2. Tunia, 3. PR-142 (26), 4. IAC 11, 5. Alamo, 6. FB1-7636, 7. PR-143 (14), 8. AGS 217, 9. HS 82-2136, 10. AA-7138, 11. IAC 73-5115, 12. AA-42-52, 13. AGS 234, 14. Coker 240, 15. AGS-3-1, 16. Essex-1, 17. Hardee-1, 18. Bossire-2, 19. AGS-7-1, 20. TGX-297-6E-1, 21. AGS-62, 22. Protana 2, 23. H 16, 24. H 3, 25. H 6, 26. Ocepara 4, 27. SCS-1, 28. Clark 63-K, 29. G 9945, 30. JSL-1, 31. SR-4-3, 32. IAC 6, 33. H 7, 34. PR-162-11, 35. OC-78503, 36. SR-4-1)

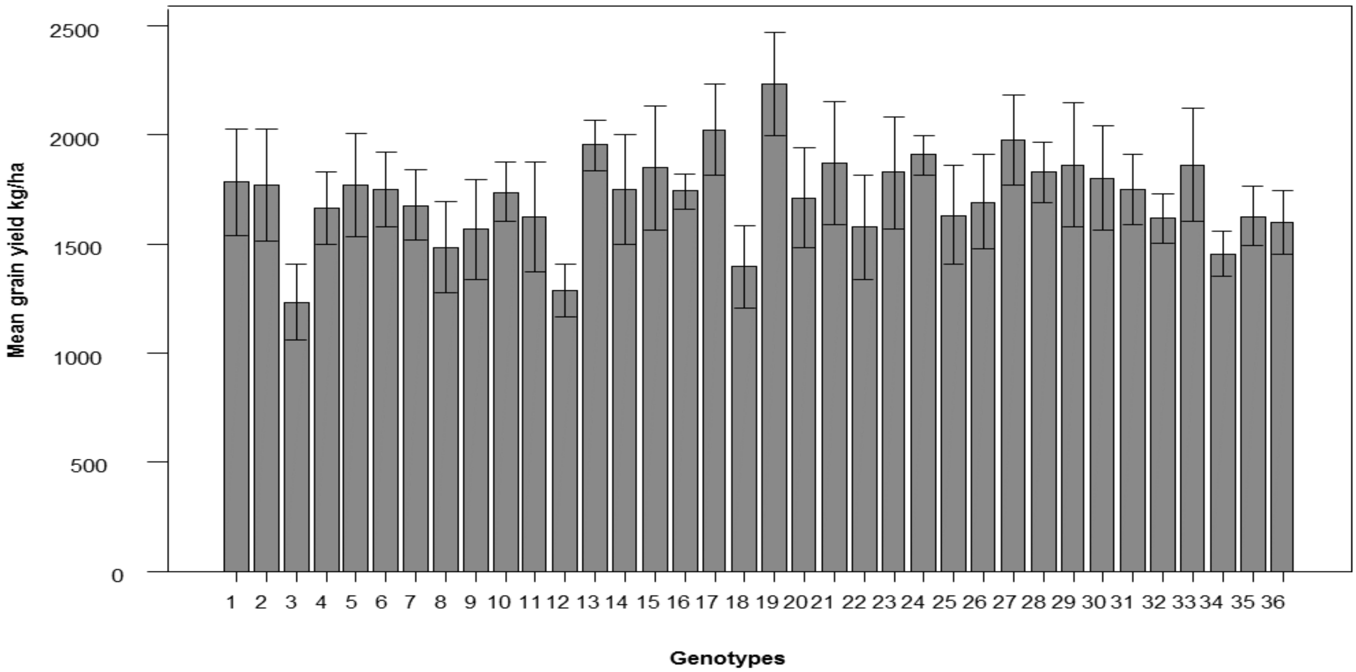

Figure 4.4-2 Mean grain yield of soybean genotypes at high P conditions (numbers and corresponding genotypes are: 1. Davis, 2. Tunia, 3. PR-142 (26), 4. IAC 11, 5. Alamo, 6. FB1-7636, 7. PR-143 (14), 8. AGS 217, 9. HS 82-2136, 10. AA-7138, 11. IAC 73-5115, 12. AA-42-52, 13. AGS 234, 14. Coker 240, 15. AGS-3-1, 16. Essex-1, 17. Hardee-1, 18. Bossire-2, 19. AGS-7-1, 20. TGX-297-6E-1, 21. AGS-62, 22. Protana 2, 23. H 16, 24. H 3, 25. H 6, 26. Ocepara 4, 27. SCS-1, 28. Clark 63-K, 29. G 9945, 30. JSL-1, 31. SR-4-3, 32. IAC 6, 33. H 7, 34. PR-162-11, 35. OC-78503, 36. SR-4-1)

4.4.3 Genotypic and phenotypic variances

Both the genotypic and phenotypic variances of the accessions at 100 kg ha^{-1} applied P was higher than at zero for most of the characters. This is indicated in Table 4.4-2 for the traits days to maturity, above ground biomass weight, root biomass weight, tap root length, pod number, plant height, and hundred seed weight. In contrast, both genotypic and phenotypic variances were higher at zero than 100 kg ha^{-1} applied P for grain yield, pod length and days to flowering. The genotypic variance for root volume at zero applied P was higher than at 100 kg ha^{-1} applied P; while the phenotypic variances were nearly the same for both P levels.

The percent PCV and GCV of the accession was higher at zero than 100 kg ha^{-1} applied P for characters, such as days to flowering, above ground biomass weight, root biomass weight, root volume, pod number, pod length, number of seeds per pod, 100 seed weight and grain yield (Table 4.4-2). In contrast, the percent PCV and GCV was higher at 100 kg ha^{-1} than zero applied P for characters, such as days to maturity, tap root length and plant height.

4.4.4 Genetic parameters

The broad sense heritability estimates were higher at zero than 100kg ha^{-1} applied P for grain yield, days to flowering, plant fresh weight, root fresh weight, root volume, tap root length, pod number, pod length, and number of seeds per pod. The reverse trend was observed for traits, such as days to maturity, and plant height (Table 4.4-2). However, similar heritability estimates were obtained for 100-seed weight at both zero and 100 kg ha^{-1} applied P.

Both the genetic advance (GA), and genetic advance as percent of mean (GAM) estimates were higher for plant fresh weight at both zero and 100 kg ha^{-1} applied P (Table 4.4-2). Although grain yield produced the highest GA value, GAM was very low at both zero and 100 kg ha^{-1} applied P. On the contrary, GAM values were relatively higher at both zero and 100 kg ha^{-1} applied P for root fresh weight, root volume, plant height, 100-seed weight, tap root length, pod number and pod length.

Table 4.4-2 Estimates of genetic parameters for 36 soybean genotypes under low and high P conditions on acidic soils

Traits	P level	Range	Mean	σ^2g	σ^2p	σ^2e	σ^2gxe	r intra class	GCV (%)	PCV (%)	H^2	GA	GAM
DF	-	58-70	63	5.7	9.0	8.2	5.8	29.0	3.8	4.8	63.4	3.9	6.2
	+	61-70	65	4.3	7.6	10.5	4.7	22.0	3.2	4.2	56.4	3.2	4.9
DM	-	120-134	125.3	8.7	12.5	9.23	6.75	35.12	2.35	2.82	69.5	5.1	4.0
	+	120-138	127.0	12.5	14.8	7.8	2.9	54.0	2.8	3.0	84.7	6.7	5.3
FBW	-	86.4-273.8	150.2	1190	1684.2	3458	-247	27.04	22.97	27.32	70.67	59.7	39.8
	+	174-390.3	285.6	1812	3350	12127	-1451	14.5	14.9	20.3	54.1	64.5	22.6
RFW	-	6.0-17.6	10.8	7.07	9.3	11.43	1.12	36.04	24.5	28.18	75.63	4.8	43.9
	+	12.1-39.0	22.5	19.5	32.3	104.8	-14.1	17.7	19.7	25.3	60.4	7.1	31.5
Rtv	-	10.6-25.9	17.85	9.11	14.4	24.54	3.68	24.41	16.91	21.28	63.15	4.9	27.7
	+	16.7-35.7	25.0	7.4	14.6	71.4	-13.9	11.3	10.8	15.3	50.3	4.0	15.8
TRL	-	12.7-21.3	16.46	1.99	4.4	12.05	1.3	12.98	8.57	12.79	44.91	1.9	11.8
	+	14.9-31.2	24.0	5.4	17.1	31.0	19.5	9.7	9.5	17.2	31.7	2.7	11.2
PDN	-	20.3-40.9	28.79	10.6	22.8	116.3	-21.5	10.06	11.31	16.59	46.45	4.6	15.9
	+	28.9-59.4	41.8	13.2	39.2	166.3	-5.01	7.6	8.7	15.0	33.6	4.3	10.4
PDL	-	3.6-5.1	4.12	0.09	0.1	0.107	0.011	42.19	7.13	7.961	80	0.5	13.1
	+	3.5-5.1	4.3	0.07	0.09	0.1	0.02	38.0	6.2	7.1	76.5	0.5	11.2
NSPPD	-	2.3-2.9	2.59	0.01	0.02	0.069	0.006	12.7	4.017	6.0	44.83	0.1	5.6
	+	2.3-2.8	2.6	-0.01	0.02	0.1	0.01	-1.9	0.0	4.7	-11.2	-0.03	-1.1
Pht	-	32.7-57.6	46.3	37.7	47.8	55.71	2.52	39.29	13.26	14.93	78.82	11.2	24.3
	+	43.8-77.5	57.9	69.2	79.6	36.6	12.8	58.3	14.4	15.4	87.0	16.0	27.6
100-SW	-	9.5-17.24	13.24	3.3	3.8	2.32	0.334	55.18	13.65	14.66	86.78	3.5	26.2
	+	11.8-19.3	14.8	3.5	4.1	1.7	0.8	57.9	12.6	13.6	86.2	3.6	24.2
Gyld	-	809-1748	1234	10184	37316	81881	40458	7.68	8.18	15.66	27.29	108.6	8.8
	+	1186-2007	1698	7201	36435	82699	46351	5.3	5.0	11.2	19.8	77.7	4.6

DF=days to 50% flowering, DM=days to maturity, FBW=fresh biomass weight, RFW=root fresh weight, RTV=root volume, TRL=tap root length, PDN=pod number, PDL=pod number, NSPPD=number of seeds per pod, Pht=plant height, 100-SW=100-seed weight, Gyld=grain yield, σ^2g=genotypic variance, σ^2p=phenotypic variance, σ^2e=environmental variance, σ^2gxe=variance of genotype x environment interaction, r intra class=intra class correlation, GCV (%)=percent genotypic coefficient of variation, PCV (%)=percent phenotypic coefficient of variation, H^2= broad sense heritability, GA=genetic advance, GAM=genetic advance as percent of mean, under the column P level - =without P, and +=at 100 kg ha^{-1} applied P)

NB: the values of some environmental variances are greater than phenotypic variances. The reason is the phenotypic variance is calculated based on an adjusted environmental variance for the number of replication and location i.e., $\sigma_{ph}^2=\sigma_g^2 + \sigma_{ge}^2/e + \sigma_e^2/re$ (see more details of the formula in the materials and methods)

4.4.5 Principal component analysis

At zero and 100 kg ha^{-1} level of applied P, the first five PCs with eigen values greater than one accounted for more than 84.6 and 76.9% of the total variation among the accessions for most traits, respectively (Table 4.4-3). The variation explained by each PC is indicated in Table 4.4-4 and 4.4-5 for low and high P conditions, respectively.

Table 4.4-3 Some principal component estimates for the soybean genotypes under low and high P conditions on acidic soils

Principal components	Zero applied P		100 kg ha^{-1} applied P	
	Latent roots (λ)	% variation	Latent roots (λ)	% variation
PC-1	5.65	37.7	5.23	34.9
PC-2	2.41	16.1	2.24	14.96
PC-3	1.76	11.8	1.71	11.38
PC-4	1.47	9.8	1.31	8.74
PC-5	1.38	9.2	1.04	6.9
PC-6	0.64	4.3	0.85	5.68
PC-7	0.48	3.2	0.67	4.48
PC-8	0.35	2.3	0.6	4.03
PC-9	0.3	2.0	0.38	2.52
PC-10	0.17	1.1	0.28	1.85

Table 4.4-4 Principal component score values of the first five PCs of soybean genotypes evaluated across three locations on acidic soils of western Ethiopia under low P conditions

Traits	PC 1	PC 2	PC 3	PC 4	PC 5
100-seed weight	0.1956	-0.3702	-0.3301	0.0452	-0.36085
Days to flowering	0.32	0.07079	-0.03616	0.24776	0.21289
Days to maturity	0.33386	0.00773	0.17818	0.24624	0.1794
Grain yield	-0.01066	-0.26884	-0.51037	-0.40282	0.07255
Number of seeds per pod	0.01545	-0.14891	0.41728	-0.59247	-0.04212
Fresh biomass weight	0.39493	0.02272	-0.1044	-0.11771	0.07283
Plant height	0.28656	-0.10921	-0.37211	0.05626	0.07866
Pod length	0.19249	-0.32964	0.20449	-0.14938	-0.48125
Pod number	0.11665	0.21409	-0.24319	-0.42907	0.45895
Root fresh weight	0.39853	-0.01016	0.09329	0.02908	-0.02743
Root volume	0.36191	0.00059	0.15709	-0.07829	0.03784
Tap root length	0.37341	-0.03486	0.17222	-0.05127	0.00687

Table 4.4-5 Principal component scores values of the first five PCs of 36 soybean genotypes evaluated across three locations on acidic soils of western Ethiopia under high P conditions

	PC 1	PC 2	PC 3	PC 4	PC 5
100-seed weight	-0.13125	-0.05083	0.61293	-0.2833	-0.23218
Days to flowering	-0.30579	-0.01884	-0.29791	0.05711	-0.17528
Days to maturity	-0.35401	0.1209	-0.07012	0.0995	0.21568
Grain yield	0.2562	-0.00701	0.18415	-0.20491	-0.50657
Number seeds per pod	0.00878	-0.48113	-0.17947	0.32791	-0.39865
Fresh biomass weight	-0.37565	0.1846	-0.04815	-0.09857	-0.11589
Plant height	-0.26908	0.25067	0.04558	-0.42826	0.08319
Pod length	-0.16575	-0.42697	0.2647	0.18123	-0.0135
Pod number	0.14433	0.3057	-0.35931	-0.08773	-0.38677
Root fresh weight	-0.40464	0.0989	0.01659	0.05232	-0.17505
Root volume	-0.375	-0.11872	0.19551	0.04283	-0.01744
Tap root length	-0.35083	-0.02043	-0.21905	0.10737	-0.29333

4.4.6 Cluster analysis

On the basis of pseudo F, CC and pseudo T^2 values, the appropriate number of clusters at both zero and 100 kg ha^{-1} P levels was four. However, the dendrograms (Figure 4.4-3 and 4.4-4) identified seven cluster groups under both low and high P conditions at cluster distance of 0.5, and three cluster groups at cluster distance one.

The squared distance between each of the four clusters was highly significant for both zero (Table 4.4-6), and 100 kg ha^{-1} (Table 4.4-7). The longest cluster distance at zero applied P was found between cluster three and four; followed by the cluster distances of two and four and one and four (Table 4.4-6). The longest cluster distance at 100 kg ha^{-1} applied P was observed between clusters three and four; followed by cluster distances of one and four, and two and four (Table 4.4-7). The smallest cluster distance at zero applied P was found between clusters two and three, while the smallest cluster distance at 100 kg ha^{-1} applied P was obtained between cluster one and three.

At zero applied P, cluster I contains 23 soybean genotypes (Table 4.4-10, Figure 4.4-3). This cluster is characterized by the highest cluster mean for the number of seeds per pod, and produced the second highest cluster mean for all of the rest of the traits studied (Table 4.4-8). Cluster II, which contained nine genotypes, was characterized by the highest cluster mean for days to flowering, days to maturity, number of seeds per pod, pod length, root biomass, root volume and tap root length. This cluster produced the third highest cluster mean for grain yield, pod number, weight of 100 seeds, plant biomass, and plant height. Cluster III, which contained only three genotypes was characterized by the lowest cluster mean for all of the studied traits. Cluster IV that was characterized by the highest cluster mean for most of the productivity traits, such as grain yield, pod number, hundred seed weight, number of seeds per pod, plant biomass, plant height, and pod length contained only one genotype i.e., AGS-7-1. Similarly, the dendrogram (Figure 4.4-3) grouped this genotype alone in one cluster at cluster distance of 0.5.

At 100 kg ha^{-1} P, cluster one contained 16 genotypes (Table 4.4-11), and was characterized by the highest cluster mean for most of the important productivity traits i.e., grain yield, pod number, hundred seed weight, and number of seeds per pod (Table 4.4-9). Cluster II at 100 kg ha^{-1} applied P contained 14 genotypes and was characterized by the highest cluster mean for all of the traits, except for grain yield and 100-seeds weight. This cluster produced the second highest cluster mean for grain yield and 100-seeds weight. Cluster three contained four genotypes, and was characterized by the third highest cluster mean for all of the studied traits. Cluster IV contained only two genotypes i.e., PR 142 (26), and AA-42-52, and was characterized by the lowest cluster mean for all the studied traits. These two genotypes were also uniquely assigned in cluster 7 of the dendrogram (Figure 4.4-4) at the cluster distance of 0.5.

Table 4.4-6 Generalized squared distance between clusters 1-4 under low P conditions

	1	2	3	4
1	0	37.6**	79.7**	101.5**
2		0	18.0**	252.3**
3			0	343.4**
4				0

*= significant at (P<0.05), and ** = significant at (P<0.01)

Table 4.4-7 Generalized squared distance between clusters 1-4 under high P conditions

	1	2	3	4
1	0	32.4**	27.8**	368.0**
2		0	111.3**	221.1**
3			0	584.1**
4				0

*= significant at (P<0.05), and ** = significant at (P<0.01)

Table 4.4-8 Cluster mean and cluster mean difference of clusters 1-4 under low P for each of the studied traits

Traits	Cluster I	Cluster mean diff	Cluster II	Clsuter mean diff	Cluster III	Clsuter mean diff	Cluster IV	Clsuter mean diff	Mean of the traits
DF	62.6	-0.1	63.1**	0.44	41.8*	-15.6	60.8	-1.8	62.65
DM	124.8	-0.5	126.3**	1	83.5*	-31.3	124.7	-0.6	125.3
GYLD	1323.7	89.7	1075.3	-158.7	829.5*	-303.3	1743.0**	509	1234
100-SW	13.5	0.3	12.7	-0.52	8.8*	-3.3	15.6**	2.3	13.24
NSPPD	2.61**	0.01	2.61**	0.01	1.7*	-0.6	2.6**	0	2.6
FBW	154.3	4.1	141.9	-8.28	100.1*	-37.6	178.2**	28	150.2
PHT	46.7	0.4	42.7	-3.57	29.9*	-12.3	55.9**	9.6	46.3
PDL	4.1	0	4.2**	0.07	2.8*	-1	4.2**	0.1	4.12
PDN	30.2	1.4	26.7	-2.09	19.4*	-7	30.6**	1.8	28.79
RFW	10.8	-0.1	11.2**	0.33	7.3*	-2.7	10.2	-0.6	10.84
RTV	17.7	-0.1	18.7**	0.87	12.1*	-4.3	15.5	-2.4	17.85
TRL	16.2	-0.3	17.4**	0.91	11.1*	-4	15.9	-0.6	16.46

* the lowest cluster mean, ** the highest cluster mean, DF=days to 50% flowering, DM=days to maturity, Gyld=grain yield (kg ha^{-1}), 100-SW=100-seed weight (gm), NSPPD=number of seeds per pod, FBW=fresh biomass weight (gm), Pht=plant height (cm), PDL=pod length (cm), PDN=pod number, RFW=root fresh weight (gm), RTV=root volume (lt), TRL=tap root length (cm)

Table 4.4-9 Cluster mean and cluster mean difference of clusters 1-4 under high P for each of the studied traits

Traits	Cluster I	Cluster mean diff	Cluster II	Cluster mean diff	Cluster III	Cluster mean diff	Cluster IV	Cluster mean diff	Mean of the parameters
DF	63.8	-1.02	65.8**	0.97	42.8	-16.47	36.5*	-19.8	64.8
DM	126.3	-0.78	126.6**	-0.44	84.1	-32.27	70.1*	-40.05	127.08
GYLD	1795.7**	97.69	1582.6	-115.4	1158.7	-404.5	875.3*	-583.3	1698
HSW	15**	0.26	14.5	-0.32	9.9	-3.64	8*	-4.77	14.78
NSPPD	2.6**	0.02	2.6**	0.02	1.7	-0.64	1.4*	-0.81	2.58
PBM	271.8	-13.78	289.8**	4.22	182.6	-77.23	158.9*	-88.6	285.6
PHT	55.4	-2.5	57.9**	-0.04	36.9	-15.74	31.6*	-18.44	57.93
Plen	4.2	-0.07	4.4**	0.09	2.8	-1.08	2.4*	-1.29	4.27
Pnum	42.2**	0.33	42.2**	0.33	28.3	-10.2	23.6*	-12.82	41.85
RBM	21.6	-0.88	22.4**	-0.034	14.4	-6.06	12.2*	-7.14	22.45
RtVol	24.3	-0.73	25.3**	0.25	16.3	-6.56	13.9*	-7.78	25.04
TRL	23.8	-0.69	24.7**	0.23	15.9	-6.41	13.6*	-7.6	24.47

* the lowest cluster mean, ** the highest cluster mean, DF=days to 50% flowering, DM=days to maturity, Gyld=grain yield (kg ha^{-1}), 100-SW=100-seed weight (gm), NSPPD=number of seeds per pod, FBW=fresh biomass weight (gm), Pht=plant height (cm), PDL=pod length (cm), PDN=pod number, RFW=root fresh weight (gm), RTV=root volume (lt), TRL=tap root length (cm)

Table 4.4-10 Distribution of the 36 soybean genotypes tested at Zero P

Cluster	Number of genotypes	Name of genotypes
Cluster I	23	H 3, H 7, SCS-1, SR-4-1, Tunia, H 16, AGS 234, AGS-3-1, Alamo, HS 82-2136, Bossire-2, Davis, Hardee-1, Clark 63 K, AA 7138, Ocepara 4, PR-143 (14), Coker 240, AGS-62, Protana-2, G 9945, IAC 6, IAC 11
Cluster II	9	AGS-217, PR-162-11, Essex-1, H 6, SR-4-3, FB1-7636, OC-78503, TGX-297-6E-1, PR-142 (26)
Cluster III	3	IAC 73-5115, AA-42-52, JSL-1
Cluster IV	1	AGS-7-1

Table 4.4-11 Distribution of soybean genotypes in four clusters under high P conditions

Cluster	Number of genotypes	Name of genotypes
Cluster I	16	FB1-7636, Coker 240, AGS-3-1, H 7, H 16, Clark 63-K, TGX-297-6E-1, Alamo, JSL 1, Tunia, Essex-1, SR-4-3, Davis, AGS 234, G 9945, AGS 62
Cluster II	14	AA-7138, SR-4-1, IAC 6, OC-78503, HS 82-2136, Protana 2, IAC 11, H 6, PR-143 (14), Ocepara 4, AGS 217, PR-162-11, Bossire-2, IAC 73-5115
Cluster III	4	AGS-7-1, SCS-1, H 3, Hardee-1
Cluster IV	2	PR-142 (26), AA-42-52

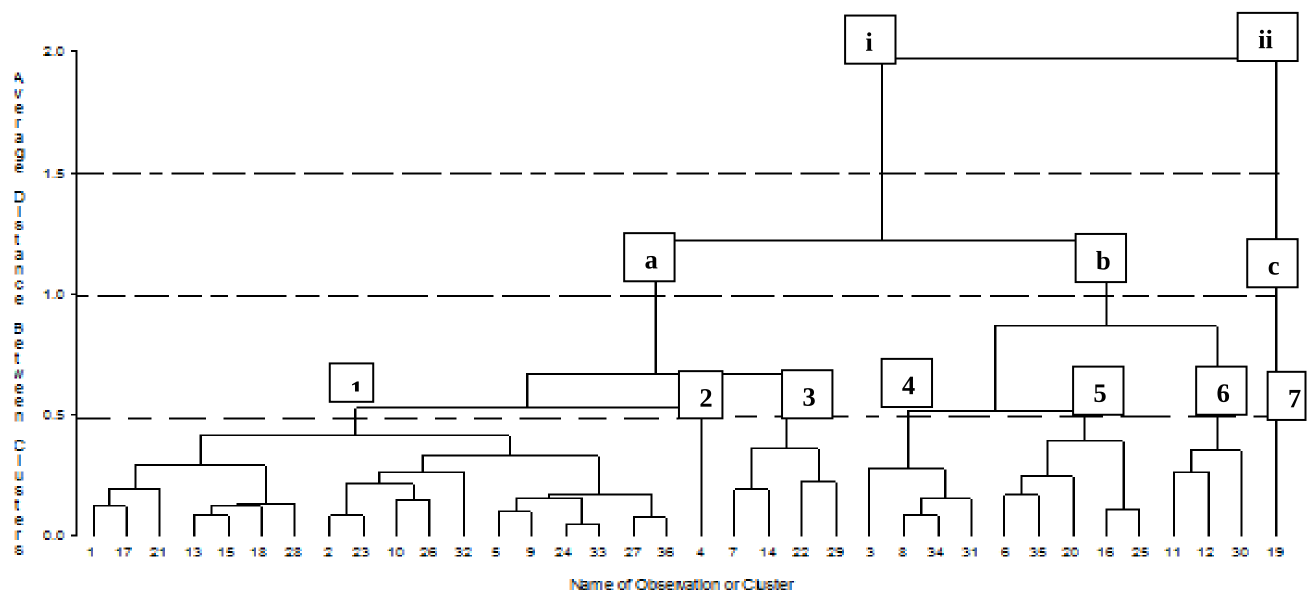

Figure 4.4-3 Dendrogram of 36 soybean genotypes evaluated across three locations on acidic soils of western Ethiopia under low-P conditions (numbers and corresponding genotypes are: 1. Davis, 2. Tunia, 3. PR-142 (26), 4. IAC 11, 5. Alamo, 6. FB1-7636, 7. PR-143 (14), 8. AGS 217, 9. HS 82-2136, 10. AA-7138, 11. IAC 73-5115, 12. AA-42-52, 13. AGS 234, 14. Coker 240, 15. AGS-3-1, 16. Essex-1, 17. Hardee-1, 18. Bossire-2, 19. AGS-7-1, 20. TGX-297-6E-1, 21. AGS-62, 22. Protana 2, 23. H 16, 24. H 3, 25. H 6, 26. Ocepara 4, 27. SCS-1, 28. Clark 63-K, 29. G 9945, 30. JSL-1, 31. SR-4-3, 32. IAC 6, 33. H 7, 34. PR-162-11, 35. OC-78503, 36. SR-4-1)

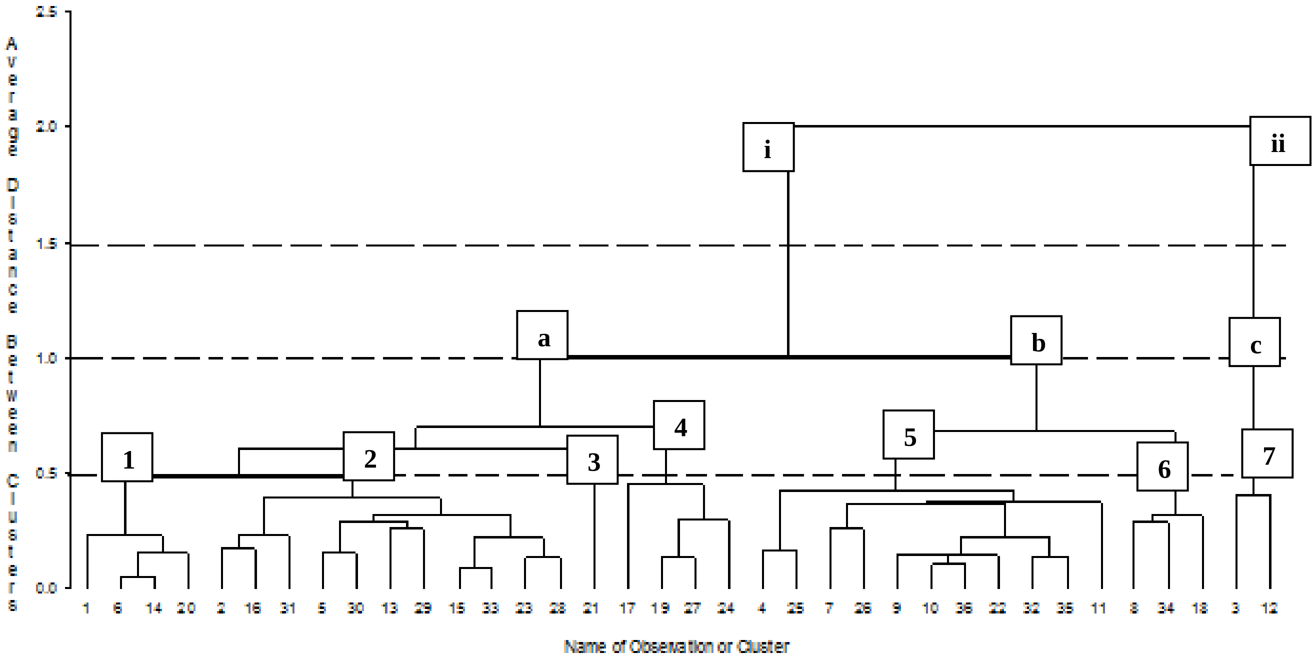

Figure 4.4-4 Dendrogram of 36 soybean genotypes evaluated across three locations on acidic soils of western Ethiopia under high P conditions (numbers and corresponding genotypes are: 1. Davis, 2. Tunia, 3. PR-142 (26), 4. IAC 11, 5. Alamo, 6. FB1-7636, 7. PR-143 (14), 8. AGS 217, 9. HS 82-2136, 10. AA-7138, 11. IAC 73-5115, 12. AA-42-52, 13. AGS 234, 14. Coker 240, 15. AGS-3-1, 16. Essex-1, 17. Hardee-1, 18. Bossire-2, 19. AGS-7-1, 20. TGX-297-6E-1, 21. AGS-62, 22. Protana 2, 23. H 16, 24. H 3, 25. H 6, 26. Ocepara 4, 27. SCS-1, 28. Clark 63-K, 29. G 9945, 30. JSL-1, 31. SR-4-3, 32. IAC 6, 33. H 7, 34. PR-162-11, 35. OC-78503, 36. SR-4-1)

4.5 Discussion

4.5.1 Genetic differences and implications for selection

The highly significant differences among the soybean genotypes for all the traits, except for pod number at low P conditions (Table 4.4-1), and the fact that more number of traits showed significant difference for the genotypes at low than high P conditions indicates the existence of sufficient variability for the traits, and that selection for low P tolerance would be effective. Though the phenotypic variances did not show much difference for root volume at both low and high P conditions, the fact that higher genotypic variance exhibited at low P than high P condition (Table 4.4-2) indicates that the low P stress triggered genetic expression for root formation in search of P. This agrees with the report of

Ragothma (1990) that P starvation activates some specific genes. Although the phenotypic and genotypic variances were higher for most of the traits at high than low P conditions, the fact that grain yield and days to flowering showed higher phenotypic and genotypic variances, and higher percent genotypic and phenotypic co-variances for most of the important traits at low than high P conditions (Table 4.4-2), confirms the existence of higher genetic variability for low P tolerance. The application of high P levels might have masked the genetic differences between genotypes, which were indicated by lower discrimination capacity of the high P environment. However, the wider range, and higher mean value of most of the important attributes, such as grain yield at 100 kg ha^{-1} compared to zero applied P (Table 4.4-2) indicates observation of better overall performance of the genotypes under higher P conditions. This indicates that higher genetic variability might not necessarily ensure higher performance, rather the existence of sufficient variation to undertake selection and the possibility of identifying varieties that are adapted to low P conditions.

Generally, PCV, GCV and genetic advance as percent of mean (GAM) values were classified as low, medium and high with respective values of 0-10%, 10-20% and >20%; and regarded H^2 values as low (0-30%), moderate (30-60%) and high (60% and above) in soybean (Gadde, 2006). Based on these criteria the percent PCV values can be regarded as high, for traits, such as fresh biomass weight and root fresh weights at both low and high P conditions, and root volume only at low P; while the GCV of only fresh biomass weight and root fresh weights can be considered high under low P conditions (Table 4.4-2). Similarly, based on the classification of Gadde (2006), the GAM of plant fresh weight, root fresh weight, plant height and weight of hundred seeds can be considered high at both low and high P conditions; while root volume was high only at low P conditions. The H^2 estimates of most of the traits studied i.e., days to maturity, root fresh weight, pod length, plant height and hundred seed weight can be regarded as high as per the classification of Gadde (2006) at both low and high P conditions; while the H^2 of days to flowering, plant fresh weight, and root volume was high only under low P conditions. The H^2 of grain yield was low at both P levels. This is expected for quantitative traits, such as grain yield, which is highly influenced by environmental variances, and this result is in-line with the findings of Harer and Deshmukh (1992). The traits such as root fresh weight, plant height, and weight of hundred seeds at both low and high P conditions, and plant fresh weight and root volume only under low P conditions combined high H^2 and genetic advance as percent of mean value. According to Gohil *et al*. (2006) and Aditya *et al*. (2011), such traits are controlled by additive gene action and can easily be improved by selection.

At both low and high P conditions, the first five PCs were found to be important, as the eigen values were greater than one and accounted for 84.6 and 76.9% of the total variations in the genotypes, respectively (Table 4.4-3). The higher total percentage variation in the first five PCs and the higher contribution of each of the first five PCs at low than high P conditions is also another indicator of the higher genetic variation of the genotypes for low P tolerance compared to response to high P. These results are in-agreement with the report of Ding and Li (1998); Tong *et al.* (1999); Tang *et al*. (2007); XiangWen *et al*. (2008) who reported high genetic variability in soybean for performance under low P conditions for various economically important attributes. The first PCs at both low and high P conditions that contributed to 37.7 and 34.9% of the total variation (Table 4.4-3), respectively, were influenced by the same traits i.e., days to flowering, days to maturity, fresh biomass weight, root fresh weight, root volume, and tap root length (Table 4.4-4 and 4.4-5), despite the contrasting direction of the influence. This implies that these traits are the major contributors for the total variation in the studied genotypes, because of the higher percentage variation contributed by the first PCs to the total variation under both low and high P conditions. Hundred seed weight and pod length influenced the second PC at low P that contributed to 16.1% of the total variation; while PC II that accounted for 14.96% of the total variation at high P was influenced by pod number, number of seeds per pod, and pod length, regardless of the direction of influence (Table 4.4-4 and 4.4-5).

4.5.2 Clusters

The fact that all the cluster distances were significant at both low and high P conditions (Table 4.4-6 and 4.4-7), might be due to the careful determination of the number of clusters based on the procedures described by SAS Institute (2008), which might have provided the optimum distance between each clusters. Though cluster II at low P was characterized by the highest cluster mean for several traits viz., days to flowering, days to maturity, number of seeds per pod, pod length, root biomass, root volume and tap root length, it produced the third highest cluster mean for most productivity attributes (Table 4.4-8). Cluster IV that contained only one genotype, i.e., AGS-7-1 (Table 4.4-10) was the cluster that produced the highest cluster mean for most of productivity measures i.e., grain yield, pod number, hundred seed weight, number of seeds per pod, plant biomass, plant height, and pod length (Table 4.4-8), indicating that this genotype is exceptionally the best genotype for performance under low P conditions. This genotype was also uniquely grouped as a single cluster group in the dendrogram (Figure 4.4-3). The fact that this genotype was recently released by Pawe Agricultural Research Center in Ethiopia strengthens this finding. Cluster one at low P, contained 23 genotypes, and included most of the released varieties, such as Davis, Clark 63 K, Coker 240, and one pipeline variety SCS-1 (Table 4.4-10), produced the highest cluster mean for number of seeds per pod, and the second highest mean for all other traits (Table 4.4-8), indicating the availability of some other promising genotypes in this cluster for performance under low P condition. The fact that genotypes of released varieties were fitted in the same cluster indicates that breeders have been emphasizing the same set of traits during selection due to market requirements. This can partly explain the low genetic variation in soybean, and suggests the need to introgress some exotic germplasm to enhance variation.

Under high P condition, cluster I that contained 16 genotypes and most of the released soybean varieties i.e., Coker 240, Clark 63 K, and Davis (Table 4.4-11), produced the highest cluster mean for most of the productivity related traits i.e., grain yield, pod number, hundred seed weight, and number of seeds per pod (Table 4.4-9), confirming their adaptation to non-P stress condition. Cluster II was also the cluster that showed the highest cluster mean for all of the traits, except for grain yield and 100-seed weight (Table 4.4-9). Cluster II also produced the second highest cluster mean for grain yield and hundred seed weight (Table 4.4-9), indicating the two clusters i.e., Cluster I and II, contained the genotypes that can best perform under high P conditions.

4.6 Conclusions and implications

Overall, the study reveals the availability of sufficient genetic variation among soybean genotypes under both low and high P conditions on acidic soils, and that genetic variability was relatively higher under low P than high P conditions. Results also demonstrate that reasonably high heritability genetic advances can be obtained with implications for breeding. Our findings suggest that selection for low P tolerance would be effective to improve grain yield and the essential agronomic traits of soybean varieties under low soil fertility and acidic soils in the smallholder sector. Future studies would investigate the variation of these genotypes for qualitative traits such as protein and oil content under both conditions.

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CHAPTER 5

Response of soybean (*Glycine max* L.) genotypes to levels of phosphorus and locations for root and nodulation characteristics on acidic soils

5.1 Abstract

Dense and deep root systems are desirable traits in maintaining the tolerance of soybean to adverse soil and moisture conditions; while high and effective nodulation are important in improving soil fertility. This study was conducted to assess the response of soybean genotypes to levels of phosphorus for some of the important root and nodulation characteristics. The study was conducted across three locations of Western Ethiopia i.e., Jimma, Assossa, and Mettu experimental sites, which are characterized by acidic soils. Treatments were laid out in a split-plot design, whereby levels of phosphorus (P) were main plots, and genotypes were sub-plots. The study comprised of 36 soybean genotypes and three levels of P i.e., 0, 100, and 200 kg ha^{-1} of P. The results revealed that genotype x phosphorus (GXP) interactions were significant for number of nodules and total nodule weight at Jimma, and Assossa; while root weight and root volume were significant at Mettu. None of the root and nodulation parameters showed significant difference for GXP, and location XGXP interactions in the across location analysis, while genotypes showed significant difference for all the parameters, except for number of nodules and total nodule weight. Significant and positive correlations were found for root traits, such as root volume and tap root length at low P, and root fresh weight and tap root length at 100 kg ha^{-1} applied P with grain yield. Total nodule weight showed highly significant correlations with grain yield at 100 kg ha^{-1}. Both the mean separation and cluster analysis indicated that genotype PR-142 (26) was the best genotype for most of the attributes, while AGS-3-1, SCS-1, AGS 234, and H3 performed well for most of the traits studied.

Key words: soybean, rooting, nodulation, response to P, Pearson correlations, cluster analysis

5.2 Introduction

Soybean is a crop of diverse uses; especially for subsistence farmers in developing countries. It is considered as a strategic crop for fighting world hunger and malnutrition (Thoenes, 2004). Its role for crop rotation and improving the fertility of the soil is most appreciated by farmers (Tesfaye *et al*., 2010). This soil fertility improvement and crop rotation role of soybean can be enhanced through breeding for high nitrogen fixation and desirable root characteristics. The desirable root characteristics can help the crop to tolerate adverse soil conditions. One of such adverse soil conditions is low soil fertility due to acidity of the soil.

Soil acidity is a worldwide problem (Foy, 1988) and occurs on more than 50% of the world's potentially arable land (Liao *et al*., 2006). The major problem of acidic soils is the abundance of Al, Mn and Fe, which has toxic effects on plants, and limited availability of essential plant nutrients, such as phosphorus, nitrogen and potassium (Liao *et al*., 2006). Such problematic soils require careful soil fertility management practices to enhance soybean production and productivity. These include: the application of lime to neutralize soil acidity and developing varieties with desirable root attributes to overcome the acidity related problems.

Nian *et al.* (2003) reported that root system on acidic soil need to have, not only Al tolerance, but also the capacity to supply the optimum phosphorus nutrient required for good growth and productivity of the crop. The remarkable role of improving root characteristics in enhancing the productivity of crops on low fertility soil was reported by Lynch *et al.* (2007). The author's reason for emphasizing in improving root characteristics was the low level of fertility of the soil, and inadequate use of fertility improving inputs in most developing countries. According to Lynch *et al*. (2007), genetic variation in the length and density of root hairs is essential for the absorption of immobile nutrients, such as P and K, and such traits contribute to considerable yield improvement on low fertility soils.

Nodulation and nitrogen fixation are also very important attributes to improve the fertility of the soil by supplying plant usable nitrogen for the soybean crop itself, and crops succeeding it. The nodulation characteristics of soybean is dependent on the nutrient availability in the soil, such as Ca and P fertilization (Waluyo *et al*., 2004) and the types of soybean genotypes (Moharram *et al*., 1994). According to Waluyo *et al*. (2004), P is important in the initiation of nodule formation and the development and functioning of the produced nodules. Olufajo (1990) also reported that P fertilization enhanced the nodulation of promiscuous soybean for *Bradyrhizobium japonicum* inoculation. Moharram *et al*. (1994) reported improved nodulation and nitrogen fixation of soybean as a result of P application. The author's also reported varietal difference in the nodulation and N-fixation character in which variety Clark gave better response than Crowford. However, since this study used only two varieties, it is inadequate to conclude the existence of varietal differences for the attributes. Therefore, the objectives of this study were to assess the response of soybean genotypes to different levels of P, locations, and their interaction for the nodulation and root characteristics of soybean on acidic soils of Western Ethiopia.

5.3 Materials and methods

5.3.1 Experimental sites

The field experiments were conducted at Jimma Agricultural Research Center, Mettu Agricultural Research sub-station, and Assosa Agricultural Research Centers, in Ethiopia (Table 5.3-1), which are characterized by strong to moderate acidic soil and low soil P (see Table 5.3-2 below for Jimma, and Table 4.3-1 in Chapter four for Assossa and Mettu)..

Table 5.3-1 Agro-ecological characteristics of the experimental sites

Testing Location	AEZ	Altitude (masl)	Location	Annual mean RF	Annual mean temperature		Soil type
					Min	Max	
Jimma	H_2	1750	$7^0$46'N 36^0E	1754	11	26	Reddish brown
Mettu	H_2	1550	$8^0$3' N 30^0E	1835	12	27	Dark red brown
Assosa	Hot to warm sub-humid lowlands	1550	NA	1056.2	12.4	27.8	Reddish brown

H_2- Tepid to cool humid mid highlands, RF=rainfall, and
AEZ=agro-ecological zone according to EIAR classification; NA=Not available

5.3.2 Experimental design and treatments

A split plot design, where levels of P were main plots and genotypes were subplots was used for the experiment. The treatments were 36 genetically diverse soybean genotypes, and three levels of P i.e., low, medium, and high i.e., 0, 100, and 200 kg ha^{-1} P, respectively. The 36 genotypes within each of the main plot were laid-out in a 6X6 lattice design in two replications. The seeds of all the soybean genotypes used in the experiments were uniformly dressed with Rhizobium bacteria, and no nitrogen source commercial fertilizer was applied.

5.3.3 Laboratory analysis

Soils from all the experimental sites were analyzed for P content before the experiments were conducted. The procedure described by Sahlemedhin and Taye (2000) was used to analyze soil P using Bray II method, N using Kjeldhal method, K using flame photometry, organic carbon (OC) and organic matter (OM) using Walkley and Black method. In addition, the procedures described by Sahlemedhin and Taye (2000) were followed to analyze soil pH and exchangeable acidity, Al and H.

Table 5.3-2 Results of soil analyses conducted on three samples collected from each of the experimental sites (Jimma, Assosa and Mettu) before the experiment

No.	Location	K (ppm)	% N	% OC	% OM	P (ppm)	pH (H_2O)	Exchangeable Acidity (meq/ 100g soil	Al (meq/ 100g soil	H (meq/ 100g soil
1	Assossa	10	0.13	2.19	3.77	4.90	4.92	0.24	0	0.24
2	Assossa	5	0.12	2.33	4.02	5.28	5.50	0.24	0	0.24
3	Assossa	5	0.12	2.02	3.48	3.35	4.50	1.68	0.08	1.60
4	Mettu	20	0.28	2.30	3.97	1.80	5.11	1.52	0.8	0.72
5	Mettu	15	0.28	2.62	4.52	2.84	4.86	0.72	0.32	0.40
6	Mettu	20	0.26	2.82	4.87	1.16	4.50	2.48	1.28	1.20
7	Jimma	5	0.14	1.73	2.98	2.96	5.35	0.24	0	0.24
8	Jimma	55	0.13	1.99	3.43	4.77	5.34	0.24	0	0.24
9	Jimma	10	0.14	1.79	3.08	6.96	5.68	0.08	0	0.08

5.3.4 Data collection

Some of the important root and nodulation characters were measured in all the experiments. These traits were measured by carefully uprooting five random plants along with the soil from each plot. Then the soil was removed by washing the root and nodules gently in a plastic container taking care not to damage the root and not to lose any nodule. Total number of nodules, which is the count of all the nodules formed by the root; total nodule weight, which is the weight of all the nodules produced, and weight of effective nodules, which is the weight of actively N-fixing nodules (nodules that are pinkish in color upon splitting using knifes) were measured on randomly selected five plants from each plot.

In addition, root characteristics, such as root fresh weight, which is the weight of the roots; root volume that is the volume of water displaced from the measuring cylinder by the root, and taproot length, which is the length of the central taproot were measured on randomly selected five plants from each treatment.

5.3.5 Statistical analysis

Analysis of variance for the experiment was computed using Genstat Statistical Software. Test of homogeneity of error variance for the levels of P and locations was made before combined analysis using the maximum error variance divided by the minimum, and all these ratios were less than three indicating homogeneity of error variances as per Gomez and Gomez (1984). Similarly the normality of each data was check during the analysis using genstat residual plot technique and the result revealed that all the traits showed normality; except total nodule weight at Assossa. The combined analysis of GXL, GXP, and GXLXP was analyzed using genstat, split plot analysis program. Square root transformation was performed for number of nodules, as it is a count data and lacks normality (Gomez and Gomez, 1984). Other parameters which failed to satisfy the normality assumption were also transformed using log transformation (Gomez and Gomez, 1984). The Pearson's correlation analysis was done using genstat statistical software to understand the interrelationship of the rooting and nodulation traits with grain yield other yield related traits.

The linear statistical model for split plot design experiment conducted across locations is given by:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + (\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\tau\alpha\beta)_{ijk} + \varepsilon_{ijk}$$

Where, $i = 1,2, \ldots, r, j = 1,2, \ldots, a, k = 1,2, \ldots, b$; α_i, and β_j represent the main plot and subplot, respectively; τ_k represents the location; $(\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\tau\alpha\beta)_{ijk}$ represents main plot X subplot, main plot X location, subplot X location, and main plot X subplot X location interactions, respectively and ε_{ijk} is the residual term.

5.4 Results

5.4.1 Response of genotypes and Genotype X P interactions in each locations

There were highly significant differences among genotypes for all the root and nodulation parameters i.e., total nodule weight, weight of effective nodule, root weight, root volume and tap root length, except for number of nodules that was significant at Jimma (Table 5.4-1). The interaction of PXG was highly significant for number of nodules and total nodule weight at Jimma, while weight of effective nodules, root weight, root volume, and tap root length were not significantly different. At Assossa, the genotypes were significantly different for number of nodules, and highly significant for root weight, root volume, and tap root length, while there was no significant difference for total nodule weight and weight of effective nodule. It was only root weight and tap root length that showed significant difference among the P levels at Assossa. The GXP interaction was highly significant and significant for number of nodules and total nodule weight, respectively. There weres highly significant differences among genotypes for root volume and tap root length; while the rest of the parameters were non-significant at Mettu. There was significant difference among the P levels for number of nodules, and total nodule weight, and highly significant difference for root weight. The GXP interaction was significant for root weight and root volume.

Table 5.4-1 Mean squares of genotypes, and genotype X phosphorus (GXP) interaction for each of the three locations i.e., Jimma, Assosa and Mettu

Traits	Jimma		Assossa		Mettu	
	G	G X P	G	GXP	G	G X P
¥Number of nodules	7.23*	10.39**	13.63*	16.73**	10.1ns	6.97ns
Total nodule weight (gm)	46.33**	26.69**	19.77ns	21.1*	14.48ns	18.99ns
Weight of effective nodule (gm)	2.36**	1.46ns	2.68ns	2.49ns	0.8645ns	0.7231ns
Root weight (gm)	222.47**	50.88ns	180.42**	56.66ns	1303.4ns	18.13*
Root volume (lt)	256.67**	83.9ns	40.15**	8.8ns	148.07**	46.68*
Tap root length (cm)	20.67**	5.08ns	266.42**	85.51ns	32.95**	9.16ns

¥Mean squares are based on square root transformation, *= significant at ($P<0.05$), and ** = significant at ($P<0.01$)

5.4.2 Response of genotypes and Genotype X P interactions over locations

The across locations combined analysis revealed that the genotypes displayed highly significant difference for all the parameters, except for number of nodules that was non-significant, and weight of effective nodules, which was significant (Table 5.4-2). Locations x P levels interactions were highly significant for all the nodulation and root characteristics; while location X genotypes interaction was highly significant for number of nodules, root volume and tap root length. It was only total nodule weight that showed significant GXP interaction. None of the traits showed significant Location X P-Levels X Genotypes (LXPXG) interactions.

Table 5.4-2 Mean squares for locations, genotypes, and P levels and their interactions across three locations i.e., Jimma, Mettu and Assossa

Factors	¥Number of nodules	¥Total nodule weight (gm)	¥Weight of effective nodule (gm)	Root weight (gm)	Root volume (lt)	Tap root length (cm)
Location	295.35**	70.9**	117.26**	1043.74**	2742.16**	5090.94**
P levels	26.8**	18.79**	14.6**	9054.43**	3465.33**	4108.75**
Genotypes	1.16ns	0.61ns	1.71*	344.52**	246.19**	154.19**
LocationXP Levels	5.77**	5.23**	14.88**	811.93**	708.93**	2853.61**
LocationXGenotypes	0.75ns	0.34ns	0.13ns	67.82ns	75.81**	69.51**
P-LevelsXGenotypes	1.07ns	0.35ns	0.14ns	50.35ns	58.09ns	34.78ns
LXPXG	8.9ns	0.31ns)	(0.14ns)	38.29ns	38.04ns	32.11ns

¥ mean squares are based on square root transformations, *= significant at (P<0.05), and ** = significant at (P<0.01)

5.4.3 Performance of genotypes in each location

Significantly higher weight of effective nodules was produced by genotypes PR-142 (26), AA-42-52, AGS-3-1, H-7, and SR-4-1 at Jimma (Table 5.4-3). Three of these genotypes i.e., PR-142 (26), AA-42-52, and H7 produced the highest fresh root weight. Significantly higher root volume was produced by genotypes AA-42-52, PR-142 (26), H7, IAC 6, PR-143 (14), and IAC 11. The genotypes which produced the highest tap root length at Jimma were IAC 6, H6, SCS-1, and Bossire-2. At Assosa, PR 142(26), H6, AGS-3-1, SR-4-3, AA 42-52, and both AGS-217 and G 9945, produced the highest root weight. Genotype H6, exceptionally, produced the highest root volume, followed by H7, SCS-1, IAC 6, PR-142 (26), SR -4-3, AA-42-52, H 16, Bossire-2, Essex-1, HS 82-2136, AGS

217, and Clark 63 K. The genotypes which produced the longest tap root length at Assosa were PR 142 (26), AGS 217, H 16, SR-4-3, Essex-1, AA-42-52, AGS-3-1, G 9945, PR-143 (14), Ocepara-4, Clark 63 K, JSL-1, H7, SCS-1 and HS 82-2136. At Mettu, the highest tap root length was produced by genotypes IAC-6, PR 142 (26), IAC 11, H 6, SR-4-3, SCS-1, AA-42-52, AGS 7-1, Bossire-2, Ocepara 4, H 7, and G 9945.

At Jimma, the highest number of nodules was produced at 200 Kg ha^{-1} level of P by two genotypes i.e., H3 and PR-142 (26), and at 100 Kg ha^{-1}, SCS-1 was among the genotypes that produced the highest number of nodules per five plants (Table 5.4-4). The number of nodules at 0 level of P was generally low and H 16, AA 7138, Davis and Hardee-1 produced relatively higher number of nodules at this level of P. The highest nodule weight was produced by genotype AA-7138 followed by FB1-7636 at 100 Kg ha^{-1} P rate. The highest nodule weight at the 200 Kg ha^{-1} P was produced by FB1-7636, followed by PR 142 (26) and H3. Similar to the number of nodules, the total nodule weight was generally low at 0 level of P and the highest nodule weight at this P level was produced by genotype PR-143 (14).

At Mettu, the highest root weight was produced at 200 Kg ha^{-1} P rate by genotypes PR-142 (26) and AGS-3-1, and at 100 Kg ha^{-1} P by genotype PR-142 (26) (Table 5.4-5). The highest root weights at 0 level of P were produced by genotypes PR-142 (26), Essex-1, G-9945, SCS-1, H7, IAC-6, IAC 11, H 16, Ocepara-4 and SR-4-3. The highest root volume was produced by genotypes AGS-3-1, PR-142 (16), and Essex-1. The root volume at 0 level of P was generally low.

The highest number of nodules at Assossa was produced by genotypes SCS-1, H3 and PR-142 (26) at 200 Kg ha^{-1} applied P (Table 5.4-6). The nodule formation was relatively lower in both the control and 100 kg ha^{-1} levels of P. The highest nodule forming genotypes SCS-1, and H 3 produced low mean number of nodules at 100 kg ha^{-1} P. Three genotypes i.e., PR-143 (14), Hardee-1 and IAC 6 were relatively the better nodule forming genotypes at zero P. The highest total nodule weight at Assossa was produced by genotype H 3 at 200 kg ha^{-1} applied P. The total nodule weight produced was generally low for the control and 100 kg ha^{-1} P level. Some of the genotypes which produced relatively higher nodule weight at 0 level of P were PR-143 (14), AGS 234, IAC 6, AGS-217, and Coker 240.

Table 5.4-3 Mean values of root and nodulation characters measured at Jimma, Assossa, and Mettu

Genotypes	Jimma				Assossa			*Mettu*
	WEN (gm)	Root Weight (gm)	Root Volume (ml)	TRL (cm)	Root Weight (gm)	Root Volume (ml)	TRL (cm)	*TRL (cm)*
1. Davis	1.993	10.55	18.13	14.82	15.17	18.64	17.18	16.8
2. Tunia	1.257	19.07	21.73	13.52	20.45	19.85	25.33	22.54
3. PR-142 (26)	3.765	33.55	41.8	17.63	33.43	22.22	37.5	26.18
4. IAC 11	2.415	22.8	32.53	16.37	21.18	19.24	25.67	25.74
5. Alamo	1.907	15.72	24	15.68	20.33	18.13	22.17	18.76
6. FB1-7636	1.46	11.82	24.5	17.39	16.77	16.81	22.03	20.22
7. PR-143 (14)	2.272	19.55	33.17	17.8	24.08	18.9	31.67	21.91
8. AGS 217	2.353	19.53	30.3	17.69	26.45	19.95	34.37	17.98
9. HS 82-2136	1.323	12.25	21.83	16.4	23.93	20.05	28.67	21.29
10. AA-7138	2.272	11.88	23.87	16.46	22.92	19.42	26.73	21.11
11. IAC 73-5115	1.645	10.13	19.97	16.75	20.35	17.91	21.83	21.31
12. AA-42-52	3.013	32.57	42	16.97	27.3	21.84	32.83	24.13
13. AGS 234	1.83	11.75	19.62	15.3	11	18.77	17.33	20.12
14. Coker 240	1.32	8.55	20.4	13.74	13.97	15.54	13.83	21.62
15. AGS-3-1	2.842	16.97	26.33	14.91	28.28	19.85	32.33	21.44
16. Essex-1	0.995	17.57	29.37	18.39	23.45	20.06	33.67	22.54
17. Hardee-1	2.368	9.02	15.25	15.31	11.75	17.1	17.83	20.68
18. Bossire-2	1.727	17.55	28	18.76	22.35	20.09	28	23.47
19. AGS-7-1	1.747	13.07	18.2	15.76	21.58	19.17	24.17	23.55
20. TGX-297-6E-1	0.858	14.2	23.6	16.88	20.77	18.89	23.92	20.97
21. AGS-62	1.28	7.57	12.67	11.8	9.1	13.69	10.33	19.4
22. Protana 2	2.442	13.75	19.37	13.51	13.1	17.05	17.67	18.5
23. H 16	2.185	20.58	29.17	17.18	22.67	20.96	34.33	22.26
24. H 3	2.167	13.58	22.93	16.13	13.78	17.59	20.23	20.49
25. H 6	1.822	20.15	29.83	19.82	28.43	28.53	33.07	25.16
26. Ocepara 4	2.145	20.72	31.83	16.62	25.15	19.31	31.53	23.26
27. SCS-1	1.945	19.92	28.5	18.82	20.65	23.59	29.33	24.4
28. Clark 63-K	2.292	16.13	27.5	16.36	21.63	19.89	31.33	20.69
29. G 9945	1.787	15.98	32.25	15.87	26.45	20.52	31.75	22.83
30. JSL 1	1.493	17.13	25.47	16.53	23.23	18.59	30.42	19.11
31. SR-4-3	1.738	18.17	29.08	14.3	27.33	22.07	33.83	24.52
32. IAC 6	1.783	24.17	33.17	21.35	16.77	23.00	19.52	26.22
33. H 7	3.207	29.02	33.83	18.03	21.48	23.74	29.50	22.96
34. PR-162-11	1.322	13.35	25.67	16.49	18.52	18.76	24.05	19.11
35. OC-78503	1.428	16.62	28.27	17.56	20.93	18.93	27.93	20.13
36. SR-4-1	2.613	20.1	28.7	16.67	15.8	18.19	20.83	20.56
Mean	1.97	17.08	26.47	16.49	20.85	19.63	20.19	*21.72*
CV %	54.20	45.30	31.80	14.20	31.00	17.20	30.30	*14.10*
Significance level	**	**	**	**	**	**	**	**
LSD (5%)	1.22	8.85	9.65	2.67	7.40	3.88	9.08	3.51

*NB. WEN= weight of effective nodules, TRL= tap root length, *= significant at (P<0.05), and ** = significant at (P<0.01)*

Table 5.4-4 Mean number of nodules and total nodule weight obtained at 0, 100 and 200 kg ha^{-1} P under Jimma condition

Genotypes	Number of nodules						Total nodule weight (gm)		
	0 P	¥0 P	100 P	¥100 P	200 P	¥200 P	0 P	100 P	200 P
1. Davis	107.5	10.3	69.5	8.1	134.0	11.5	1.63	2.39	2.95
2. Tunia	39.0	6.2	134.6	11.2	81.0	8.8	1.24	3.25	2.64
3. PR-142 (26)	39.0	6.2	80.5	8.8	390.0	19.6	1.15	4.82	10.03
4. IAC 11	41.0	6.2	210.0	14.1	160.0	12.4	0.92	6.41	3.22
5. Alamo	46.5	6.7	129 9	11.3	143.5	12.0	0.77	3.76	2.67
6. FB1-7636	71.5	8.3	165.0	12.8	177.0	13.2	0.81	24	18.5
7. PR-143 (14)	83.0	8.9	83.5	8.8	135.0	11.5	8.92	6.33	3.23
8. AGS 217	72.0	8.3	91.0	9.5	220.0	14.8	2.19	4.38	4.5
9. HS 82-2136	64.5	8.0	96.5	9.3	172.0	13.1	1.16	1.66	2.47
10. AA-7138	124.0	11.1	151.5	12.3	200.0	11.1	2.68	33.5	3.96
11. IAC 73-5115	80.5	9.0	157.5	11.8	133.5	11.5	1.51	3.4	3.01
12. AA-42-52	76.0	8.7	170.5	12.2	239.5	15.4	1.75	5.66	6.52
13. AGS 234	60.0	7.5	230.0	15.0	127.0	11.3	1.06	4.7	1.72
14. Coker 240	98.5	9.8	105.5	10.0	120.0	10.9	1.07	1.81	2.24
15. AGS-3-1	93.5	9.7	238.0	14.9	203.5	14.2	1.44	10.25	3.38
16. Essex-1	34.5	5.8	125.0	11.1	135.5	11.6	0.5	2.32	1.56
17. Hardee-1	101.5	9.8	115.0	10.7	156.5	12.5	1.87	2.61	4.53
18. Bossire-2	87.5	9.3	130.5	11.2	74.5	8.4	1.19	4.08	1.29
19. AGS-7-1	62.5	7.9	126.0	11.2	86.0	9.2	0.92	4.04	1.65
20. TGX-297-6E-1	73.0	8.5	61.0	7.5	100.5	10.0	1.14	0.95	1.56
21. AGS-62	72.0	8.3	283.0	16.4	90.5	9.4	1.02	2.7	1.31
22. Protana 2	72.5	8.5	130.0	11.2	199.0	14.1	2.64	3.8	5.23
23. H 16	125.0	11.1	111.0	10.1	188.5	13.7	1.14	3.71	4.63
24. H 3	59.0	7.4	107.5	10.3	410.0	19.5	0.87	1.78	9.11
25. H 6	65.0	7.7	82.0	8.5	252.0	15.8	1.04	1.87	4.57
26. Ocepara 4	86.0	9.2	138.0	11.5	135.5	11.6	1.9	4.41	3.01
27. SCS-1	89.0	9.4	329.5	18.1	89.0	9.4	0.94	6.05	1.34
28. Clark 63-K	81.5	8.7	180.5	13.0	138.5	11.7	1.15	5.29	3.25
29. G 9945	66.0	8.1	117.5	10.7	231.0	15.2	1.6	2.53	4.8
30. JSL 1	85.5	9.2	119.5	10.8	132.0	11.4	1.26	2.33	2.56
31. SR-4-3	59.0	7.7	136.0	11.0	73.0	7.8	1.17	4.5	2.51
32. IAC 6	98.5	9.9	158.5	12.2	175.5	13.1	1.32	3.46	2.93
33. H 7	84.5	9.1	158.5	11.9	180.0	13.3	1.44	5.68	5.6
34. PR-162-11	59.0	7.5	116.5	9.4	174.0	13.2	0.88	2.46	2.56
35. OC-78503	73.0	8.5	138.0	10.5	116.5	10.5	0.92	3.54	1.84
36. SR-4-1	73.0	9.8	138.0	13.3	116.5	13.0	2.27	4.84	4.04
Mean	75.8	8.5	143.1	11.4	165.1	12.5	1.54	5.26	3.91
CV %	19.9						52.4		
Significance level	**						**		
LSD (5%)	4.26						3.7		

¥ Values are based on square root transformation, *= significant at (P<0.05), and ** = significant at (P<0.01)

Table 5.4-5 Mean root weight and root volume of soybean genotypes obtained at 0, 100 and 200 kg ha^{-1} P at Mettu

	Root weight (gm)			Root volume (lt)		
Genotypes	0	100	200	0	100	200
1. Davis	5.0	12.0	13.5	4.0	14.1	22.5
2. Tunia	8.0	13.0	15.5	13.5	20.0	25.0
3. PR-142 (26)	20.5	30.5	35.0	21.5	34.0	44.0
4. IAC 11	16.5	31.0	22.0	26.5	25.25	24.0
5. Alamo	9.5	15.0	15.0	13.5	22.5	17.0
6. FB1-7636	9.5	19.0	23.5	19.0	20.85	22.0
7. PR-143 (14)	10.5	18.0	20.5	17.5	24.0	29.5
8. AGS 217	10.5	13.0	16.0	13.9	15.2	23.5
9. HS 82-2136	11.0	13.5	21.0	18.0	20.1	34.0
10. AA-7138	9.5	18.5	16.5	29.0	20.2	19.0
11. IAC 73-5115	11.0	18.5	18.5	20.5	21.0	18.0
12. AA-42-52	13.5	28.0	25.5	17.0	22.6	30.0
13. AGS 234	8.0	17.5	11.0	17.6	17.8	15.0
14. Coker 240	11.5	14.0	14.5	21.5	19.05	16.0
15. AGS-3-1	12.0	18.5	33.5	17.5	19.95	46.0
16. Essex-1	18.5	26.0	31.0	34.0	30.0	35.5
17. Hardee-1	6.5	13.5	10.0	12.5	15.5	12.5
18. Bossire-2	13.5	15.5	19.5	18.5	20.0	22.0
19. AGS-7-1	11.5	24.5	26.0	19.1	33.0	31.5
20. TGX-297-6E-1	9.0	17.0	19.5	12.5	20.0	14.5
21. AGS-62	12.5	15.5	15.0	17.0	18.0	17.5
22. Protana 2	10.5	16.5	16.5	13.5	17.7	19.0
23. H 16	15.5	15.0	13.5	20.0	15.5	15.0
24. H 3	11.5	19.0	17.0	19.0	21.1	21.0
25. H 6	12.0	23.5	26.5	17.5	25.5	34.0
26. Ocepara 4	14.5	13.5	20.0	26.0	19.0	24.5
27. SCS-1	18.0	20.5	23.5	22.0	24.2	16.5
28. Clark 63-K	13.0	20.5	19.5	22.5	25.4	24.0
29. G 9945	18.5	21.0	26.5	25.0	26.0	25.0
30. JSL 1	7.5	18.0	14.5	11.0	21.3	22.0
31. SR-4-3	14.5	23.5	26.5	20.0	25.0	24.0
32. IAC 6	17.0	21.5	29.5	28.5	27.0	30.0
33. H 7	18.0	20.5	19.5	23.6	23.0	20.0
34. PR-162-11	12.0	16.5	19.0	19.0	17.6	22.5
35. OC-78503	6.5	13.0	16.0	12.5	14.1	15.5
36. SR-4-1	11.5	14.5	18.0	15.0	19.0	15.0
Mean	12.18	18.58	20.24	18.86	21.51	23.53
CV %	20.30			26		
Significance level	*			*		
LSD (5%)	6.80			10.97		

**= significant at (P<0.05), and ** = significant at (P<0.01)*

Table 5.4-6 Mean numbers of nodules and total nodule weight obtained at 0, 100 and 200 kg ha^{-1} applied P, at Assossa

Genotypes	Number of nodules						Total nodule weight (gm)		
	0 P	¥0 P	100 P	¥100 P	200 P	¥200 P	0	100	200
1. Davis	140.5	10.69	45.0	6.64	157.0	12.06	3.8	3.6	5.7
2. Tunia	95.5	9.77	142.5	11.10	98.5	9.88	3.2	4.3	3.8
3. PR-142 (26)	100.0	9.58	84.5	9.18	360.5	18.96	3.2	4.7	12.9
4. IAC 11	42.0	6.48	113.5	9.76	96.0	9.78	2.3	2.7	3.3
5. Alamo	104.5	9.40	74.5	8.59	97.5	9.85	2.3	1.3	4.2
6. FB1-7636	65.0	7.76	85.0	9.18	46.0	6.77	2.8	2.6	1.7
7. PR-143 (14)	256.5	15.93	78.0	8.82	127.5	11.09	11.	2.7	8.3
8. AGS 217	107.5	10.36	106.5	9.58	193.5	13.36	9.1	6.0	6.0
9. HS 82-2136	50.5	6.90	92.0	9.58	79.0	8.68	2.2	1.2	3.1
10. AA-7138	75.0	8.66	146.0	12.08	316.0	17.71	2.1	2.6	12.9
11. IAC 73-5115	56.0	7.48	55.0	7.35	167.0	12.59	3.6	1.8	6.7
12. AA-42-52	83.0	9.03	184.0	12.65	107.0	9.85	3.4	2.9	3.2
13. AGS 234	193.0	13.79	152.5	12.25	282.5	14.76	11.2	3.3	7.8
14. Coker 240	193.0	13.63	140.0	11.82	46.5	6.81	7.5	4.4	1.5
15. AGS-3-1	145.0	12.04	80.0	8.55	236.5	14.54	5.8	2.7	11.3
16. Essex-1	90.0	8.56	79.5	8.87	210.5	13.14	2.2	2.5	5.7
17. Hardee-1	220.5	14.59	81.0	8.85	205.5	14.26	5.8	3.4	5.2
18. Bossire-2	162.5	12.64	40.0	6.31	101.0	9.24	5.2	1.1	2.0
19. AGS-7-1	153.0	12.10	119.5	10.84	167.5	11.87	3.5	2.9	16.8
20. TGX-297-6E-1	107.0	10.34	127.5	10.94	147.5	11.77	3.8	2.7	3.8
21. AGS-62	70.0	8.28	175.5	13.08	130.5	11.30	1.9	3.7	4.2
22. Protana 2	143.5	10.95	142.5	11.79	185.0	13.19	4.8	2.3	4.9
23. H 16	46.0	6.78	142.0	11.60	149.0	12.18	1.4	3.2	5.1
24. H 3	91.5	9.50	58.5	7.51	500.0	20.58	4.3	1.3	24.5
25. H 6	128.5	11.08	89.5	9.32	194.0	13.58	3.2	2.8	6.7
26. Ocepara 4	45.0	6.61	177.5	13.03	74.5	8.22	3.8	9.1	2.0
27. SCS-1	123.5	10.93	47.0	6.54	505.0	22.46	3.2	0.7	10.4
28. Clark 63-K	125.0	11.16	102.0	10.00	72.5	8.35	6.3	3.1	2.5
29. G 9945	165.0	12.25	68.5	7.95	122.0	10.30	4.0	2.8	6.5
30. JSL 1	54.0	7.12	55.5	6.61	107.0	9.82	2.9	1.5	4.0
31. SR-4-3	85.0	9.18	163.5	12.45	103.5	9.87	2.6	2.1	3.7
32. IAC 6	205.0	14.32	29.5	5.34	79.5	8.85	9.2	0.3	2.3
33. H 7	96.0	9.24	177.0	13.23	146.5	11.77	3.5	5.8	4.2
34. PR-162-11	186.0	13.17	163.0	12.75	195.5	12.24	6.3	4.1	7.7
35. OC-78503	125.0	10.83	95.0	9.74	244.0	14.57	4.7	2.7	5.3
36. SR-4-1	134.0	11.48	72.0	8.46	106.0	9.70	3.1	2.5	3.1
Mean	118.4	10.35	105.1	9.79	171.0	12.06	4.41	2.95	6.17
CV%	27.6						82.6		
Significance level	**						*		
LSD (5%)	5.86						7.39		

*¥ Values are based on square root transformation, *= significant at (P<0.05), and ** = significant at (P<0.01)*

5.4.4 Performance of genotypes over P levels and locations

The genotypes that produced the overall longest tap root includes: PR-142 (26), H-6, Essex-1, PR-143 (14), G-9945, AA-42-52, H-16, AGS-217, Ocepara-4, SCS-1, H-7, Bossire-2, and IAC-11 (Table 5.4-7). Two genotypes VIZ., AA-7138, and AGS-7-1 produced the highest total nodule weight. PR-142 (26), IAC-6 (28.23), G-9945 (26.17), H-6 (29.62), Essex-1 (28.18), AA-42-52 (29.07), and PR-143 (14) were the genotypes with the highest root volume. The highest weight of effective nodules was produced by genotypes AGS-3-1, AGS-217, Protana-2, IAC 73-5115, and Cocker 240.

Table 5.4-7 Mean values of the root and nodulation parameters measured over P levels and locations

Genotypes	Number of nodules	Root weight (gm)	Tap root length (cm)	Total nodule weight (gm)	Root volume (lt)	Weight of effective nodule (gm)	¥Weight of effective nodule (gm)
1. Davis	73.22	10.61	15.72	2.50	16.13	1.52	0.81
2. Tunia	75.20	18.21	20.25	2.98	20.98	1.06	0.63
3. PR-142 (26)	123.15	32.04	26.54	3.95	31.06	2.21	0.91
4. IAC 11	84.16	21.92	22.55	2.42	25.59	1.52	0.77
5. Alamo	80.75	16.53	19.46	2.00	20.72	1.58	0.81
6. FB1-7636	81.07	15.55	18.86	5.85	19.71	1.06	0.66
7. PR-143 (14)	82.01	21.29	24.60	3.73	26.75	1.37	0.74
8. AGS 217	105.46	20.62	24.17	4.97	22.82	2.19	1.11
9. HS 82-2136	70.46	17.36	21.95	2.28	22.66	1.28	0.75
10. AA-7138	113.16	16.40	21.07	9.22	22.22	1.44	0.75
11. IAC 73-5115	82.48	15.82	19.90	2.80	20.56	1.69	0.95
12. AA-42-52	94.38	27.04	24.37	2.98	29.07	1.74	0.87
13. AGS 234	127.71	12.13	18.49	3.46	18.83	1.52	0.84
14. Coker 240	92.13	11.47	16.59	2.92	18.35	1.91	0.94
15. AGS-3-1	129.53	21.51	21.76	4.89	24.47	3.27	1.26
16. Essex-1	72.06	22.02	25.36	1.68	28.18	0.83	0.58
17. Hardee-1	94.56	9.86	16.64	3.30	13.33	1.68	0.88
18. Bossire-2	64.96	19.98	23.49	1.17	23.22	0.84	0.54
19. AGS-7-1	89.89	18.29	21.68	6.11	21.52	1.52	0.77
20. TGX-297-6E-1	89.14	17.48	21.15	3.18	19.64	1.11	0.70
21. AGS-62	108.07	11.03	14.72	2.62	15.96	1.48	0.78
22. Protana 2	105.23	13.10	17.34	3.62	16.82	2.13	1.07
23. H 16	96.41	19.48	24.19	2.72	22.27	1.86	0.87
24. H 3	142.27	13.20	17.79	4.78	19.93	2.20	0.88
25. H 6	105.01	24.39	26.33	3.46	29.62	1.50	0.79
26. Ocepara 4	77.33	20.46	23.83	3.11	24.09	1.36	0.77
27. SCS-1	131.32	19.78	23.67	3.46	23.85	1.35	0.66
28. Clark 63-K	80.80	18.14	22.34	2.05	22.98	1.34	0.67
29. G 9945	97.00	20.97	24.46	2.78	26.17	1.36	0.80
30. JSL-1	65.68	17.10	21.41	2.07	19.30	1.09	0.64
31. SR-4-3	67.58	21.56	23.62	2.50	24.80	1.45	0.83
32. IAC 6	90.94	21.55	21.74	2.67	28.23	1.47	0.73
33. H 7	94.14	21.70	23.55	3.17	25.57	1.85	0.87
34. PR-162-11	92.48	16.15	19.90	2.74	20.59	1.33	0.69
35. OC-78503	100.61	16.82	22.37	3.01	20.75	1.30	0.70
36. SR-4-1	98.11	17.61	20.91	3.22	22.09	1.78	0.90
Mean	93.8	18.3	21.5	3.3	22.5	1.6	0.80
Significance level	Ns	Ns	**	**	**	**	*
CV %	---	---	25.48	125.69	30.79	91.92	53.76
LSD 5%	---	---	4.01	3.13	5.16	1.07	0.32

¥=values are based on log transformation, ns=non-significant, *=significant at 5%, and **=significant at 1%

5.4.5 Clustering of the genotypes

The multivariate analysis using cluster analysis grouped the 36 genotypes into four clusters for the root and nodulation characteristics (Table 5.4-8). The dendrogram (Figure 5.4-1) grouped the genotypes into seven cluster group at cluster distance 0.5, and three cluster groups at cluster distance 1.0. Genotype PR-142 (26), which was the top performing genotype for most of the studied traits across the three locations and levels of P was exclusively assigned in cluster IV (Table 5.4-8). Cluster III also included some of the well performing genotypes namely: AGS-3-1, SCS-1, AGS 234, and H3 for the root and nodulation characteristics.

Table 5.4-8 Summary of cluster groups of soybean accessions grown across three locations i.e., Jimma, Mettu and Assossa

Cluster group	Entries	Number of genotypes
I	Alamo, IAC 73-5115, IAC 11, PR-143 (14), Bossire-2, SR-4-3, FB1-7636, Ocepara-4, Clark 63-K, Tunia, HS 82-2136, JSL-1, Essex-1, Davis	14
II	G-9945, H-7, OC-78503, SR-4-1, AGS-7-1, TGX-297-6E-1, H-16, PR-162-11, AGS-62, Protana-2, Coker-240, Hardee-1, IAC-6, AA-42-52, AGS 217, AA-7138, H-6	17
III	AGS-3-1, SCS-1, AGS 234, H-3	4
IV	PR-142 (26)	1

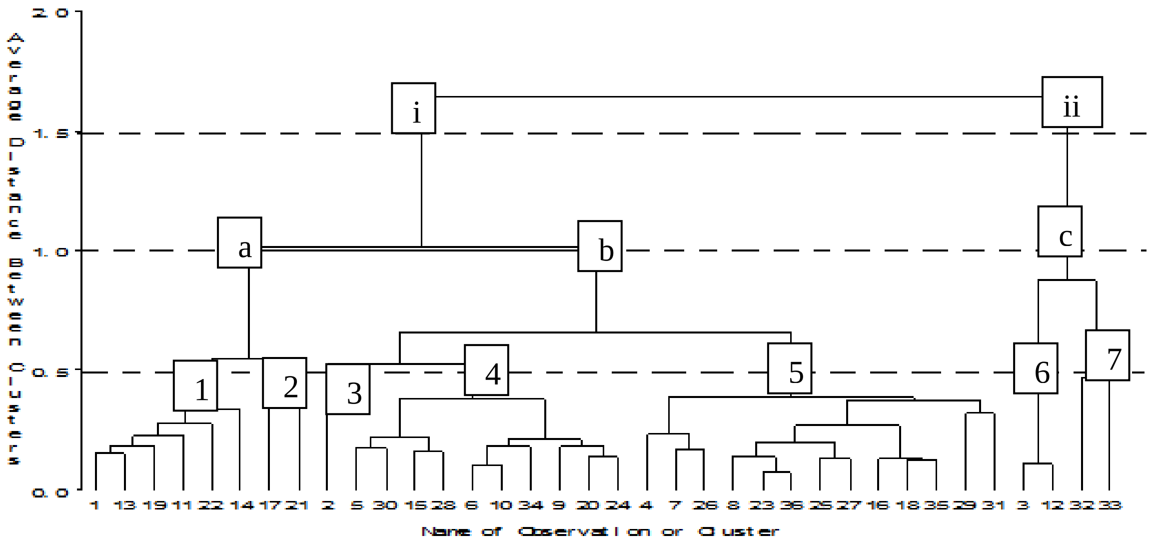

Figure 5.4-1 Dendrogram of the 36 soybean genotypes across locations and P-levels (numbers and corresponding genotypes are: 1. Davis, 2. Tunia, 3. PR-142 (26), 4. IAC 11, 5. Alamo, 6. FB1-7636, 7. PR-143 (14), 8. AGS 217, 9. HS 82-2136, 10. AA-7138, 11. IAC 73-5115, 12. AA-42-52, 13. AGS 234, 14. Coker 240, 15. AGS-3-1, 16. Essex-1, 17. Hardee-1, 18. Bossire-2, 19. AGS-7-1, 20. TGX-297-6E-1, 21. AGS-62, 22. Protana 2, 23. H 16, 24. H 3, 25. H 6, 26. Ocepara 4, 27. SCS-1, 28. Clark 63-K, 29. G 9945, 30. JSL-1, 31. SR-4-3, 32. IAC 6, 33. H 7, 34. PR-162-11, 35. OC-78503, 36. SR-4-1)

5.4.6 Pearson correlation of root and nodulation traits with yield and related traits

Grain yield was significantly and positively correlated with 100-seed weight, plant fresh weight, pod number, root volume and tap root length at zero P (Table 5.4-9). Similarly, pod number which is one of the most important yield components was positively and significantly associated with plant fresh weight, root fresh weight and root volume.

There was highly significant and positive associations of grain yield with plant fresh weight, root fresh weight, tap root length, and total nodule weight at 100 kg ha^{-1} applied P (Table 5.4-10). Significant and negative associations were found for grain yield with 100-seed weight, and root volume. Pod number has also established significant and positive associations with number of nodules, plant fresh weight, root fresh weight, root volume, tap root length and total nodule weight.

Table 5.4-9 Pearson correlations of root and nodulation traits with some of yield and yield related traits at zero P

Traits	1	2	3	4	5	6	7	8	9	10
1. 100-seed weight (gm)	X									
2. Grain yield (kg ha^{-1})	0.21**	X								
3. Number of nodules	-0.35**	0.01	X							
4. Plant fresh weight (gm)	0.32**	0.38**	-0.21**	X						
5. Pod number	-0.18*	0.58**	0.12	0.59 **	X					
6. Root fresh weight (gm)	0.42**	0.04	-0.24**	0.70**	0.18*	X				
7. Root volume (lt)	0.29**	0.20**	-0.11	0.69**	0.32**	0.75**	X			
8. Tap root length (cm)	0.52**	0.15*	-0.46**	0.47**	-0.12	0.53**	0.47**	X		
9. Total nodule weight (gm)	-0.23**	-0.12	0.60**	-0.10	-0.04	-0.08	-0.02	-0.24**	X	
10. Weight of effective nodules (gm)	-0.25**	-0.13n	0.66**	-0.12	0.001	-0.12	-0.09	-0.38**	0.75**	X

*=significant at (P<0.05), **= significant at (P<0.01)

Table 5.4-10 Pearson correlations of root and nodulation traits with some of yield and yield related traits at 100 kg ha^{-1} applied P

Traits	1	2	3	4	5	6	7	8	9	10
1. 100-seed weight (gm)	X									
2. Grain yield (kg ha^{-1})	-0.21**	X								
3. Number of nodules	-0.14	0.2	X							
4. Plant fresh weight (gm)	-0.41**	0.66**	0.55**	X						
5. Pod number	-0.01	-0.03	0.77**	0.23**	X					
6. Root fresh weight (gm)	0.02	0.31**	0.60**	0.50**	0.59**	X				
7. Root volume (lt)	-0.09	-0.32**	0.29**	-0.20**	0.41**	-0.14*	X			
8. Tap root length (cm)	-0.22**	0.23**	0.38**	0.38**	0.35**	0.35**	-0.11	X		
9. Total nodule weight (gm)	-0.35**	0.36**	0.43**	0.49**	0.35**	0.33**	0.01	0.70**	X	
10. Weight of effective nodules (gm)	-0.11	0.10	0.10	0.10	0.04	0.15*	-0.03	0.30**	0.29**	X

*=significant at (P<0.05), **= significant at (P<0.01)

5.5 Discussion

The fact that genotypic difference existed for the entire root and nodulation characteristic in Jimma and Assosa, except for total nodule weight and weight of effective nodules in Assossa is in-line with the finding of Moharram *et al*. (1994) report, where varietal difference was found for nodulation and N-fixation characters, though their result was based on only two varieties. The significance of P levels for total nodule weight at Mettu (Table 5.4-1), and for number of nodules, total nodule weight, and weight of effective nodules in the across locations analysis (Table 5.4-2) is in agreement with the report of Olufajo (1990) and Moharram *et al*. (1994) that P fertilization enhances nodulation and nitrogen fixation. The presence of significant GXP interaction for number of nodules and total nodule weight at Jimma and Assosa, and root weight and volume at Mettu (Table 5.4-1) indicates the differential response of genotypes for high and low P conditions, thus implying the possibility of selecting genotypes that perform exceptionally to low and high P conditions. The value of coefficient of variation for most of the nodule characters was very high indicating that nodule formation lacks consistency from plot to plot.

The high performance of genotype PR-142 (16) for almost all of the nodulation and root characteristics was shown in Tables 5.4-3, 5.4-4, 5.4-5, 5.4-6 and 5.4-7. The unique and high performance of this genotype was verified by cluster analysis, as it was assigned alone in cluster IV (Table 5.4-8). However, the performance of this genotype under zero level of P was very low relative to other genotypes (Table 5.4-4 and 5.4-6). This imply that this genotype is more of responsive than tolerant. Cluster III also contained some of the better performing genotypes under low P condition i.e., AGS-3-1, AGS-234, SCS-1 and H-3.

The significant and positive correlations of grain yield and 100-seed weight with the rooting traits viz., root volume and tap root length, and plant fresh weight, at low P (Table 5.4-9) indicates the importance of the root traits for low P tolerance. This also implies that selection for low P tolerance should take into account these important root traits. The highly significant and negative correlation of nodulation characters viz., number of nodules, total nodule weight and weight effective nodule with 100-seed weight under low P (Table 5.4-9) indicates the competitiveness of these traits. On the other hand, yield has non-significant association with all of these nodulation traits under low P (Table 5.4-9) indicates that nodule formation has little effect on yield. The fact that total nodule weight was significant at high P; while non-significant at low P indicates the importance of P availability in the soil to enhance nodule formation. This finding is in-line with the finding of Waluyo *et al*. (2004) who reported that nodulation character of soybean is dependent on P availability in the soil.

5.6 Conclusions and implications

1) The existence of significant GXP interactions for number of nodules and nodule weight at Jimma and Assossa; for root weight and root volume at Mettu imply the presence of differential response of genotypes for varying P levels.

2) The fact that significant correlations with grain yield were recorded for rooting at both low P and high P, and for nodulation at high P indicates that these traits were important contributors to yield and yield related traits, although they are among the traits that receive little attention in most soybean research. These findings also suggested that in soybean screening experiments for low P tolerance, rooting traits, were more important than nodulation.

3) Genotype PR-142 (26) gave the best performance for all the rooting and nodulation traits, followed by AGS-3-1, SCS-1, AGS 234, and H 3, and thus, these genotypes should be used in future soybean breeding program for low P tolerance.

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CHAPTER 6

Response of soybean (*Glycine max* L.) genotypes to phosphorus regimes for yield and related traits

6.1 Abstract

Low phosphorus (P) availability is one of the major soybean production limiting factors, especially on acidic soils. The objectives of this study were to assess the interaction of soybean genotypes (G) with levels of P, and identify genotypes that are tolerant to low P conditions. A total of 36 soybean genotypes were evaluated on three levels of P i.e., 0, 100, and 200 kg ha^{-1} at three locations (L) of Western Ethiopia in a split plot design; with P levels as main plots and genotypes as the sub plots. The GXP interaction effects were significant for grain yield at one site only. The genotypes showed highly significant differences for most of the traits studied in all the locations. The combined analysis revealed that most traits were significant for G, and LXG interactions. Essex-1, IAC 11 and AGS-3-1 were the best performing genotypes at levels of P, while IAC 11, AA-7138, G 9945 and AGS-7-1 exhibited tolerance to low P. Additive Main Effect and Multiplicative Interaction (AMMI) analysis for grain yield at Assossa revealed that zero and 200 kg ha^{-1} were highly interactive, but with opposite Interactive Principal Component Axis 1 (IPCA1) sign. Genotypes, AGS-7-1, Pr-143 (14), and H16 had better interaction with zero level of P with above average main effect. AA-7138, PR-142 (26) and H 3 were more stable genotypes across the P levels with relatively high main effect; and hence, such genotypes are useful in breeding soybeans for consistent response to varying P conditions.

Key words: Soybean genotypes, low P tolerance, AMMI, Stable performance

6.2 Introduction

Soybean is an important crop in the world. Demand for the crop has risen tremendously in the recent past. Some of the reasons for worldwide increase in soybean production include: it's high protein and oil content, its health benefits derived from long-term consumption (Wang *et al*., 2010), the role it plays in improving soil fertility, and for crop rotation (Tesfaye *et al*., 2010). The crop is in high demand for oil and poultry feed in Northern Guinea Savanna zone of Nigeria (Chiezey and Odunze, 2009). However, the productivity of soybean has been low on acidic soils (von Uexku¨ ll and Mutert, 1995). On acidic soils that accounts for 50% of the world's arable land (von Uexku¨ ll and Mutert, 1995) most of the P is found in a form that is unavailable to plants; bound by free Fe and Al (Barber, 1995).

Phosphorus is one of the major nutrients that limit crop production on more than 30% of the world's arable land (Vance *et al*., 2003). It is the most immobile, inaccessible and unavailable of all plant nutrients, and the second most crop production limiting nutrient, after nitrogen (Holford, 1997; Otani and Ae, 1996). Phosphorus is insoluble in most of its natural forms and hence, its concentration in the soil solution is usually low (2-10 *m*M) (Raghothama, 1999). The nutrient is recycled very slowly in contrast to nitrogen (Holford, 1997). Chemically, P is very reactive and found in more than 170 compounds.

The application of inorganic fertilizers has for a long time been considered as one of the best options to amend the deficiency of this nutrient in the soil. Chiezey and Odunze (2009) reported significant soybean grain yield increase in response to the application of phosphorus fertilizer. Xiang-wen *et al*. (2008) reported that the application of P increased biomass production. Aluminum toxicity might be ameliorated through application of phosphorus, which in-turn might improve root growth and P uptake (Tan and Keltjens, 1990). Kapoor and Gupta (1977) reported increased fractions of protein and P compounds in soybean seed as a result of increased P supply. On the other hand, Payne *et al*. (1986) reported non-significant effect of P on grain yield of two soybean (one low P tolerant, and the other P-sensitive) varieties.

Despite the importance of the use of inorganic P fertilizers to enhance the productivity of soybean and other crops, it has several drawbacks that limits its accessibility and sustainability to subsistence farmers. High price of P fertilizers (Wang *et al*., 2010; Tesfaye *et al*., 2011) and unavailability of fertilizers at the right planting time and in a sufficient amount, and problem of distribution systems (Tesfaye *et al*., 2011) are some of the most common problems of subsistence farmers in the use of commercial fertilizers. The reserve P (rock phosphate) is very limited and estimated to be exhausted within the next 60-90 years (Runge-Metzger, 1995), by 2050 (Vance *et al*., 2003). The P applied to crops may pollute waterways causing eutrophication (Withers *et al*., 2001).

Developing crop varieties that are tolerant to low soil fertility and low P conditions is considered as a sustainable and environmentally safe practice (Yan *et al*., 2006; Li *et al*., 2010). Producing soybean varieties that can efficiently utilize both the soil and applied P is a sustainable and economical way of soybean production (Wang *et al*., 2010). Individual genes that respond to low P were reported, and grouped into two i.e., ‘early’ and ‘late’ genes (Vance *et al*., 2003). The ‘early’ genes have immediate and specific response to P; while the ‘late’ genes change the morphology, physiology or metabolism of plants upon extended P deficiency (Vance *et al*., 2003).

The literature indicates that soybean genotypes have variable responses to P levels which form the basis for identifying stress tolerant genotypes. Li *et al*. (2010) classified 156 cultivars into 29 tolerant, 59 moderate and 68 sensitive cultivars, respectively. The authors also identified eight highly tolerant genotypes. Xiangwen *et al*. (2008), using principal component analysis, classified 96 soybean genotypes into three categories: high, moderate, and low P efficiency. Furlani *et al*. (2002) also classified 29 soybean genotypes into efficient-responsive (ER); efficient non-responsive (ENR); inefficient responsive (IR); inefficient non-responsive (INR).

Analytical tools, such as Genotype X Environment interactions and Additive Main Effect and Multiplicative Interaction (AMMI) model have been employed to interpret large genotype x environment x replicate tables without missing values (Crossa *et al*., 1991; Romagosa and Fox, 1993). In this particular study, the P levels are considered as environments. AMMI uses PCA to explain pattern in the GXE, or residual, matrix through extracting genotype and environment main effects (Romagosa and Fox, 1993). It is a combination of ANOVA and PCA analysis (Yan and Hunt, 1998), and the most effective model to explore the GXE interaction with a minimum number of degrees of freedom (Ramagosa and Fox, 1993). Over 90% of the total sum of squares is explained by an AMMI biplot with main effects plotted against the IPCA1. IPCA1 value of close to zero indicates that the genotypes have general adaptation to the tested environments (Ramagosa and Fox, 1993), and are the most stable genotypes (Yan and Hunt, 1998). IPCA1 scores of larger value depict specific adaptation to environments having similar IPCA1 score sign. Environments were reported to have little interaction with the genotypes when the IPCA1 scores are small and vice versa (Yan and hunt, 1998). These authors also reported that, the biplot of IPCA1 versus IPCA 2 explains only a small portion of the total variation, and genotypes that are far from the origin are reported to be responsive. In this biplot the two axis partition the plot into four sectors, and genotypes that occur in the same sector interact positively; while those occurring in the opposite sector interact negatively (Yan and Hunt, 1998). The 36 soybean genotypes used in this study had not been previously evaluated for their response to varying P regimes, on acidic soils. Therefore, the objectives of this study were to understand the GXPXL interactions of soybean genotypes, and especially to identify genotypes that are low P tolerant and responsive to high P applications. This was done with the aid of the AMMI model. Analytical tools, such as Genotype X Environment interaction and Additive Main Effect and Multiplicative Interaction (AMMI) model have been employed to interpret large genotype x environment x replicate tables without missing values (Crossa *et al*., 1991; Romagosa and Fox, 1993).

6.3 Materials and methods

6.3.1 Experimental sites, designs, and management

The study was conducted at three locations in Western Ethiopia, namely Jimma, Mettu, and Assosa (Table 6.3-1). The three sites are characterized by strong to moderate acidic soil and low P availability (Table 6.3-2).

A total of 36 genetically diverse soybean genotypes were used in the study. A split plot design, where levels of P were the main plots and genotypes were subplots, was used for the experiment. Three levels of P i.e., 0, 100, and 200 kg ha^{-1} P, representing low, medium, and high levels, respectively. Triple super phosphate (TSP) was used as the source of P. The 36 genotypes within each of the main plots were laid-out in a 6X6 lattice design with two replications. The seeds of all genotypes were uniformly dressed with Rhizobium bacteria, and no commercial N-fertilizer was applied.

In the statistical analysis of split-plot designs, it is important to take into account the presence of two different sizes of experimental units used to test the effect of whole plot treatment and split-plot treatment. Factor A effects are estimated using the whole plots and factor B and the A*B interaction effects are estimated using the split plots. Since the size of whole plot and split plots are different, they have different precisions.

Therefore, the linear statistical model for split plot design experiment conducted across locations is given by:

$$y_{ijk} = \mu + \alpha_i + \beta_j + \tau_k + (\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\tau\alpha\beta)_{ijk} + \varepsilon_{ijk}$$

Where, $i = 1,2,\ldots,r, j = 1,2,\ldots,a, k = 1,2,\ldots,b$; α_i, and β_j represent the main plot and subplot, respectively; τ_k represents the location and $(\alpha\beta)_{ij} + (\alpha\tau)_{ik} + (\beta\tau)_{jk} + (\tau\alpha\beta)_{ijk}$ represents main plot X subplot, main plot X location, subplot X location, and main plot X subplot X location interactions, respectively.

Table 6.3-1 Agro-ecological characteristics of Jimma Assossa and Mettu experimental sites

Testing Location	AEZ	Altitude (masl)	Location	Annual mean RF	Annual mean Temperature		Soil type
					Min	Max	
Jimma	H_2	1750	$7^0$46'N 36^0E	1754	11	26	Reddish brown
Mettu	H_2	1550	$8^0$3' N 30^0E	1835	12	27	Dark red brown
Assosa	Hot to warm sub-humid lowlands	1550	NA	1056.2	12.4	27.8	Reddish brown

H_{2-} Tepid to cool humid mid highlands, RF=rainfall,
AEZ= agro-ecological zone according to EIAR classification; NA=Not available

Table 6.3-2 Soil analysis results for soil samples collected from the plots before the experiment at Jimma, Assossa and Mettu sites

No.	Location	K (ppm)	% N	% OC	% OM	P (ppm)	pH (H_2O)	Exchangeable Acidity (meq/ 100g soil	Al (meq/ 100g soil	H (meq/ 100g soil
1	Jimma	5	0.14	1.73	2.98	2.96	5.35	0.24	0	0.24
2	Jimma	55	0.13	1.99	3.43	4.77	5.34	0.24	0	0.24
3	Jimma	10	0.14	1.79	3.08	6.96	5.68	0.08	0	0.08
4	Assossa	10	0.13	2.19	3.77	4.90	4.92	0.24	0	0.24
5	Assossa	5	0.12	2.33	4.02	5.28	5.5	0.24	0	0.24
6	Assossa	5	0.12	2.02	3.48	3.35	4.5	1.68	0.08	1.6
7	Mettu	20	0.28	2.30	3.97	1.80	5.11	1.52	0.8	0.72
8	Mettu	15	0.28	2.62	4.52	2.84	4.86	0.72	0.32	0.4
9	Mettu	20	0.26	2.82	4.87	1.16	4.5	2.48	1.28	1.2

6.3.2 Laboratory analysis

Soil samples from the experimental plots were collected from the plough layer (0-20 cm) before the experiments. Three samples were collected from each location and analysed for nutrient content according to various procedures described in Sahlemedin and Taye (2000): soil P using Bray II method, N using Kjeldhal method, K using flame photometry, organic carbon (OC) and organic matter (OM) using Walkley and Black method. In-addition, the procedures described in Sahlemedin and Taye (2000) were used to analyze pH and exchangeable acidity, Al and H. Data on yield and related traits were collected at maturity.

6.3.3 Statistical analysis

Data collected in the experiment were analysed using SAS Statistical Software package (SAS Institute, 2008). Test of homogeneity of error variances of the locations was made before combined analysis. The combined analysis of GXL, GXP, and GXLXP was analyzed using SAS, split plot analysis program. Square root transformation was performed for count data such as number of seeds per pod and pod number, as suggested by Gomez and Gomez (1984). AMMI analysis was used to examine the response of genotypes to the varying levels of P. Mean separation was done using LSD at 5% level of probability.

6.4 Results

6.4.1 Response of genotypes to different P regimes in each location

Genotypes showed highly significant differences for all the traits studied, except for pod number at Jimma (Table 6.4-1). The P main effects and G X P interactions were non-significant for all the traits at Jimma. At Assossa, the genotypes showed highly significant differences for all the traits, except for days to flowering. The P main effects also showed significant differences at ($P<0.05$) level of significance for 100 seed weight and days to flowering. The GXP interaction effects were significant at ($P<0.05$) level of significance for grain yield, 100 seed weight, days to flowering, days to maturity, and pod length at Assossa.

At Mettu, the genotypes were significantly different at (P<0.01) level of significance for all the traits, except for number of seeds per pod, pod length and pod number. It was only days to maturity that showed highly significant GXP interactions at Mettu.

6.4.2 Response of genotypes to different P regimes over locations

The homogeneity test revealed that there was no significant difference among the error variances for all the traits; therefore, results from the combined analysis of variance are reported (Table 6.4-2). The genotypes showed highly significant differences for grain yield, days to flowering, days to maturity, fresh biomass and plant height; and significant difference for pod length and pod number. The genotype X P-levels (GXP) interaction was significant only for 100-seed weight; while all the traits showed highly significant genotype X location (GXL) interactions, except for fresh biomass weight, number of seeds per pod and pod number.

Table 6.4-1 Mean squares of genotypes, levels of phosphorus (P), and genotype X phosphorus (GXP) interaction for each of the three locations i.e., Jimma, Assosa and Mettu

Traits	Jimma		Assossa		Mettu	
	G	G X P	G	GXP	G	GX P
Grain yield (kg ha^{-1})	750846**	75615ns	235445**	86523*	295002**	132696ns
100-seed weight (gm)	24.14**	2.102ns	36.919**	1.564*	19.54**	3.51ns
Days to flowering	106.55**	5.21ns	13.89ns	23.59*	59.49**	15.12ns
Days to maturity	174.27**	4.7ns	19.20**	5.32*	92.85**	18.2**
Fresh biomass (gm/plant)	39190**	7771ns	11200**	3220ns	28238**	11754ns
¥Number of seeds per pod	0.0137**	0.0069ns	0.0167**	0.00945ns	0.0066ns	0.0062ns
Plant height (cm)	841.22**	36.47ns	232.42**	12.73ns	451.97**	67.55ns
Pod length (cm)	0.685**	0.0743ns	0.8895**	0.1015*	0.276ns	0.211ns
¥Pod number	1.794ns	0.798ns	0.965**	0.342ns	1.299ns	0.741ns

¥Mean squares are based on square root transformation, *=significant at (P<0.05), **= significant at (P<0.01)

Table 6.4-2 Mean squares for P levels, genotypes, and locations and their interactions for the combined analysis across three locations i.e., Jimma, Mettu and Assossa

Traits	Genotypes	P-Levels X Genotypes	Location X Genotypes	Location X P-levels X genotypes
Grain yield (kg ha^{-1})	513333**	91490ns	391218**	95974ns
100-seeds weight (gm)	68.66**	3.02*	5.97**	2.08ns
Days to 50% flowering	37.5**	12.97ns	56.26**	12.24ns
Days to maturity	75.29**	11.20ns	66.86**	13.1ns
Fresh biomass (gm/plant)	21993**	9257ns	16505ns	9748ns
¥Number of seeds/pod	0.0074ns	0.0059ns	0.012n	0.00776ns
Plant height (cm)	467.4**	64.22ns	292.9**	88.53ns
Pod length (cm)	0.3179*	0.1321ns	0.381**	0.173ns
¥Pod number	1.18*	0.646ns	0.788ns	0.758ns

¥Mean squares are based on square root transformation, *=significant at (P<0.05), **= significant at (P<0.01)

6.4.3 Performance of genotypes in each location

The high yielding genotypes at 200 kg ha^{-1} P level at Assossa were Essex-1, IAC-11, AGS-3-1, HS 82-2136 and Tunia (Table 6.4-3). At 100 kg ha^{-1} P level, several genotypes i.e., IAC-11, AGS-7-1, Alamo, Hardee-1, HS 82-2136, Essex-1, Clark-63-K, PR-142 (26), SR-4-1, AA-42-52, AA-7138, and PR-143 (14) were statistically at par with the top yielding genotypes at the rate of 200 kg ha^{-1}. Genotypes IAC 11, AA-7138, G 9945, and AGS-7-1 produced the highest grain yield at zero level of P, and were among the top performing genotypes across the different P levels. The performance of genotypes AA-7138, G-9945, and H16 was relatively higher at zero level of P compared to their performance at 100 and 200 kg ha^{-1} of P. Essex-1, and IAC-11 showed increasing performance with increasing P level. Three genotypes i.e., IAC 6, Ocepara-4, and Protana-2 produced nearly stable performance across the three levels of P. The performance of most genotypes at 200 kg ha^{-1} showed decline compared to their performance at 100 kg ha^{-1} P, even though the decline was significant only for two genotypes i.e., AGS 7-1 and SCS-1.

The 100-seed weight of Alamo, HS 82-2136, Ocepara-4 and SCS-1 was significantly higher at both 100 and 200 kg ha^{-1} P level than the control treatment; while PR-143 (14), AGS 217, AGS 3-1 and AGS 7-1 produced significantly higher weight of 100 seeds only at 100 kg ha^{-1} P as compared to the control (zero applied) P level (Table 6.4-4). Similarly, number of days to 50% flowering of SCS-1 and G-9945 was significantly higher at 100 kg ha^{-1} than the control P level. The increase in the P level from zero to both 100 and 200 kg ha^{-1} has resulted in significant increase of number of days required to the maturity of two genotypes IAC 11 and AA-42-52. Increasing the level of P from zero to 100 kg ha^{-1} significantly increased the number of days required to the maturity of genotypes PR 142 (26), and H3; while significantly reducing the maturity of AGS-234.

Table 6.4-3 Mean grain yield values of 36 soybean genotypes evaluated at each of the three levels of P i.e., 0, 100 and 200 kg ha^{-1} at Assossa

	Grain yield kg ha^{-1}		
Genotypes	0	100	200
1. Davis	704	1080	1026
2. Tunia	1087	1108	1466
3. PR-142 (26)	1418	1538	1382
4. IAC 11	1604	1783	1881
5. Alamo	1058	1715	1384
6. FB1-7636	1014	1262	1297
7. PR-143 (14)	1386	1484	1039
8. AGS 217	977	1200	1243
9. HS 82-2136	1335	1660	1498
10. AA-7138	1600	1517	1308
11. IAC 73-5115	958	1056	809
12. AA-42-52	1145	1533	1325
13. AGS 234	885	1412	970
14. Coker 240	1192	1006	600
15. AGS-3-1	1136	1313	1549
16. Essex-1	1249	1613	1920
17. Hardee-1	803	1674	1282
18. Bossire-2	1337	1030	1312
19. AGS-7-1	1514	1747	925
20. TGX-297-6E-1	1144	1043	1081
21. AGS-62	989	1151	676
22. Protana 2	1265	1115	1314
23. H 16	1348	1222	1058
24. H 3	1258	1790	1269
25. H 6	1005	1062	1322
26. Ocepara 4	1065	1153	1130
27. SCS-1	879	1414	705
28. Clark 63-K	1121	1559	1109
29. G 9945	1563	1227	1369
30. JSL 1	667	1315	1123
31. SR-4-3	1047	1365	976
32. IAC 6	1363	1321	1394
33. H 7	923	1157	974
34. PR-162-11	899	1168	1060
35. OC-78503	870	1377	978
36. SR-4-1	797	1535	1264
Mean	1128	1353	1195
Level of significance	*		
LSD 5%	486.6		
CV %	19.7		

Table 6.4-4 Mean values of 36 soybean genotypes for some yield related traits evaluated at each of the three levels of P i.e., 0, 100 and 200 kg ha^{-1} at Assossa

	100 seed weight (gm)			Days to flowering			Days to maturity			Pod length (cm)		
Genotypes	0	100	200	0	100	200	0	100	200	0	100	200
1. Davis	16.5	15.5	14.0	46	44	45	114	115	116	3.5	3.6	3.6
2. Tunia	14.0	15.5	15.0	47	44	53	115	115	115	3.5	3.7	3.8
3. PR-142 (26)	19.5	20.5	19.5	52	48	47	118	123	121	4.5	4.4	4.4
4. IAC 11	16.0	16.5	18.0	48	55	44	116	121	122	4.1	4.0	4.1
5. Alamo	14.5	20.5	19.0	45	44	51	115	115	116	3.8	3.6	4.0
6. FB1-7636	13.0	14.0	14.0	44	51	44	115	115	116	4.0	3.9	4.1
7. PR-143 (14)	14.0	17.0	15.5	46	47	45	118	115	116	3.7	4.0	4.0
8. AGS 217	13.5	17.0	15.0	43	47	46	117	115	115	4.1	3.3	3.7
9. HS 82-2136	13.0	15.5	14.0	50	49	48	118	115	116	3.1	3.3	3.3
10. AA-7138	14.5	16.5	15.5	50	52	43	117	115	116	4.4	4.2	4.4
11. IAC 73-5115	12.5	13.0	12.5	47	48	43	114	115	116	3.5	4.1	4.1
12. AA-42-52	16.0	16.5	15.5	46	45	49	117	125	125	4.4	4.1	4.5
13. AGS 234	13.0	14.0	15.0	46	51	45	120	115	116	3.3	3.1	2.8
14. Coker 240	13.0	14.0	14.5	44	45	44	114	115	116	3.7	3.6	3.2
15. AGS-3-1	15.0	17.5	16.0	44	54	45	115	115	116	3.4	3.7	3.7
16. Essex-1	18.0	20.0	18.5	45	53	44	121	122	116	3.8	4.1	3.7
17. Hardee-1	14.0	16.0	16.0	46	51	44	114	115	115	3.4	4.0	4.0
18. Bossire-2	16.0	17.5	16.5	47	55	44	118	115	116	4.4	4.2	4.1
19. AGS-7-1	17.0	19.5	19.0	48	44	45	115	115	116	4.0	4.1	4.5
20. TGX-297-6E-1	12.5	13.0	14.5	48	51	50	114	115	116	3.9	4.2	3.9
21. AGS-62	13.5	14.0	12.5	48	48	42	115	115	116	3.9	3.6	3.7
22. Protana 2	18.5	20.0	21.0	46	49	50	114	115	116	3.7	4.4	3.9
23. H 16	17.0	19.0	17.5	54	47	47	115	115	116	4.1	3.8	3.9
24. H 3	13.5	14.0	13.5	44	48	49	117	122	116	3.8	3.6	3.9
25. H 6	20.0	21.5	21.0	44	52	44	114	115	116	5.2	4.6	4.8
26. Ocepara 4	15.5	19.5	18.5	46	51	49	117	115	116	4.0	3.7	4.1
27. SCS-1	16.5	19.5	20.0	44	53	50	119	115	116	3.5	3.9	3.7
28. Clark 63-K	14.0	16.0	16.0	47	50	43	114	115	116	4.0	4.1	4.3
29. G 9945	19.5	21.5	20.5	44	53	43	115	115	116	4.4	4.4	4.2
30. JSL 1	17.5	19.0	18.5	45	46	50	114	115	116	3.3	3.7	3.9
31. SR-4-3	14.5	18.0	19.0	45	49	50	114	115	116	4.0	4.2	3.7
32. IAC 6	21.0	21.5	21.0	47	47	53	117	115	116	5.1	4.5	4.7
33. H 7	15.5	17.5	18.0	50	44	47	119	115	116	4.0	4.0	4.4
34. PR-162-11	12.0	13.0	11.5	42	50	44	115	115	116	3.7	4.1	3.8
35. OC-78503	12.5	15.5	13.5	53	48	51	118	115	116	3.2	3.2	3.2
36. SR-4-1	18.0	19.0	20.0	54	46	45	115	115	116	3.3	4.0	3.9
Mean	15.4	17.2	16.7	47	49	46	116	116	116	3.86	3.9	3.92
Level of significance	*			*			*			*		
LSD 5%	2.04			8			4			0.523		
CV %	6.1			8.3			1.6			6.7		

6.4.4 AMMI analysis

The IPCA1 versus the P-levels main effects that accounted for 31% of the total treatment sum of squares (Table 6.4-5) bi-plot revealed that zero and 200 kg ha^{-1}

P showed relatively higher IPCA1 scores of opposite sign (Figure 6.4-1). The bi-plot of IPCA1 scores versus the genotype and P levels main effects accounted for more than 80.1% of the total treatment sum of squares. The IPCA1 score of 100 kg ha^{-1} P level was small and close to zero. The main effect of 100 kg ha^{-1} P level was the highest; while the main effect of 200 kg ha^{-1} was close to average. Zero P-level showed the lowest main effect (Figure 6.4-2). Genotypes, Clark 63 K, Bossire-2 and Protana-2 showed nearly average main effect and very small IPCA scores. Genotypes IAC 6 and AA 42-52 produced IPCA1 score of close to zero and with above average main effect. The highest main effects with relatively small IPCA scores were produced by genotypes AA-7138, PR-142 (26) and H3. There was no genotype with exceptionally high IPCA1 score closer to the IPCA 1 score of 200 kg ha^{-1} of P. However, AGS-3-1, Hardee-1, Tunia and SR-4-1 are the genotypes with relatively high negative IPCA1 scores and high main effects.

Table 6.4-5 Analysis of variance for the GXP interaction using the AMMI model for Assossa site

Source	Df	SS	MS	F	F Probability	% variation
Total	215	24479010	113856	*	*	
Treatments	107	16218039	151570	2.59	0.000	
Genotypes	35	8240589	235445	4.03	0.000	50.8
P levels	2	1920824	960412	1.36	0.262	11.8
Block	3	2126033	708678	12.13	0.000	13.1
Interactions	70	6056626	86523	1.48	0.034	37.3
IPCA 1	36	3098705	86075	1.47	0.067	19.1
IPCA 2	34	2957921	86998	1.49	0.065	18.2
Error	105	6134938	58428			

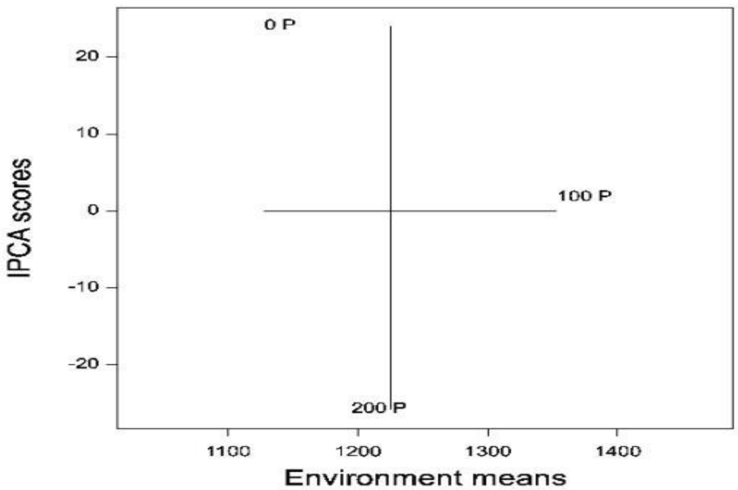

Figure 6.4-1 The IPCA1 scores of P levels versus the P levels main effect for Assossa site

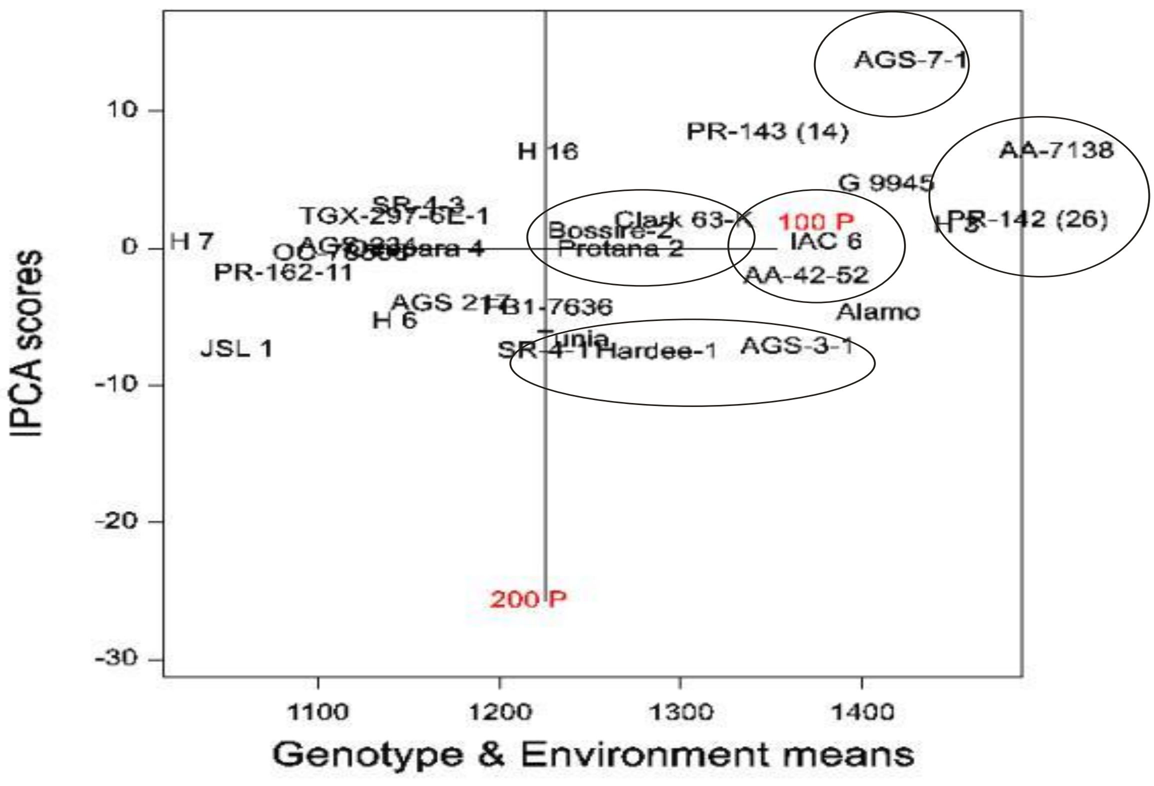

Figure 6.4-2 The bi-plot of IPCA1 scores of genotypes and P levels versus the main effects of genotypes and P levels main effect for Assossa site

6.4.5 Performance of genotypes over-locations

The across locations analysis revealed that genotypes AGS-7-1, G-9945 and SCS-1 were the highest yielding (Table 6.4-6). Genotypes Hardee 1, Davis, H 7, AGS-3-1, Alamo, Essex-1, Cocker 240, H 3, Tunia, Protana-2, H 16, AGS 62, and FB1-7636, were also the highest yielding. Genotypes G-9945, Protana-2, and AGS-7-1 were among the highest yielding genotypes that also produced the highest weight of 100-seeds. Essex-1 and Tunia were late maturing genotypes, while Cocker 240, AGS 62, and Protana 2 were early maturing.

Table 6.4-6 Mean performance of soybean genotypes over three locations i.e., Jimma, Assossa and Mettu, and three levels of P

Genotypes	100-seed weight (gm)	Days to flowering	Days to maturity	Fresh biomass Weight (gm)	Pod number	¥Pod number	Pod length (cm)	Number of seeds per pod	Plant Height (cm)	GYLD kg ha^{-1}
1. Davis	16.66	62	127	213.92	37.97	(6.01)	4.22	2.60	48.61	1684.46
2. Tunia	15.81	63	129	285.68	40.64	(6.08)	4.14	2.56	65.04	1617.63
3. PR-142 (26)	18.26	66	131	294.89	32.76	(5.61)	4.36	2.48	63.26	1146.57
4. IAC 11	16.34	66	130	320.19	42.83	(6.33)	4.24	2.63	61.77	1478.13
5. Alamo	17.74	63	126	217.39	36.84	(5.86)	4.10	2.57	57.48	1641.69
6. FB1-7636	13.94	63	125	225.8	39.79	(6.09)	4.27	2.59	47.67	1585.37
7. PR-143 (14)	15.53	64	129	231.21	39.91	(6.09)	4.29	2.67	52.85	1554.20
8. AGS-217	14.96	65	128	286.31	39.99	(6.14)	4.19	2.60	54.07	1411.38
9. HS 82-2136	13.59	64	126	230.82	38.69	(6.02)	3.82	2.54	58.26	1533.38
10. AA-7138	14.71	66	129	238.22	37.16	(5.94)	4.19	2.58	55.29	1411.3
11. IAC 73-5115	13.02	63	124	200.66	33.73	(5.62)	4.07	2.56	43.89	1340.37
12. AA-42-52	14.65	65	131	270.56	36.64	(5.82)	4.14	2.53	56.04	990.32
13. AGS 234	14.50	61	124	240.89	42.88	(6.34)	4.16	2.60	58.71	1572.38
14. Coker 240	15.21	63	123	209.91	41.58	(6.17)	4.11	2.66	46.89	1628.41
15. AGS-3-1	16.90	64	126	256.03	43.63	(6.36)	4.26	2.53	54.29	1671.29
16. Essex-1	17.53	65	130	291.26	39.99	(6.07)	4.20	2.58	54.22	1630.87
17. Hardee-1	15.87	62	126	251.88	40.29	(6.11)	4.19	2.64	59.21	1699.25
18. Bossire-2	15.40	65	126	260.95	42.11	(6.27)	4.29	2.69	47.47	1455.24
19. AGS-7-1	18.56	62	126	248.08	39.6	(6.07)	4.22	2.58	58.55	1911.86
20. TGX-297-6E-1	13.63	63	124	201.19	38.67	(6.03)	4.19	2.64	47.92	1539.69
21. AGS-62	14.66	62	123	170.45	32.99	(5.56)	4.05	2.49	45.13	1596.76
22. Protana 2	19.59	62	124	221.69	36.81	(5.87)	4.41	2.52	55.51	1601.99
23. H 16	17.19	63	126	266.68	39.72	(6.09)	4.48	2.70	48.83	1598.44
24. H 3	14.17	65	128	309.46	47.93	(6.62)	4.22	2.66	58.51	1627.66
25. H 6	19.18	65	127	272.21	37.59	(5.94)	4.39	2.46	52.93	1468.48
26. Ocepara 4	17.26	62	127	280.37	40.79	(6.11)	4.27	2.64	50.12	1550.95
27. SCS-1	17.08	66	127	280.92	42.20	(6.31)	4.02	2.61	55.08	1721.89
28. Clark 63-K	15.27	64	129	261.23	38.94	(6.04)	4.29	2.64	53.74	1566.67
29. G 9945	20.01	62	127	206.37	33.95	(5.68)	4.31	2.52	50.15	1792.06
30. JSL 1	16.52	64	127	236.76	35.51	(5.77)	4.08	2.52	50.59	1480.83
31. SR-4-3	16.82	64	126	234.93	39.24	(6.06)	4.15	2.56	54.57	1443.39
32. IAC 6	19.87	62	127	267.08	35.71	(5.78)	4.52	2.57	55.55	1490.63
33. H 7	17.27	65	126	306.74	45.76	(6.35)	4.23	2.50	56.43	1679.26
34. PR-162-11	13.18	64	127	275.06	43.38	(6.32)	4.33	2.70	49.83	1351.24
35. OC-78503	13.96	65	127	281.69	46.49	(6.5)	4.14	2.62	56.37	1384.43
36. SR-4-1	18.31	65	125	250.23	45.08	(6.43)	4.16	2.52	59.31	1532.82
Mean	16.20	63.73	126.69	252.71	39.66	(6.07)	4.21	2.58	54.00	1538.65
Level of significance	**	**	**	**	*	*	*	ns	**	**
LSD 5%	1.799	5.011	4.63	122.47	15.99	(1.15)	0.561	---	10.54	337.14

¥ values are based on square root transformation

6.5 Discussion

The results showed highly significant differences for most of the traits studied indicating that there is sufficient variation among the soybean genotypes for further genetic improvement (Tables 6.4-1 and 6.4-2). These results were in agreement with the report of Chiezey and Odunze (2009). The P-levels did not show significant difference for all the traits at Jimma, which is in-agreement with the report of Payne *et al*. (1986); while the P levels were significantly different for

100 seed weight and days to flowering at Assossa. The P levels were also significantly different for grain yield, days to flowering, fresh biomass weight, plant height, and pod number at Mettu, which is in-agreement with the report of Chiezey and Odunze (2009).

The fact that genotypes IAC 6 and AA 42-52 produced IPCA1 score of close to zero and with above average main effect indicates that these genotypes are relatively stable across the different P levels with above average performance. Similarly, the highest main effect with relatively small IPCA scores of genotypes AA-7138, PR-142 (26) and H3 reflects the relative stable and high performance of these genotypes.

The difference for P response in each location can be justified by the relatively high P and pH at Jimma, and vice versa at Assossa and Mettu (Table 6.3-2). The absence of significant genotype x P level interaction for all the traits at Jimma, and most of the traits at Mettu and Assossa indicates that there is very limited change in the relative performance of genotypes with changing P level. The genotype X P interaction was significant for grain yield, 100 seed weight, days to flowering, days to maturity and pod length at Assossa, and days to maturity at Mettu. This validates the need to conduct such variety evaluation trials across locations. Thus, the relative performance of genotypes in each of the three levels of P for grain yield was determined based on Assossa data.

6.6 Conclusions and implications

1) Although, it was only at one location, the significant genotype X P interaction for grain yield, signify the existence of differential response of genotypes to varying P levels. This also indicates the possibility of identifying low P tolerant and high P responsive genotypes.

2) The significant genotypic difference for most of the studied traits also indicates the existence of sufficient variation among the genotypes for improvement.

3) Genotypes Essex-1, IAC 11 and AGS-3-1 showed best overall performance; while IAC 11, AA-7138, G 9945 and AGS-7-1 were tolerant to low-P. Genotypes AA-7138, PR-142 (26) and H3 were stable across the different P levels.

4) In general, the varieties identified for different desirable responses to P, will have much significance in breeding programs to improve soybean.

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CHAPTER 7

Combining ability of soybean genotypes for selected agronomic traits under low and high phosphorus conditions on acidic soils

7.1 Abstract

Knowledge of the type of gene action governing the traits in a segregating population of soybean (*Glycine max* L.) is important for devising the breeding strategy. This study was undertaken to determine gene action for selected agronomic traits in a nine-parent half-diallel cross. The experiment was laid-out as an alpha lattice design with two levels of phosphorus and two replications across two sites in Western Ethiopia, which are characterized by acidic soils. Results indicated that GCA effects were highly significant for grain yield, pod length, days to maturity and plant height under low-P conditions. Under high-P conditions, GCA effects were highly significant for grain yield, 100-seed weight, days to maturity, plant height and pod number, pod length, and significant for number seeds per pod. Relative contribution of GCA was higher than SCA for pod length, under low P, and plant height under high P conditions. Generally, productivity under low P was low, ranging between 700 and 2600 kg ha^{-1}. In sharp contrast, yield ranged significantly from 1600 to 3700 kg ha^{-1} under P application. Genotype “Hardee-1” was the best general combiner for yield and some of yield related agronomic traits under both low and high P conditions; qualifying it as a suitable candidate for use in breeding new varieties which are adapted to the low input environments. Overall, the results suggest that additive gene action was important for several of the studied traits implied by significant GCA effect, indicating that selection for this trait could be effective in later segregating generations. However, observation of significant GCA X environment interaction effects, especially for grain yield ($P<0.01$) indicates some possible challenges.

Keywords: Soybean, GCA, SCA, P stress tolerance, selection

7.2 Introduction

Soybean production on small scale and subsistence farmer's fields in developing countries encounters several constraints that compromise productivity. The production constraints are partly attributed to the lack of capital to invest in basic inputs such as fertilizer. Soil acidity associated soil fertility problem is one of the most important soybean production constraints in several countries, for example in Western Ethiopia (Tesfaye *et al*., 2011), where most soils are characterized by moderate to strong acidity (van Straaten, 2002).

Soil acidity is a worldwide phenomenon occurring on more than half of the world arable land (von Uexku¨ ll and Mutert, 1995). It prevails in wider areas of the humid tropics and subtropics (Van Wambeke, 1976). It is not the hydrogen ion activity of the soil *per se*, but rather the toxic level of aluminum and manganese, and insufficient availability of phosphorus, nitrogen, potassium, calcium, magnesium, sulfur, zinc and molybdenum that limit productivity of crops on acidic soils (Rao *et al*., 1993). The insufficient availability of phosphorus on acidic soils has been attributed to high concentration of aluminum which converts it into unavailable form.

Phosphorus is one of the most important plant nutrients, and is required in large quantities next to nitrogen (Lambers and Shane, 2007). It comprises of 0.2 % of plant dry weight (Schachtman *et al*., 1998), ranging from 0.05 to 0.5% (Vance *et al*., 2003). However, P is one of the least available plant nutrients, and deficient on many soils of the world (Bieleski, 1973). The land which is affected by P deficiency is estimated to be greater than two billion hectares (Shenoy and Kalagudi, 2005). Though the total phosphorus in the soil is usually 100-fold higher than available P (Al-Abbas and Barber, 1964), and more than 80% is immobile and is not available to plants (Schachtman *et al*., 1998). The global P reserve is tending to deplete (Lynch and Beebe, 1995; Lambers and Shane, 2007) with consequences for soybean productivity. It is indicated in the literature that the yield loss due to low P availability reaches 5-15% (Shenoy and Kalagudi, 2005). Amending such P deficiency through increased application of inorganic fertilizer is not economical and is not an environmentally safe option. Only 10% of the applied fertilizer can be efficiently utilized by the plant (Schachtman *et al*., 1998; Shenoy and Kalagudi, 2005), 80-90% of the applied fertilizer will be converted to unavailable form by soil particles (Parfitt, 1979; Jones, 1998). This quadruples the fertilizer requirement of farmers for crop production (Goldstein, 1992) which present challenges to the smallholder farming sector in developing countries. Predominantly soybean producing subsistence farmers reported high fertilizer prices as the number one reason for less fertilizer use (Tesfaye *et al*., 2011) and fertilizer prices are expected to increase (Lambers and Shane, 2007). This along with low purchasing capacity of subsistence farmers makes inorganic fertilizers inaccessible to farmers. On the other hand, excess use of P fertilizers in agricultural farms has undesirable effects on the environment. It negatively affects water quality through eutrophication i.e., increased fertility of the natural water that promotes the growth of algae in the water (Mullins, 2001).

Although application of lime is another option to amend soil acidity, and improve availability of applied fertilizer, the high quantity and price of lime, and the technical and economical difficulty to amend the subsoil with lime makes it a less feasible option for resource poor farmers (Rao *et al*., 1993). Thus, the development of soybean varieties that can respond better to low soil P condition should be incorporated in breeding programmes. Lambers and Shane (2007) also emphasized the urgency of developing crop varieties that are efficient in P acquisition and utilization.

Availability of genetic variation is crucial for success in any breeding programme. Therefore, large genetic differences among soybean genotypes for the uptake, use and utilization efficiency of P is required. Furlani *et al*. (2001, 2002) reported sufficient genetic variation in soybean genotypes for P uptake and use efficiency. Such genetic variation can be exploited further through employing different breeding procedures. However, selection of breeding strategy is best achieved by determining the nature of gene action that control inheritance of various adaptive traits. The gene effects that govern these traits, especially under acidic soils have not been quantified.

Genetic analysis of soybean under varying P regimes provides very useful information that helps to devise a viable breeding strategy. Based on diallel analysis, Spehar (1995) reported quantitative inheritance that is explained by the additive-dominance model for the response of soybean to plant mineral nutrient absorption. The general (GCA) and specific combining ability (SCA) effects and their interaction with the environment provide relevant information, which can be used to identify the best parents to initiate pedigree crosses. Significant GCA, SCA, GCA X Location and SCA X Location effects have been reported for seed yield in soybean (Lopes *et al*., 2001). Spehar (1995) also reported higher GCA for P uptake indicating that additive gene effects were influential. The significance of GCA variance suggests the possibility of employing selection to improve soybean varieties for efficient utilization of P.

Literature on the combining ability of soybean under low and high P conditions was not found, indicating that this study might be the first of its kind. Nonetheless, some work has been conducted on other leguminous crops under tropical conditions. Kimani and Derera (2009) reported highly significant GCA effects that indicated the importance of additive effects. Further they reported a significant role of genotype x environment effects such as GCA X Environment and SCA X Environment interaction effects in conditioning the response of dry bean varieties to P. However, such studies have not been conducted on acidic soils especially for soybean. Therefore, this study was designed to assess the combining ability of soybean lines for quantitative traits under low and high P conditions on acidic soils.

7.3 Materials and methods

7.3.1 Germplasm

The parental lines included: three released varieties (Clark 63 K, Crowford, and Davis), one variety SCS-1,that was in the pipeline for release, and five genotypes (Hardee-1, Alamo, PR-142 (26), H 3, and G 9945) that were selected from a screening experiment involving 36 soybean lines evaluated under low, medium and high P conditions. These genotypes were selected based on their superior performance under low and high P conditions. SCS-1 was obtained from CIMMYT along with other nitrogen fixing legumes for the purpose of green manure research at Jimma Agricultural Research Center. H 3 was introduced from Mozambique Agricultural Research Institute, which was specifically selected for its performance under low P condition; while all the other parents existed in the country for more than two decades, having been introduced from different international research institutions, such as INTSOY and IITA. No documentation was available on the history of their introduction. The nine parental lines were crossed manually in a 9 X 9 half diallel mating scheme. The diallel experiment was conducted using F3 progenies, due to inadequate quantities of seeds obtained in the F1 and F2 generations.

7.3.2 Experimental design and management

Soybean genotypes were evaluated at Assossa (alt. 1550 ma.s.l, location 10^{0}02'N34^{0}33'E), and Metu (alt. 1550 m.a.s.l., location 8^{0}3' N 30^{0}E) in Western Ethiopia. The locations are characterized by acidic soils. The two experimental sites are characterized by reddish brown soil with strong to moderate acidity, and low P availability (Table 7.3-1). The trials were designed as a two factor experiment consisting of 45 entries and two levels of P (zero and 100 kg ha^{-1} applied P), representing low and high P conditions. Phosphorus fertilization was applied as a triple super phosphate (TSP) fertilizer that contains 45% P_2O_5

(which translates to 20% P). The experiments were laid out as 5 X 9 alpha lattice designs with two replications.

The seeds of all genotypes were uniformly dressed with Rhizobium bacteria, and no commercial N-fertilizer was applied. Soil samples were collected from the top layer (0-20 cm) of the fields, before the experiments were planted. Three samples were collected from each location and analyzed for nutrient content as described in Sahlemdhin and Taye (2000): soil P using Bray II method, N using Kjeldhal method, K using flame photometry, organic carbon (OC) and organic matter (OM) using Walkley and Black method. In-addition, the procedures described in Sahlemdhin and Taye (2000) were used to analyze pH and exchangeable acidity, Al and H. Data on grain yield and related agronomic traits (100-seed weight, number of seeds per pod, pod length, days to flowering, days to maturity, plant height and pod number) were collected at maturity.

Table 7.3-1 Results of soil sample analysis from the experimental plots collected before the experiment

Field sample code	pH (1:2.5 water)	% OC	% N	P (ppm)	K (ppm)	Exch. Al (meq/100 gm soil)	Exch. Aci. (meq/100 gm soil)	Exch. H+ (meq/100 gm soil)
Assosa 1	5.05	2.38	1.35	6.8	0.09	0.1	0.24	0.14
Assosa 2	4.95	2.42	1.2	5.8	0.12	0.16	0.39	0.23
Assosa 3	4.94	2.65	1.21	5.6	0.19	0.1	0.34	0.24
Mettu 1	4.07	2.49	2.19	8.2	0.59	4.39	6.11	1.72
Mettu 2	4.12	2.77	2.25	8.8	0.67	4.06	5.6	1.54
Mettu 3	4.23	2.61	2.27	8.2	0.62	3.73	5.07	1.34

7.3.3 Statistical analysis

Quantitative agronomic data were analysed using SAS Statistical Software (SAS Institute, 2008). Test of homogeneity of error variances of the locations was performed before the combined analysis was done. The combined analysis of Entries X Location for each P level was analyzed using Genstat version 12 software. The diallel analysis for Griffing's method two, model one was performed using the Diallel SAS 05 program (Zhang *et al*., 2005). Mean separation was done using LSD at 5% level of probability.

The statistical model for the Griffing's Diallel analysis Method 2 Model (Modified from Farshadfar et al. (2012)) is:

$$X_{ij} = \mu + g_i + gj + S_{ij} + L_k + (gL)_{ik} + (gL)_{jk} + (SL)_{ijk} + e_{ijk}/b$$

Where, μ = the population mean, g_i = the general combining ability effect of the i^{th} parent, g_j = the general combining ability effect of the j^{th} parent, s_{ij} = the specific combining ability effect of the cross between i^{th} and j^{th} parents such that $s_{ij} = s_{ji,}$ $(gL)_{ijk}$ = the interaction effect if general combining ability of i^{th} parent with K^{th} locations, $(gL)_{jk}$= the interaction effect of general combining ability of j^{th} parent with K^{th} locations, $(SL)_{ijk}$= the interaction effect of specific combining ability with locations, and e_{ijk} is the residual associated with ijk^{th} observation.

7.4 Results

7.4.1 Combining ability of selected agronomic traits under low P conditions

There were highly significant differences among genotypes for grain yield, pod length, and plant height and 100-seed weight, and significant differences for days to maturity, under low P condition (Table 7.4-1). The GCA effects showed highly significant differences only for grain yield, pod length, days to maturity and plant height. Specific combining ability showed highly significant differences for grain yield, 100-seed weight, pod length and plant height, and significant differences for days to maturity. The relative contribution of SCA was higher than GCA for all of the studied traits, except for pod length, and plant height. Both the GCA X Environment and SCA X Environment effects were highly significant for grain yield. In addition, the GCA X Environment effects were highly significant for plant height, and significant for pod length, days to flowering, and pod number.

7.4.2 General and specific combining abilities of parents and crosses under low P conditions

The GCA effect of Hardee-1 was highly significant and positive for number of seeds per pod, pod length, plant height, pod number, and significant for grain yield under low P condition (Table 7.4-2). The GCA effect of Davis was significant and negative for pod length. The GCA effects of H-3 were positive, and highly significant and significant, for pod length and plant height, respectively.

7.4.3 Combining ability variation under high P conditions

Under high P condition, the entries showed highly significant differences for 100-seed weight, plant height, pod length, and days to maturity, and significant for number of seeds per pod, and days to flowering (Table 7.4-1). The GCA effects of grain yield, 100-seed weight, days to maturity, plant height, pod number, pod length were highly significant; while number of seeds per pod showed significant GCA effect. There was highly significant difference among the SCA effects of 100-seed weight, and significant differences for number of seeds per pod and pod length. The relative contribution of SCA was higher than GCA, for all the traits, except for plant height, and days to maturity. GCA X E interactions were also highly significant for grain yield and 100-seed weight, and significant for plant height. The SCA X E interaction effects were significant only for 100-seed weight.

7.4.4 General combining abilities of parents under high P conditions

Under high P conditions, Hardee-1 displayed positive and highly significant GCA effects for pod length, plant height, grain yield and pod number, and significant for 100-seed weight (Table 7.4-2). The GCA effect of Davis was positive and significant for plant height. H 3 and Clark 63 K produced positive and significant GCA effects for plant height and number of seeds per pod, respectively. The GCA effect of SCS-1 was positive and highly significant for grain yield and significant for pod number. The GCA effect of G 9945 was significant, and positive and negative for 100-seed weight and plant height, respectively.

Table 7.4-1 Mean squares for selected agronomic traits in soybean diallel cross under high and low P conditions

Source of variation	Df	Traits							
		Grain yield (kg ha^{-1})	100-seed weight (gm)	Number of seeds per pod	Pod length (cm)	Days to flowering	Days to maturity	Plant height (cm)	Pod number
Analysis under low-P environments									
Environment (E)	1	17680435.11***	8.58	0.39	7.14***	6636.9***	20934.4***	4.92	2097.2***
Rep (E)	2	33519361.52***	94.88***	0.17	1.59***	93.9***	130.3***	1308.1***	2901.5***
Entries (Ent)	44	1319442.04***	4.97**	0.18	0.39***	6.1	8.1*	90.92***	73.7
Entries X E	44	132,0440.64***	3.31	0.11	0.12	8.5*	5.4	39.20	51.1
GCA	8	2355017.83***	4.59	0.25	1.33***	8.9	24.1***	261.9***	98.9
SCA	36	1284835.03***	5.00**	0.15	0.20**	5.7	8.3*	57.2**	69.8
GCA X E	8	219,9057.50***	4.40	0.09	0.25*	12.9*	2.1	99.0**	102.1*
SCA X E	36	1140196.38***	3.07	0.11	0.09	7.5	4.0	25.7	42.0
Relative contribution of GCA		29.77	16.96	26.49	59.74	25.92	14.63	50.42	23.95
Relative contribution of SCA		70.23	83.04	73.51	40.26	74.07	85.37	49.58	76.05
Analysis under high-P conditions									
Environment(E)	1	11187776.28***	0.73	0.60*	11.2***	6242.2***	20118.2***	27.6	1663.5***
Rep (E)	2	74364727.47***	16.9***	0.63*	3.01**	103.6***	108.4***	706.8***	3036.9***
Entries (Ent.)	44	41969520.42	6.3***	0.23*	0.92**	9.2*	9.2**	78.3***	86.7
Entries X Environment	44	43868869.40	3.9**	0.13	0.54	8.0	5.5	38.5	73.1
GCA	8	2784714.59***	10.0***	0.31*	1.7**	9.6	30.5***	288.9***	246.2***
SCA	36	571739.47	5.5***	0.21*	0.83*	8.5	6.9	41.0	60.4
GCA X E	8	1943,203.89**	7.3**	0.09	0.41	7.4	0.15	65.0*	50.6
SCA X E	36	842685.93	3.5*	0.14	0.60	8.0	0.77	35.1	79.3
Relative contribution of GCA		42.29	28.74	24.83	31.29	20.08	50.82	61.04	47.52
Relative contribution of SCA		57.71	71.26	75.17	68.71	79.92	49.18	38.96	52.47

* = significant at P<0.05 and **= significant at P<0.01, and ***= significant at 0.001

Table 7.4-2 GCA effects of parents for selected agronomic traits under high and low P conditions on acidic soils

***GCA effects of each parents* at low P**	**Traits**							
	Grain yield (kg ha^{-1})	Hundred seed weight (gm)	Number of seeds per pod	Pod length (cm)	Days to 50% flowering	Days to maturity	Plant height (cm)	Pod number
Hardee-1	454.68*	0.42	0.18***	0.30***	-0.04	0.78	4.96***	3.39**
Davis	268.25	-0.16	-0.05	-0.20**	-0.43	-0.72	1.47	0.37
Alamo	-320.85	-0.61*	-0.07	-0.28***	-0.15	-1.31	-3.69***	-2.07
Pr-142 (26)	-207.63	-0.18	0.02	-0.06	-0.04	-0.62	-1.19	-1.23
H-3	74.94	0.41	-0.03	0.19**	0.90	0.59	2.42*	0.44
Clark 63 K	-4.00	-0.22	-0.05	-0.03	0.29	0.84	-0.81	-0.20
SCS-1	38.27	0.14	0.07	0.09	0.35	0.64	-1.10	0.83
G-9945	101.91	0.24	-0.04	-0.04	-0.71	0.20	-0.80	-0.66
Crowford	-405.57*	-0.03	-0.03	0.03	-0.18	-0.41	-1.26	-0.86
***GCA effects of each parents* at high P**								
Hardee-1	424.52**	0.57*	0.07	0.40***	-0.02	1.05	4.85***	3.74**
Davis	-47.96	-0.45	0.01	-0.15	-0.50	-1.65	2.09*	1.04
Alamo	-321.37*	-0.85***	-0.09	-0.33**	0.23	-1.12	-4.22***	-3.40*
Pr-142 (26)	-31.45	0.30	0.05	0.14	-0.75	-0.04	-0.22	-1.24
H-3	-51.83	0.38	-0.08	0.06	0.89	0.60	2.07*	-1.47
Clark 63 K	-30.76	-0.28	0.12*	-0.03	0.003	0.35	-0.78	1.26
SCS-1	389.17**	-0.08	0.07	0.06	-0.16	0.66	-0.23	3.36*
G-9945	-1.40	0.60*	-0.01	0.001	-0.14	0.32	-1.91*	-1.77
Crowford	-328.93	-0.21	-0.15**	-0.14	0.45	-0.18	-1.65*	-1.53

* = significant at P< 0.05 and **= significant at P<0.01, and ***=significant at P<0.001

7.4-5 Average heterosis, and heterotic effects of each parents under low and high P conditions

The average heterosis under low P condition was non-significant for all the traits (Table 7.4-3). However, Hardee-1 produced positive and significant mean heterosis for grain yield, plant height, and highly significant heterosis for pod number. Alamo produced negative and highly significant heterosis for pod length. The average heterosis was highly significant for plant height under high-P condition (7.4-4). It was only Clark 63 K that produced positive and significant heterosis for plant height.

Table 7.4-3 Average heterosis and mean of the heterotic effects of each parents under low-P condition

Source	Grain Yield (kg ha^{-1})	Plant height (cm)	Pod number	Pod length (cm)
Average heterosis	-135.93	-0.36	-2.06	-0.01
Hardee-1	425.29*	2.99*	5.57**	0.17
Davis	122.61	-1.39	-0.39	-0.08
Alamo	-174.95	-2.46	-1.47	-0.32**
Pr-142 (26)	54.11	-0.58	0.22	0.13
H-3	120.29	4.10**	2.72	0.22
Clark 63 K	-1.49	0.47	-0.31	-0.03
SCS-1	-241.91	-0.29	-0.83	0.04
G-9945	-32.33	-1.26	-1.55	-0.02
Crowford	-271.62	-1.57	-3.96*	-0.11

* = significant at P< 0.05 and **= significant at P<0.01, and ***=significant at P<0.001

Table 7.4-4 Average heterosis and mean of the heterotic effects of each parents under high-P condition

Source	Grain yield (kg ha^{-1})	100-seed weight (gm)	Plant height (cm)	Pod number
Average heterosis	266.52	0.46	4.83**	1.65
Hardee-1	370.66	-0.08	1.90	3.37
Davis	158.41	-0.20	2.85	1.35
Alamo	-317.32	-0.82	-4.05*	-3.31
Pr-142 (26)	-185.98	-0.38	-0.37	-0.95
H-3	220.93	0.65	2.84	3.04
Clark 63 K	470.50	1.07*	0.62	2.63
SCS-1	-61.57	0.10	-0.53	1.55
G-9945	232.23	-0.96*	-1.10	-0.49
Crowford	-887.86*	0.62	-2.17	-7.18*

* = significant at P< 0.05 and **= significant at P<0.01, and ***=significant at P<0.001

7.4.6 Mean performances of parents and crosses under low P conditions

Except H-3, the yield performance of all the parents was statistically similar under low P condition (Table 7.4-5). However, the top four yielding parents were SCS-1, Hardee-1, Clark 63 K, and G-9945. The best yielding crosses were Hardee-1 X G-9945, Hardee-1 X Clark 63 K, Hardee-1 X Pr-142 (26), Davis X SCS-1, Hardee-1 X Alamo, and Hardee-1 X Davis, in the order of importance. Parents, Crowford, and SCS-1; and crosses Hardee-1 X G-9945, Hardee-1 X Pr-142 (26), Hardee-1 X Clark 63 K, Davis X SCS-1 and Hardee-1 X Alamo were the highest performing entries for pod number. Among the parents PR 142 (26) was the earliest to mature; while Davis X Pr-142 (26), Davis X Clark 63 K, Davis X Crowford, Davis X Alamo, Davis X SCS-1, and Alamo X Crowford were the crosses that matured earlier. Cross Alamo X Pr-142 (26) was, the latest maturing entry. All the parents, except Davis and Pr-142 (26) produced the long pods. Several crosses produced the longest pod, of which Hardee-1 X Pr-142 (26), Hardee-1 X Clark 63 K, Hardee-1 X SCS-1, and Hardee-1 X G-9945 were the top four. G-9945 was the only parent that was among the highest 100-seed weight producing entries; while several crosses i.e., Hardee-1 X Crowford, H-3 X G-9945, Clark 63 K X SCS-1, G-9945 X Crowford, Hardee-1 X Pr-142 (26), Pr-142 (26) X Clark 63 K, H-3 X SCS-1, Hardee-1 X Clark 63 K, Davis X Crowford, Alamo X G-9945, and Pr-142 (26) X H-3, were among the highest 100-seed weight producing entries.

Table 7.4-5 Mean performances of parents and crosses for major agronomic traits under low-P conditions over two locations

Entries	Plant height (cm)	Pod Number	Days to 50% flowering	Days to maturity	Number of seeds per pod	Pod length (cm)	Hundred seed weight (gm)	Grain yield (kg ha^{-1})
Hardee 1	29.54	16.20	51	104	2.25	4.23	13.32	1786.87
Davis	29.09	17.20	53	102	2.35	3.81	12.47	1376.87
Alamo	24.16	15.40	54	104	2.00	3.95	12.70	1351.04
PR 142 (26)	25.79	13.85	54	101	2.10	3.64	12.00	1213.12
H 3	22.13	10.25	55	107	2.40	3.98	13.15	1034.70
Clark 63 K	24.82	15.75	54	106	2.40	4.07	12.97	1692.50
SCS-1	26.55	21.00	52	105	2.60	4.08	13.62	1890.41
G-9945	25.85	17.65	52	105	2.15	3.99	15.17	1672.29
Crowford	26.34	21.65	55	104	2.15	4.15	11.95	1417.08
Mean of parents	**26.03**	**16.55**	**53**	**104**	**2.27**	**3.99**	**13.04**	**1492.76**
Hardee-1 X Davis	24.33	14.25	54	104	2.20	4.09	13.02	1774.37
Hardee-1 X Alamo	27.89	18.50	54	103	2.50	3.86	13.12	1807.71
Hardee-1 X Pr-142 (26)	31.52	23.80	54	105	2.60	4.41	14.75	1906.25
Hardee-1 X H-3	26.84	15.05	54	104	2.20	4.28	12.10	1253.33
Hardee-1 X Clark 63 K	34.71	22.35	53	106	2.35	4.37	14.70	2351.66
Hardee-1 X SCS-1	29.96	16.75	54	107	2.15	4.32	14.07	1625.83
Hardee-1 X G-9945	33.28	25.25	54	105	2.55	4.31	16.37	2561.87
Hardee-1 X Crowford	30.02	17.70	55	105	2.15	4.18	14.07	1580.00
Davis X Alamo	22.31	9.65	54	101	2.00	3.46	12.30	1026.13
Davis X Pr-142 (26)	25.66	14.15	52	100	2.35	3.61	12.87	1299.71
Davis X H-3	29.43	14.30	54	105	2.45	4.04	13.35	1327.50
Davis X Clark 63 K	22.38	11.85	53	100	2.10	3.89	13.17	1392.06
Davis X SCS-1	27.65	21.55	54	101	2.20	3.63	13.77	1875.55
Davis X G-9945	25.86	12.50	53	104	2.55	4.00	14.12	1423.24
Davis X Crowford	28.73	17.20	53	100	2.50	3.89	14.70	1188.75
Alamo X Pr-142 (26)	20.86	13.70	54	117	2.15	3.56	14.15	1081.67
Alamo X H-3	26.75	12.15	55	103	2.10	4.06	14.17	1171.96
Alamo X Clark 63 K	23.30	12.50	53	105	2.35	3.64	10.62	1180.00
Alamo X SCS-1	19.18	12.05	54	104	2.30	3.39	11.75	712.92
Alamo X G-9945	21.24	11.65	53	103	2.15	3.76	14.65	1224.02
Alamo X Crowford	20.09	11.35	52	101	2.15	3.73	11.37	929.58
Pr-142 (26) X H-3	26.97	12.95	54	104	2.10	4.18	14.40	1415.83
Pr-142 (26) X Clark 63 K	23.66	12.80	54	106	2.70	4.10	14.75	1582.92
Pr-142 (26) X SCS-1	23.94	10.45	55	105	2.70	4.13	12.95	942.50
Pr-142 (26) X G-9945	26.35	12.40	52	102	2.30	4.07	13.90	1187.29
Pr-142 (26) X Crowford	21.49	7.70	55	107	2.00	3.46	13.25	838.54
H-3 X Clark 63 K	27.60	12.95	54	105	2.40	4.14	14.07	1226.67
H-3 X SCS-1	30.04	18.00	54	105	2.15	4.22	14.72	1360.21
H-3 X G-9945	25.49	12.50	54	105	2.20	4.09	15.50	1173.83
H-3 X Crowford	27.30	15.00	55	104	2.25	4.32	14.07	1164.10
Clark 63 K X SCS-1	28.92	15.50	53	107	2.20	4.24	15.07	1720.21
Clark 63 K X G-9945	20.12	9.75	54	105	2.35	3.45	10.40	989.59
Clark 63 K X Crowford	23.74	13.25	53	106	2.10	4.09	13.67	1100.21
SCS-1 X G-9945	22.50	16.20	53	106	2.60	4.30	12.97	1562.71
SCS-1 X Crowford	22.97	15.15	53	104	2.25	4.21	12.95	753.12
G-9945 X Crowford	21.10	8.65	51	105	2.00	3.75	15.07	1134.13
Mean of crosses	**25.67**	**14.49**	**54**	**104**	**2.29**	**3.98**	**13.64**	**1356.83**
Mean	25.74	14.90	54	104	2.28	3.98	13.52	1384.02
Level of significance	***	ns	ns	*	ns	***	**	***
LSD (5%)	6.19	7.05	2.527	6.0	0.47	0.47	2.25	833.5
CV%	17.1	33.7	3.4	4.4	14.6	8.3	11.8	27.3

* = significant at P< 0.05 and **= significant at P<0.01

7.4.7 Mean performances of parents and crosses under high P conditions

Five parents i.e., G-9945, Hardee-1, PR-142 (26), SCS-1, and Alamo gave high 100-seed weights. Several crosses also produced significantly high 100-seed weight, of which Hardee-1 X G-9945, H-3 X Clark 63 K, and H-3 X G-9945 were the top three (Table 7.4-6). Parents Hardee-1, Clark 63 K, SCS-1, and PR-142 (26) produced high number of seeds per pod. Several crosses produced high number of seeds per pod, of which Hardee-1 X Crowford, SCS-1 X G-9945, Hardee-1 X Pr-142 (26), and Hardee-1 X H-3 were the top four. All the parents, except Davis, and all the crosses, except Davis X Alamo, Alamo X Pr-142 (26), Alamo X Clark 63 K, Alamo X SCS-1, Alamo X Crowford, and Pr-142 (26) X Crowford produced high pod lengths, and were statistically at par. Among the parents, only Hardee-1 produced significantly the taller plants, while crosses Davis X Pr-142 (26), Davis X H-3, Davis X SCS-1, Davis X G-9945, Alamo X H-3, H-3 X SCS-1, and all the crosses that used hardee-1 as a female, except Hardee-1 X Alamo, produced the taller plant. Except Davis and Alamo, all the parents were significantly the latest in days to flowering. In addition, all the crosses, except Hardee-1 X Crowford, Davis X H-3, Davis X Crowford, Alamo X Pr-142 (26), Pr-142 (26) X H-3, and Pr-142 (26) X SCS-1, produced significantly the latest days to flowering. Two parents i.e., Hardee-1, and H-3 were significantly the latest maturing entries; while crosses Hardee-1 X SCS-1, Hardee-1 X Pr-142 (26), Hardee-1 X G-9945, Alamo X H-3, Pr-142 (26) X Crowford, and H-3 X Clark 63 K were significantly the late maturing.

Table 7.4.6 Mean performances of parents and crosses for major agronomic traits under high-P conditions over two locations

Entries	Hundred seed weight (gm)	Number of seeds per pod	Pod length (cm)	Pod number	Plant height (cm)	Days to flowering	Days to maturity	Grain yield (kg ha^{-1})
Hardee 1	15.92	2.75	4.50	25.40	36.25	54	107	2780.96
Davis	14.20	2.15	3.81	25.35	29.50	50	104	2449.56
Alamo	14.55	2.25	3.95	22.35	23.91	50	105	2254.58
PR 142 (26)	15.20	2.40	4.14	23.60	26.63	53	106	2511.93
H 3	14.40	2.25	4.36	19.95	29.80	53	107	2503.19
Clark 63 K	12.53	2.65	4.00	24.00	24.06	53	105	1698.75
SCS-1	14.57	2.50	4.46	27.50	25.82	51	106	3346.37
G-9945	16.43	2.05	4.00	21.90	26.15	54	106	2147.64
Crowford	13.35	2.35	4.46	32.15	27.41	55	106	3147.19
Mean of parents	**14.57**	**2.37**	**4.19**	**24.69**	**27.73**	**53**	**106**	**2537.80**
Hardee-1 X Davis	15.38	2.60	4.60	35.95	40.02	51	107	3225.41
Hardee-1 X Alamo	14.40	2.65	4.22	19.95	30.17	54	106	2426.80
Hardee-1 X Pr-142 (26)	14.55	2.70	4.93	32.30	40.04	52	108	3187.97
Hardee-1 X H-3	15.90	2.70	4.66	29.10	39.59	52	107	3467.65
Hardee-1 X Clark 63 K	16.12	2.40	4.40	30.85	37.03	52	107	3624.79
Hardee-1 X SCS-1	15.88	2.55	4.57	30.35	38.41	51	109	3661.04
Hardee-1 X G-9945	16.62	2.15	4.37	30.35	38.28	51	108	3251.40
Hardee-1 X Crowford	15.57	2.90	4.42	27.95	39.99	50	107	3035.21
Davis X Alamo	13.80	2.15	3.68	16.45	28.89	52	104	2329.22
Davis X Pr-142 (26)	13.67	2.50	4.13	26.75	35.66	51	106	2271.66
Davis X H-3	15.40	2.30	4.22	26.05	36.32	50	107	3437.54
Davis X Clark 63 K	14.85	2.25	3.95	30.60	33.54	54	107	2722.42
Davis X SCS-1	14.85	2.25	3.99	37.30	35.96	53	107	3035.98
Davis X G-9945	15.22	2.50	4.39	26.25	41.90	51	107	3503.04
Davis X Crowford	14.35	2.35	4.09	23.15	34.33	50	105	2709.27
Alamo X Pr-142 (26)	12.88	2.10	3.78	24.90	23.27	50	104	1943.51
Alamo X H-3	16.18	2.40	4.58	31.65	43.21	55	108	3722.34
Alamo X Clark 63 K	12.65	2.45	3.78	23.10	23.91	51	105	2553.12
Alamo X SCS-1	15.40	2.25	3.85	22.40	21.41	52	106	2628.75
Alamo X G-9945	15.30	2.15	3.95	19.15	24.76	51	106	1976.50
Alamo X Crowford	13.85	2.55	3.72	21.75	23.08	53	104	1641.75
Pr-142 (26) X H-3	15.38	2.65	4.31	20.95	28.37	50	107	2316.57
Pr-142 (26) X Clark 63 K	16.27	2.50	4.24	20.50	33.86	52	107	2666.56
Pr-142 (26) X SCS-1	16.10	2.65	4.50	27.55	33.01	50	106	3603.11
Pr-142 (26) X G-9945	15.15	2.25	4.13	21.35	27.17	51	107	2714.13
Pr-142 (26) X Crowford	15.82	1.95	3.83	25.95	32.64	52	108	2338.65
H-3 X Clark 63 K	16.47	2.10	4.30	36.80	34.96	55	108	2956.94
H-3 X SCS-1	13.40	2.20	4.25	28.95	37.83	55	105	3434.26
H-3 X G-9945	16.35	2.20	4.54	21.20	33.21	52	106	2592.29
H-3 X Crowford	15.12	2.05	4.19	20.75	34.11	55	106	1932.30
Clark 63 K X SCS-1	15.82	2.45	4.57	28.75	30.06	53	107	2706.46
Clark 63 K X G-9945	12.42	2.65	4.18	32.30	28.42	52	106	3526.87
Clark 63 K X Crowford	15.93	2.30	4.47	23.80	30.18	51	107	2034.16
SCS-1 X G-9945	14.40	2.85	4.72	29.90	28.51	53	107	3116.66
SCS-1 X Crowford	15.15	2.45	4.36	26.20	24.88	53	106	2647.29
G-9945 X Crowford	14.52	2.00	4.12	17.00	24.95	53	104	2013.71
Mean of crosses	**15.03**	**2.39**	**4.25**	**26.34**	**32.55**	**52**	**106**	**2804.31**
Mean	14.94	2.39	4.28	26.01	31.59	52	106	2751.01
Significance level	***	***	***	ns	***	*	**	ns
LSD 5%	2.00	0.52	1.01	13.16	7.95	4.14	2.48	1560.9
CV %	9.5	15.6	16.7	36	17.9	5.7	1.7	40.3

* = significant at P< 0.05, and **= significant at P<0.01

7.5 Discussion

The analysis of variance showed highly significant differences among entries for grain yield under low P condition; and non-significant differences under high P condition (Table 7.4-1). However, the GCA effect of grain yield was highly significant under both P conditions. This showed that the phenotypic variation among the entries was higher under low P than high P condition, though the additive genetic variations are equally important under both P conditions. The GCA effects were also significant for pod length, days to maturity and plant height, under low P condition (Table 7.4-1), and for hundred seed weight, number of seeds per pod, pod length, days to maturity, plant height and pod number under high P conditions, indicating the importance of additive gene effects in the inheritance of these traits. The SCA effects were highly significant for grain yield, 100-seed weight, pod length, and plant height, and significant for days to maturity, under low P; while only 100-seed weight showed highly significant difference, and number of seeds per pod and pod length showed significant difference under high P, indicating the importance of non-additive gene action in these traits. In general, both the GCA and SCA variances were important for most traits; however the SCA has greater contribution most of the quantitative traits under both conditions. This shows that SCA effects were predominant over the GCA effects indicating that genes with non-additive effects were preponderant in governing the expression of these traits under both conditions on acidic soils. This indicates that there could be some challenges that can be encountered in improving soybean varieties for these traits under acidic soil conditions; because SCA cannot be fixed. Therefore, more selfing generations are required to eliminate the masking effect of the non-additive gene action in the expression of the traits before undergoing selection of individual plants to improve the segregating generation to breed soybean for adaptation to acidic soils under high and low P conditions.

The relative contribution of GCA was higher than that of SCA for pod length and plant height under low, and high P conditions, respectively, and was similar to finding by Spehar (1995) and Kimani and Derera (2009). This indicates that the inheritance of such traits is controlled by additive genes, and selection would be the best approach to improve these traits. This also indicates the conditional expression of additive genes under low and high P conditions for the respective traits. This fining is in-agreement with the report of Raghothama (1999) who reported that P starvation triggers the expression of genes. More number of traits showed significant GCA effects under high P condition than low P (Table7.4-1); indicating the importance of additive genetic variance and more number of traits could possibly be improved through selection for performance under high P than low P condition.

GCA X Environment interaction effects were higher than the entries x environment interaction for all agronomic traits studied under low P condition (Table 7.4-1). The results were in agreement with those of Patil and Chopde (1981) and Kimani and Derera (2009), indicating the higher contribution of GCA than the environment for the expression of these traits under low P conditions. In contrast, the overall mean squares of entries X environment was much higher than the mean squares of GCA X environment interactions for grain yield, number of seeds per pod, pod length, days to flowering, days to maturity and pod number under high P condition (Table 7.4-1), indicating that the environment has higher contribution than GCA in the expression of these traits.

The GCA X environment interactions were significant for many traits under low and high P conditions (Table 7.4-1), which were in-agreement with those reported in dry beans by Kimani and Derera (2009), and this indicates that the GCA effect lacks stability which can negatively impact on selection. The GCA X environment interaction was much higher than SCA X environment interaction for the quantitative traits under both P conditions, which is in-agreement with the findings of Kimani and Derera (2009), indicating the importance of additive, and additive X additive type of gene action.

Genotypes Hardee-1, and H-3 displayed good GCA effects (Table 7.4-2), indicating that these parents contributed significantly to improve the respective traits under low P, and therefore have utility in programs that aim to breed varieties with low P tolerance.

Superior GCA effects of the parents Hardee-1, Davis, H 3, Clark 63 K, SCS-1, and G-9945 (Table 7.4-2) indicates their importance in contributing additive genes to the progenies emerging from their crosses and the significant role they play to improve the respective traits for performance under optimum P fertilization. The significant mean heterosis of Hardee-1 for grain yield and plant height, and the highly significant heterosis for pod length (Table 7.4-3) was also an indication that the superiority of this parent in crosses, and making it a desirable parent in improving soybean for performance under low-P condition.

Though the SCA effects of several traits and specific crosses showed significant differences, SCA does not have much significance for self-pollinated crops, such as soybean. The main reasons for these are: hybrid varieties (F1 progenies) are not the desired out-come of soybean crosses, rather pure line varieties that are generated from the evaluation and selection of segregating generation through successive selfing, a process which splits and dilute SCA effect at every stage of selfing, making SCA effect unavailable at the final stage of pure line development. For this reason the SCA effects for the individual crosses have not been presented.

In general, sufficient additive genetic variance that was reflected by significant GCA effects was found for the major yield related quantitative traits under both low and high P conditions. This indicates the possibility of improving the segregating generation for low P tolerance, and performance under high P conditions. This finding is in-agreement with the result of Spehar (1995) who reported the uptake of several nutrients is controlled by additive gene, and the possibility of improving soybean for efficient utilization of nutrients and tolerance to toxic factors in the soil.

7.6 Conclusions and implications for future research

The GCA effects of several traits were significant under both low and high P conditions. Besides, the relative contribution of GCA was higher than SCA for some of the quantitative traits. This indicates that additive genetic variance plays a major role in the inheritance of these traits. Hardee-1 exhibited high GCA effects for several quantitative traits under both low and high P conditions indicating that it is the best parent and general combiner to improve the traits; while SCS-1 was specifically a good combiner under high P condition. This indicates that crossing soybean with Hardee-1 as a parent will have more chance of generating segregating generations (recombinant inbred lines) with high performance for grain yield that can be identified by simple selection for both low and high P conditions. The identification of better general combiners based on diallel analysis need to be strengthened further, so as to increase the chance of obtaining superior recombinant inbred lines from the segregating generations.

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CHAPTER 8

An overview of the research findings

8.1 Introduction and objectives of the study

Soybean was introduced to Ethiopia in the 1960s. Despite the recent introduction, (Asfaw *et al*., 2006) its production has tremendously increased in both small scale and commercial farms of the country, owing to increased awareness among the researchers, governmental and non-governmental institutions about the wide range of benefits it can provide to subsistence farmers in particular, and the country's economy at large. In addition, there has been an increase in the number of oil and fortified food processing companies and increased price of soybean in the local market, which have also contributed to increased soybean production in the country. Despite its growing importance, production and productivity of the crop has been constrained in Western Ethiopia by several production constraints; among which poor soil fertility that is mainly attributed to soil acidity is one of the most important factor. Phosphorus (P) is critically deficient in acid soils due to fixation by aluminium and iron forming compounds such as that are not used by plants (Liao *et al*., 2006). Assessment of farmers' perception on the various soil fertility problems and management practices, examining the extent of genetic variability, and genetic analysis of soybean for performance under low and high P conditions has not been done in Western Ethiopia, and hence, this study was undertaken.

The objectives of this study were to:-

a) Understand farmers perception and experience on the existing soil fertility problems and management practices that help make decision on plant breeding intervention in the development of low P tolerant varieties

b) Estimate the magnitude and pattern of genetic diversity of the crop using morphological data under low and high P conditions,

b) Identify low P-tolerant, and high P-responsive soybean genotypes

e) Determine gene actions and estimate combining ability of soybean for low and high P conditions

8.2 Brief summary of the research findings

8.2.1 Farmers perception on the different kinds of soils, the fertility status of the soil and the use of inorganic fertilizers

- The respondent farmers utilized soybean more in crop rotation and soil fertility improvement than in household consumption and marketing.
- Most farmers kept their harvest for 3-6 months before sell, and believed that the time of sell was not appropriate. Farmers' assessment also revealed poor demand of soybean compared to other crops in the local market.
- Most respondent farmers believed that soil fertility has been declining over time.
- Most farmers reported that obtaining inorganic fertilizers at the right application time was a problem; mainly due to the high price of fertilizer.
- Farmers' cooperatives were identified as the major suppliers of fertilizers. However, farmers rated the quality of their services in supplying fertilizers as poor

8.2.2 Evaluation of soybean for performance under varying P regimes

- The analysis of variance revealed significant GXP interaction for number of nodules and total nodule weight at Jimma, and Assossa, and for root weight and root volume at Mettu. Though the GXP and GXPXL interactions showed non-significant difference for the over locations combined analysis, the genotypes displayed significant difference for root fresh weight, root volume, tap root length, and weight of effective nodule.

- Genotypes Pr-142 (26), AGS-3-1, SCS-1, AGS 234, and H 3 were identified as the best performing for the root and nodulation characteristics.
- Significant GXP interaction was revealed for grain yield only at one site (Assosa); while the genotypes exhibited highly significant difference for most of the traits in all the sites. Most traits showed significant difference for G and GXL interaction in the over locations combined analysis.
- Essex-1, IAC 11, and AGS-3-1 were the best performing genotypes at high P; genotypes IAC 11, AA 7138, G 9945 and AGS-7-1 displayed tolerance to low P; while genotypes AA-7138, PR-142 (26) and H3 exhibited stable performance across the three P levels.

8.2.3 Assessment of the genetic variability of soybean under low and high P conditions

- Plant fresh weight, root fresh weight and root volume exhibited high GCV and PCV under both high and low P conditions
- Both principal component and cluster analysis verified the presence of high genetic variations in the population
- The traits 100-seed weight, plant height, roots and plant fresh weight combined high heritability and genetic advance estimates

8.2.4 Combining ability of the soybean genotypes under low and high P conditions

- The GCA effects were highly significant for grain yield, pod length, days to maturity and plant height under low-P conditions; while grain yield, 100-seed weight, days to maturity, plant height, pod number, and pod length showed highly significant, and number of seeds per pod significant GCA effects under high P condition.

- The relative contribution of SCA was higher than GCA for most of the studied traits under both P conditions, indicating that the non-additive gene actions were more important than the additive. The fact that non-additive gene actions are non-fixable, more selfing generations are required to eliminate the undesirable effects of the non-additive gene action.
- Genotype Hardee-1 was the best general combiner for most of the quantitative traits under both low and high P conditions

8.3 Implications of research findings for breeding soybean for low P tolerance and acid soils

- The fact that farmers' acknowledged the crop rotation and soil fertility improvement role of soybean as a major reason for producing soybean could be considered as an important motive for scaling up soybean, and it was learnt that much needs to be done to improve the value chain of the crop both in the local and central market.
- Farmers report on the deteriorating soil fertility and limited capacity to use inorganic fertilizers, can be related to the very low productivity of soybean relative to its potential productivity in the research field. This shows that there is a great challenge to enhance soybean production and productivity on small scale farmers' field. In such conditions, breeding programs need to play a vital role in developing varieties that are adapted to and perform well on low fertile soil. Among the major plant nutrients phosphorus is critically important, as the soybean has inherent capacity to fix atmospheric nitrogen. Thus, breeding for low P tolerance should be at the

top of the priorities for crops like soybean, and in areas, where the majority of the soil is acidic, and P is deficient.

- Rooting traits play an important role in the screening of genotypes for tolerance to low soil fertility (Lynch, 2007); while genotypes with high nodule formation are important in improving the fertility of soils. The fact that genotypes, Pr-142 (26), AGS-3-1, SCS-1, AGS 234, and H 3 combined both high root and nodule formation made them some of the best suited for soils with low fertility. These genotypes can be used in breeding programs to improve root and nodulation characteristics in soybean.

- The significant difference among the genotypes in each of the locations, and in the over locations and P levels combined analysis indicates that the genotypes exhibited significant variation that enable identify genotypes with superior performance. The existence of significant GXP interaction at Asssosa also indicates the existence of differential performance of the genotypes under the varying P regimes.

- The fact that AMMI bi-plot reveled that Essex 1, IAC 11, and AGS-3-1 were the best performing genotypes at high P; while genotypes IAC 11, AA 7138, G 9945 and AGS-7-1 exhibited tolerance to low P, and AA-7138, PR-142 (26) and H3 were stable for varying P regimes indicates that these genotypes will have important role in breeding soybean for low P tolerance and stable performance for varying P conditions

- Traits 100-seed weight, plant height, roots and plant fresh weight combined high heritability and genetic advance, indicating that the inheritance of such traits is controlled by additive gene actions under both P conditions.

- The different techniques employed revealed high genetic variation among 36 genotypes which indicates that there is the possibility of improving the crop for performance under both low and high P conditions.

- The inheritance of traits that exhibited highly significant GCA effect, viz. grain yield, pod length, days to maturity and plant height under low-P conditions, and grain yield, 100-seed weight, days to maturity, plant height, pod number, and pod length under high P conditions is controlled by more of additive gene action, and selection is the appropriate procedure to improve the segregating generation for performance under low and high P conditions, respectively.

- The fact that Hardee-1 uniquely exhibited high GCA effect for several traits under both low and high P conditions indicates that it is the best general combiner, and can be used in breeding programs to improve soybean for better response to low P tolerance and applied P.

8.4 Challenges encountered and recommendations

- Soybean crossing was one of the most challenging tasks that affected the progress of the thesis research. The major reasons for this were:

  - Soybean flowers are very small and the stigma is very delicate. Thus, handling the female flower during emasculation and artificial pollination can easily damage the stigma and the flower itself.

  - The fact that the night temperature was very low at Jima, getting viable pollen from the male parents for pollination was challenging. Therefore, strategies, such as timing the artificial crossing of soybean during the season, where the night temperature gets optimum, and constructing the crossing tunnel that has better capacity to retain the day temperature throughout the night. Future crossing programs need to target crossing blocks in warm locations, such as Teppi Agricultural Research Center, or Gojeb private farm. Other possibility is to renew the existing crossing tunnel in a way that the inside temperature can be maintained optimum under conditions of cool external environment.

- There was severe epidemic of soybean rust around Jimma, and Mettu in the years 2008, 2009, and 2010, which caused the death of pods of a successful cross. Thus, disease control strategies, such as spraying need to be prepared; when planning a crossing program in situations of heavy rust incidence.

• Future directions of soybean research and development in Jimma Research Center

- As the oil and fortified food processing companies are increasing in number, variety development programs need to work in-line with the quality requirements of these companies

- Screening for resistance to emerging diseases, such as rust, need to be prioritized

- Strengthening the soybean breeding program through introduction of soybean germplasm; screening and identification of superior genotypes; and hybridization and selection of best segregants using pedigree breeding procedure will be emphasized

- Soybean germplasm storage and maintenance requires major reform

- Improving the value chain of soybean by working closely with various stakeholders' viz., farmers', non-governmental and governmental organizations; processing companies and donor organizations will be dealt with.

In general the study clearly displayed that farmers' realized that the fertility of their soil is declining, their fertilizer use is reducing over time mainly due to fertilizer price increase. This clearly shows that farmers are producing soybean and other crops under sub-optimum fertility conditions. Therefore, the author recommends the country's extension program to give more emphasis in enhancing and popularizing integrated and sustainable soil fertility management practices that reduce farmers cost of fertilizer. This includes: crop rotation with nitrogen fixing legumes; enhance biological nitrogen fixation in leguminous crops; and encourage farmers to use low cost soil fertility management practices, such as the use of manures and compost, along with modest rate of inorganic fertilizer. Policy measures that reduce fertilizer price and enhance farmers' fertilizer use, such as improving fertilizer transport and distribution system, build capacity to produce fertilizer locally, avoid unnecessary chains in the fertilizer market, and provide modest subsidy to fertilizer need to be considered. Breeding options, such as creating genetic variability of soybean through introduction of exotic germplasm, and hybridization followed by selection of superior recombinant inbred lines; development of varieties that are efficient in utilizing limited plant nutrients, and tolerant to problematic soils; developing varieties that are efficient in biological nitrogen fixation need to be among the top priorities of breeding programs in areas of problematic soils.

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