ASSESSING THE EFFICIENCY OF SOYBEAN [*GLYCINE MAX* (L.) MERRILL] GENOTYPES IN PHOSPHORUS UPTAKE AND NITROGEN FIXATION

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP SCIENCE OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA.

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ABSTRACT

An experiment was conducted at Ilonga Agricultural Research Institute during the 2013 cropping season in order to assess the efficiency of soybean genotypes in phosphorus uptake and nitrogen fixation. The study was conducted between March 2013 and July 2013. The experiment was designed as 4 x 7 factorial experiments in randomized complete block and laid out in split-plots arrangement with three replications. The main plots were four P fertilizer levels (0, 15, 30 and 45 kg P ha^{-1}), while seven soybean genotypes (TGX 1895-33F, TGX 1895-4F, TGX 1954-1F, TGX 1871-12E, TGX 1844-4E, TGX 1440-1E and Bossier) constituted the sub-plots. The N fertilizer at a rate of 10 kg N ha^{-1} was applied in all experimental plots as a starter dose. Plant height, days to 50% flowering, P and N uptake, number of nodules, number of active nodules and reduced ethylene were measured at full flowering. Number of pods per plant, seeds per pod, 100 seeds weight and grain yield were obtained at harvest. Results showed that TGX 1895-33F and TGX 1954-1F were identified as high P uptake genotypes with 0.4064 and 0.3831 mg P/plant, respectively. Also they were identified as efficient in N_2 fixation with the highest amounts of reduced acetylene from detached nodules with 7.14 and 6.96 μ mol C_2H_4 h^{-1} g^{-1}, respectively. The high yielding genotypes were identified to be TGX 1954-1F, TGX 1844-4E and TGX 1440-1E ($P \leq 0.05$) which had grain yield of 1706, 1892 and 1863 kg ha^{-1}, respectively. Based on the results from this study, it is recommended that genotypes TGX 1895-33F, TGX 1954-1F and TGX 1844-4E be used in the breeding programmes at the Institute.

DECLARATION

I, **Abubakari Mshamu,** do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree award in any other institution.

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(Supervisor)

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

PLATE

LIST OF APPENDICES

LIST OF SYMBOLS AND ABBREVIATIONS

%	Percent
µ	Micro
Al	Aluminium
ANOVA	Analysis of Variance
ARA	Acetylene Reduction Assay
ARI	Agricultural Research Institute
ATP	Adenosine Triphosphate
BIDCO	Business and Industrial Development Corporation
BNF	Biological Nitrogen Fixation
C	Carbon
Ca^{++}	Calcium ion
CEC	Cation Exchange Capacity
cm	Centimetre
cmol/kg	Centimole per kilogram
CO_2	Carbon dioxide
C_2H_4	Ethene
COSTECH	Commission for Science and Technology
CV	Coefficient of Variation
DM	dry matter
DNMRT	Duncan's New Multiple Range Test
^oE	East
e.g.	for example

FAO	Food and Agriculture Organisation
FAOSTAT	Food and Agriculture Organisation statistics
Fe	Iron
Fig.	Figure
FID	Flame Ionization Detector
g	Gram
H_2O	Water
ha	Hectare
HI	Harvest Index
h	Hour
i.e.	that is
IITA	International Institute of Tropical Agriculture
K^+	Potassium ion
kg	Kilogram
m	Metre
m.a.s.l	Metre above sea level
MAFC	Ministry of Agriculture, Food Security and Cooperatives
Max.	Maximum
mg	Milligram
Mg^{++}	Magnesium ion
Min.	Minimum
mL	Millilitre
mm	millimetre
Mo	Molybdenum

m^2s^{-1}	metre square per second
MT	Metric tonne
N	Nitrogen
NMC	National Milling Corporation
N_2	Nitrogen gas
N_2O	Nitrite
Na^+	Sodium ion
NH_3	Ammonia
NH_4^+	Ammonium ion
NO	Nitrogen monoxide
NO_3^-	Nitrate
ns	not significant
^oC	degree of Celsius
OC	Organic carbon
OM	Organic matter
P	Phosphorus
P_2O_5	Di-phosphorus pentaoxide
pH	Hydrogen ion concentration
PUE	Phosphorus Use Efficiency
PUPE	Phosphorus Uptake Efficiency
PUTE	Phosphorus Utilization Efficiency
r	correlation coefficient
R_2	Flowering stage
R_3	pod formation stage

R_4	complete pod formation stage
R_5	seed formation stage
R_6	complete seeding stage
R_7	physiological maturity stage
RCBD	Randomized Complete Block Design
^oS	South
S	Sulphur
SED	Standard error deviation
SOM	Soil Organic Matter
SUA	Sokoine University of Agriculture
t	Tonne
t	Time
T	Temperature
TGX	Tropical glycine
TFDA	Tanzania Food and Drug Authority
TMA	Tanzania Meteorological Agency
TSP	Triple Super Phosphate
TZ	Tanzania
USA	United State of America
USDA	United State Department of Agriculture
v	Volume

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

The origin of soybean (*Glycine max* (L.) Merrill) goes back as far as 5000 years ago (BIDCO, 2005). It originated from Eastern Asia, probably in north and central China (Myaka, 2007). Soybean cultivation reached Africa in the late 1800s; although little is known of the countries to which it was first introduced (Shurtleff and Aoyagi, 2007). It is possible, perhaps likely, that soybean was cultivated at an early date on the eastern coast of Africa since that region had long traded with the Chinese. The earliest known cultivation of soybeans in Africa was in 1896 by French. Algeria, then a French colony, was important to France as a place for acclimatizing plants. The next record of soybean cultivation in Africa dates from 1903, when it was grown in South Africa at Cedara in Natal and in the Transvaal. In about 1907 soybean was introduced to Mauritius and to Tanganyika, at that time a German colony (Shurtleff and Aoyagi, 2007).

In Tanzania, soybean was first introduced at Amani, Tanga, by the German traders in 1907 (Myaka *et al.,* 2005). During World War II the British tried unsuccessfully to grow soybeans (Shurtleff and Aoyagi, 2007). The potential of soybeans was later realized and a breeding program which started in 1955, showed good results by the early 1960s, with hectareage expanding during the 1970s, when production was steady at about 3 000 tonnes a year for the decade (Myaka and Mwemezi, 1990). At this time there arose a strong interest in expanding the use of soybeans for human

foods. Soybeans were bought by the National Milling Corporation (NMC). In 1973 tests were run in three villages making whole soy flour using the simple process developed at the USDA Northern Regional Research Centre in the United States (Shurtleff and Aoyagi, 2007).

The importance of soybean cannot be over emphasized. Its importance lies on its nutritional value and wide utilization. Soybean contains high percentage of high quality protein and it is a rich source of edible oil. The crop contains 20-23% oil and 39-45% protein (Auckland, 1982). Soybean meal is a major component in livestock feed. Livestock and poultry feeds containing soybean meal as their major protein ingredient are used worldwide (Wilcox, 1987). Soybean can be used to improve soil characters through its ability to produce root nodule which may contain bacteria that transform atmospheric nitrogen into form that is usable by plants in the soil (Abdul-Jabbar and Saud, 2012).

Soybean grows on nearly all types of soil, but it is especially productive on fertile loams (Wilcox, 1987). It is better adapted to low fertility soils than maize, provided that proper nitrogen fixing bacteria are present. Soybean plant is strictly annual in growth habit. The leaves are trifoliate, the leaflets generally being ovolate-lanceolate in shape. A few types have narrow linear leaves nearly always begin to turn yellow. They usually drop off before the pods mature, when the seeds still contain about 20 per cent moisture (Martins *et al*., 1997). High soybean yields require adequate levels of P and K, and rates of application should be based on soil tests and local recommendations (Wilcox, 1987).

1.2 Problem Statement and Justification

The major limiting factor in soybean production among farmers is low yield (MAFC, 2010). The yield ranges from 0.3-1.1t ha^{-1}, which is relatively low as opposed to the potential yield of 3.0 t ha^{-1}. The low yield is associated with current grown varieties of 3H/1 and Bossier. These varieties, which are commonly grown in the lower altitudes particularly in the Eastern zone, are old and poor yielding (Myaka and Mwemezi, 1990). Despite the fact that farmers apply fertilizers and the soil characteristics are suitable for soybean production, the yields have continued being low (MAFC, 2010). The present soybean germplasm in the Eastern Zone has various lines which have never been evaluated for their nutrient uptake potential. These lines were evaluated for oil content, resistance to lodging, shattering and major soybean diseases (Myaka, 2007). The need to evaluate these lines for their nutrient P uptake potential is therefore important.

Soybean, like other legumes, has the potential for increasing soil fertility in low-input cropping systems through its nitrogen fixing ability. This is due to the fact that legumes have high P requirement for nodule development (Singh and Rachie, 1985). Nodulation can be achieved by inoculating the seeds with rhizobia before planting. DeMooy and Pesek (1966) reported that very high rates of P (120 kg P ha^{-1}) increased the number of nodules in field-grown soybeans. These high levels of P were also associated with increased dry matter production (Singh and Rachie, 1985). A study conducted by Xiang-wen *et al.* (2008) indicated a substantial genotypic variation in P use efficiency in existing germplasm of soybean. The P use efficiency was found to be positively correlated with dry weight of shoots and roots, root to

shoot ratio, dry weight, root length and surface area, root P content and total P uptake (Xiang-wen *et al.,* 2008)**.** It is for this reason that the use of promiscuously nodulating soybean cultivars, which form an effective symbiotic relationship with *Bradyrhizobia* may remove the need for application of inoculants which is limited among resource poor farmers in the Tropics.

On the other hand very little is known about factors that determine differences in the ability of soybean genotypes for phosphorous efficiency (uptake and utilization). Therefore, the identification of genotypes and to know the mechanism of efficiency that causes the differences in P uptake and utilization is required. The presence of genetic variation in P uptake is essential to devise breeding strategies for the development of appropriate genotypes, which could utilize fixed forms of P more efficiently.

1.3 Objectives

1.3.1 Overall objective

Establish soybean genotype(s) that are high in Phosphorus use efficiency and N_2-fixation which could be used in breeding programmes.

1.3.2 Specific objectives

i. To identify soybean genotype(s) that are efficient in P uptake

ii. To identify the soybean genotypes that are efficient in N_2-fixation

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Soybean Global Production Levels and Trends

The world soybean production increased by 4.6% annually from 1961 to 2007 and reached average annual production of 217.6 million tons in 2005-07 (Masuda and Goldsmith, 2009). World production of soybeans is predicted to increase by 2.2% annually to 371.3 million tons by 2030 using an exponential smoothing model with a damped trend (Masuda and Goldsmith, 2009).

In 2003, about 190.1 million MT of soybean (representing 56% of world production of oilseed) was produced in the world. The United States of America accounted for about 65.8 million MT (or 34%) of the soybeans (Chianu *et al.,* 2010). The other major producers of soybean are Brazil (53.5 million MT or 28%), Argentina (34 million MT or 18%), China (16.2 million MT or 9%), India (6.8 million MT or 4%), Paraguay (4.0 million MT or 2%), and others (9.8 million MT or 5%). The logarithmic trend in the world production of soybean reveals that between 1994 and 2003, there was steady growth in production (FAO, 2008). Soybean growers in leading producing countries have been using the Biotechnology options. As a result, most of the soybean that is currently grown has undergone biotechnological modification (Jagwe and Nyapendi, 2004). Based on the 2003 production records, about 81% of the soybean produced in the United States of America has been modified using biotechnology. The corresponding figure for Argentina is 99% and for Brazil is 34% (Jagwe and Nyapendi, 2004). The use of biotechnology modified

planting materials confers the advantages of higher crop yields and greater tolerance to soybean diseases and pests. High crop yield increases the profit farmers make from selling their produce.

Table 1: World soybean production

	World soybean production 2011			
Country	**million bushels**	**% global productivity**	**millions metric tones**	**% global production**
USA	3056	33.08	83.2	33.09
Brazil	2645	28.63	72	28.64
Argentina	1764	19.09	48	19.09
China	496	5.37	13.5	5.37
India	404	4.37	11	4.38
Paraguay	235	2.54	6.4	2.55
Canada	156	1.69	4.2	1.67
Other	483	5.23	13.1	5.21
Total	**9239**	**100**	**251.4**	**100**

Source: USDA (2009)

2.2 Soybean Production in Tanzania

Soybean production in Tanzania has tended to remain stagnant over the years 1961-1983 (FAO, 2008). However, total national production area and yield showed a slight increasing trend after 1983 (Chianu *et al.,* 2010). The crop production estimates is however, still very low when compared to major soybean producing countries (Table 2).

Table 2: Comparing soybean production ('000 MT) in TZ with other three highly producing countries in the world

Country	Year				
	2000	**2001**	**2002**	**2003**	**2004**
USA	75.07	78.68	75.01	66.79	85.49
Brazil	39	43.5	52	52.6	53
Argentina	27.8	30	35.5	33	39
Tanzania	0.43	1.27	2.06	1.06	1.15

Adapted from Chianu *et al*. (2010)

The crop is rapidly becoming an important component of the cropping systems of most tropical. In Tanzania, the southern highlands regions and some part of the eastern zone constitute the major soybean producing areas. The crop is highly grown in the southern highlands of Tanzania, in the regions of Rukwa, Mbeya, Ruvuma and Iringa. It is also grown in some parts of the eastern zone particularly in Morogoro region. The potential for soybean production in different regions of Tanzania (Table 3) depicts that Mbeya, Iringa and Ruvuma ranked as very high potential regions for soybean production, and Morogoro where this study was conducted is ranked as high potential region. Dar es Salaam and Coast regions are ranked as very low potential soybean growing regions with the production potential of 500 tonnes.

2.3 Soybean Distribution

Soybeans can grow from the coastal belt to areas of Tanzania 2000 m.a.s.l. This means that soybeans can grow in almost all areas of the country (including areas where there is widespread malnutrition) provided there is adequate moisture and that the right varieties are planted (Myaka *et al*., 2005, Malema, 2005). Even zones such as the Lake, Southern and Western also have good potential for soybean production (Malema, 2005). There are however, significant differences in the potential of the

different regions to support soybean with Mbeya, Ruvuma, and Rukwa being regions of very high potential, Morogoro, Tanga, Kigoma, Arusha, and Kilimanjaro belonging to regions of high potential, Kagera, Mara, and Manyara being of medium potential, while Mwanza, Tabora, Shinyanga, Singida, Mtwara, Lindi, and Dodoma are low potential regions, and Dar es Salaam and Coast belonging to regions of very low potential (Table 3).

Table 3: Potential for soybean production in different regions of Tanzania

Region	Production (tons)	Rank
Mbeya	300 000	Very high
Iringa	260 000	Very high
Ruvuma	225 000	Very high
Rukwa	225 000	Very high
Morogoro	120 000	High
Tanga	120 000	High
Kigoma	120 000	High
Arusha	120 000	High
Kilimanjaro	115 000	High
Kagera	100 000	Medium
Mara	100 000	Medium
Manyara	100 000	Medium
Mwanza	65 000	Low
Tabora	50 000	Low
Shinyanga	45 000	Low
Singida	30 000	Low
Mtwara	30 000	Low
Lindi	25 000	Low
Dodoma	15 000	Low
Dar Es Salaam	500	Very low
Coast	500	Very low
Total	**2 166 000**	

Adapted from Malema (2005)

2.4 Phosphorous as a Nutrient in Soybeans

Phosphorus availability in the soil depends considerably on its concentration in the soil solution (Wahba, 2013). It is often the most limiting nutrient for crop and forage production. Phosphorus' primary role in a plant is to store and transfer energy produced by photosynthesis for use in growth and reproductive processes (Wahba, 2013). Soybean requires relatively large amounts of phosphorus than other crops. Phosphorus is taken up by soybean plant throughout the growing season. The period of great demand starts just before the pods begin to form and continues until about ten days before the seeds are fully developed (Wahba, 2013).

Soybean is more efficient at producing good yield at low soil phosphorus (P) levels than other major agronomic crops. Phosphorus is the most critical nutrient limiting soybean production, and is deficient in the majority of soybean - cultivated tracts (Hellal and Abdelhamid, 2012). Legume fertilization is often P-based, since it is highly essential for intensive N fixation. Thus, P, by way of its role in energy transformation and enhancing root growth, is essential for nodulation and effective N fixation. The response to P fertilization depends on soil moisture status, as soil moisture stress may decrease the availability of applied P, resulting in poor biomass production and reduced P uptake. The need for P fertilization is usually more in acidic soils than in others due to higher P fixation. In general, all the sources of P are equally effective in soybean, except rock phosphate. Rock phosphate is a poor source of P in neutral to alkaline soils, but a fairly good source for acidic soils (Hellal and Abdelhamid, 2012).

2.4.1 Variability of soybean genotypes in P uptake

Crop response to P fertilizer depends on genetic and physiological characteristics of the plant that help for efficient P uptake and utilization. This will be facilitated by the development of more P-efficient crop cultivars which will yield more per unit of phosphorus input (Jakkeral *et al.,* 2009). Genetic variation for P uptake has been reported for agriculturally useful crops but the knowledge on the extent of genetic variation for P uptake and utilization efficiency within semi-arid crops is very inadequate (Jakkeral *et al.,* 2009).

Phosphorus being a major limiting factor for crop production in many tropical and subtropical soils, production of higher quantities of soybean will therefore be achieved by soil amendment techniques, using lime and fertilizers, supplying the nutrients required for best crop performance. The yield potential is a basic factor and depends on plant germplasm characters that can be modified by selection and breeding (Furlani *et al*., 2002). Variation in grain yield among soybean cultivars for phosphorus (P), potassium (K) and N-efficiencies were also reported by Sarawgi and Tripathi (1998) and Hanumanthappa *et al.* (1999) in field experiments.

2.4.2 Soybean P requirement

Phosphorus is an essential macronutrient for plant growth and function. The requirements of host plants for optimal growth and symbiotic dinitrogen fixation processes for P have been assessed by determination of nodule development and functioning (Sa and Israel, 1991). The influence of P on symbiotic nitrogen fixation in leguminous plants has received considerable attention, but its role in the process

remains still unclear. Robson and Hara (1981) reported that P nutrition increased symbiotic dinitrogen fixation in subterranean clove by stimulating host plant growth rather than by exerting specific effects on rhizobial growth or on nodule formation and function. The increases of whole plant growth and plant nitrogen concentration in response to increased soil P supply have been noted in several leguminous species including soybeans (Robson and Hara, 1981). Phosphorus availability, however still constitutes a major constraint as it is well recognized that low levels of soil P could limit growth, dinitrogen fixation and yield of legumes, particularly soybeans (Sarawgi and Tripathi, 1998). Therefore the application of P fertilizer is very important for the growth and development of soybeans.

2.5 Nitrogen as a Nutrient in Soybean

Nitrogen nutrition in soybean, as in other legumes, is ensured both by dinitrogen fixation and mineral nitrogen assimilation. These two sources can be complementary or antagonistic in relation to the environmental or developmental factors (Werry *et al.,* 1986). In most soils where the nitrate content is moderate, the proportion of nitrogen which is derived from symbiotic fixation in soybean is about 50% (Bergersen *et al.,* 1985) but can reach 75% in sandy loam soils (Matheny and Hunt, 1983). The highest rate of nitrogen fixation occurs at the end of flowering and during pod filling (Obaton *et al.,* 1987). The nitrogen assimilated between the start of pod development and the start of maturity seems to be the predominant source of nitrogen for seed development (Warembourg *et al.,* 1982).

2.5.1 Soybean N requirement

Soybean like other leguminous crops, when nodulated it is capable of fixing atmospheric nitrogen (Waluyo *et al.,* 2004). Thus, application of N fertilizer will have little effect on growth of the crop. However, soybean as a C_3 plant has poor N utilization. Basically, C_4 plants have greater N use efficiency (biomass production per unit of N in the plant) than do C_3 plants. This difference presumably results from the relatively smaller investment of N in the photosynthetic carboxylation enzymes of C_4 plants than C_3 plant (Wilcox, 1987). Nitrogen fertilizer however, is applied in soybean production as a starter N to reduce competition with microorganisms in the soil. A starter dose of 10 to 20 kg/ha N is beneficial for good early growth (FAOSTAT, 2011).

2.6 Relationship between Phosphorus as a Nutrient and BNF

Biological nitrogen fixation (BNF) is a natural alternative method of providing N to plants and enriching soil N resources (Silva and Uchida, 2000). Many members of the leguminous family, such as beans, peas, alafalfa, and leucaena, have special ability to use BNF to meet their needs. Legume BNF involves a remarkable symbiosis or mutually beneficial relationship, between the plant and N-fixing soil bacteria called rhizobia. The bacteria invade the host plant's roots and cause the formation of structures called nodules. Within the nodules the rhizobia use enzymes to biologically convert N_2 gas from the atmosphere into a form that can be used by its host plant to make proteins. In turn the plant provides the rhizobia with products of photosynthesis: sugars and carbohydrates that fuel the bacteria and the BNF process (Silva and Uchida, 2000). A study conducted by Israel (1993) found out that an

increase of whole plant growth and plant nitrogen concentration in response to increased soil P supply has been noted for several leguminous species including soybean. Decreased specific- nitrogenase activity in nodules of P- deficient soybean plants was associated with decreased energy status of host plant cells of nodules (Silva and Uchida, 2000). These latter observations imply specific involvement of phosphorus in symbiotic nitrogen fixation, and hence the relationship between phosphorus nutrient and the BNF.

2.7 Phosphorous Availability in Plants

Although the total amount of P in the soil may be high, it is often present in unavailable forms or in forms that are only available outside of the rhizosphere (Schachtman *et al*., 1998). Few unfertilized soils release P fast enough to support the high growth rates of crop plant species. In many agricultural systems in which the application of P to the soil is necessary to ensure plant productivity, the recovery of applied P by crop plants in a growing season is very low, because in the soil more than 80% of the P becomes immobile and unavailable for plant uptake because of adsorption, precipitation, or conversion to the organic form (Holford, 1997).

Soil P is found in different pools, such as organic and mineral P (Schachtman *et al*., 1998). It is important to emphasize that 20 to 80% of P in soils is found in the organic form, of which phytic acid (inositol hexaphosphate) is usually a major component (Richardson, 1994). The remainder is found in the inorganic fraction containing 170 mineral forms of P (Holford, 1997). Soil microbes release immobile forms of P to the soil solution and are also responsible for the

immobilization of P. The low availability of P in the bulk soil limits plant uptake. More soluble minerals such as K move through the soil via bulk flow and diffusion, but P is moved mainly by diffusion. Since the rate of diffusion of P is slow (10^{-12} to 10^{-15} m^2s^{-1}), high plant uptake rates create a zone around the root that is depleted of P (Schachtman *et al.,* 1998).

Plant root geometry and morphology are important for maximizing P uptake, because root systems that have higher ratios of surface area to volume will more effectively explore a larger volume of soil (Lynch, 1995). For this reason mycorrhizae are also important for plant P acquisition, since fungal hyphae greatly increase the volume of soil that plant roots explore (Smith and Read, 1997). In certain plant species, root clusters (proteoid roots) are formed in response to P limitations. These specialized roots exude high amounts of organic acids (up to 23% of net photosynthesis), which acidify the soil and chelate metal ions around the roots, resulting in the mobilization of P and some micronutrients (Marschner, 1995).

2.8 Nitrogen Fixation

Nitrogen nutrition in soybean, as in other legumes, is ensured both by dinitrogen fixation and mineral nitrogen assimilation. These two sources can be complementary or antagonistic in relation to the environmental factors or developmental stages. Biological nitrogen fixation and mineral soil or fertilizer N, are the main sources of meeting the N requirement of high yielding soybeans. However, antagonism between nitrate concentration in the soil solution and the N_2 fixation process in the nodules is the main constraint the crop faces in terms of increasing N uptake (Streeter, 1988)

when no other abiotic stress that reduce BNF activity occurs, e.g. soil moisture (Purcell *et al.,* 2004), soil pH (Parker and Harris, 1977) or soil temperature (Soares Novo *et al.,* 1999). Maximum N_2 fixation occurs between the R_3 and R_5 stages of soybean development (Zapata *et al.,* 1987) and any gaps between crop N demand and N supply by N_2 fixation must be met by N uptake from other sources. If the overall N supply does not meet soybean requirements, the crop will remobilize.

Accumulation of N in leaves to the grain diminishes the photosynthetic capacity of the canopy and thus limits yield potential. Van Kessel and Hartley (2000) suggested that N_2 fixation will increase in high-yielding environments since the nitrogenase, located in the nodules, will adjust its activity to the demand of the legume (Mengel, 1994). However the generally observed reduction in N_2 fixation activity between the R_5 and R_7 stages (Zapata *et al.,* 1987) could lead to a shortage of N during seed-filling in high-yielding environments.

2.9 Soil Factors Affecting Availability of Phosphorus to Plants

2.9.1 Soil pH

Soil pH is a characteristic that describes the relative acidity or alkalinity of the soil (Jensen, 2010). Technically, pH is defined as the negative (-) log or base 10 value of the concentration of hydrogen ions (H^+). Pure water will be close to a neutral pH, that is 10 to the minus 7 concentration of H+ ions (10^{-7} [H^+]). This concentration is expressed as 7. Any value above 7 means the H^+ ion concentration is lower than at a neutral pH and the solution is alkaline and there are more hydroxyl (OH^-) ions present than H^+ ions. Any value below 7 means the H^+ ion concentration is greater

than at neutral pH and the solution is acidic (Jensen, 2010). Soils are considered acidic below a pH of 5, and very acidic below a pH of 4. Conversely, soils are considered alkaline above a pH of 7.5 and very alkaline above a pH of 8.

The availability of some plant nutrients is greatly affected by soil pH. The ideal soil pH is close to neutral, and neutral soils are considered to fall within a range from a slightly acidic pH of 6.5 to slightly alkaline pH of 7.5. It has been determined that most plant nutrients are optimally available to plants within this 6.5 to 7.5 pH range, plus the fact that this range of pH is generally very compatible to plant root growth (Jensen, 2010).

Nitrogen (N), Potassium (K), and Sulphur (S) are major plant nutrients that appear to be less affected directly by soil pH than many others, but still are to some extent. Phosphorus (P), however, is directly affected. At alkaline pH values, greater than pH 7.5 for example, phosphate ions tend to react quickly with calcium (Ca) and magnesium (Mg) to form less soluble compounds. At acidic pH values, phosphate ions react with aluminium (Al) and iron (Fe) to again form less soluble compounds. Most of the other nutrients (micronutrients especially) tend to be less available when soil pH is above 7.5, and in fact are optimally available at a slightly acidic pH, e.g. 6.5 to 6.8. The exception is molybdenum (Mo), which appears to be less available under acidic pH and more available at moderately alkaline pH values (Marschner, 1995).

2.9.2 Cation exchange capacity

Cation exchange capacity (CEC) refers to the sum total of exchangeable cation that a soil can adsorb (Brady, 2002). Cations held on the clay and organic matter particles in soils can be replaced by other cations; thus, they are exchangeable. For instance, potassium can be replaced by cations such as calcium or hydrogen, and vice versa. The total number of cations a soil can hold or its total negative charge is the soil's cation exchange capacity. The higher the CEC, the higher the negative charge and the more cations that can be held (Marschner, 1995).

2.9.3 Soil types

Soil is a critical component in the germination, growth and survival of plants. Different soils influence differently nutrient availability to plants. The availability of phosphorus is influenced by soil types (Torres-Dorante *et al.,* 2006). Nutrient availability varies depending on the soil types. Clay, for instance, can retain more phosphorus and can slow water movement through the soil, making nitrogen more available. Sandy soil is less effective at holding nutrients, and therefore the soil with appreciable amount of sand particles will render the nutrient P unavailable for the plant uptake. The compacted soil will have impact on the nutrient availability and therefore P. Soil compaction can make root permeability difficult for plants (Martonas, 2012). Aside from root penetration, compacted soil can make water and oxygen movement through the soil difficult. Aerating the soil and mixing the top several inches can loosen the soil, improving soil permeability and increasing movement of water, air and nutrients through the soil.

2.10 Phosphorus Uptake, Use and Utilization Efficiency

Besides increased acquisition of soil P, efficient utilization of acquired P is also considered an important adaptation for plant growth on low P soils. Phosphorus utilization efficiency (PUTE) refers to the ability of a plant species/genotype to produce higher dry matter per unit of P absorbed (Blair, 1993; Richardson *et al.,* 2011).

The mechanism of higher internal PUTE is not clearly known. However, it may be related to the ability of a plant in releasing inorganic P from the storage pool (vacuole) to the cytoplasm (cytoplasmic P homeostasis) (Plaxton and Carswell, 1999; Raghothama, 1999) or to selective allocation of P between cytoplasm and vacuole in favour of cytoplasm thereby ensuring sufficient Pi concentration in metabolically active compartments for normal functioning of plant metabolism (Lauer *et al.,* 1989; Raghothama, 1999). Additionally, higher internal P UTE may also be due to lower metabolic requirement for inorganic P at cellular level under P stress possibly due to the presence of alternative P-independent enzymes/metabolic pathways and/or energy sources (Duff *et al.,* 1989; Plaxton and Carswell, 1999). P uptake efficiency (PUPE) measures the ability of the plant to absorb the available P in the soil (Parentoni *et al.,* 2005). It is defined as the ratio between the total P in the plant (grain+straw) per unit of P available in the soil. On the other hand P use efficiency is a multiplicative relationship from uptake efficiency and utilization efficiency. Phosphorus use efficiency (PUE) is also an important P efficiency phenomenon which is actually the product of PUPE and PUTE and it measures the amount of grain produced per unit of available P in the soil (Parentoni *et al.,* 2005).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Description of the Study Area

The study was conducted at Ilonga Agricultural Research Institute experimentation fields. The Institute is located in Kilosa District, about 99Km away from Morogoro municipality on the North-west side. Ilonga Agricultural Research Institute is found at an altitude of 506m a.s.l, latitude of 6-7^{o}S and longitude 37-39^{o}E. The area dominated by sandy clay loam soil with pH 6.74 and experiences a bimodal rainfall pattern, where short rains (*Vuli*) start from October to December and long rain (*Masika*) start from March and end in May (Msanya *et al*., 2003). Annual rainfall ranges from 840mm-1100mm with an average of 970 mm per annum, whereas the annual temperature of the experimental site is observed to be 31^{o}C (Msanya *et al*., 2003).

3.2 Soil Sampling and Analysis

Soil from the field experimental site was sampled at 0 - 20 cm depth five weeks before planting. Soil samples were obtained randomly in the experimental field using method described by Uchida *et al*. (2000) and a composite sample was prepared. This composite sample was packed, labelled and taken to the Department of Soil Science Laboratory at SUA for both physical and chemical analysis. Soil samples for chemical analysis were air dried, ground, sieved through 2 mm sieve and analyzed for pH, total nitrogen (N), extractable P, cation exchange capacity (CEC), exchangeable bases (Ca, Mg, K and Na) and organic carbon.

3.2.1 Soil pH determination

This was determined using the Eutech 510 pH meter in a 1:2.5 soil to distilled water ratio. A 10 g air-dried soil was weighed into a 100 ml beaker. To this, 25 ml distilled water was added from a measuring cylinder, stirred thoroughly for 20 minutes. The soil 22 – water suspension was allowed to stand for 15 minutes. After calibrating the pH meter with buffer solution at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension.

3.2.2 Soil organic carbon determination

The modified Walkley and Black procedure as described by Nelson and Somers (1982) was used to determine organic carbon. The procedure involves a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid after which the excess dichromate was titrated against ferrous sulphate. One gram soil was weighed into a conical flask. A reference sample and a blank were included. Ten millilitres of 0.166 *M* (1.0 *N*) potassium dichromate solution was added to the soil and the blank flask. To this, 20 ml of concentrated sulphuric acid was carefully added from a measuring cylinder, swirled and allowed to stand for 30 minutes on an asbestos mat. Distilled water (250 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. One milliliter of diphenylamine indicator was added and titrated with 1.0 *M* ferrous sulphate solution.

Calculation:

% Organic C = $M\ X\ \ 0.39\ X\ mcf\ \frac{V1-V2}{g}$……..…….(1)

Where:

M = molarity of the ferrous sulphate solution

V1 = ml ferrous sulphate solution required for blank titration

V2 = ml ferrous sulphate solution required for sample titration o 23

g = weight of air – dry sample in grams

mcf = moisture correction factor (100 + % moisture) / 100

0.39 = 3 x 0.001 x 100 % x 1.33 (3 = equivalent weight of C)

1.3 = a compensation factor for the incomplete combustion of organic matter

3.2.3 Total nitrogen determination

The Kjeldahl method involving digestion and distillation method as described by Bremner and Mulvancy (1982) was used to determine the total nitrogen. Ten grams of soil sample was weighed into a Kjeldahl digestion flask and 10 ml distilled water was added to it. After 30 minutes, 5 ml concentrated sulphuric acid and selenium mixture were added, mixed carefully and digested for 3 hours until a colourless solution was observed. The digest was diluted with 50 ml distilled water and allowed to cool. The digest was made to 100 ml with distilled water and mixed well. A 10 ml aliquot of the digest was transferred to the reaction chamber and 20 ml of 40% NaOH solution was added followed by distillation. The distillate was collected over 4% boric acid. Using bromocresol green as an indicator, the distillate was titrated with 0.02 *N* HCl solution. A blank distillation and titration was also carried out to take care of traces in the reagents as well as the water used.

Calculation:

14g of N contained in one equivalent weight of NH3

(*A-B*0) x $\frac{N}{1000}$.....(2)

Where:

A = volume of standard HCl used in the sample titration 24

B = volume of standard HCl used in the blank titration

N = Normality of standard HCl

Mass of soil sample used, considering the dilution and the aliquot taken for distillation

$= (10g - 10ml)$/100ml

= 1g

Thus, the percentage of nitrogen in the soil sample is,

% Total N= $\frac{14\ X\ (A - B)XN\ X\ 100}{1000X1}$

Note:

When N = 0.1 and B = 0

% Total N = A x 0.14

3.2.4 Available phosphorus determination

The readily acid – soluble forms of phosphorus were extracted with Bray No. 1 solution as outlined by Olsen and Sommers (1982). Phosphorus in the sample was determined on a spectrophotometer (210 VGP Buck scientific) by the blue ammonium molybdate with ascorbic acid as a reducing agent.

A 5 g soil was weighed into 100 ml extraction bottle and 35 ml of Bray 1 solution (0.03 *M* NH4F and 0.025 *M* HCl) was added. The bottle was placed in a reciprocal shaker and shaken for 10 minutes and filtered through Whatman No. 42 filter paper. An aliquot of 5 ml of the filterate was pipetted into 25 ml flask and 10 ml colouring reagent (ammonium paramolybdate) was added followed by a pinch of ascorbic acid. After mixing well, the mixture was allowed to stand for 15-25 minutes to develop a blue colour. The colour was measured using a 21D spectrophotometer at 660 nm wavelengths. The available phosphorus was extrapolated from a standard curve. A standard series of 0, 1.2, 2.4, 3.6, 4.8, and 6.0 mg P/ l was prepared by pipetting respectively 0, 10, 20, 30, 40 and 50 ml of 12.0 mg P/ l in 100 ml volumetric flask and made to volume with distilled water.

Calculation;

$$P\ (mg/kg) = \frac{(a-b) X\ 35\ X\ 15\ X\ mcf}{g} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

a = mg P/l in the sample extract

b = mg P/l in the blank

g = sample weight in grams

mcf = moisture correction factor

35 = volume of extraction solution

15 = final volume of the sample solution

3.2.5 Exchangeable cations extraction

Calcium, magnesium, potassium and sodium in the soil were determined in 1.0 *M* ammonium acetate (NH4OAc) extract (Moberg, 2001). A 10 g sample was transferred into a leaching tube and leached with a 250 ml of buffered 1.0 *M* ammonium acetate (NH4OAc) solution at pH 7.

3.3 Weather Data

The meteorological data were collected from TMA-ARI-Ilonga (2012/13) and included rainfall amount (mm) and temperature for maximum and minimum (^{0}C) as shown in (Fig. 1).

3.4 Materials

Six soybean genotypes namely TGX 1895-33F, TGX 1895-4F, TGX 1954-1F,TGX 1448-2E,TGX 1908-8F,TGX 1889-12F plus the released soybean variety (Bossier), and triple superphosphate (TSP) fertilizer were used in the experiment at four levels 0, 15, 30 and 45 kg P ha^{-1}. N fertilizer (Urea 46%N) at a rate of 15 kg N ha^{-1} was also applied at planting as a starter fertilizer so as to reduce competition between crop and the microorganisms in the soil. Gas chromatography equipment was used for N_2-fixation determination using acetylene reduction (ARA) technique.

3.5 Experimental Design and Treatments

The experiment was laid out in split-plot arrangement using a randomized complete block design (RCBD). The whole plot factor was fertilizer levels, while the sub

factors were seven genotypes and were replicated three (3) times. The size of whole plots was 28 m^2, while the size of the subplots was 4 m^2.

3.6 Cultural Operations

The selected site was ploughed to produce fine seedbed (suitable tilth for soybeans). The crop was sown by hand hoe in plots of size 4 m^2 at a spacing of 50 cm x10 cm (recommended spacing for soybeans in the Eastern Zone) with 1 plant $hill^{-1}$. Each plot had 4 rows of 2 m length. The seeds were sown on 27th March, 2013.

3.7 Data Collected

The following data were collected during the implementation of the study:-

3.7.1 Crop establishment

This was recorded by counting the number of plants in each plot after completion of seedling emergence.

3.7.2 Days to 50% flowering

This was collected by counting number of days from seedling emergence to the time when at least half of the total number of plants in a plot had flowered. The days to reach at least half of the total number of plants in a plot had flowered were recorded as the number of days taken to 50 % flowering from the date of seedling emergence.

3.7.3 Number of nodules per plant

A sample of 5 plants were dug randomly using hand hoe from each plot and the number of nodules were counted and averaged as number of nodules per plant.

3.7.4 Number of active nodules per plant

Nodules were plucked and cut to observe leghemoglobin. Nodules with pink colouration were recorded as number of active nodules per plant.

3.7.5 Nitrogen fixation determination

Nitrogen fixation was determined by the Acetylene Reduction (ARA) Method. Detached nodulated roots from samples of plants were put in glass jar (700 mL) containing 10 % (v/v) acetylene. The mixture was incubated at 25^{o}C for 20 minutes. After this time 0.5 mL of gas in the jar was taken and the concentration of ethylene analyzed using gas chromatography technique with flame ionization detector (FID). The concentration of ethylene produced was obtained by the following equation:

$$\frac{C_E}{E} = \frac{K_E}{S_E} \qquad \text{……..……(4)}$$

Where, C_E and K_E are ethylene concentration in the sample gas and standard respectively, (µL/L or parts per million by volume), and E (sample) and S_E (standard) are the respective areas obtained after chromatographic analyses. The amount of ethylene produced was directly related to the nitrogenase activity in the nodules which is directly related to the amount of N_2 fixed. The higher the amount of ethylene produced, the higher will be the N_2 fixation by the nodules. The concentrations of

ethylene produced were recorded as micromole of ethylene per hour per gram of detached nodule ($\mu molC_2H_4\ h^{-1}\ g^{-1}$).

3.7.6 Plant material for N and P determination

The shoots of the plants were milled in a miller, after which nitrogen and phosphorus contents were determined. Total nitrogen was determined according to the procedure described in section 3.2.3.

Total phosphorus was determined by using the spectrophotometric vanadium phosphomolybdate method. One gram of plant sample was weighed into the digestion tube. One milliliter of digestion mixture ($HCIO_4HNO_3$) was added. It was digested and made up to 500 ml in a volumetric flask. Ten milliliters of the digest was measured into a 50 ml volumetric flask. Ten milliliters of vanadomolybdate was then added. Distilled water was added to make the required volume. It was shaken vigorously and kept for 30 minutes. It was read on 430 nm spectrophotometer after a yellow color had developed. The percentage transmittance was recorded. The absorbance and the P content were determined from a standard curve.

3.7.7 Number of pods per plant

During the harvest, five plants were selected at random and pods were plucked separately from each plant counted and the average was recorded as number of pods plant $^{-1}$.

3.7.8 Number of seeds per pod

Each pod collected in section 3.7.7 was shelled, and number of seeds per pod were counted and averaged as number of seeds per pod.

3.7.9 Days to 95% maturity

These are the number of days after emergence to maturity. During crop maturation, the plots were visited 3 times a week to determine days to maturity when 95% of the pods had changed from yellow to tan. The days taken to reach this time were recorded as number of days to 95% maturity.

3.7.10 Plant height

At physiological maturity, five randomly selected plants from each plot were measured from the ground surface to the tip of the main stem by using measuring ruler and the mean plant height computed and recorded in centimetres (cm).

3.7.11 Biomass

One square meter quadrant ($1m^2$) from each plot were harvested at physiological maturity from the ground surface and all materials were sun dried until constant weight then weighed using an electronic measuring balance. Weight for each plot was recorded in grams (g).

3.7.12 Grain yield

A net harvesting area of $1m^2$ was demarcated in each plot and harvested, and the grains weighed to obtain yield per m^2, then converted to grain yield in kg ha^{-1}.

3.7.13 Harvest index (HI)

The harvest index in percentage was determined by dividing the grain yield (Economic yield) by total dry mass (TDM) (Biomass yield) multiplied by one hundred for each plot.

The harvest index was calculated using the relation hereunder

$$Harvest\ Index = \frac{Grain\ yield}{Total\ biomass} X\ 100\% \quad \text{……..…...…….. (5)}$$

The values obtained after the calculation were recorded as harvest index in percent.

3.7.14 P uptake, use and utilization efficiencies

These data were obtained arithmetically from the field collected data. Phosphorus uptake efficiency (PUPE) was determined as a Total P in the plant in mg per plant over available P in the soil, also in mg per plant. P utilization efficiency (PUTE) was determined as grain yield in mg per plant over total P (determined as described in section 3.7.7) in the plant also in mg per plant. And P use efficiency (PUE) was calculated as a product of PUPE and PUTE, or grain weight in mg per plant over available P in the soil in mg per plant.

3.8 Soil and Weather Conditions

3.8.1 Soil characteristics

3.8.1.1 Particle size distribution

Soil particle distribution was determined by haydrometer method. Fifty – one grams of air dried soil was weighed into a 1L screw lid shaking bottle. Hundred millilitres distilled water was added and swirled thoroughly. Twenty millilitres of 30% H_2O_2 was added, followed by 50 ml of 5% sodium hexametaphosphate and drops of amyl

alcohol and swirled gently. It was then shaken on a mechanical shaker for 2 h and the content transferred into a 1L sedimentation cylinder. The first hydrometer reading was recorded after 40 seconds and the first temperature reading was also taken with the help of a thermometer. The 1L sedimentation cylinder with its content was allowed to stand undisturbed for 3 h and the second hydrometer and temperature readings recorded respectively.

Calculations,

% Sand=[H1+0.2(T1-20)-2] x2……..(6)

%Clay=[H2+0.2(T2-20)-2] x2……..……..(7)

%Silt=[% Sand+% Clay] …….……..(8)

Where,

H1 = 1st hydrometer reading at 40 seconds

T1 = 1st temperature reading at 40 seconds

T2 = Temperature reading at 3 hours

H2 = 2nd hydrometer reading at 3 hours

Soil texture influences nutrient availability within the crop growing environment. The texture of the soil also influences the porosity which in turn influences the storage of air and water and their rate of movement (air and water). The soil textural class of the soil in this study is Sandy clay loam (Table 4). Such soil texture implies the soil can hold nutrients, allow air to get in and also store moisture for the crop growth and development (Landon, 1991).

Table 4: Soil characteristics of the experiment site

Soil characteristic	Values	Rating*
Physical		
Soil texture		
Clay (%)	21	
Silt (%)	12	
Sand (%)	67	Sandy clay loamy
Chemical		
pH(H_2O)	6.51	Slightly acidic
Organic carbon (%)	1.08	Very low
Total N (%)	0.11	Low
Extractable P(Bray 1,mg/kg)	3.22	Very low
CEC (cmol/kg)	16.1	Moderate
Exchangable Ca^{2+}(cmol/kg)	6.25	Medium
Exchangable Mg^{2+}($cmol_c$/kg)	1.11	Medium
Exchangable K^{+}($cmol_c$/kg)	0.86	High
Exchangable Na^{+}($cmol_c$/kg)	0.14	Low

*Rating for soil characteristics was according to Landon (1991)

3.8.1.2 Soil pH

Soil pH was determined as described in Section 3.2.1. The pH of the soil influences soil nutrient uptake especially P. The pH of the soil in which the study was conducted was 6.51 (Table 4) which is slightly acidic, and cannot negatively affect soybean nutrients uptake from the soil. Soybean suitable pH in nutrient uptake ranges between 6.0 and 7.5. Sodic and saline soils inhibit germination of seeds. In acidic soils, liming has to be done to raise the pH to about seven.

3.8.1.3 Soil organic carbon

Soil organic carbon was determined as described in Section 3.2.2. Soil organic carbon is crucial in soybean growth and development as it indicates the organic matter of the particular soil which influences the microbial activity in the soil. The organic carbon of the soil in this study ranks very low (Table 4) implying that the soil requires supplement of organic matter to influence microbial activities for optimal crop growth and development.

3.8.1.4 Total nitrogen

Total nitrogen was determined as described in section 3.2.3. Nitrogen nutrition in soybean, as in other legumes, is ensured both by dinitrogen fixation and mineral nitrogen assimilation. Since legume can fix atmospheric nitrogen into usable form, the nitrogen nutrient in the soil is used as a starter nutrient in order to minimize nutrient competition by the microorganisms within the growing environment**.** The total N of the soil in this study ranks low (Table 4) implying the need to apply N as a supplement starter nutrient to minimize competition with microorganisms in the soil.

3.8.1.5 Available phosphorus

Soybean requires relatively large amounts of phosphorus than other crops. Phosphorus is very important nutrient in soybeans growth and development as it offers various significances. It enhances the photosynthesis rate, enzymatic activity, energy transfer, root development, uptake and transfer of other nutrients, nodulation and nitrogen (N)-fixation by symbiotic bacteria, water use efficiency, reproductive growth and maturation, seed number, seed size, and seed germination. It also works with potassium (K) in decreasing damage from several plant diseases**.** In this study the Available P was 3.22mg/kg (Table 4) which ranks very low implying that application of phosphorus will trigger response to the crop.

3.8.1.6 Cation exchange capacity

The total number of cations a soil can hold or its total negative charge is the soil's cation exchange capacity. The higher the CEC, the higher the negative charge and the more cations that can be held. CEC influences when and how often nitrogen and

potassium fertilizers have to be applied. On low-CEC soils (less than 5 meg/20000g), for example, some leaching of cations can occur. Fall applications of ammonium N and potassium on these soils could result in some leaching below the root zone, particularly in the case of sandy soils with low-CEC subsoils. The CEC of the soil in this study ranks moderate (Table 4), therefore the soil is capable of holding nutrients for the plant uptake and so utilization.

3.8.2 Weather conditions

3.8.2.1 Rainfall

The effect of moisture stress on soybean performance is variety-dependent. Absolute yield reductions range from 1.0 megagram per hectare (Mg/ha) or 14.9 bushels per acre in the most sensitive varieties to 0.2 Mg/ha in the least sensitive varieties (Hellal and Abdelhamid, 2012). Soybeans require adequate water during full bloom and during the pod fill stage for maximum yields. The mean rainfall during the time of this study (Fig. 1) was adequate (540mm) for the crop to perform optimally.

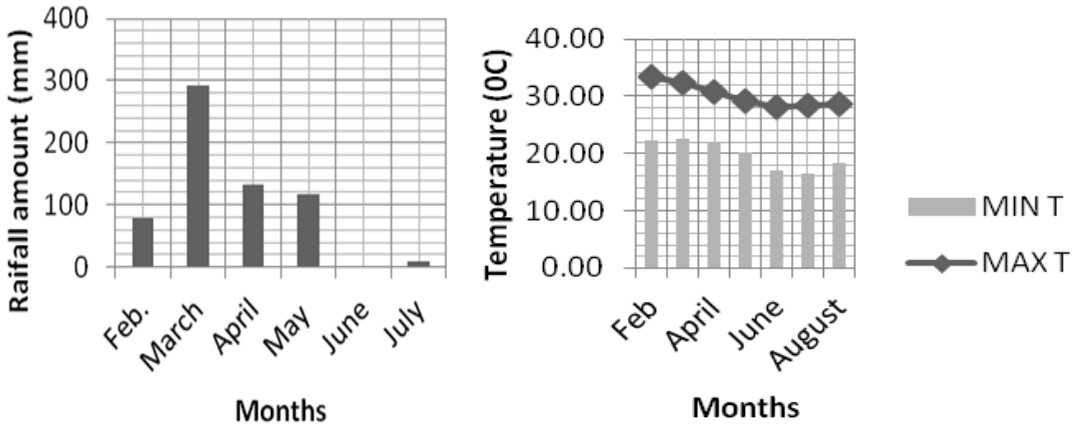


Figure 1: Monthly variation of rainfall and temperature for the whole period of the study (year 2013)

3.8.2.2 Temperature

Soybean grows under a wide range of temperatures, but the optimum for growth and development is 30 ^{o}C whilst for proper emergence of seedlings, a seedbed temperature of 25–33 ^{o}C is optimal. The average temperature of the study area was optimal (Fig. 1) implying that the crop can perform optimally. Soybean is grown under warm conditions in the tropics, subtropics and temperate climates. The crop is relatively resistant to low and very high temperatures but growth rates decrease above 35°C and below 18°C.

3.9 Data Analysis

The collected data were statistically analysed using the analysis of variance (ANOVA) technique as per model below:

$$Y_{ijk} = \mu + \alpha_i + \gamma_k + (\alpha\gamma)_{ik} + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ijk.} \quad \text{.......................................(9)}$$

Where,

Y_{ijk} =Observation from whole plot *i*, block *j*, and sub plot *k*,

μ = Overall mean effect

α_i =the effect of the *i*th level of the whole plot *A,*

γ_k = the effect of kth of the sub plot *k,*

$(\alpha\gamma)_{ik}$ = the interaction effect between whole plot factor and sub plot factor

β_j *jth* =block effect

$(\alpha\beta)_{ij,}$ =the interaction effect between whole plot *i* factor and the *jth* block

ε_{ijk}, =sub plot residual component.

Mean separation test was done using Duncan's New Multiple Range Test (DNMRT) at 5% level of significance.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Tables 5 to 14 and Figures 2 to 14 depict the study results in different categories. Table 4 and Fig. 1 respectively present results of soil analysis done prior to planting and rainfall data collected at TMA rainfall recording centre near the experimental site. Tables 5 and 6 represent the analysis of variance (ANOVA) results of the mean squares indicating the significance according to *F-test* of each of the two treatments i.e. phosphorus levels and genotypes, and their interactions on growth parameters, yield and yield components and nutrient uptake. Table 7 shows the mean effect of genotypes and growth parameters, yield and yield components whereas Table 8 depicts the mean effect of genotypes on growth parameters, yield and yield components as well as N and P uptake of soybeans. Figs. 2 to 14 illustrate the mean effect of interaction between genotypes and phosphorus levels on evaluated parameters.

As shown in the ANOVA (Tables 5 and 6 results, genotypes had highly significant differences for all the evaluated parameters except for seeds per pod ($P \leq 0.05$). Phosphorus concentration, ethylene concentration and days to 95% maturity showed significant differences ($p \leq 0.05$) whereas the rest of the evaluated parameters showed no significant effects following phosphorus application. Plant height, days to 50% flowering, total number of nodules, number of active nodules, days to 95% maturity, pods plant^{-1}, Seeds pod^{-1}, nutrient P concentration, biomass, 100 seeds weight, grain

yield, harvest index and ethylene concentration were not affected by interaction between phosphorus levels and genotypes, however the nutrient N concentration was affected by the interaction of phosphorus and genotypes ($p \leq 0.05$).

4.1.1 Effect of genotypes on growth and yield parameters of soybeans

Results of the effects of genotypes on growth and yield parameters of soybeans are presented in Tables 7 and 8. Mean values of plant height, days to 50% flowering, total number of nodules, number of active nodules, days to 95% maturity, pods plant^{-1}, nutrient N concentration, nutrient P concentration, biomass, 100 seed weight, grain yield, harvest index and ethylene concentration indicate that in each of the 7 genotypes used in the experiment were statistically significantly different from the others ($p \leq 0.05$) using DNMRT. On the other hand, regarding seeds pod^{-1}, all genotypes were statistically similar.

Outcomes of the yield components (pods plant^{-1}, 100 seed weight, grain yield and harvest index) reveal that genotypes A (TGX 1895-33F), C (TGX 1954-1F) and F (TGX 1440-1E) were constantly better than the others, although they were inferior to genotype E (TGX 1844-4E) on the basis of the yield. The genotype E (TGX 1844-4E) produced higher yield as opposed to all other genotypes (1892 kg ha^{-1}) whereas the genotype G (bossier) produced the lowest average yield of all assessed genotypes (541 kg ha^{-1}).

Genotypes F (TGX 1440-1E) and E (TGX 1844-4E) had higher 100 seed weights than the rest of the genotypes, being 15.79 g and 17.41 g respectively. The lowest

100 seeds weight was produced by genotype D (TGX 1844-4E) which produced an average of 12.73 g. Genotypes A (TGX 1895-33F) and E (TGX 1844-4E) produced significantly higher number of pods plant^{-1} (43.25 and 43.75, respectively) than the rest of the assessed ($P \leq 0.05$). Genotype G (bossier) produced the least number of pods plant $^{-1}$ (27.17). On the basis of harvest index (HI), genotypes A (TGX 1895-33F), C (TGX 1954-1F) and E (TGX 1844-4E) had higher harvest index than the rest of genotypes with 47.20%, 52.44% and 55.57% respectively. The lowest harvest index was shown by genotype G (bossier) with 24.60%. The harvest indices of genotypes B (TGX 1895-4F), D (TGX 1871-12E) and F (TGX 1440-1E) were statistically similar at DNMRT's 5% level of probability. On the basis of variables other than growth and yield parameters, there were significant differences ($p \leq 0.05$) between genotypes in nutrient N concentrations, nutrient P concentrations and ethylene concentrations (Table 8).

4.1.2 Effect of phosphorus levels on growth and yield of soybeans

Results on effects of phosphorus levels on growth and yield parameters of soybeans are presented in Table 9. Mean values of plant height, days to 50% flowering, total number of nodules, number of active nodules, pods plant^{-1}, nutrient N concentration, biomass, grain yield, harvest index and 100 seeds weight showed no significant differences among the phosphorus levels ($p \leq 0.05$). However, mean values of seeds pod^{-1}, days to 95% maturity, nutrient P concentration and ethylene concentrations indicated significant differences ($P \leq 0.05$). Phosphorus at 15 kg P ha^{-1} resulted into higher (0.1936%) nutrient P concentration than the other levels. The least values were obtained with 0 kg P ha^{-1} (0.1536%). Statistically, there were no significant

differences among the three levels of P (15, 30 and 45 kg P ha^{-1}). Results for days to 95% maturity showed that 45 kg P ha^{-1} took significantly longer time to reach 95% maturity (99.33 days) and had significantly higher ethylene concentration (6.028 μ mol $C_2H_4h^{-1}g^{-1}$). Results for seeds pod^{-1} showed that 45 kg P ha^{-1} produced slightly significantly higher number of seeds pod^{-1} (2.762) than the rest of P levels i.e. at 0 kg P ha^{-1}(2.429), 15kg P ha^{-1} (2.524) and 30kg P ha^{-1}(2.524).

4.1.3 Effect of interaction of phosphorus levels and genotypes on growth and yield parameters of soybeans

The results on the effect of interaction of phosphorus levels and genotypes on growth and yield parameters are presented in Figs 2 to 14. There were also no significant differences ($p \leq 0.05$) in the interaction of P levels and genotypes on the amount of reduced acetylene, although results show that the combination of 45 kg P ha-1 with genotype A (TGX 1895-33F) produced highest concentration of ethene than the other interactions. However, N concentration seems to have been affected by the interaction between phosphorus levels and the genotypes. The results also show that N concentrations differed significantly ($p \leq 0.05$) with the interactions of phosphorus levels and the genotypes (Fig. 14). The highest values were observed with the combination of 30 kg P ha-1 with genotype C TGX 1954-1F (3.277%) followed by the combination of 45 kg P ha-1 with genotype A (TGX 1895-33F) (3.208%), while combination of 0 kg P ha-1 with genotype A (TGX 1895-33F) was one which resulted in the smallest percentage of N concentration (2.188%).

Table 5: Analysis of variance (ANOVA) results of the mean squares of growth and yield parameters of soybeans

Source of variation	D.F	50% flowering (days)	95% maturity (days)	Plant height (cm)	Total nod./pl	Active nod./pl	Pods/pl	Seeds/pod
Reps								
P level	3	36.83^{ns}	32.857**	7.812ns	16.39$_{ns}$	39.651$_{ns}$	584.0$_{ns}$	0.4246**
Genotypes	6	271.21***	327.611***	1 820.346***	248.43***	121.456***	654.2***	0.1865ns
P level * Genotype	48	28.16^{ns}	4.542^{ns}	9.789^{ns}	16.39^{ns}	16.345^{ns}	130.1^{ns}	0.2765^{ns}
Residual	24	62.59	4.959	21.36	57.64	21.702	395	0.2977
C.V (%)		10.8	1.7	2.3	37.6	33	29.7	19.7

Table 6: Analysis of variance (ANOVA) results of the mean squares of growth and other parameters of soybeans

Source of variation	D.F	Biomass	%P	%N	Red. Ethene ($\mu MC_2H_4/hr/g$)	100 seeds wt (g)	Yield (kg/ha)	HI (%)
Reps								
P level	3	72 082^{ns}	0.007 245***	0.18 640$_{ns}$	4.7399***	1.674^{ns}	17527^{ns}	61.2^{ns}
Genotype	6	1 971 168***	0.005 790***	0.20 388**	11.9 482***	30.356***	2 592 242***	1 352.1***
P level * Genotype	48	73 330^{ns}	0.000 971^{ns}	0.10 080*	0.1 352^{ns}	0.670^{ns}	99258^{ns}	100.6^{ns}
Residual	24	253 916	0.00 144	0.09 891	0.234	1.972	362 794	311.4
C.V (%)		13.5	19.2	8.4	7.9	7.1	29.6	28.7

Note: ***, **, * =significance at 0.1%, 1% and 5% level of significance respectively and *ns*=not significant

Table 7: Mean effect of genotypes on growth and yield parameters of soybeans

Genotype	50% flowering (days)	95% maturity (days)	Plant height (cm)	Total nod/plant	Active nodule/plant	pods/plant	seeds/pod
TGX 1895- 33F	56.2 b	104.92 f	67.71 d	21.50 c	14.500c	43.25b	2.667a
TGX 1895-4F	56.9 b	102.58 e	57.62 b	11.67 ab	8.083 ab	28.00a	2.500a
TGX 1954-1F	55.7 b	100.17 d	73.25 e	18.58 c	8.083 ab	40.25b	2.667a
TGX 1871-12E	55.7 b	96.83 c	61.88 c	13.00 b	9.333 b	30.08a	2.500 a
TGX 1844-4E	55.2 b	95.42 b	58.29 b	13.08 b	7.833 ab	43.75b	2.667 a
TGX 1440-1E	44.6 a	99.42 d	34.08 a	12.08 ab	8.250 ab	30.42a	2.333 a
Bossier	48.3 a	89.00 d	48.88 b	8.00 a	5.667 a	27.17a	2.583 a
Mean	**45.3**	**98.33**	**57.39**	**13.99**	**7.67**	**34.7**	**2.56**
***F*pr**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**0.624**
SED	**4.706**	**0.695**	**1.219**	**2.147**	**1.259**	**4.2**	**0.2057**

Means of the same column followed by the same letter are not significantly different at Duncan's 5% level of significance

Table 8: Mean effect of varieties on growth and other parameters of soybeans

Genotype	Biomass (kg/ha)	%P	%N	Ethene (µmolC_2H_4/h/g)	100 seeds wt (g)	Yield (kg/ha)	HI (%)
TGX 1895- 33F	3083c	0.2136 b	2.830 bc	7.14 c	14.48c	1457c	47.2 bc
TGX 1895-4F	2610b	0.1859 ab	2.746 bc	4.74 a	13.80 bc	1016 b	37.4 b
TGX 1954-1F	3227c	0.2067 b	2.710 bc	6.96 c	14.48 c	1706 cd	52.44 c
TGX 1871-12E	2613b	0.1635 a	2.730 bc	5.31 b	12.73 a	1043 b	39.3 b
TGX 1844-4E	3329c	0.168 a	2.865 c	5.04 ab	17.41 e	1892 d	55.57 c
TGX 1440-1E	2685b	0.157a	2.475 a	5.00 ab	15.79 d	1863 d	36.8 b
Bossier	2199a	0.171 a	2.630 ab	5.096 ab	13.29 ab	541 a	24.6
Mean	**2 820.86**	**0.1 575**	**2.712**	**5.61**	**14.57**	**1 359.73**	**41.89**
***F*pr**	**<0.001**	**<0.001**	**0.003**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
SED	**155.7**	**0.0142**	**0.0926**	**0.018**	**0.42**	**148.4**	**4.91**

Means of the same column followed by the same letter are not significantly different at Duncan's 5% level of significance

Table 9: Effect of Phosphorus levels on growth and yield parameters of soybeans

P level (kg PHa^{-1})	50% flowering (days)	95% maturity (days)	Plant height (cm)	Total nod./pl	Active Nod.	Pods/pl	Seeds/pod
O	52.19 a	96.52 a	58.38a	12.76 a	8.000 a	32.8a	2.429a
15	52.00 a	98.52 b	59.12a	14.76 a	10.905b	29.33a	2.524a
30	54.48 a	98.95 b	59.52a	14.48a	10.524ab	34.7a	2.524a
45	54.29 a	99.33 b	58.24a	13.95a	8.85ab	41.8 a	2.762b
Mean	**53.24**	**98.33**	**58.82**	**13.99**	**9.57**	**34.66**	**2.560**
***F*pr**	**0.375**	**0.003**	**0.623**	**0.666**	**0.095**	**0.212**	**0.010**
SED	**1.682**	**0.443**	**1.089**	**1.685**	**1.057**	**5.25**	**0.0645**

Means within columns followed by the same letter are not significantly different at $P \leq 0.05$

Table 10: Effect of phosphorus levels on growth and other parameters of soybeans

P level (kg Pha^{-1})	Biomass (kg/ha)	%P	%N	Red. Ethene ($\mu MC_2H_4/hr/g$)	100 seeds wt (g)	Yield (kg/ha)	HI (%)
O	2741a	0.1 536 a	2.700ab	4.955a	14.94 a	1243a	43.34 a
15	2873a	0.1 918 b	2.660a	5.600b	14.59 a	1195a	39.45 a
30	2854a	0.1 844 b	2.640a	5.881c	14.46 a	1261a	42.59 a
45	2815a	0.1 936 b	2.848b	6.028c	14.2 a	1218a	42.31 a
Mean	**2820.75**	**0.1 809**	**2.712**	**5.616**	**14.55**	**1 229.25**	**41.92**
***F*pr**	**0.604**	**<.001**	**0.073**	**<0.001**	**0.242**	**0.971**	**0.780**
SED	**101.7**	**0.00 479**	**0.0 673**	**0.0 614**	**0.295**	**148.2**	**3.99**

Means within columns followed by the same letter are not significantly different at $P \leq 0.05$

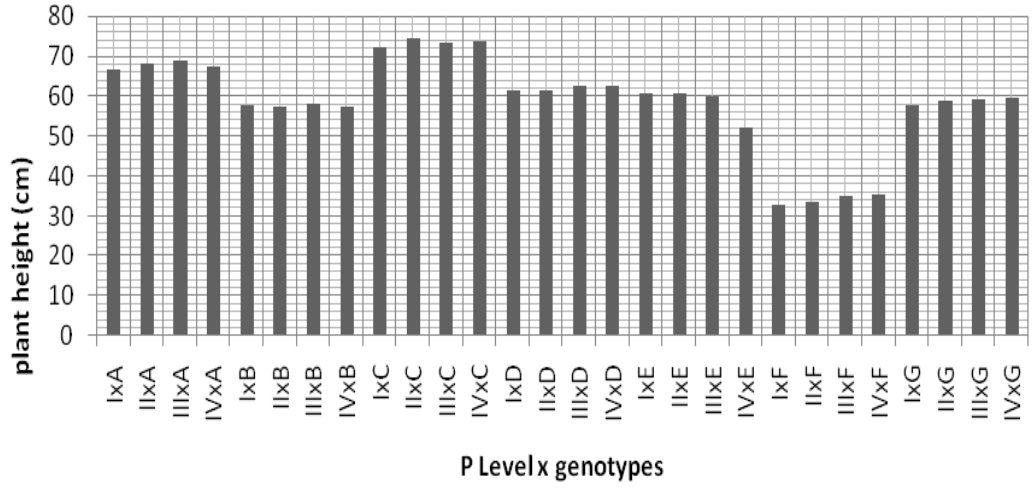


Figure 2: Effect of genotypes and phosphorus levels on plant height

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

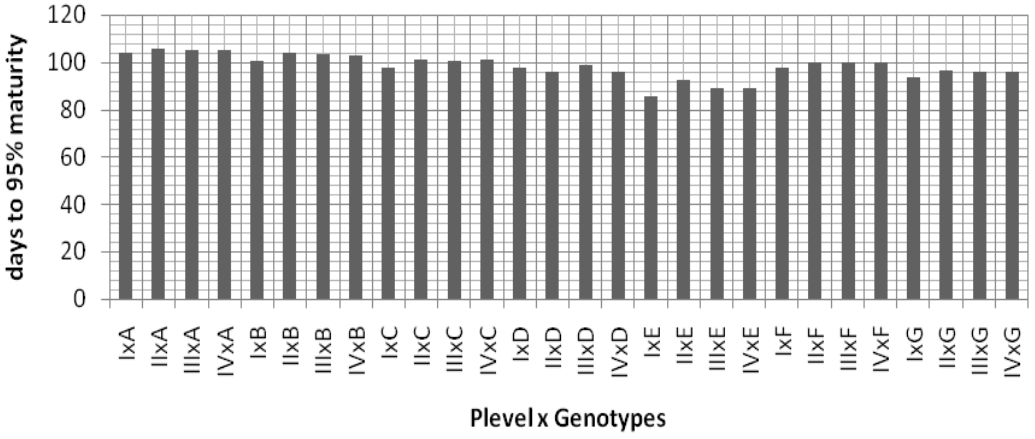


Figure 3: Effect of genotypes and phosphorus levels on days to 95% maturity

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

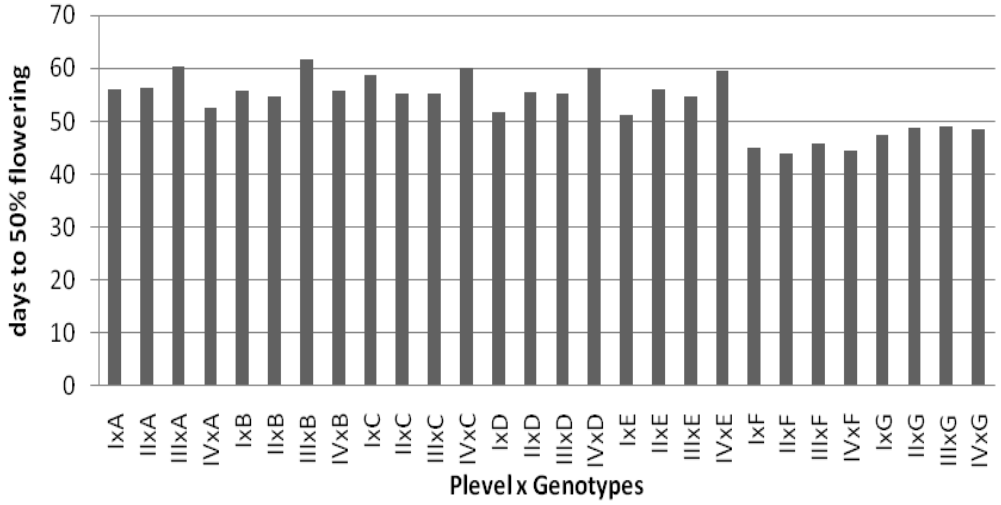


Figure 4: Effect of genotypes and phosphorus levels on days to 50% flowering

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

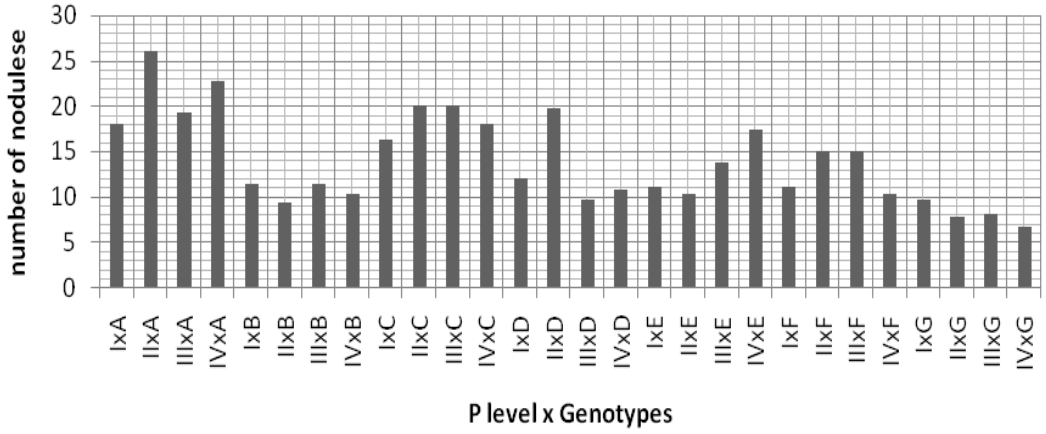


Figure 5: Effect of genotypes and phosphorus levels on number of nodules

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

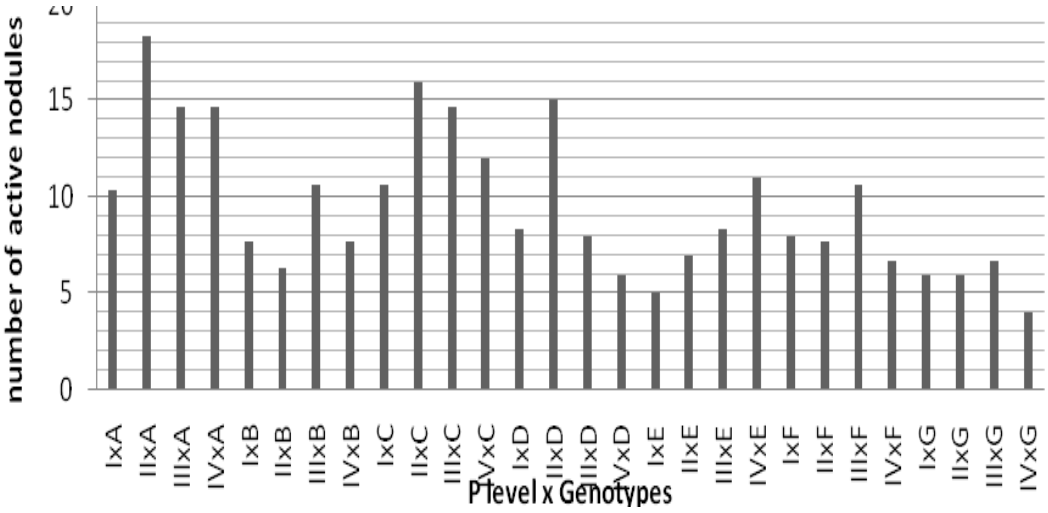


Figure 6: Effect of genotypes and phosphorus levels on active nodules

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

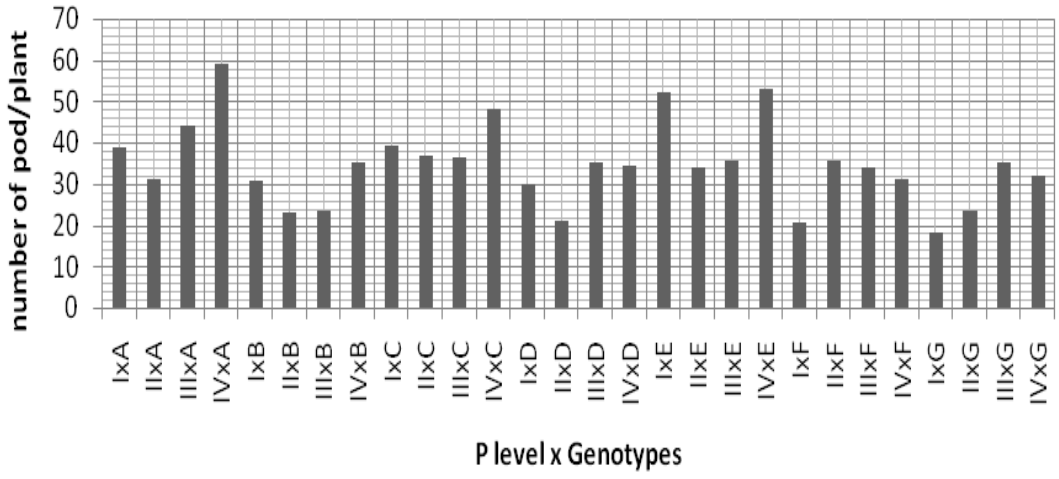


Figure 7: Effect of genotypes and phosphorus levels on pods per plant

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

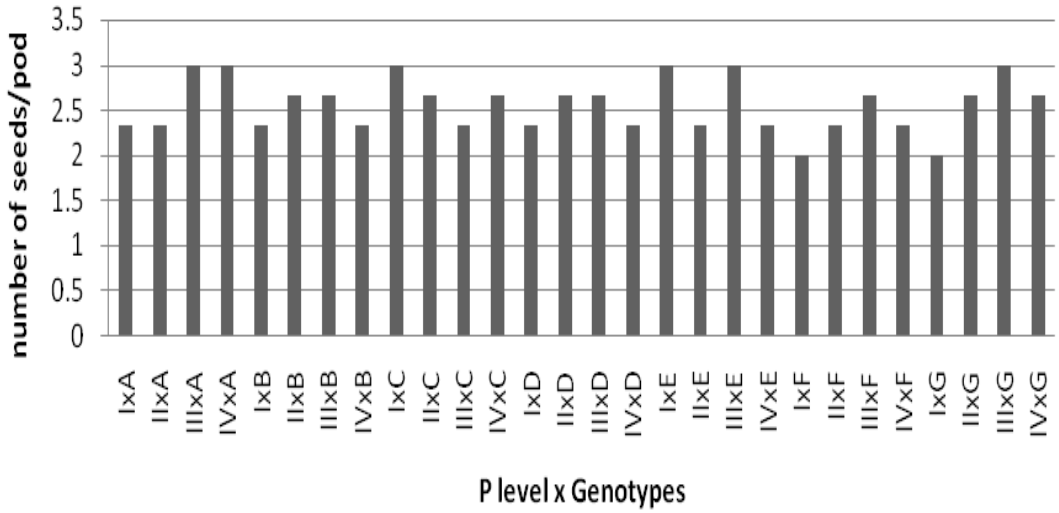


Figure 8: Effect of genotypes and phosphorus levels on seeds per pod

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

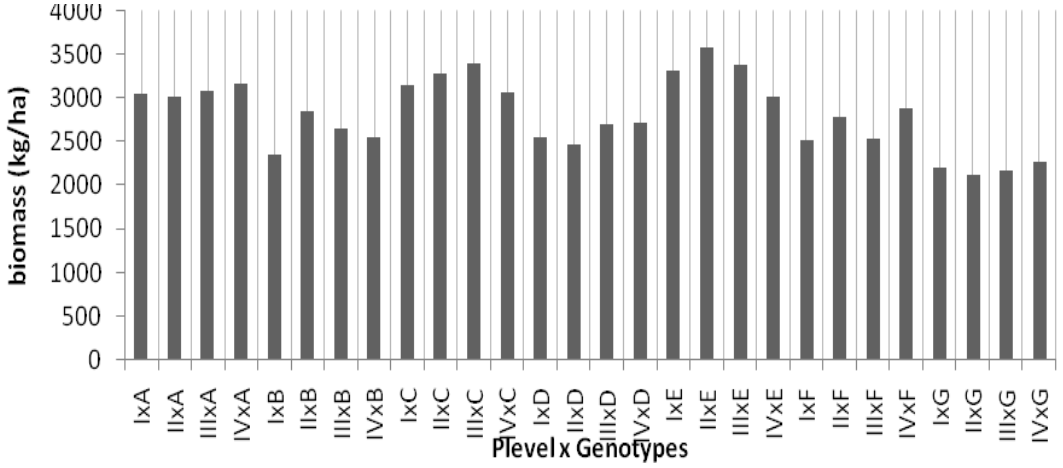


Figure 9: Effect of genotypes and phosphorus levels on biomass

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

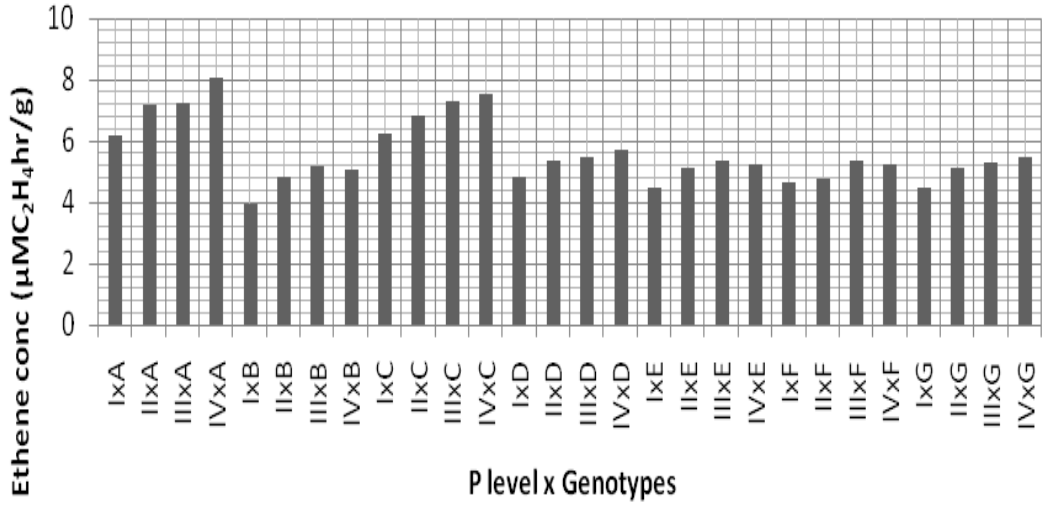


Figure 10: Effect of genotypes and phosphorus levels on N_2 fixation

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

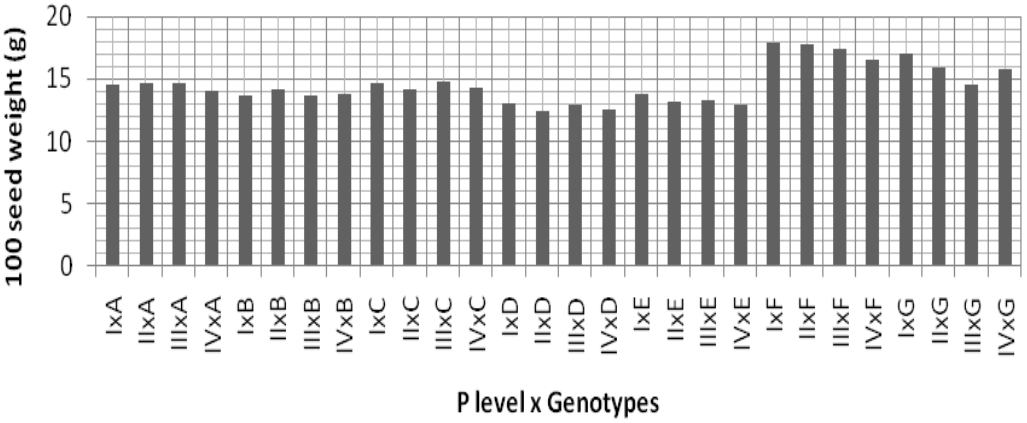


Figure 11: Effect of genotypes and phosphorus levels on 100 seeds weight

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

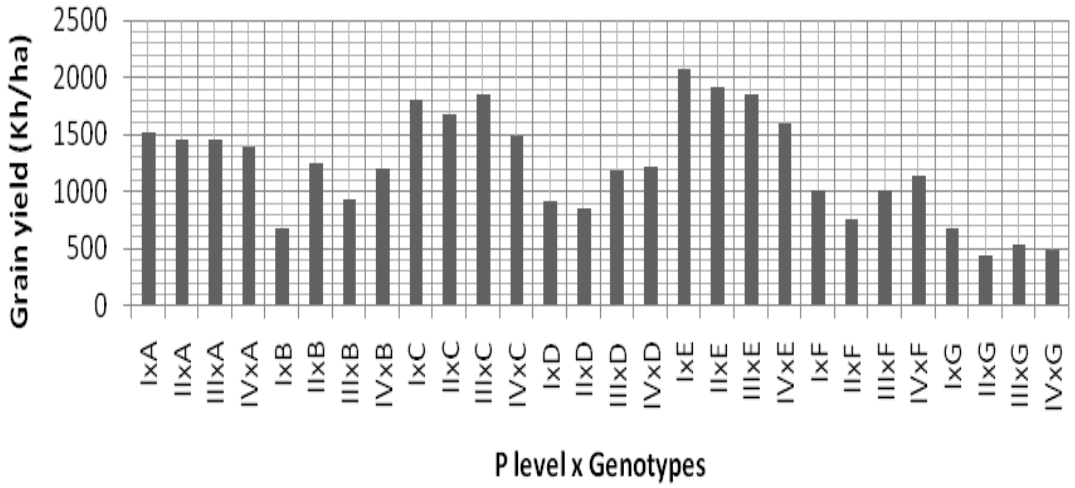


Figure 12: Effects of genotypes and phosphorus levels on grain yield

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier

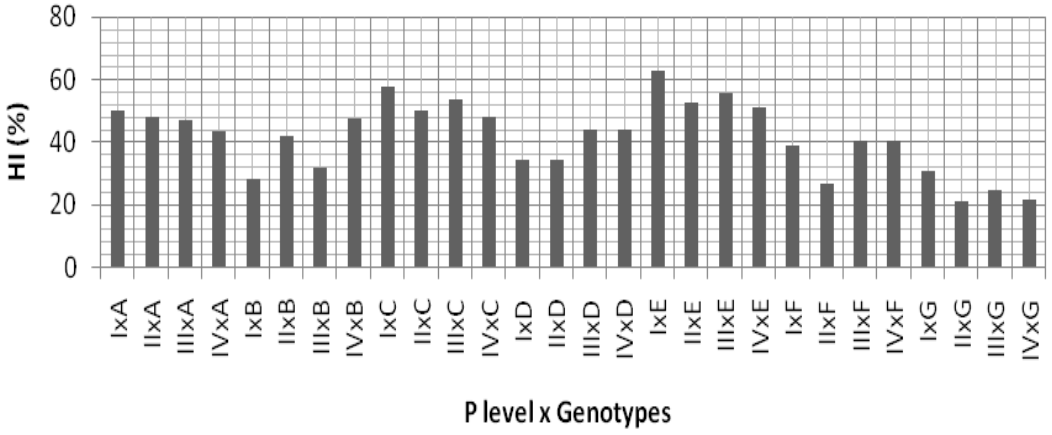
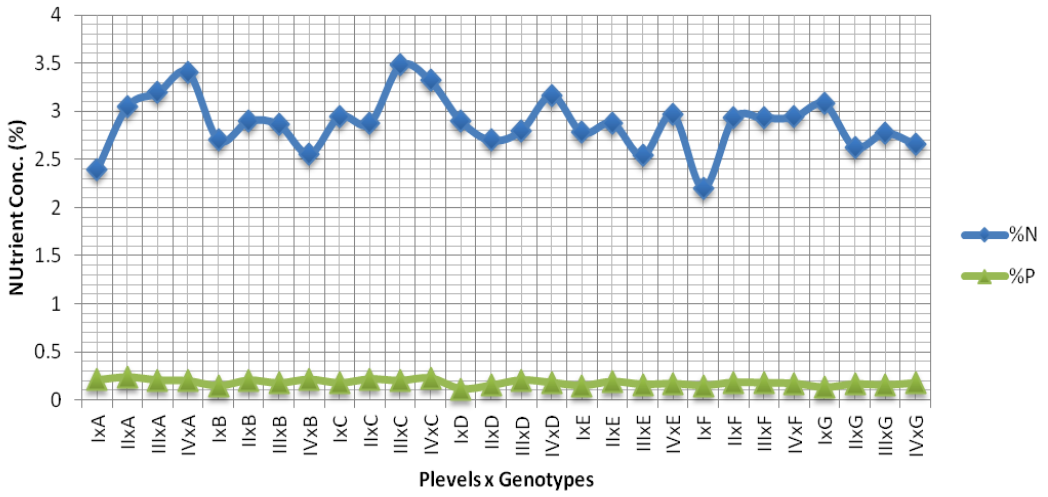


Figure 13: Effect of genotypes and phosphorus levels on harvest index

Note:

I=0 kg P/ha, II=15kg P/ha, III=30kg P/ha, IV=45kg P/ha

A=TGX 1895- 33F, B= TGX 1895-4F, C= TGX 1954-1F, D= TGX 1871-12E, E=TGX 1844-4E, F= TGX 1440-1E, G= Bossier



%N *F*pr=0.03

%P *F*pr=0.596

Figure 14: Effect of interactions of Phosphorus levels and genotypes on P and N (%)

4.1.4 Phosphorus uptake, use and utilization efficiencies

Results of the phosphorus uptake (PUPE), use (PUE) and utilization (PUTE) efficiencies of soybean genotypes are presented in Tables 11, 12, 13 and 14. Mean values of these parameters show that there were significant differences among the genotypes on PUPE, PUE and PUTE. The mean values for PUPE, PUE and PUTE were 0.2949, 76.8 and 239.6 mg P/plant, respectively. The genotypes with high value of PUPE were observed to be TGX-1895-33F and TGX 1954-1F, which respectively had a P uptake average of 0.4064 and 0.3831 mg P/plant. On the other hand genotype bossier (control) had relatively smaller P uptake efficiency of 0.1964 mg P/plant.

With regard to the phosphorus use efficiency, the results in Table 11 depict that genotypes, TGX 1954-1F and TGX 1844-4E, had higher P use efficiencies (109.74

and 123.59 mg P/plant, respectively) as opposed to the other genotypes assessed. Just as it was with the uptake efficiency, Bossier had poor P use efficiency (37.91 mg P/plant). On the aspect of PUTE, TGX 1844-4E recorded higher mean value (340.2 mg P/plant). This genotype was followed by TGX 1954-1F (258.5 mg P/plant) and bossier, which had the least mean PUTE (169. 5 mg P/plant).

Table 11: Mean effect of soybean genotypes on P uptake, Use and Utilization efficiencies (mg P/plant)

Genotypes	PUPE	PUE	PUTE
TGX 1895- 33F	0.4 064c	92.73b	225.0 ab
TGX 1895-4F	0.2 618b	53.37a	200.8 ab
TGX 1954-1F	0.3 831c	109.74bc	258.5 bc
TGX 1871-12E	0.2 193ab	59.56a	255.7 bc
TGX 1844-4E	0.3 353bc	123.59c	340.2 cd
TGX 1440-1E	0.2 616b	60.46a	227.2 ab
Bossier	0.1 964a	37.91a	169. 5 a
Mean	**0.2 949**	**76.8**	**239.6**
S.E.D	**0.02 331**	**10.59**	**66.44**
$LSD_{0.05}$	**0.04 686**	**41.71**	**133.24**

Means within columns followed by the same letter are not significantly different at P≤0.05

Table 12 presents variation of PUPE and PUE under different levels of applied phosphorus. There were no significant variations of PUTE among levels of P applied. The average PUPE, PUE and PUTE were 0.2949, 76.8 and 239.6 mg P/plant respectively. The results show that, soybean genotypes had higher P uptake, use and utilization when there was no P applied.

Table 12: Mean effect of P levels on P uptake, Use and Utilization efficiencies

P levels	PUPE	PUE	PUTE
0	0.4643d	193.03c	283.2 b
15	0.2640c	55.74b	205.0 a
30	0.1457b	34.61a	243.1 ab
45	0.1054a	23.67a	227.0 ab
Mean	**0.2449**	**76.8**	**239.6**
S.E.D	**0.0143**	**6.93**	**25.49**
$LSD_{0.05}$	**0.0349**	**16.95**	**62.38**

Means within columns followed by the same letter are not significantly different at $P \leq 0.0\ 05$

There were also significant differences in the interaction between P levels and soybean genotypes on P uptake and use (Table 13). No significant differences were observed in the interactions between P levels and soybean genotypes on phosphorus utilization efficiency. The highest numerical P uptake efficiency values were however, observed in the interaction of 0 kg P /ha with genotype TGX 1895-33F and 0 kg P /ha with genotype TGX 1954-1F, which had 0.8769 and 0.6872 mg P/plant, respectively. The least P uptake values were recorded in the interaction between 45 kg P/ha with Bossier, which had 0.0786 mg P /plant (Table 13). On the basis of the PUE, the highest values were recorded with the interaction of 0 kg P/ha with genotypes TGX 1844-4E, TGX 1954-1F and TGX 1895-33F which had PUE of 322.93, 281.04 and 235.99 mg P/plant, respectively. Just as it was with PUPE, the interaction of 45 kg P/ha with Bossier also recorded the least PUE (9.45 mg P/plant).

Table 13: Effect of interaction of phosphorus levels and genotypes on P uptake (PUPE), use (PUE) and utilization (PUTE) in mg P/plant

PlevelxGenotypes	PUPE	PUE	PUTE
0*TGX 1895-33F	0.8769i	235.99g	239.6a-e
15*TGX 1895-33F	0.3382e	67.83b-e	206.01-e
30*TGX 1895-33F	0.1774a-c	39.88a-c	234.4a-e
45*TGX 1895-33F	0.1225a	27.22ab	220.1a-e
0*TGX 1895-4F	0.5374f	106.41ef	195.2a-d
15*TGX 1895-4F	0.2736c-e	58.08a-d	207.9a-e
30*TGX 1895-4F	0.1297ab	25.67ab	182.7a-d
45*TGX 1895-4F	0.1063a	23.32ab	217.5a-e
0*TGX 1954-1F	0.6872h	281.04g	325.3d-f
15*TGX 1954-1F	0.3391e	78.32c-e	228.3a-e
30*TGX 1954-1F	0.1893a-c	50.60a-d	269.8a-f
45*TGX 1954-1F	0.1369ab	29.00a-c	210.5a-e
0*TGX 1871-12E	0.4558f	142.17ef	301.6c-f
15*TGX 1871-12E	0.1757a-c	39.93a-c	223.9a-e
30*TGX 1871-12E	0.1514a	32.56a-c	226.4a-e
45*TGX 1871-12E	0.0945a	23.56ab	271.0a-f
0*TGX 1844-4E	0.5765g	322.93g	422.6f
15*TGX 1844-4E	0.3193de	89.56de	276.6a-f
30*TGX 1844-4E	0.1535ab	50.79a-d	361.1ef
45*TGX 1844-4E	0.1032a	31.07a-c	300.3b-f
0*TGX 1440-1E	0.5884fg	156.39fg	262.0a-e
15*TGX 1440-1E	0.2361b-d	35.47a-c	154.8a-c
30*TGX 1440-1E	0.1258a	27.88ab	256.2a-e
45*TGX 1440-1E	0.0962a	22.10ab	235.9a-e
0*Bossier	0.4485f	106.29ef	236.1a-e
15*Bossier	0.1657ab	21.01ab	137.5ab
30*Bossier	0.0929a	14.88a	171.0a-d
45*Bossier	0.0786a	9.45a	133.4a
Mean	**0.2949**	**76.8**	**239.6**
***F*pr**	**0.001**	**0.001**	**0.971**
S.E.D	**0.04571**	**20.89**	**66.4**

Means within column followed by the same letter are not significantly different at P≤0.05

4.1.5 Simple correlation analysis of P uptake, use and utilization efficiencies and yield components

Simple correlations between soybean phosphorous uptake (PUPE), use (PUE) and utilization (PUTE) were done as indicated in Table 14. Linear relationships among soybean components and PUPE, PUE and PUTE were established. The most significant and positive correlation was observed between PUE and PUPE(r= 0.92).

The results also show that soybean PUTE was highly and positively correlated with grain yield (r=0.73). Furthermore, results show that soybean P use was highly and positively correlated with grain yield (r=0.55). Positively and highly significant linear correlation was also recorded by number of active nodules with nitrogen fixation (r=0.55). However, the results show presence of negative correlations among various soybean components. Negative correlations were recorded from the following components; 100 seeds weight with PUTE (r=-0.14ns), N_2 fixation with PUE (r=-0.15ns), 100 seeds weight with grain yield (r=-0.13ns), N_2 fixation with P utilization (r=-0.06ns), pods/plant with P uptake (r=-0.02ns), 100 seeds weight with pods/plant (r=-0.20ns), and number of active nodules with P use (r=-0.03ns). All the negative correlations were however insignificant ($P \leq 0.05$).

Table 14: Simple correlations on yield and other soybean parameters assessed

	Yield (kg/ha)	**Biomass (kg/ha)**	**Pods/plant**	**100 seeds wt(g)**	**Active nodules**	**% N**	**N fixation**	**P uptake**	**P use**	**P utilization**
Yield (kg/ha)	1									
Biomass (kg/ha)	0.8 009**	1								
Pods/plant	0.4 352*	0.2945**	1							
100 seeds wt(g)	-0.1 273ns	-0.0858ns	-0.1 978ns	1						
Active nodules	0.3 968***	0.2 943**	0.1 622ns	0.0 309ns	1					
% N	0.0 040ns	-0.0576ns	-0.1 216ns	0.1 947ns	0.0843ns	1				
N_2 fixation	0.3 080**	0.3 772***	0.3 446***	-0.1 007ns	0.5 477***	0.0 468ns	1			
P uptake	0.2 703***	0.2 218*	-0.0 152ns	0.0 966ns	-0.0 246ns	0.3 389***	-0.1 480ns	1		
P use	0.5 452***	0.3 035**	0.1 472ns	0.0 298ns	-0.0 318ns	0.2 149*	-0.1 511ns	0.9 226***	1	
P utilization	0.7 293***	0.3 527**	0.3 549***	-0.1 446ns	0.1 518ns	-0.0 900ns	-0.0 594ns	0.2 576*	0.5 153***	1

NOTE:

*, **, *** significant at 5%, 1% and 0.1% respectively, *ns*=not significant

4.2 Discussion

4.2.1 Soil characteristics of the experimental area

The results of the soil analysis (Table 4) show that the area is characterised by sandy clay loamy soil type with pH of 6.51 (slightly acidic). Soil pH is a general indicator of the balance between soil acidity and the cation elements calcium, potassium, magnesium and sodium. Soil pH has a dramatic impact on plant growth and soil microbial activity. A pH of 7.0 is neutral. Below 7.0 the soil is considered acidic; above 7.0 the soil is alkaline. Most plants, and all beneficial soil microbes, do best when the pH is between 6.0-6.5, slightly acid (Landon, 1991). Therefore, this soil pH is optimum for soybean growth and development.

The soil had extractable P of 3.22 mg kg $^{-1}$ which Landon (1991) ranked as very low extractable P. Soil with low extractable P requires P supplementation, although the pH of the particular soil should be taken into account because P availability is greatly affected by the soil pH, which should be maintained between 6.0 and 6.5. If pH levels are outside this range, the soil will require supplementation with P, even though the soil test may show adequate levels (Landon, 1991). Organic carbon of the soil in the experimental area shows that the soil had very low organic carbon (1.08%), which is equivalent to 1.85% organic matter. Soils with low organic matter do not have enough essential food (carbon) to feed the micro and macro organisms, which provide all fertility to plants (Brady, 2002). It is therefore advisable to add organic matter and humus at least once a year to most soil, more often to soils with very low (less than 2%) OM content (Marschner, 1995). The two best ways to increase the OM are to add compost and to grow cover crops.

The soil had the CEC of 16.1 c mol kg $^{-1}$ soil, which is categorized as moderate, implying that the soil has capacity to hold nutrients. Marschner (1995) reported that the CEC in good quality soils ranges from about 15 to 30 or 40 milliequivalent per 100 gm (meq/100g). Soils with CEC below 15 have little capacity to hold cations and prevent their leaching. In these soils it is necessary to add any cations that are low, i.e. add smaller amounts more frequently, since large amounts will merely leach out of the soil before the plants and microbes can make use of the nutrient (Richardson, 1994).

The soil of the study area is also characterised to have the exchangeable bases of 6.25, 1.11, 0.86 and 0.14 c mol kg^{-1}of soil for Calcium, Magnesium, Potassium and Sodium respectively (Table 4). All of these positively charged cation minerals are competing for positions on the negatively charged clay and humus particles in the soil. There is an optimum balance of these cationic elements, and maximum biological activity and plant growth will occur when this balance is achieved. For the cations mentioned, the optimum balance for many soils is approximately 0.3-0.6 K, 0.5-1.5 Mg, 5-10 Ca, and 0.3-0.7 c mol kg^{-1} Na (Landon 1991).

4.2.2 Weather

Figure 2 shows that rainfall was high during the first month of the experiment with the average of 290 mm, and declined towards the end of the experiment allowing the crop to reach physiological maturity without encountering any moisture obstacles. The total amount of rainfall during the experiment (from planting to harvesting) was 540 mm which was distributed evenly. For maximum production of soybeans rainfall

requirement should be between 450 to 700 mm in a season (FAOSTAT, 2011). The particular rainfall distribution would probably have an influence in N_2-fixation as well as P availability in soil such that the potential genotypes could be to uptake P. Generally, the field crop performance was fairly good and was not affected by weather in the experimental area (plate 1).

Plate 1: Soybean general performance at week 3 (Left) and week 8 (Right) after emergence

With regards to temperature, the weather data indicate the average maximum and minimum temperature of 32.5 ^{o}C and 16 ^{o}C, respectively. IITA (2011) reported that soybean grows under a wide range of temperatures, but the optimum for growth and development is 30 ^{o}C whilst for proper emergence of seedlings, a seedbed temperature of 25–33 ^{o}C is optimal. Soybean is grown under warm conditions in the tropics, subtropics and temperate climates. The crop is relatively resistant to low and very high temperatures but growth rates decrease above 35°C and below 18°C. In some varieties, flowering may be delayed at temperatures below 24°C. Minimum temperature for growth is about 10°C and for crop production is about 15°C (FAOSTAT, 2011).

4.2.3 Performance of soybean genotypes

Based on the mean difference comparison on the evaluated genotypes, it was reported that genotypes C (TGX 1954-1F), E(TGX 1844-4E) and F(TGX 1440-1E) were better than the others in terms of yield and yield components. The genotype E (TGX 1844-4E) was best in terms of yield (1892 kg ha^{-1}), while Bossier was the least in yield (541 kg ha^{-1}). Variations in crop yields have been explained by different scholars. Some environments may be favourable to one variety and the same may be unfavourable to the other. The study conducted by Punto and Lantican (1992) in mungbean concluded that when one genotype is observed to be high yielding in the favourable environment and the other is unstable in yield in the same environment, the implication is that the stability in yield is of genetic influence. Genotype E also was observed to be better on the basis of nutrient uptake as it was leading other genotypes on N uptake (2.865%).

The least efficient genotype in N uptake was F (TGX 1440-1E), which had percentage nutrient concentration of 2.475 %. As far as N_2 fixation is concerned, genotypes TGX 1895-33F and TGX 1954-1F converted higher amounts of atmospheric nitrogen into usable form than the rest of the genotypes. Means of the reduced acetylene were 7.14 and 6.96 μ mol $C_2H_4h^{-1}g^{-1}$ for genotypes TGX 1895-33F and TGX 1954-1F, respectively. The findings comply with study conducted by Vance (2001) on legumes. The variation in N_2 fixation is due to differences existing among genotypes in nodules number, weight, speed of nodulation and acetylene reduction activity, which collectively have influence in N_2 fixation.

4.2.3.1 Performance of soybean genotypes on growth parameters

The results from analysis of variance show significant effects of genotypes. Genotypes differed in terms of days to 50% flowering. The period ranged from 44.6 (TGX 1440-1E) to 56.2 (TGX 1895-33F). Variations in days to 50 per cent flowering in soybeans were also observed in a study conducted by Purnima *et al*. (2008). Similar results have been reported bay Manjaya and Bapat (2008). Salient reason attributed to such differences in days to 50 per cent flowering among the genotypes is that the character is dependent on a gene that controls the quantitative traits of the genotypes, a minor gene complex (More, 2008). The environmental conditions also have selective influence on flowering.

The genotypes also exhibited different plant heights. Tallest plants were from TGX 1954-1F (73.25 cm) while the shortest plants were from Bossier (34 cm). Based on plant height, the genotypes can be grouped into two categories as short (two genotypes) and tall (five genotypes). Similar results have been reported by Tarasatyavathi *et al*. (2004) and Manjaya and Bapat (2008) in soybean. Broad variation in plant height was probably due to variations in the biophysical characters in the environment where the genotypes were planted.

The genotypes exhibited variation in the number of days towards physiological maturity. The longest days to 95 % maturity were observed with genotype TGX 1895-33F (104.92 days) while the earliest was bossier which took 89 days. Similar findings have been reported by Panthee and Pantalone (2006). Govindarao (2010) reported that growth characteristics differ among soybean genotypes due to the fact

that the characters are dependent on a minor gene complex. So the variations in days to physiological maturity observed in this study would have been due to due genetic differences.

4.2.3.2 Performance of genotypes in yield and yield parameters

There were highly significant variations among genotypes ($p \leq 0.05$) in yield and yield parameters except for the seeds pod^{-1}. Number of pods per plant is among the most important yield component that influenced yield variation in soybeans. The number of pods per plant varied among genotypes and ranged from 27.17 (bossier) to 43.75 (TGX 1844-4E). Genotypes A (TGX 1895-33F) and E (TGX 1844-4E) gave high number of pods per plant than the others while Bossier was the. Genotypic variation in this character has also been also been reported by Rasaily *et al*. (1986), Chowdhary *et al.* (2002). The variation in pod number may be due to differences in pod bearing ability of the genotypes in response to environmental conditions and nutritional status of the soil.

On the basis of 100 seeds weight, E (TGX 1844-4E) was the heaviest. Differences in 100 seeds weight were also reported by Muhammad *et al*. (2006). Variation in seed weight may also be caused by variation existing in the seed architecture. Seeds of a certain crop may vary in their morphology and hence exerting differences in their weights (Mahmood, 2008). Grain yield per hectare variation among genotypes could be classified into low yielding and high yielding whereupon TGX 1844-4E represented highest yield (1.89 t/ha) and Bossier the lowest (0.57t/ha). Genotypic variation in grain yield is extensively reported (Reddy *et al*. (1989); Purnima *et al*.

(2008); and Zafar *et al.* (2008)). The differences in grain yield seem to have depended upon days to maturity among other parameters. Late and early maturing genotypes gave high and low grain yields, respectively. This could be due to heritable characters of the genotypes, seed size, influence of cultural practices and environmental conditions and more importantly differences in percent field emergence.

4.2.3.3 Phosphorus uptake, use and utilization efficiencies and N_2 fixation

PUPE measures the ability of the plant to absorb the available P in the soil. It is defined as the ratio of total P in the plant (grain+straw) per unit of P available in the soil. The mean value for PUPE at the high and low P level was 0.11 and 0.66, respectively (Table 12). The differences in PUPE among the genotypes across P treatments show the diversity in efficiency with which soybean plants are able to absorb phosphorus from the soils of varying availability. Similar findings were reported by Mourice and Tryphone (2012) in common beans. Values in this study are higher than those obtained by Baligar *et al.* (2001) on P recovery studies. The main reason accounting for this is the fact that soybean root system can grow much deeper than 20cm from top soil (Liu *et al.,* 2008). Genotypes TGX 1895-33F and TGX 1954-1F had higher mean values of PUPE as compared to other genotypes tested (40.6 % and 38.3% of P was extracted by genotypes TGX 1895-33F and TGX 1954-1F, respectively, while the smallest mean value (19.6%) was extracted by Bossier). The differences in uptake is due to the fact that the genotypes differ in their uptake potential with differences in the root morphology and architecture, root symbiosis, and root exudation of organic acids into the rhizosphere, which had been proposed to

increase P availability to the plant by mobilizing the sparingly soluble mineral P and, possibly, organic P sources (Dong *et al.,* 2004). These findings comply with the findings obtained by Ashok (2002); Furlani *et al*. (2002), Kajjidoni *et al.* (2002), Sharma *et al.* (2011) and Machado and Furlani (2004). The interactions effect of P level and genotypes has shown to be significant ($p<0.001$) on the P uptake aspect.

The interaction involving 0 kg P/ha with genotypes TGX 1895-33F had the highest value of P uptake (87.6%) followed by the interaction between 0 kg P/ha with genotype TGX 1954-1F which had the mean value of PUPE of 68.7% (Table 13). This implies that at a very low available P in the soil the genotypes were developing an adaptation mechanism to extract as much P as they could from the low P soil. Phosphorus use efficiency is the product of PUPE and PUTE. It measures the amount of grain produced (mg plant^{-1}) per unit of available P in the soil (mg plant^{-1}). The mean value for PUE at for four P levels in the soil where the study was conducted is 76.8, while lowest PUE at 45 kg P/ha. The observation is contrasted with that reported by Kakar *et al*. (2002) who found that PUE in two soybean genotypes increased with an increased P application rates. Higher PUE value was recorded by genotypes at 0 kg P/ha than the rest of applied levels of P. This implies that genotypes were efficient at low than at high P levels applied in this experiment. Also it implies that applied P was rendered unavailable for the plant uptake and therefore use and utilization. Highest mean values of P use were observed with genotype TGX 1844-4E and TGX 1954-1F with the P use value of 123.59 and 109.74, respectively (Table 11). The interaction between P levels and genotypes also had significant effect on P use efficiency whereby the highest values of PUE were recorded by the

interaction of 0 kg P /ha with genotype TGX 1844-4E (322.9mg P/plant) followed by TGX 1895-33F (236.0 mg P/plant). The lowest PUE values were recorded by the interaction between 45 kg P/ha with Bossier which had the mean value of (9.45 mg P/plant). The variation in PUE in the interactions between P levels and genotypes was probably due to the genetic differences existing between genotypes.

PUTE measures the amount of grain produced (mg plant^{-1}) per unit of P absorbed by the plant (grains + straw), also in mg plant^{-1}. The interactions between P levels and soybean genotypes had no effect on the PUTE, although numerically the interaction of 0 kg P /ha with TGX 1895-33F had highest PUTE (239.6 mg P/plant) compared with other interaction combinations. The least mean value of P utilization efficiency was recorded by the interaction of 45 kg P/ha with Bossier. Higher mean values of PUTE indicate the ability of the genotypes in converting the available P in the soil into dry matter. The findings from this study comply with the study conducted by Gourley *et al*. (1993) who reported that the mechanisms of P efficiency should only be investigated after certain criterion has been satisfied. Basically, a truly efficient genotype could require less nutrients than an inefficient genotype. The results of this study show that the genotypes that emerged to have higher P efficiency i.e. use, uptake and utilization were the ones that received less or no nutrients applied. With regards to nitrogen fixation, effective genotypes were identified by the amount of ethene produced during the process of determination. The genotypes with higher values of ethene produced were categorized as more efficient in N_2 fixation than the others. The mean values of reduced ethylene were highly affected by P levels and genotypes.

The results depicted that genotypes TGX 1895-33F and TGX 195-1F fixed higher amounts of the N_2 than the other genotypes assessed, with value of 7.14 and 6.96 µmol $C_2H_4h^{-1}g^{-1}$, respectively. With respect to the different levels of P applied to the soybeans, it showed that the genotypes fixed higher amounts of nitrogen at a rate of 45 kg P/ha and 30 kg P/ha with mean values of 6.03 and 5.88 µmol $C_2H_4h^{-1}g^{-1}$, respectively. The least value of produced ethylene was recorded with 0 kg P/ha (4.96 µmol $C_2H_4h^{-1}g^{-1}$). These findings confirm that phosphorus enhances the symbiotic nitrogen fixation process in legume crops as reported by different scholars. Snapp (1998) reported that the N_2 fixation process requires a readily available source of energy for bacterial growth and the transformation of N_2 into NH_3. Photosynthesis generates the high energy sugars. Phosphorus provides the mechanism for energy storage in the form of ATP and the transfer of that energy source to fuel vital plant functions such as N_2 fixation. The Variation between genotypes in nitrogen fixation was also reported by Sall and Sinclair (1991). The differences of genotypes in nutrient P uptake are due to genotypic variations exhibited by the soybean genotypes evaluated.

4.2.4 Effect of phosphorus levels on growth parameters

The results of this study showed insignificant effects of P levels on the soybean growth parameters. Similar findings have been reported by Ogoke *et al*. (2004), who reported that at sites where responses were observed due to low initial soil test P, 30kg P ha^{-1} application was not different from 60kg P ha^{-1} on plant height, days to 50 flowering, number of pod per plant, pod weight and grain weight, suggesting that applying P at rates above 30kg P ha^{-1} may not be desirable for soybean even when

soil test P is low. Rotaru (2010) showed that the response of applied P was not large, despite the low level of available P in the soil. Growth parameters such as plant height, stem girth, number of branches, nodules weight and nodules number were not significantly influenced by P application. Further, Erhabor *et al*. (1999); Agboola and Obigbesan (1997); Chiezey (2001); and Olofintoye (2007) reported that grain yields in soybean were not significantly influenced by P applied.

4.2.5 Effect of phosphorus levels on yield and yield parameters

Since there were no significant differences of levels of phosphorus fertilizer on the yield and yield parameters ($p \leq 0.05$), the results are in contrast with report of Mahmood (2008) and Mahmood *et al*. (2009) who indicated that P application in soybeans resulted in significantly more number of pods per plant and grain yield. However, Mabapa *et al*. (2010) also found that P fertilizer had no significant effect on grain yield of soybeans. Insignificant differences among levels of P on yield and yield parameters could be due to effects of P availability in the soil for effective plant uptake. Nutrient availability in soils is characterized by complex interactions between the nutrients and other chemical components of the soil. P availability to plants is affected by several factors such as precipitation and pH, which prevent nutrients availability due to soil fixation. Since pH of the soil was found to be optimum for the nutrient uptake, the insignificant response could probably be caused by poor rainfall distribution during the effective growth stage for the nutrient uptake. Schachtman *et al*. (1998) reported that in many agricultural systems in which the application of P is necessary to ensure plant productivity, the recovery of applied P by crop plants during a growing season is low because more than 80% of the P

becomes immobile and unavailable for plant uptake as a result of adsorption, precipitation, or conversion to the organic form. So this could be the reason as to why no significant differences were observed among P levels on the yield and yield parameters among the soybean genotypes assessed.

4.2.6 Effect of phosphorus levels on plant nutrient uptake

The highest concentrations of P uptake by soybean genotypes were observed with the rates of 45 kg P ha^{-1} (0.1936%), 15 kg P ha^{-1}(0.1918%) followed by 30 kg P ha^{-1}(0.1844%). Basically, mean differences between 15, 30 and 45 kg P ha^{-1} were insignificant. Similar findings have been reported by Furlani *et al.* (2002) and Sharma *et al*. (2011). The variations in nutrient P uptake are likely to be due to variations in soil characteristics within the experimental site. On the basis of nutrient N uptake, slightly significant differences ($p \leq 0.05$) were observed. Genotypes observed to uptake higher amount of N at 45 kg P ha^{-1} (2.848%) followed by at 0 kg P ha^{-1}(2.700%). The mean differences among all P levels were insignificant. Sharma *et al*. (2011) reported that the application of P on soybean improved the efficiency of cultivars in accumulating N and K. Therefore, this difference, though insignificant, might have been caused by the applied P.

4.2.7 Significance of interactions (phosphorus levels and genotypes)

The ANOVA results (Table 5 and 6) show that the only variable observed to be significant ($p \leq 0.05$) on the basis of the interaction of genotypes with phosphorus levels was N uptake. All variables, i.e. growth parameters, yield and yield parameters, were associated with reduced concentrations and P uptake. Though

statistically ($p \leq 0.05$) the variables were not observed to be affected by the interaction effect, the values of the variables differed from one another (Fig 1 to 13). On the basis of N uptake, the highest percentages were observed from the interaction III (30 kg P ha^{-1}) x C (TGX 1954-1F) and IV (45 kg P ha^{-1}) x A (TGX 1895-33F) with nutrient N concentrations of 3.277% and 3.208%, respectively.

4.2.7.1 Effect of interactions on growth parameters

There were no significant interactions among phosphorus levels and soybean genotypes on the growth parameters ($p \leq 0.05$). The interactions of phosphorus levels and the genotypes did not statistically influence any of the growth parameters. Similar observations have reported by Mahmood *et al*. (2009) on soybeans and DeLong *et al*. (2002) in wheat.

4.2.7.2 Effect of interactions on yield and yield parameters

There were no significant interactions on yield and yield components of soybean genotypes ($p \leq 0.05$). Similar observations have been reported by Mahmood *et al*. (2009) in soybeans and Ndomondo (2008) in common beans. Mahmood *et al.* (2009) found that there were no significant interaction effects among phosphorus levels and soybean genotypes in one season (2003); however, results contrasted sharply with results of the following season (2004). The reason behind these contrasting findings were explained as being due to seasonal weather variations, particularly rainfall distribution, which also influenced P availability and hence uptake by specific soybean plants. Thus, absence of interaction effects on yield might be due to P being rendered unavailable for plant uptake.

4.2.7.3 Effect of interactions on plant nutrient uptake

The results of ANOVA have shown that the interactions between phosphorus levels and genotypes affected slightly N uptake. The data revealed that the lowest value (2.088%) of N uptake was observed the combination of 0 kg P ha^{-1} and genotype TGX 1440-1E, implying that this genotype was poor in nutrient uptake under low phosphorus soils and thus requires high fertilizer P input in order to show high nutrient N uptake from the soil. The reason behind the significant differences in the interactions of P levels and soybean genotypes on N uptake has not been clearly described by previous researchers. This could probably be due to genotype's compatibility with that rate of P (30 kg P ha^{-1}) to favour higher nutrient uptake than the other rates of P.

4.2.7.4 Simple correlation analysis

Genotypic correlation coefficients help to identify characters that have little or no importance in selection program. They provide basic information extremely useful to the breeder in understanding the species with which they work. From correlation results of this study, P utilization efficiency was positively correlated with grain yield (r = 0.729) implying existence of a relationship of P acquisition among genotypes with their ability to convert it into economic dry matter (Table 13). PUPE was positively correlated with PUE (r=0.923) i.e. the increase in the amount of P taken up by the plant increased the amount of grain produced per unit of available P in the soil.

CHAPTER FIVE

5.0 CONCLUSSIONS AND RECOMMENDATIONS

5.1 Conclusions

The results of the study have shown that two soybean genotypes; TGX 1895-33F and TGX 1954-1F are efficient in P uptake and N_2 fixation, while TGX 1954-1F, TGX 1844-4E and TGX 1440-1E were identified as high yielding genotypes. From this study it is therefore concluded that;

Soybean genotypes differ in P uptake and N_2 fixation characters. Some are ranked as highly efficient while others are ranked as less efficient in phosphorus uptake and hence nitrogen fixation. The difference in nutrient uptake is brought about by the genetic differences existing among genotypes. Thus the development of P efficient technology will benefit resource poor farmers more than development of optimum P level(s), which farmers may not adopt and/or may not have resources to purchase.

5.2 Recommendations

In view of the above conclusion, the study recommends;

i. More emphasis should be placed on growing soybean varieties that are efficient in P uptake and N_2 fixation than increased P fertilizer application. This is because most of the resource poor farmers in the Tropics do not afford use of P in soybeans, because of high price of P fertilizers in local markets

ii. The promising genotypes identified in the study should be maintained in order to ensure their availability for use in upcoming researches at the station

iii. Further studies involving more P rates, growing seasons, planting densities and multiple sites in Kilosa District need to be undertaken before definite recommendations can be made.

iv. Soybean breeders should conduct further studies on promising soybean genotypes on other important attributes such as seed or grain size, oil and protein content, grain color, resistance to diseases, tolerance to drought just to mention the few, before releasing new soybean cultivars.

v. Further studies on soybean genotypes physiology to understand more clearly physiological characteristics of the promising genotypes so identified may yield valuable information especially on aspects such as root morphology and architecture, which actually play an important role in P acquisition phenomenon.

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APPENDICES

Appendix 1: Genotypes used in the experiment with their representative letter

Letter	Genotype name
A	TGX 1895- 33F
B	TGX 1895-4F
C	TGX 1954-1F
D	TGX 1871-12E
E	TGX 1844-4E
F	TGX 1440-1E
G	Bossier

Appendix 2: Weather data during the research period

Month	Week	**Max ^{0}C**	**Min ^{0}C**	Rainfal (mm)
Feb-13	1	33.3	23.1	32.4
	2	31.3	22.2	4.7
	3	32.2	21.4	34
	4	32	20.8	8.4
Mar-13	1	34.6	23	2.3
	2	32.1	22.5	55
	3	32.9	22.8	68.5
	4	30.9	22.3	151.9
Apr-13	1	31	22.3	28.9
	2	30.6	21.9	82.7
	3	30.7	22	17.6
	4	30.4	21.3	3.3
May-13	1	28.9	21.2	39.2
	2	29.3	19.7	31.2
	3	29.7	19.8	6.5
	4	29.3	20.2	40.8
Jun-13	1	28.5	17.4	1
	2	28.5	15.3	0
	3	27.7	17.4	0
	4	28.1	18.8	0
Jul-13	1	28.5	17.7	0
	2	28.2	14.5	0
	3	28.9	15.9	0
	4	28.3	17.3	9
Aug-13	1	26.7	18	0
	2	28.7	18.9	5.3
	3	29.4	17.9	0
	4	29.7	18.8	2.2

Source: TMA station-Ilonga