PHENOTYPING AND YIELD STABILITY STUDIES IN SOYBEAN (*Glycine max* (L.) Merrill) UNDER RHIZOBIA INOCULATION IN THE SAVANNA REGION OF NIGERIA

BY

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PhD/SAAT/2014/541

DEPARTMENT OF CROP PRODUCTION
FEDERAL UNIVERSITY OF TECHNOLOGY
MINNA

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (PhD) IN CROP PRODUCTION

NOVEMBER, 2017

DECLARATION

I hereby declare that this thesis titled: “Phenotyping and yield stability studies in soybean (*Glycine max* (L.) Merrill) under rhizobia inoculation in the savanna region of Nigeria” is a collection of my original research work and it has not been presented for any other qualification anywhere. Information from other sources (published or unpublished) has been duly acknowledged.

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CERTIFICATION

The thesis titled: “Phenotyping and yield stability studies in soybean (*Glycine max* (L.) Merrill) under rhizobia inoculation in the savanna region of Nigeria” by: TOLORUNSE, Kehinde Dele (PhD/SAAT/2014/541) meets the regulations governing the award of the degree of Doctor of Philosophy (PhD) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

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DEDICATION

This work is dedicated to my beloved parents Venerable David Olorunfemi Tolorunse and Mrs Racheal Modupe Tolorunse who laid the foundation for my education.

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ABSTRACT

Despite the importance of soybean in Nigeria, yields on farmers' field have remained relatively low. The crop holds considerable potential for arresting soil fertility decline and enhancing household food nutrition. Therefore, the study was aimed at exploiting soybean genotypes differences, assessing genotype by environment effect on seed yield and rhizobia inoculation. The study was carried out in three agroecological zone of Nigeria at Abuja (Sourthern Guinea Savanna), Igabi (Northern Guinea Savanna) and Gwarzo (Sudan Savanna) during the 2015 and 2016 rainy seasons. Treatments were twenty-four soybean genotypes and three levels of rhizobia inoculation (uninoculated, inoculated with LegumeFix and NoduMax) arranged in a split plot design and replicated three times. Data were collected on percentage emergence, plant height, number of leaves per plant, chlorophyll content, number of days to 50 % flowering, number of branches per plant, number of pods per plant, total biomass yield, above ground biomass, seed yield, harvest index and 100-seed weight. Results indicated that, the variation of genotypes and inoculation on percentage emergence, height, number of leaves, number of branches per plant, total biomass yield, above ground biomass and seed yield were significant ($P=0.05$). In Abuja, TGx 1990- 110FN recorded the highest seed yield of 2717.5 kg ha^{-1} during the 2015 cropping season and TGx 1990-46F gave the highest yield of 2145.9 ka ha^{-1} during the 2016 cropping season. Combined data analysis revealed that TGx 1990-110FN and TGx 1989-45F gave higher seed yield of 2278.3 kg ha^{-1} and 1905 kg ha^{-1} respectively. Also, LegumeFix inoculated plants gave the highest yield of 1988.1 kg ha^{-1} and 2008.3 kg ha^{-1} for 2015 and 2016 cropping seasons. In Igabi, TGx 1989-45F and TGx 1990-110FN plants gave higher seed yield of 2154.5 kg ha^{-1} and 2073.6 kg ha^{-1} in 2015 cropping season, the same genotypes produced 2242.5 kg ha^{-1} and 1961.6 kg ha^{-1} in 2016 cropping season. Combined data showed that both genotypes gave 2198.5 kg ha^{-1} and 2017.6 kg ha^{-1} respectively. Also, LegumeFix inoculated plants produced the highest yield of 2174.5 kg ha^{-1} and 2262.5 kg ha^{-1} in the 2015, 2016 cropping seasons. In Gwarzo, the seed yield among genotypes were similar for both 2015, 2016 cropping season and the combined data. Uninoculated plants produced significantly lower seed yield compared to plants treated with either NoduMax or LegumeFix. The effects of genotypes (G), environment (E) and G × E interactions on seed yield were also significant. Two soybean genotypes (TGx 1989-45F and TGx 1990-110FN) were identified as the most promising in relation to yield stability. Of the three locations, Abuja produced the least interaction effects followed by Igabi and may be most appropriate environments for large scale soybean production. Gwarzo may be appropriate for soybean evaluation as effective selection will be obtained due to relatively uniform performance of the genotypes. It is also necessary to inoculate soybean with *Bradyrhizobium japonicum* inoculants (LegumeFix or NoduMax) in order to enhance productivity in farmer's field.

TABLE OF CONTENTS

Content **Page**

CHAPTER ONE

CHAPTER TWO

CHAPTER THREE

CHAPTER FOUR

CHAPTER FIVE

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of the Study

Soybean (*Glycine max* (L.) Merrill) is a legume native to East Asia perhaps in North and Central China (Laswai *et al*., 2005) and belongs to the family Leguminosea. Soybean has been recognized as one of the premier agricultural crops today, thus it is the best source of plant protein and oil and has now been recognized as a potential supplementary source of nutritious food (Wilcox and Shibles, 2001). It has been found to substitute other sources of good quality protein such as milk, meat and fish. Therefore, it has become very suitable to other protein sources that are scarce or too expensive to afford (Asrat *et al*., 2009).

Soybean contains a good quality protein of 42 % and 19.5 % oil (Wilcox and Shibles, 2001). Soybean protein is considered complete, because it supplies sufficient amounts of the types of amino acids that are required by the body for building and repair of tissues (Jinze, 2010). Essential amino acids found in soybean are methionine, isoleucine, lysine, cystine, phenylalanine, tyrosine, theonine, tryphophan as well as valine (Bellaloui *et al*., 2009). Amino acids are used in the formation of protoplasm, the site for cell division and therefore facilitate plant growth and development. Soybean has been found to have different uses; for example in food industry, soybean is used for flour, oil, cookies, candy, milk, vegetable cheese, leathin and many other products (Coskan and Dogan, 2011).

The pods, stems, and leaves are covered with fine brown or gray hairs. The leaves are trifoliate, having three to four leaflets per leaf, and the leaflets are 6–15 cm long and 2–7 cm broad. The leaves provide the photosynthates needed by the newly formed seeds as they begin filling. As the seeds continue to get bigger, their need for photosynthates will eventually become greater than what the leaves can provide through normal photosynthesis. As this happens, the plants will move carbohydrates and proteins from the leaves and stems into the seeds. This eventually causes leaves to turn yellow and drop, and the stems to turn brown and die. The inconspicuous, self-fertile flowers are borne in the axil of the leaf and are white, pink or purple. The fruit is a hairy pod that grows in clusters of three to five; each pod is 3–8 cm long and usually contains two to four seeds, 5–11 mm in diameter. The height of the plant varies from less than 0.2 to 2.0 m. Soybeans occur in various sizes, and in many hull or seed coat colors, including black, brown, blue, yellow, green and mottled. The hull of the mature bean is hard, water-resistant, and protects the cotyledon and hypocotyl (or "germ") from damage. If the seed coat is cracked, the seed will not germinate. The scar, visible on the seed coat, is called the hilum (colors include black, brown, buff, gray and yellow) and at one end of the hilum is the micropyle, or small opening in the seed coat which can allow the absorption of water for sprouting (Jandong *et al*., 2011).

Plant phenotyping is certainly not an exclusively human activity. In so-called ‘cafeteria experiments’ herbivores such as snails, grasshoppers or deer that are offered equal amounts of leaves of different species show clear preferences for some species, whereas they disfavour others (Pérez-Harguindegu *et al*., 2003). In relation to humans, their ability to phenotype and thereby select for the best-yielding individuals of species for domestication has been one of the prerequisites for the development of human civilisation (Diamond, 1997). Agronomy and ecophysiology have a strong tradition in phenotyping. Agronomic evaluation of different genotypes or cultivars has been routinely conducted for more than a century (Pearson *et al*., 2008). Phenotypic expression of genotype strongly depends on the environment for evaluation in agricultural fields of various geographical locations (Roland and Hendrik, 2012). The routine use of phenotyping in soybean breeding strategies is vital to the understanding of the nature of the different mechanisms that can contribute to sustained crop yields under field conditions. Only then can desired traits be incorporated in an informed manner in soybean improvement programmes.

The terms phenotypic stability, yield stability, and adaptation are often used in different senses. In this regard, Akoura *et al*. (2004) remarked that the concept of stability is in many ways dependent on how the scientist wishes to look at the problem. Depending on the goal and on the character under consideration, two different concepts of stability exist, namely static concept of stability and the dynamic concept of stability (Ufuk and Asli, 2012). Concepts of stability are valuable, but their application depends on the trait considered. With static concept, a stable genotype possesses an unchanged performance regardless of any variation of the environmental conditions. The stable genotype shows no deviation from the expected character means whose variance among environments is zero. In static concept, a stable genotype has a constant performance level whereas the dynamic concept permits a predictable response to environments (Jandong *et al*., 2011). For each environment, the performance of a stable genotype corresponds completely to the estimated level of the prediction. In the dynamic concept of stability, it is not required that genotypic response to environmental conditions is equal for all genotypes. What is important, however, is the agreement of the estimated or predicted level with the level of performance actually measured when defining stability'. Jason and Palle (2008) termed this type of stability the agronomic concept and distinguished it from the biological concept of stability, which is equivalent to the static concept. Numerous methods have been proposed to estimate phenotypic stability or to analyse genotype environment (GE) interactions, which are strongly related to stability according to the dynamic concept.

Among the wide range of possible morphological characteristics that can be used in the selection of soybean varieties for enhanced yield, shoot parameters are generally considered to be the easiest to assess under field conditions (Houle, 2010). Shoot markers remain major targets in breeding programmes, particularly in developing countries, where variations in shoot morphology are often determined subjectively under field or glasshouse conditions (Violle *et al*., 2007). This involves visual monitoring of easily detectable plant characteristics such as the number of leaves per plant or the shoot height. These simple parameters can be measured easily in soybean at different intervals during the growing period, and they can be assessed together with a range of other less easily determined parameters such as dry matter yield per plant (Udensi *et al*., 2010).

Inoculation of legumes is widely practiced and has been found to increase production. Rhizobium inoculation of soybean has been reported to increase growth and seed yield which needs to be expanded (Eutropia and Ndakidemi, 2013).

1.2 Statement of the Problem

Limited numbers of soybean cultivars have enormously contributed to the existing yield gap associated with seed yield in Nigeria savanna agro ecologies**.** Low yield production by farmers which are partly due to biotic and abiotic stresses, including decline in soil fertility, low yield related to high instability in different environments and inadequate access to fertilizer by farmers to address the soil fertility challenges. Soybean yield has been associated with high instability at different environments in the savanna, and the use of stable genotypes, capable of high seed yield is an important objective for sustainable production (Alghamdi, 2009). In Nigeria, soybean yield per hectare in farmer's field is still oscillating between 1 to 2 tonnes across the savanna agro ecological zones, there is need to address this yield gap through this study.

1.3 Justification of the Study

Interest in soybean production in Africa has increased considerably over the past few decades. Nigeria currently is importing vegetable oils for local consumption, thus the introduction of adaptable cultivars will substitute these imports and help in the self sufficiency of such vital commodity. The development of new cultivars with desired characteristics such as high economic yield, tolerance or resistance to biotic and abiotic stresses, traits that add value to the product, and the stability of these traits in target environments will result to increase in yield. The interaction existing between genotypes and the different environments is one of the major impediments in the selection of competitive soybean genotypes for a wide range of cultivation. There is need for the evaluation of promising breeding lines across savanna agro ecological zones that provide stable and high yield for higher economic returns for farmers. This is attributable to a number of factors such as increased utilization of most commercially grown pulses as supplements in livestock feed (Blount *et al.*, 2013), usefulness as a source of cheap quality plant protein (Felton and Kerley,

2004) and the increasingly prohibitive cost of animal protein (Poore, 2003). To satisfy the demand by producers and consumers, a number of soybean varieties with excellent seed quality and agronomic characteristics have been released for cultivation in the tropical Africa (FAO, 2011). This aimed at increasing production and enhancing protein intake for low and middle income earners. Farmers have shown increasing interest in soybean production which has extended to the high rainfall belts of sub-Saharan Africa. Although there is considerable potential for soybean production in these belts, yield varied considerably in farmers' fields (Akparobi, 2009). This is attributable to continous decline in soil fertility, due to deficiency in organic matter and other essential nutrients (Zarei *et al*., 2012).

Inoculation with effective strains of rhizobia results in higher nodulation, nitrogen fixation and more pods per plant which inturn results in higher grain yields (Singh *et al*., 2011). Although soybean could satisfy some of its nitrogen requirement through biological nitrogen fixation, inadequate native rhizobia in soil in sufficient quantity or quality may necessitate inoculation with effective strain of rhizobia. In other studies, Ibrahim *et al*. (2011) reported increase in yield and yield component of legumes by inoculating the seeds with specific strain of rhizobia. This was due to the fact that seed inoculation with proper *Rhizobium* strain at early growth stage stimulated the root nodulation and increased biological nitrogen fixation. This eventually improves yield components such as number of branches per plant, number pods per plants, number of seeds per pod and seed weight (Morad *et al*., 2013). In view of increasing price of mineral fertilizers, it seems the cost of nutrients will be increasing in most cropping systems. It is therefore necessary to develop alternative production practice with application of little or no mineral fertilizers especially for grain legumes. Evidently, legumes production technology will remain the backbone of farming system in farmers residing in poor areas due to their capacity to fix nitrogen.

In the present day of climate change, genotype-by-environment interaction (GEI) is a major focus of study for resilience, especially in crop improvement programme to respond to global climate change. Some genotypes can have high yield in few environments and very low yield in other environments, showing better mean performance across environments (Fekadu *et al*., 2009). But few genotypes may have average yield that is stable over wider environments. Therefore, the pattern and magnitude of GEI and stability analysis is important for understanding the response of different genotypes to various environments and for identification of stable and widely adapted and unstable but specifically adapted genotypes. Moreover, it is important to develop new cultivars with improved adaptation to the environmental constraints prevailing in the target environments. Stable yield of a cultivar across a range of production environments is very crucial for variety recommendation. Therefore, cultivars must have the genetic potential for superior performance under ideal growing conditions, and must also produce acceptable yields under less favorable environments. However, in Nigeria, information on the extent and pattern of GEI, and stability analysis on soybean is scanty.

1.4 Aim and Objectives of the study

The aim of this study was to evaluate soybean genotypes for stability and productivity under rhizobia inoculation in three agro-ecological zones of the Nigeria savanna.

The objectives are to:

i. identify stable soybean genotype(s) for yield and its component traits under rhizobia inoculation;
ii. evaluate the performance of soybean genotypes in individual environment and across environments;
iii. assess the extent of genotype by environment interaction (GEI) for seed yield in soybean;
iv. identify promising soybean genotypes for advance yield trials.

CHAPTER TWO

2.0 LITERATURE REWIEV

2.1 Origin and Distribution

Scholars generally agree that the origin of soybean cultivation is in China and that annual wild soybean (*Glycine soja*), the kindred ancestor of the current cultivated soybean (*Glycine max*), is found throughout China (Grieshop and Fahey, 2001). Archaeological records have shown that soybean was cultivated in China over 2,590 years ago (Thomas *et al*., 2003). Record of soybean cultivation in Africa dated back to 1903, when they were grown in South Africa at Cedara in Natal and in the Transvaal (Grieshop and Fahey, 2001). The maximum yield that year was 1,031 kg ha^{-1}. In 1907, soybean was introduced to Mauritius, a tiny island by British agriculturalists (Grieshop and Fahey, 2001).

Starting from 1908, there were increased interests in growing of soybean in Africa, as Europe for the first time began to import large quantities of soybeans from Manchuria in response to severe shortages and high prices of oil in Europe. European nations turned to their African colonies as potential areas for soybean cultivation. English colonies were most actively involved while very little was done to introduce soybeans to many French colonies. The earliest soybean trials in English West Africa (Gambia, Sierra Leone and Nigeria) took place in 1910, with results showing yields to be 400 – 500 kg ha^{-1} (Thomas *et al*., 2003). Later results, however, were successful, as soybeans were grown in all these areas and in Mauritius. Extensive investigations were made on all British government experimental farms in Africa and by 1915, it was found that, given the present demand and prices, the colonies could compete very successfully with imported soybeans (Thomas *et al*., 2003). The most vigorous and extensive cultivation work was done in South Africa.

Grieshop and Fahey (2001), who reviewed the history of the crop in Nigeria, reported that soybeans were first introduced in 1908, by the British, looking for new sources of supply from their colonies. Attempts to grow the crop at Moor Plantation, Ibadan, at that time failed. In 1928, soybean was successfully introduced to Samaru, from where it spread into other parts of Northern Nigeria. To meet the high European demand for oilseeds during World War II, acreage expanded rapidly and in 1947, the first export of 9 tonnes was recorded. The soybean soon became a cash crop in the Tiv division in Benue Province, which thereafter became the leading center of production in Nigeria.

2.2 General Description of Soybean

Cultivated soybean, *G. max* (L.) Merr., is a diploidized tetraploid (2n=40), in the family Leguminosae, the subfamily Papilionoideae, the tribe Phaseoleae, the genus *Glycine* willd and the subgenus *soja* (Moench). It is an erect, bushy herbaceous annual plant that can reach a height of 1.5 metres. Three types of growth habit can be found among soybean cultivars; determinate, semi-determinate and indeterminate (Grieshop and Fahey, 2001). Determinate growth is characterized by the cessation of vegetative activity of the terminal bud when it becomes an inflorescence at both axillary and terminal racemes. Indeterminate genotypes continue vegetative activity throughout the flowering period while semi-determinate types have indeterminate stems that terminate vegetative growth abruptly after the flowering period (Temperly and Borges, 2006). The primary leaves are unifoliate, opposite and ovate, the secondary leaves are trifoliolate and alternate, and compound leaves with four or more leaflets are occasionally present. The parts of most cultivars are covered with fine trichomes. The papilionaceous flower consists of a tubular calyx of five sepals, a corolla of five petals (one banner, two wings and two keels), one pistil and nine fused stamens with a single separate posterior stamen. The stamens form a ring at the base of the stigma and elongate before pollination, at which time the elevated anthers form a ring around the stigma. The pod is straight or slightly curved, varies in length from two to seven centimetres, and consists of two halves of a single carpel which are joined by a dorsal and ventral suture. The shape of the seed, usually oval, can vary among cultivars from almost spherical to elongated and flattened shape (Wilhelm and Wortmann, 2004).

2.3 Nutrient Composition of Soybean Seed

Soybean oil and protein contents account for about 60 % of dry soybeans by weight (protein at 40 % and oil at 20 %) (Thomas *et al*., 2003). The remainder consists of 35 % carbohydrate and about 5 % ash. Soybean cultivars comprise approximately 8 % seed coat or hull, 90 % cotyledons and 2 % hypocotyl axis or germ. Soybean seeds also contain about 18-20 % oil on a dry matter basis (Imas and Magen*,* 2009), and this is 85 % unsaturated and cholesterol-free and 40 to 44 % protein (Shahid *et al.,* 2009). Worknel and Asfaw (2012) reported that soybean contains 43.2 % protein with lysine and 22 % oil which is mainly unsaturated fatty acids. Most soy protein is a relatively heat-stable storage protein. This heat stability enables soy food products requiring high temperature cooking, such as tofu, soy milk and textured vegetable protein (soy flour) to be made (Thomas *et al*., 2003). The principal soluble carbohydrates of mature soybeans are the disaccharide sucrose (ranging 2.5–8.2 %), the trisaccharide raffinose (0.1–1.0 %) composed of one sucrose molecule connected to one molecule of galactose, and the tetrasaccharide stachyose (1.4 to 4.1 %)

composed of one sucrose connected to two molecules of galactose (Wilhelm and Wortmann, 2004).

The oligosaccharides raffinose and stachyose protect the viability of the soybean seed from desiccation, which therefore contribute to flatulence and abdominal discomfort in humans and other monogastric animals, comparable to the disaccharide trehalose. Undigested oligosaccharides are broken down in the intestine by native microbes, producing gases such as carbon dioxide, hydrogen, and methane. Since soluble soy carbohydrates are found and broken down during fermentation, soy concentrate, soy protein isolates, tofu, soy sauce, and sprouted soybeans are without flatus activity. On the other hand, there may be some beneficial effects to ingesting oligosaccharides such as raffinose and stachyose, namely, encouraging indigenous bifidobacteria in the colon against putrefactive bacteria.

The insoluble carbohydrates in soybeans consist of the complex polysaccharides cellulose, hemicellulose, and pectin. The majority of soybean carbohydrates can be classed as belonging to dietary fiber (Nacer *et al*., 2010). Within soybean oil, the lipid portion of the seed contained four phytosterols; stigmasterol, sitosterol, campesterol, and brassicasterol accounting for about 2.5 % of the lipid fraction, which can be converted into steroid hormones (Jason and Palle, 2008). Saponins, a class of natural surfactants (soaps), are sterols that are present naturally in a wide variety of food-plants; vegetables, legumes and cereals, ranging from beans and spinach to tomatoes, potatoes and oats. Whole soybeans contain from 0.17 to 6.16 % saponins, 0.35 to 2.3 % in defatted soy flour. Legumes such as soybean and chickpeas are the major source of saponins in the human diet. Soy contains isoflavones like genistein and daidzein. It also contains glycitein, an

O-methylated isoflavone which accounts for 5–10 % of the total isoflavones in soy food products. Glycitein is a phytoestrogen with weak estrogenic activity, comparable to that of the other soy isoflavones (Jagadish *et al*., 2013).

2.4 Economic Importance of Soybean

Soybean is an economically important leguminous crop on a world wide scale and also the most important legume in China (Gan *et al.,* 2002). Soybean is a legume that occupies greater position in world agriculture by virtue of its high protein content and capacity for fixing atmospheric nitrogen (Osodeke, 2001). The crop is among the major industrial food crops grown in every continent. The crop can be successfully grown in many states in Nigeria using low agricultural input. Soybean cultivation in Nigeria has expanded as a result of its nutritive and economic importance and diverse domestic usage. Soybean is the world's leading source of oil and protein. It has the highest protein content of all food crops and is second only to groundnut in terms of oil content among food legumes (Fekadu *et al.,* 2009). It is also a prime source of vegetable oil in the international market. Soybean recorded an average protein content of 40 % and is more protein-rich than any of the common vegetable or animal food sources found in Africa (Alghamdi, 2004).

2.4.1 Importance of soybean as food

Soybean is grown primarily for the production of seed, over time recorded a multitude of uses in the food and industrial sectors, and represents one of the major sources of edible vegetable oil and of proteins for livestock feed. In Canada, the main food uses purified and salad oils. It is also used in various food products, including tofu, soya sauce, simulated milk and meat products. Soybean meal is used as a supplement in feed rations for livestock. Industrial use of soybeans ranges from the production of yeasts and antibodies to the manufacture of soaps and disinfectants (Fekadu *et al.*, 2009). The major world producers of soybeans are; USA, China, North and South Korea, Argentina and Brazil. Ontario is the major producer of soybean in Canada, accounting for 90 % of the total production in 1995. From 1945 to 1995, production increased from 18,000 to approximately 820,000 hectares in Canada and over 200,000 hectares in Nigeria (Grieshop and Fahey, 2001). Since 1970, world consumption of soybeans has grown at an annual rate of 4.8 % on average and with annual increase of 5.4 % on the average (Flaskerud, 2003). Soybean can be processed through roasting, fermentation and germination. Unprocessed de-hulled soybean has an undesirable flavour and bitterness. Moreover, they contain toxic proteins, haemagglutinins and anti-trypsin which must be destroyed to make it palatable and digestable (Martin *et al.,* 2010). Soybean is used for soymilk, soy sauce, tofu (soybean curd), yoghurt, flour, and in some beverages (FAO, 1992). Soybean can be consumed in many forms with tofu, soy milk, roasted soybeans, soy powder, and textured vegetable protein being some of the more popular (Gibson and Benson, 2005).

IITA food technologists have developed about one hundred and fifty food products with good nutritive value and consumer acceptability (Adelodun, 2011). Other independent researchers have reported possible use of soybean in addressing the major Africa’s hunger and malnutrition challenges. Soybean seeds have been exploited for the production of food products such as soybean “daddawa”, soybean fortified gari and tapioca (Kolapo and Sanni, 2009), cereal-based traditional weaning food, soy-coconut milk based yoghurt, soy-cow milk based yoghurt (Olubamiwa and Kolapo, 2008) and soy-corn milk (Kolapo and Oladimeji, 2008). Soybean is a major source of vegetable protein and oil for consumption and industrial uses (Olubamiwa and Kolapo, 2008).

2.4.2 Medicinal properties of soybean

Soybean is often described as the miracle golden bean, the pearl of the Orient, the Cinderella crop of the century, the meat that grows on vines, the protein hope of the future and the salvation crop among others (Adelodun, 2011). These attributions are mainly due to the relatively high protein content (about 40 %) in soybean seeds. It also contains approximately 20 % fat. The fatty acids in soybean are majorly unsaturated types e.g. oleic and linoleic acid. Unlike the saturated fat in animal protein, it is suitable in reducing heart ailment probably caused or aggravated by excessive intake of cholesterol from animal fat (Adelodun, 2011).

Sanni (2000) reported that adequate diet including soya lecithin will free the cholestrol deposits in the blood vessels, suspend the particles in the blood, carry them away and metabolise them. In this way, the blood vessels are free and blood pressure returns to normal. It is on this premise that Sanni (2000) recommends that people who cannot afford lecithin should include soybean in their diets. The strong link between a good nutrition and a good health must have been responsible for the invaluable role soybean has been playing in maintaining a better health in its consumers for many centuries. Data from different regions of the world have shown that consumption of food containing soybean and soybean products has been associated with improved heart disease risk factor, reduced osteoporosis, alleviation of menopausal symptoms, reduced cancer risk, diabetes and serum cholesterol. Soybean consumption also helps in reducing obesity; this is consequent upon soybean isoflavones especially which cause production of fewer and smaller fat cells (Naaz *et al.,* 2003). Report has shown that soybean could help minimize coronary heart disease through controlling cholesterol, blood pressure, vascular function and direct effects on the cells of the artery wall. Men which were at risk of developing coronary heart disease, consuming soybean diets have been found to have significant reductions in both diastolic and systolic blood pressure (Sagara *et al.,* 2004).

Studies have established the beneficial effect of soybean to diabetic patients particularly Non-Insulin Dependent Diabetes Mellitus (NIDDM). The protein and fibre in soybeans can prevent high blood sugar level and help in keeping blood sugar levels under control. In addition, the proportion of potassium to sodium (3/1- 11/1) makes soybean an ideal food for diabetes mellitus patients (Lijuan *et al.,* 2000). Furthermore, Teixera *et al.* (2000) reported that soy protein help diabetic patients prevent kidney diseases and improve the cholesterol profile. There are evidences that soy foods may help reduce bone loss that typically occurs after menopause. Soya isoflavone can help women with low bone mineral content prevent hip fractures in post menopausal years (Chen *et al.* 2003; Anderson 2003; Koh *et al.,* 2009). In areas of the world where soybeans are eaten regularly, rates of colon cancer, as well as some other cancers including breast cancer tend to be low. Soybean contains relatively high amounts of glucosycermide, which may be the reason for the cancer–preventive effect of eating soy foods (Symolon *et al.,* 2004). In more recent studies, it was established that soy food consumption was significantly associated with decreased cancer recurrence and death (Shu *et al.,* 2009; Guha *et al.,* 2009).

2.4.3 Industrial uses of soybean

The rapid growth in the poultry sector in the past five years has increased demand for soybean meal in Nigeria (IITA, 1999) with opportunities for improving the income of farmers (Ishaq and Ehirim, 2014). Oil mill processors typically sell soybean oil and meal to wholesalers and distributors, which trade oil to the retail sector and cake to the animal feed industry. Soybean processing (crush) has also grown in response, with total output of processed soybean rising from 168,000 metric tons in year 2000 to 228,000 metric tons in year 2009 representing annual growth rate of 5 %. Before 2000, the decline of the livestock industry led to the exit of major multinationals and a contraction in output; this trend reversed in 2000 following a poultry import ban imposed by the government that led to rapid expansion of the domestic poultry sector. In 2009, Nigeria processed soybean at 65 crushing facilities, with Grand Cereals, ECWA feeds, SALMA oil mills, and AFCOT oil seeds processors being the largest players. Multinational food processors such as Nestlé and Cadbury have entered the sector (IITA, 2000). Nigeria's installed crushing capacity was estimated at 580,000 metric tons in 2009, almost equivalent to the country's current production of raw soybeans. But only 40 % of that capacity was used. It is likely that most of the Nigeria's production was processed for on-farm or local consumption and thus not captured in the industry's overall capacity. Nigerian soybean processors also face substantial challenges to economic viability, including the lack of reliable scale volumes of good-quality soybeans, outdated technology with a lack of available finance to upgrade production capital, high energy and transportation costs (IITA, 2008).

2.5 Plant Phenotyping

Developments in ecology in relation to plant phenotyping are the trait-based approaches, in which phenotypic characteristics of a wider range of different species are evaluated either in the field

(Reich *et al*., 1992) or under laboratory conditions (Olivera *et al*., 2004). Phenotyping was used to derive different strategies by which the ecological niche of species could be described and to analyse the interdependence of various traits (Wright *et al*., 2004). In the last two decades, a new step has been taken in plant phenotyping, by means of studying genetically-modified organisms. Genotypes often differ from their 'wild type' in only one targeted gene, to test the relevance of that specific gene in shaping the phenotype of the plant. For a range of transformations, the genetic modifications are so dramatic that they are lethal. A non-functional hormone signalling pathway (Qin *et al*., 2011) could serve as an example where a genetic modification deeply interferes with the viability of the individual (Lloyd and Meinke, 2012). In such cases, the effect of a given gene on the phenotype is much better studied by a moderate reduction or increase of gene transcription of few tenths of a per cent (Roland and Hendrik, 2012).

In contrast to the observed lethal transformations, there is a wide range of transformations with no observable differences between wild type plant and the transformant. In such cases it becomes more and more fashionable to conclude that transformants do not have a phenotype (Crusio, 2002). There are several reasons that make such a conclusion imprecise and premature. First, these plants do certainly have a phenotype, since no individual can live with only a genotype. Secondly, the level of macroscopic phenotyping at which this conclusion is made often pertains to relatively 'simple' traits such as plant size, shape of leaves or timing of development. Likewise, as the phenotype of the plant is much broader than its visual appearance, it may be that there are more or less marked changes at, for example, the cellular level do not translate to a difference between the transformant and the wild type for the trait(s) under scrutiny. A third point of attention is that differences are often tested under one set of environmental conditions, conveniently described as ‘standard conditions’. There are clear cases indicating the importance of the environment in determining the degree of differences between transformant and wild type or between varieties within a breeding program. A particular example is given by Külheim *et al*. (2002) who found hardly any difference in seed production between a photosynthetic mutant and the wild type grown at constant low light levels, but a considerably lower seed production at fluctuating light level. Some phenotypic differences may show up only during a particular part of the diurnal cycle (Wiese *et al*., 2007).

2.6 Yield Stability in Soybean

Successful new varieties must show high performance for yield and other essential agronomic traits. Their superiority should be reliable over a wide range of environmental conditions. Plant breeders generally agree on the importance of high yield stability, but less accord on the most appropriate definition of stability and methods to measure and improve yield stability (Jandong *et al*., 2011). The basic cause of differences between genotypes in their yield stability is the wide occurrence of genotype-environment interactions (GE-interactions), i.e. the ranking of genotypes depends on the particular environmental conditions where plants are grown.

The interactions of genotypes with environments can be partly understood as a result of a differential reaction to environmental stress factors like drought or diseases (Abo-Hegazy *et al*., 2013). But generally, only a minor component of the GE interactions can be attributed to known environmental determinants and the major part is just an inexplicable quantity in the statistical analysis of yield trials. When discussing these unexpected variations in yield the term "phenotypic stability" is often used to refer to fluctuations in the phenotypic expression of yield while the genotypic composition of the varieties or populations remains stable (Jandong *et al*., 2011).

2.6.1 Stability and G×E analyses techniques

Different techniques have been developed to reveal stability and G×E interaction patterns. These techniques include joint regression, sum of squared deviations from regression, and stability variance (Yan and Tinker, 2006). Alternatively, additive main effects and multiplicative interaction (AMMI) model has been used to get a clearer view of the complicated pattern of genotypic responses to the environment (Ishaq *et al*., 2015). Yan *et al*. (2000) proposed another methodology called genotype plus genotype × environment interaction (GGE) biplot for graphical representation of GE interaction pattern of Multi-environment trial (MET) data.

Regression analysis is an approach originally proposed by Yates and Cochram in the year 1938 and later modified by Eberhart and Russel in 1966 (Ojo, 2002). It has been widely used in comparing and measuring genotypic performances of soybean (Ojo *et al*., 2002). It is used to measure the sensitivity of genotypes to production environments. The regression coefficient (b-value) is the genotypic sensitivity to changes in the environmental conditions. Values of $b>1$ means genotypes with a higher than average sensitivity and less stable; $b=1$ means the genotypes are averagely stable, while $b<1$ means genotypes that are less sensitive and more stable (Ishaq *et al*., 2015).

AMMI analysis combines a univariate method for the additive effects of genotypes and environments, with a multivariate method for the multiplicative effect of G×E interaction (Cucolotto *et al.*, 2007). It partitions the sum of squares of GEI into several principal components (PC), of which the first two principal components usually capture greater percentage of the sum of squares of G×E interaction. The results of the AMMI model analysis is usually interpreted by a biplot between Principal Component (PC) Axis 1 versus PC Axis 2. In the AMMI biplot, genotypes or environments with large negative or positive PC2 scores have high interactions, while those with PC2 scores near zero (close to the horizontal line) have little interaction across the environments and are considered more stable than those further away from the line (Agyeman *et al.*, 2015). Yan and Rajcan (2002) defined an ideal test environment as one that has small PC2 scores, that is, more representative of the overall environment; and large PC1 scores, which represents power to discriminate. Also, the environmental vector in the biplot shows the discriminating ability of an environment for the genotypes tested. A long environment vector represents good discriminating ability for a given environment and *vice versa*. Discriminant test environments accurately resolve genotype differences, thereby providing the necessary information for selection by a breeder (Tukamuhabwa *et al.*, 2012). Therefore, testing soybean genotypes for yield in an environment with high representative and discriminating ability only may suffice.

GGE biplot is a graphical tool that displays, interprets and explores two important sources of variation, namely genotype main effect and GE interaction of MET data (Fan *et al.*, 2007). GGE biplot analysis considers that only the G and GE effects are important and that they need to be considered simultaneously when evaluating genotypes. Therefore, the GGE biplot has been used in crop variety trials to effectively identify the best-performing genotype across environments; identify the best genotypes for mega-environment delineation, whereby specific genotypes can be recommended to specific mega- environments and evaluate the yield and stability of genotypes (Yan and Tinker, 2006). Mega environments are test environments having different winning genotypes located at the vertex of the polygon (Tukamuhabwa *et al*., 2012). The versatility of the GGE biplot relative to other techniques, especially in mega- environment analysis and genotype selection, is worthy of being exploited for selection of genotypes for specific environments (Agyeman *et al.*, 2015). It would also assist in guiding the direction of varietal development for stable ecology based selections.

The polygon view of the GGE-biplot shows “which-won-where”; that is the best genotype in each environment and it summarizes the GEI pattern of a multi environment yield trial data. The polygon is formed by connecting the genotypes located further away from the origin of the biplot such that all other genotypes are contained within the polygon. A perpendicular line starting from the origin is drawn to each side of the polygon and extended beyond the polygon so that the biplot is divided into several sectors, and the different environments were separated into different sectors. The genotype at the vertices of each sector of each sector is the best performer at environment(s) included in that sector (Agyeman *et al.*, 2015).

2.6.2 Genotype × environment interaction studies in soybean

Genotype × environment interaction (GEI) is commonly regarded by breeders as differential ranking of varieties according to their yields among locations or years (Abay and Bjornstad, 2009). Therefore, a multi-locational trial has to be conducted in order to identify superior genotypes for a specific region. Breeders over the years have paid attention to the analysis and understand the causes of GEI in a particular region. To have a clear picture of the effects of genotype and environment on soybean productivity, soybean multi-environment trials (MET) are conducted every year around the world. This assists in identifying superior genotypes and the evaluation of environment relationships, like determining mega environments (Yan *et al*., 2010). Crop performance is greatly influenced by weather conditions. Therefore, vulnerability of cultivars to environmental variation can be viewed as a barrier to imposing yield potential (Tyagi *et al.,* 2011). This is obvious when considering the fact that, any breeding programme must create lines that are adapted to a range of environments, at least those representing yearly weather fluctuations as well as those imposed by varying farmers practices (Alghamdi, 2004).

Rao *et a1.* (2002) found significant genotype × year × location (GYL) effects for grain yield in twelve soybean genotypes. Similarly, Cucolotto *et al.* (2007) reported differential performance of thirty soybeans genotypes in terms of yield adaptability and stability when evaluated in thirty different environments of the state of the Paraná in Brazil. Multi-environment trials make it possible to identify genotypes that are consistent in their performances from year to year (temporal stability) and the ones that perform consistently from location to location (spatial stability). As noted by Kang (2002), temporal stability is desired and appreciated by growers, while spatial stability is of immense benefit to seed companies and breeders. Therefore, there is need for plant breeders to consider genotype × environment interaction to avoid missing genotypes that, on average, perform poorly but do well when grown in specific environments or those that have good average performance, but do poorly when grown in a specific environment. If soybean yield potential is to meet future demands, there is need to target the underlying physiological causes of genotype × environment interactions for genetic improvement.

2.7 Soybean Breeding and Improvement Programmes

The improvement in Nigeria of soybean, a strictly self-pollinating legume with 2n=40 chromosomes started in IITA around 1974 (Hailu, 2011) because there was little effort in improving the crop in Africa, which resulted in extremely low yield of less than 0.5 tonne per hectare (Hailu, 2011). Other impediments recorded were low seed viability, high shattering rate, poor nodulation with native *Rhizobium* in the soil and limited post harvest uses (Kolapo, 2011). With these predicaments, IITA capitalized on the opportunities soybean could offer to tropical agriculture and initiated breeding work on the crop. Preliminary yield trial on soybean germplasm materials in 1974 showed that yields were high, up to 3.6 tonnes per hectare, as compared to other legumes (Hailu, 2011). This excellent performance under tropical Africa condition was a contributory factor for IITA to venture into soybean improvement in Nigeria.

Apart from being an excelent source of qua1ity protein and vegetable oil, the availability of ample genetic diversity to tackle some of the major constraints like poor seed longevity and efficient natural nodulation were reasons to invest in soybean. It was these constraints and opportunities that made IITA to engage in soybean improvement (Hailu, 2011). Soybean breeding has mainly focused on yield increase and stability, that is, developing cultivars that are well-adapted to various growing conditions (Popovic *et al.,* 2013). Seed yield and quality traits, which are quantitatively inherited as they are polygenetic in nature, and are strongly influenced by environmental conditions. Therefore, the heritability for these traits is relatively low (Miladinovic *et al.*, 2010). For this reason, in plant breeding, attention is given to yield component traits, which are mostly of simpler genetic base and are always more or less correlated with yield.

At the stage of preliminary variety trials, 20 to 30 superior lines are usually tested at two to three locations in three replications for one year. Better performing lines for traits of interest are promoted to the advanced variety trial, while the rest are discarded. In the advanced variety trial, lines are evaluated in a minimum of three locations in four replications per location. Lines with the best performance from this trial were forwarded to collaborators mainly in Africa in the form of international trials. The aim is to test adaptation of elite lines in different countries under diverse environmental conditions, so that breeders from different national programmes are able to compare their local varieties with the new 1ines and eventually, new varieties are released (Hailu, 2011). Within Nigeria, these superior lines were promoted to the National Soybean Variety Trials, which are part of the National Coordinated Research Projects on Soybean.

2.8 Yields and Yields Component of Soybean as Affected by Rhizobia Inoculation

In agricultural systems, stresses like nitrogen and phosphorus deficiencies result in significant reduction of crop productivity and yields. Phosphorus and nitrogen are major limiting soil nutrients in most tropical soils of which low levels could limit growth and yields of legumes (Mmbaga and friesen, 2003). Among various factors that can contribute to soybean success, phosphorus and rhizobial inoculation had quite prominent effects on nodulation, growth and yield parameters (Shahid *et al.*, 2009).

Seed yields in legumes are highly attributed to nutrients availability (Hussain *et al.*, 2011). In legumes, nitrogen is more useful because it is the main component of amino acid as well as protein. Legumes can obtain nitrogen through atmospheric fixation in their root nodules in symbiosis with soil rhizobia and as a result have a potential to fit in nitrogen deficit soils. To reduce the production cost with mineral fertilizers and provide protection to the environment, more legume production could be achieved through seed inoculation with beneficial *Rhizobium* bacteria (Hussain *et al.*, 2011), which are known to influence nodulation, symbiotic nitrogen fixation, growth and yield of legumes.

Phosphorus is the second most vital plant nutrient for legumes which presumes primary significance, which plays important role in root proliferation and atmospheric nitrogen fixation. Singh *et al.* (2008) reported that the yield and nutritional quality of legumes is greatly influenced by application of phosphorus and biofertilizers. Ability of legumes crops to fix atmospheric N_2 through symbiosis with soil bacteria has positioned the crops belonging to leguminousae family important and valuable worldwide. Legumes are able to assimilate atmospheric N_2, convert it to useful nutritional products, and contribute agronomically and economically in many cropping systems in agriculture (Belkheir *et al.*, 2001). The crop yield is a dependent variable which relies on other growth and yield contributing characters (Achakzai and Bangulzai, 2006). The maximum yield of a legume crop depends upon its yield components, such as the number of branches per plant, pods per plants, seeds per pod and seed weight, however density of the plant is an important agent that affect yield and yield components of legumes (Dahmardeh *et al.*, 2010).

Shahid *et al*. (2009) reported that seed production in soybean can increase 70-75 % when proper bacterial strains were used to inoculate soybean seeds. The higher nodulation due to inoculation resulted in higher nitrogen fixation by *Rhizobium* and eventually the number of pods per plant which bring about higher grain yields (Singh *et al*., 2011). In other studies, Ibrahim *et al*. (2011) reported increased yield and yield component of soybean by inoculating the seeds with specific strain of rhizobia. Studies carried out in some parts of African countries show that soybeans not inoculated need 24-39 kg P ha^{-1} for maximum yields to be attained.

With the worldwide emphasis on sustainable agricultural systems, increase in grain legume production such as soybean, will come mostly from supplementing the crops with phosphorus (in deficient environments) and through the use of rhizobial inoculants rather than the use of inorganic nitrogen fertilizer. This is due to the ability of the soybean to fix large quantity of atmospheric nitrogen and make it available for plant growth and increased yields.

2.9 Economic Benefits of *Rhizobium* Inoculants in Legumes

Production of grain-legumes is increasing significantly due to their vast use in different situations including human food, animal feed as well as industrial demands. Considering the increasing needs for human consumption of plant products and the economic constraints of applying fertilizer in legumes, there is a greater role for grain legumes in cropping systems, especially in regions where affordability of fertilizer is difficult (Ndakidemi *et al*., 2006).

Grain legumes such as soybean, cowpea and common bean have potential uses and are grown in different agro-ecological zones (Yagoub *et al*., 2012). They are economically important crops used in a wide range of products (Yagoub *et al*., 2012). They play a significant role in sustainability of agricultural systems. Biological nitrogen fixation is becoming more attractive and economically viable nitrogen inputs, substituting inorganic fertilizers for resource poor farmers, and environmentally friendly agricultural input (Bekere *et al*., 2012). For economically viable and environmentally sensible farming practices, nitrogen inputs should be managed successful through symbiotic nitrogen fixation (Sharma and Kumawat, 2011).

Most tropical soils experience low nitrogen, which is the major constraints in crop production in Africa (Yakubu *et al*., 2010). Small-scale agriculture which is practiced in most sub-Saharan Africa, cover the majority of people, in which, chemical fertilizers are unaffordable because of increasing prices each year (Yakubu *et al*., 2010). Through different cropping systems like intercropping of cereals and legumes, and crop rotation has found to be an alternative source and means of improving fertility of the soil and boost productivity and income of the farmers (Ndakidemi *et al*., 2006). Several studies have shown that through biological nitrogen fixation, which is enhanced by inoculation, the compatible host legume leaves residual nitrogen in the soil, through added organic matter in form of leaf litter and root residues, which become source of cheap nutrients for the next cropping season to cereal crops and other legumes as well. Biological nitrogen fixation is therefore considered to have ecological and economic benefits (Ndakidemi *et al*., 2006).

The nutrient supply in crop production is one of the key components to higher yields (Gehl, *et al*., 2005). Increased crop yields due to mineral nutrient supplementation in the developed world are widely documented. However, Africa is reported to have the lowest use of fertilizer in the world.

The per capita consumption of fertilizer in Tanzania is standing at 8 kg ha^{-1} as compared with 52 kg ha^{-1} for South Africa and Zimbabwe and 27 kg ha^{-1} for Malawi (Walter, 2007). Nitrogen (N) is the most limiting nutrient for crop yields, and nitrogen fertilizers is an expensive input in agriculture costing more than US$45 billion per year globally (Gyaneshwar *et al*., 2002).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study Location

The study was conducted during the 2015 and 2016 rainy seasons at three experimental sites across three different agro-ecologies of Nigeria. The experimental sites were as follows:

i. Southern Guinea Savanna- Research farm of International Institute of Tropical Agriculture (IITA) Kubwa (Latitude 9.07226 N and Longitude 7.491302 E), Abuja, Federal Capital Territory. Abuja has two seasons, rainy (April - October) and dry (November – March) seasons. The temperature varies between 28 °C to 35 °C during the dry season. During the rainy season, temperature drops considerably due to dense cloud cover to around 20 °C especially between July and August. The annual total rainfall is averaged between 1100 mm to 1500 mm. Abuja records a relative humidity average of about 16 % during the dry season and average of 70 % in the rainy season (IITA Kubwa Station, Abuja)

ii. Northern Guinea Savanna- Research farm of IITA, Igabi (Latitude 10.94427 N and Longitude 7.64443 E), Kaduna State. The area experienced low temperature of 21 °C and below during harmattan period in the months of November to February. It also experiences high temperature of about 40 °C and above during the dry season (March to May). The rainfall in the area falls between the months of May and September with an average rainfall of about 1050 mm. Igabi records a relative humidity average of about 17.5 % during the dry season and average of 77 % in the rainy season (Institute for Agricultural research, Zaria).

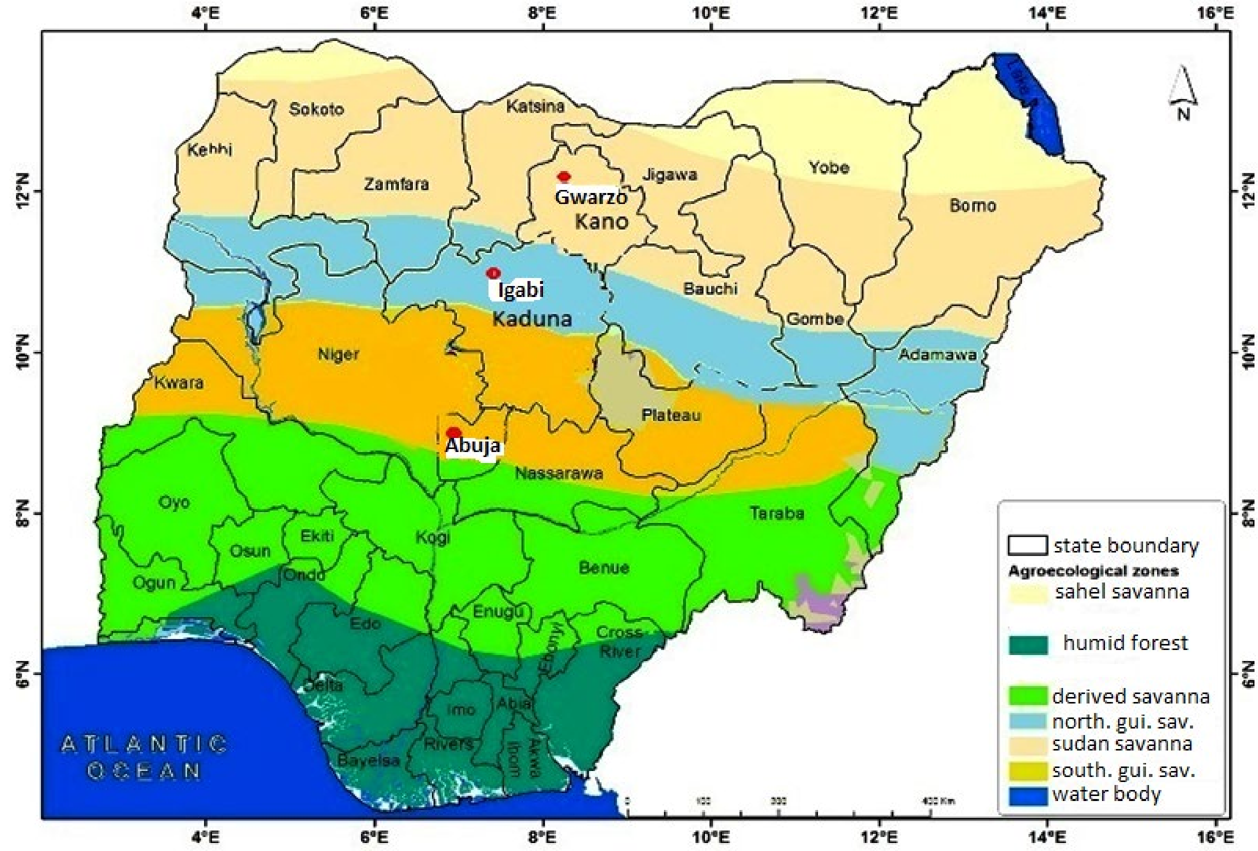

Figure 3.1: Map of Nigeria showing the experimental sites.

iii. Sudan Savanna- Research farm of IITA, Gwarzo (Latitude 11.92996 N and Longitude 7.98789 E), Kano State. The temperature usually ranges between a maximum of 42 °C and minimum of 15.8 °C. During the harmattan, it falls to as low as 10 °C. Gwarzo has two seasonal periods, which consist of four months of wet season (June to September) and a long dry season lasting from October to May. The annual average rainfall is about 850 mm. Gwarzo records a relative humidity average of about 15 % during the dry season and average of 68 % in the rainy season (Institute for Agricultural research, Zaria).

3.2 Source of Seeds

Twenty-four soybean genotypes and five commercial checks used in this study were obtained from IITA Kano station. Twelve of these genotypes were early maturing while the remaining twelve were medium maturing.

3.3 Source of Inoculants

Two peat – based rhizobial inoculants (LegumeFix and NoduMax) used in these study, were obtained from IITA. LegumeFix contained 10^9 cells / g of peat of *Bradyrhizobium japonicum* strain 532c, manufactured by Legume Technology, United Kingdom. NoduMax, contained approximately 10^9 cells / g of peat of *B. japonicum* strain USDA 110, manufactured by the Technology Incubation Centre, IITA, Ibadan, Nigeria.

3.4 Soil Sampling and Analysis

Pre-plant soil samples of the different experimental sites were taken and analyzed for physical and chemical properties using standard laboratory procedures (IUSS/FAO, 2002). Soil samples were taken across the fields with an auger at the depth of 0-15 cm, and bulked in a polythene bag. The samples were then taken to the laboratory for physical and chemical analysis. The samples were air-dried and then sieved through a 0.5 mm sieve. Particle size distribution was determined using the Bouyocous hydrometer method using sodium hexametaphosphate as dispersing agent

(IUSS/FAO, 2002). Soil pH was determined in a 1:1 soil/water ratio using a glass electrode pH meter. Total nitrogen was determined by micro Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus was extracted by Bray P1 method. Potassium (K) was extracted with 1N neutral ammonium acetate (NH_4OAc) saturation method, and K in solution was measured using a flame photometer (IUSS/FAO, 2002).

3.5 Treatments and Experimental Design

The experimental treatment was a factorial combination of 24 soybean genotypes (TGx 1989-11F, TGx 1990-110FN, TGx 1989-42F, TGx 1990-95F, TGx 1989-45F, TGx 1990-114FN, TGx 1989-53FN, TGx 1993-4FN, TGx 1989-75FN, TGx 1990-78F, TGx 1987-62F-Check, TGx 1448-2E-Check, TGx 1989-40F, TGx 1990 -52F, TGx 1989-48FN, TGx 1990-40F, TGx 1989-49FN, TGx 1990-57F, TGx 1989-68FN, TGx 1990-46F, TGx 1990-55F, TGx 1987-10F-Check, TGx 1835-10E-Check, TGx 1485-1D-Check) and three inoculation types (Without Inoculation, LegumeFix and NoduMax) fitted into a Split-plot design with three replications. The main plots consisted of the soybean genotypes and the sub-plots were the inoculation types. Gross plot size was 3 m × 4 m (12 m^2) containing five ridges of 3 m long each. Net plot size was 3 m × 2.5 m (7.5 m^2). An alley of 1 m was used to separate the blocks, and 0.5 m for the treatment plots.

3.6 Agronomic Practices

3.6.1 Land preparation

The experimental field in each location was ploughed, harrowed and ridged with tractor. Then followed by field layout in which 216 sub-plots were marked out as per the treatments

3.6.2 Seed inoculation with *Rhizobium*

The seeds were inoculated at sowing with rhizobial inoculants (LegumeFix and NoduMax) at the rate of 50 g / 5 kg seed as recommended by Woomer (2010) by mixing the seeds with each inoculant, ensuring that the seeds were completely covered by the inoculant.

3.6.3 Sowing of seeds

Seeds of each genotype inoculated and without inoculation were sown at the rate of three seeds per stand at an intra-row spacing of 30 cm and 75 cm inter-row spacing. The seedlings were later thinned to one plant per stand. Seeds were sown on 5th July, 15th July and 18th July in 2015 for Gwarzo, Igabi and Abuja respectively. Also sowing was done on 22nd June, 1st July and 16th July in 2016 for Gwarzo, Igabi and Abuja respectively.

3.6.4 Weed control

Weed control was done manually with hoes at 2, 4, and 6 weeks after sowing as recommended by Dugje *et al*. (2009).

3.6.5 Fertilizer application

Single super phosphate (SSP) was applied by hand at the rate of 40 kg P_2O_5 ha^{-1} at 2 weeks after sowing, using side placement method of fertilizer application.

3.6.6 Insect control

Cypermethrin (Best) at the rate of 0.14 kg a.i ha^{-1} (Afolayan and Braimoh, 1991) was applied once on the seedlings with knapsack sprayer to control insect pests infestation.

3.6.7 Harvesting

At physiological maturity (when the leaves turn brown and 95 % of the pods turn straw colour to brown), soybean plants were harvested from each net plot leaving the border rows on either ends of the central rows. The number of plants per net plot was recorded at harvesting from the three central rows, and the means computed and used for the analysis of final plant stands. The harvested net plots were threshed after taking the necessary parameters. The seeds were separated from the husk and kept in labeled bags representing respective plots for further observations.

3.7 Data Collection

3.7.1 Environmental data

In each of the location and year of research, the following environmental parameters were taken:

i. Mean monthly rainfall (mm)
ii. Mean monthly temperature (°C) and
iii. Mean monthly relative humidity (%)

3.7.2 Growth and yield data

The following growth and yield data were collected:

i. **Emergence (%):** calculated before thinning using the following formular, according to Baset Mia and Shamsuddin (2009):

$$\frac{\text{Number of emerged seedlings}}{\text{Number of seeds sown}} \times 100$$

Emergence (%) =

ii. **Chlorophyll content:** measured using chlorophyll meter SPAD – 502Plus with optical density difference at 2 wavelengths at 10 weeks after sowing (WAS).

iii. **Days to 50 % flowering:** determined by carefully observing the number of flowers daily until about half of the total plants in the field had flowered.

iv. **Plant height (cm):** measured at 4, 8 and 12 WAS using a metre rule. The plant height was taken from the soil surface to apical tip of five plants that were tagged and the average height per plant calculated.

v. **Number of leaves:** taken at 4, 8 and 12 WAS from five plants that were tagged and the average calculated per plant.

vi. B**ranches per plant:** taken by counting from five representative plants at 16 WAS and averaged

vii. **Pods per plant:** taken by counting from five representative plants at physiological maturity and the average calculated

viii. **Total biomass yield:** plants were removed using hoe to uproot the whole plant, measurement taken using weighing balance and then converted to kilogram per hectare.

ix. **Above ground biomass yield:** after removing the root part from the plant using cutlass, the remaining above ground biomass were measured and converted to kilogram per hectare.

x. **Seed yield:** seeds were separated from the husk and kept in labeled bags representing respective plots and then converted to kilogram per hectare.

xi. **Harvest index:** were computed by dividing seed yield to above ground biomass yield as described by Kemanian *et al*. (2007).

xii. **100 seed weight (g):** one hundred (100) seeds of each treatment were taken and their weight measured using electronic weighing balance in the laboratory and the value recorded.

3.8 Statistical Analysis

3.8.1 Analysis of variance

Data collected were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) procedure of Statistical Analytical Software (SAS) (2003). Means were compared using Duncan Multiple Range Test (DMRT) at 5 % level of probability.

3.8.2 Path coefficient analysis

A measure of direct and indirect effects of selected characters on grain yield were estimated using a standardized partial regression coefficient known as Path Coefficient Analysis, as suggested by Solomon and Hanchinal (2013). Thus, correlation coefficients of different characters with grain yield were partitioned into direct and indirect effects adopting the following formular:

$r_i = r1_iP_1 + r2_iP_2 + \ldots + rl_iP_i + \ldots + rn_iP_n$

where r_i is correlation of i^{th} character with grain yield; rl_iP_i is indirect effects of i^{th} character on grain yield through first character; rn_i is correlation between n^{th} character and i^{th} character; n is number of independent variables; P_i is direct effect of i^{th} character on grain yield; P_n is direct effects of n^{th} character on grain yield. Direct effect of different component characters on grain yield were obtained by solving the following equations:

$(r_i) = (P_i)\ (r_{ij})$; and $(P_i) = (r_{ij})^{-1}\ (r1_iP_i)$

Where, (P_i) is matrix of direct effect; (r_{ij}) is matrix of correlation coefficients among all the n^{th} component characters; (r_i) is matrix of correlation of all component characters with grain yield; ($r1_iP_i$) is indirect effect of i^{th} character on seed yield through first character.

3.8.3 Genotypic sensitivity

To determine genotypic sensitivity and stability, the following linear regression model were used (Breeding Management System (BMS), 2015):

$$Y_{ij.} = \mu + b_iL_j + \delta_{ij} + \varepsilon_{ij.}$$

Where: $Y_{ij.}$ is the mean for the genotype i at location j. μ; the general mean for genotypes. b_i ; the regression coefficient for the ith genotype at a given location index which measures the response of a given genotype to varying location. L_j ; the environmental index, which is defined as the mean deviation for all genotypes at a given location from the overall mean. δ_{ij} ; the deviation from regression for the ith genotype at the jth location. $\varepsilon_{ij.}$; the mean for experimental error.

3.8.4 Stability pattern

Additive Main Effect and Multiplicative Interaction (AMMI) were used to determine the stability pattern of the genotypes across the locations (Adie and Krisnawati (2015); BMS, 2015). The AMMI model is $Y_{ij.} = \mu + g_i + e_j + \sum \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij.}$

Where Y_{ij} is the mean of the ith line in the jth environment, μ is the grand mean, g_i is the genotype effect, e_j is the site effect, λ_k is the singular value for principal components k, α_{ik} is the eigenvector score for genotype i and component k, γ_{jk} is the eigenvector score for environment j and component k, and $\varepsilon_{ij.}$ is the error for genotype i and environment j.

The results of the AMMI model analysis were interpreted by a biplot between Principal Component (PC) Axis 1 versus PC Axis 2.

3.8.5 Best genotypes in mega environments

Genotype plus genotype × environment interaction (GGE) biplot were used to identify the best-performing genotype across environments. The polygon view of the GGE-biplot was used to show "which-won-where"; that is the best genotype in each environment and it summarized the GEI pattern of a multi environment yield trial data. The GGE biplot used is based on the Sites Regression (SREG) linear-bilinear (multiplicative) model (BMS, 2015), which is given below:

$$\bar{y}_{ij} - \mu_j = \sum^{t}_{k=1} \lambda_k \, \alpha_{ik} \, \gamma_{jk} + \bar{\varepsilon}_{ij}$$

Where $\bar{y}_{ij}$ is the cell mean of genotype i in environment j; μj is the mean value in environment j; $i = 1, \cdots g$; $j = 1, \cdots e$, g and e being the numbers of cultivars and environments, respectively; and t is the number of principal components (PC) used or retained in the model, with $t \leq \min(e, g - 1)$. The model is subject to the constraint $\lambda_1 \geq \lambda_2 \geq \cdots \lambda_t \geq 0$ and to orthonormality constraints on the α_{ik} scores, with similar constraints on the γ_{jk} scores [defined by replacing symbols (i,g,α) with (j,e,γ)]. The ε_{ij} are assumed normally and independently distributed $(0, \sigma^2/r)$, where r is the number of replications within an environment.

CHAPTER FOUR

4.0 RESULTS

4.1 Environment

4.1.1 Weather

The monthly meteorological data (rainfall, temperature and humidity) of the test environments during the 2015 and 2016 cropping seasons are presented in Tables 4.1 and 4.2 respectively. The temperature within each environment during the growing period was within the best range of temperature for soybean development (20 - 35°C) as recommended by Viana *et al*. (2013).The peak of rainfall in each environment for the year was within the production period, and was fairly distributed during the developmental stages of the crop.

4.1.2 Soil properties

The physical and chemical properties of the soil before land preparation at the three environments during the 2015 and 2016 cropping seasons are shown in Tables 4.3 and 4.4 respectively. The texture of the soils was sandy loam. The soil pH ranged from 4.8 to 6.5 with Igabi being the most acidic among the three environments during the 2015 cropping season (Table 4.3). Also, during the 2016 cropping season, the soil pH ranged from 6.2 and 7.2 as indicated in Table 4.4. Nitrogen and phosphorus were higher in Abuja, while potassium was higher in Gwarzo than the other environments (Table 4.3), similar trends were recorded in 2016 cropping season.

Table 4.1: Monthly meteorological data for the experimental locations during the 2015 cropping season

Locations	Months											
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec

Abuja	RF		2.0	8.0	29.0	80.0	155	177	233	280	284	130	10.0	1.0
	Temp	Max	32.5	34.2	35.1	34.4	31.8	29.6	28.2	27.7	28.9	30.7	32.5	32.6
		Min	17.6	19.5	21.7	22.7	22.0	20.6	20.4	20.2	19.9	19.9	18.8	16.9
		Mean	25.1	26.9	28.4	28.6	26.9	25.1	24.3	23.9	24.4	25.3	25.6	24.7
	Humi	Max	24.0	24.0	35.0	50.0	62.0	83.0	88.0	83.0	74.0	65.0	42.0	29.0
		Min	8.0	9.0	17.0	10.0	62.0	58.0	58.0	52.0	55.0	17.0	10.0	20.0
		Mean	14.0	14.0	23.0	25.0	62.0	68.0	73.0	67.0	65.0	38.0	22.0	24.0
Igabi	RF		0.0	0.0	90.0	0.0	90.1	66.4	300.	387.1	281	11.3	0.0	0.0
	Temp	Max	28.9	31.5	36.2	36.3	37.4	32.6	30.6	29.7	31.8	31.3	34.2	28.5
		Min	13.2	15.7	21.1	21.5	24.2	22.1	20.1	19.8	24.9	17.5	12.8	13.4
		Mean	21.1	23.6	28.7	28.9	30.8	27.35	25.4	24.8	28.4	24.4	23.5	20.9
	Humi	Max	22.2	21.0	34.0	34.0	63.2	73.4	85.5	84.8	84.2	62.8	27.5	31.4
		Min	16.3	15.1	34.0	18.0	37.7	57.8	69.6	67.8	73.2	54.8	24.6	25.8
		Mean	19.8	17.5	34.0	26.0	48.9	65.7	77.4	74.4	78.9	58.2	26.0	28.5
Gwarzo	RF		0.0	0.0	0.0	19.4	58.1	145.8	236	329	107	41.9	0.0	0.0
	Temp	Max	32.5	36.9	37.8	40.7	39.9	35.2	31.4	31.2	33.2	34.8	35.5	30.9
		Min	14.8	19.1	22.2	26.1	26.5	24.3	23.1	22.3	23.1	22.5	18.2	14.4
		Mean	23.7	28.0	30.0	33.4	33.2	29.8	27.3	26.8	28.2	28.7	26.9	22.7
	Humi	Max	46.2	37.5	30.8	27.3	52	75.2	77	82.8	84.3	75.2	29.8	37.8
		Min	13.2	8.5	8.2	6.4	15.7	34.2	49.9	67.7	84.3	57.1	26.5	31.1
		Mean	26.7	21.0	17.8	15	32.5	52.7	62.6	76.6	84.3	65.6	28.2	33.9

Source: Institute for Agricultural Research, Samaru, Zaria, Kaduna State (Igabi and Gwarzo locations) and International Institute of Tropical Agriculture (IITA) Kubwa Station, Abuja (Abuja location); RF =Rainfall (mm), Temp = Temperature (°C), Humi =Humidity (%), Max =Maximum, Min =Minimum

Table 4.2: Monthly meteorological data for the experimental locations during the 2016 cropping season

Locations			Months											
			Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec

Abuja	RF		1.0	8.0	36.0	90.0	165	197	253	288	294	150	13.0	2.0
	Temp	Max	26.0	31.4	31.5	32.7	27.4	26.5	23.5	25.0	28.5	29.8	27.5	30.9
		Min	22.0	23.1	28.4	28.6	24.7	25.7	17.5	16.0	26.7	25.3	24.0	22.3
		Mean	24.0	27.7	30.1	30.7	26.1	26.1	20.5	20.5	27.6	27.6	25.7	26.6
	Humi	Max	43.5	34.2	47.7	58.1	73.7	78.5	84.1	64.2	52.7	48.1	36.5	30.7
		Min	30.7	27.4	35.2	37.6	58.4	64.2	50.3	52.6	45.3	37.3	22.4	19.5
		Mean	31.1	30.8	41.5	47.9	66.05	71.4	67.2	58.4	49.0	42.7	29.5	25.1
Igabi	RF		0.0	0.0	0.0	0.0	70.0	80.0	316	373	272	68	0.0	0.0
	Temp	Max	31.1	32.2	33.5	32.8	29.0	26.5	25.5	29.0	28.5	29.3	29.5	30.4
		Min	23.3	22.0	32.6	30.0	26.4	25.3	25.5	26.0	26.7	29.3	27.0	25.3
		Mean	24.2	27.4	33.0	30.6	27.4	25.3	25.5	27.0	27.5	29.3	28.0	27.9
	Humi	Max	24.9	21.0	42.9	57.3	74.2	79.3	75.0	58.0	56.2	37.3	53.6	30.6
		Min	14.3	19.6	38.1	49.6	64.4	73.5	75.0	56.0	54.8	36.5	17.5	16.2
		Mean	19.4	20.4	40.4	53.1	69.0	76.3	75.0	57.0	55.5	37.0	34.7	23.4
Gwarzo	RF		0.0	0.0	0.0	0.0	18	66	162	381	263	84	0.0	0.0
	Temp	Max	25.8	31.0	38.0	40.5	38.2	32.3	30.1	30.0	31.8	35.1	28.9	25.1
		Min	16.8	15.3	24.9	26.3	26.0	22.8	22.1	22.3	22.4	20.5	17.0	17.1
		Mean	20.9	22.9	31.2	33.0	31.8	26.8	26.2	26.3	27.0	27.6	19.8	19.2
	Humi	Max	32.0	42.6	41.1	53.1	69.9	79.1	88.8	95.0	91.6	79.7	53.6	36.2
		Min	13.7	9.4	11.6	14.0	25.9	41.5	52.4	57.2	48.7	20.8	17.5	15.1
		Mean	22.1	23.9	25.8	31.5	48.1	60.3	72.5	78.4	73.6	50.7	35.7	24.4

Source: Institute for Agricultural Research, Samaru, Zaria, Kaduna State (Igabi and Gwarzo locations) and International Institute of Tropical Agriculture (IITA) Kubwa Station, Abuja (Abuja location); RF =Rainfall (mm), Temp = Temperature (°C), Humi =Humidity (%), Max =Maximum, Min =Minimum

Table 4.3: Soil physical and chemical properties for the experimental sites

Soil parameters	Abuja	Igabi	Gwarzo

		2015 cropping season	
Particle size distribution (g kg $^{-1}$)			
Sand	818	722	700
Silt	63	126	149
Clay	119	152	151
Texture	Sandy loam	Sandy loam	Sandy loam
Chemical properties			
pH (H_2O)	6.3	4.8	6.5
Nitrogen (g kg $^{-1}$)	1.60	0.64	0.36
Available phosphorus (mg kg $^{-1}$)	10.2	5.13	6.15
Potassium (cmol kg^{-1})	0.17	0.19	0.21
		2016 cropping season	
Particle size distribution (g kg $^{-1}$)			
Sand	780	700	760
Silt	80	160	120
Clay	140	140	120
Texture	Sandy loam	Sandy loam	Sandy loam
Chemical properties			
pH (H_2O)	6.5	6.2	7.2
Nitrogen (g kg $^{-1}$)	1.90	0.37	0.38
Available phosphorus (mg kg $^{-1}$)	11.30	8.20	7.18
Potassium (cmol kg^{-1})	0.16	0.15	0.23

4.2 Growth and Yield Attributes in Abuja

4.2.1 Emergence percentage

The effect of inoculation on emergence percentage of some soybean genotypes in 2015, 2016 and the combined means in Abuja are presented in Table 4.4. The genotypes differed significantly in their emergence, such that genotype TGx 1989-11F, TGx 1989-53FN, TGx 1989-40F, TGx 1989-68FN resulted in similar highest emergence percentage, which were inturn superior to TGx 1990-57F in 2015, TGx 1989-42FN, TGx 1993-4FN, TGx 1989-75N, TGx 1967-62F, TGx 1448-2E and TGx 1990-46F in 2016, TGx 1990-52F, TGx 1989-48FN, TGx 1989-49FN, TGx 1990-57F in the 2016 and the combined mean, respectively.

Inoculation types also had significant effect on emergence percentage in 2015, 2016 and the combined data. Application of NoduMax and LegumeFix resulted in similar highest emergence percentage than plots without inoculation in both years and the combined data. The interaction effect of genotypes and inoculation on emergence percentage of soybean was not statistically significant (P=0.05) in both cropping seasons and the combined data.

4.2.2 Chlorophyll content

The effects of genotype and inoculation on the chlorophyll content of soybean leaves are shown in Table 4.5. The genotypes effect was not significant during the 2015 and 2016 cropping seasons whereas uninoculated plants had significantly lower chlorophyll content in both 2015 and 2016 cropping seasons as well as the combined data compared to NoduMax and LegumeFix inoculation. Furthermore, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.2.3 Plant height

Table 4.6 shows the plant height of soybean as affected by genotypes and inoculation in 2015, 2016 cropping seasons and the combined data in Abuja. Plant height of soybean genotypes significantly varied during the two cropping seasons with TGX 1989-45F producing the tallest plants for 2015, 2016 and the combined data respectively. Result of inoculation was significant, with the uninoculated plants being significantly shorter than the inoculated treatments. Furthermore, the interaction between genotypes and inoculation recorded no significant difference except in the 2016 cropping season (Table 4.6).

The interaction of genotypes and inoculants on plant height of soybean in 2016 in Abuja was significant (Table 4.7). Application of NoduMax or LegumeFix resulted in a corresponding increase in plant height of all the soybean genotypes tested except with genotype, TGx 1835-10E which did not differ with or without inoculants application. The interaction also showed that the tallest plant was recorded in TGx 1989-48FN with LegumeFix. The shortest plants were recorded when the following genotypes TGx 1967-62F, TGx 1448-2E, TGx 1990-52F, TGx 1989 48FN and TGx 1990-40F were not inoculated with either NoduMax and LegumeFix, respectively.

Table 4.4: Emergence percentage of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	72.3a	75.0ab	73.7ab
TGx 1990-110FN	62.8ab	69.9abc	66.3abcd

TGx 1989 -42FN	67.0ab	68.8b	67.9abcd
TGx 1990 -95F	64.7ab	70.3abc	67.5abcd
TGx 1989-45F	66.8ab	71.8abc	69.3abcd
TGx 1990-114FN	67.3ab	72.2abc	69.8abcd
TGx 1989-53FN	72.4a	71.2abc	71.8abcd
TGx 1993-4FN	65.6ab	65.4bc	65.5abcd
TGx 1989-75FN	63.6ab	67.6bc	65.6abcd
TGx 1990-78F	65.9ab	71.1abc	68.5b
TGx 1967-62F(Check)	65.8ab	67.8bc	66.8abcd
TGx 1448-2E(Check)	64.0ab	66.4bc	65.2abcd
TGx 1989-40F	71.2a	81.6a	76.4a
TGx 1990-52F	62.4ab	63.7cd	63.1bcd
TGx 1989-48FN	63.6ab	64.6c	64.1bcd
TGx 1990-40F	60.4ab	62.3d	61.4cd
TGx 1989-49FN	61.9ab	67.6bcd	64.7bcd
TGx 1990-57F	58.1b	62.8cd	60.4d
TGx 1989-68FN	71.1a	76.9ab	74.0ab
TGx 1990-46F	65.8ab	67.3bcd	66.6abcd
TGx 1990-55F	70.1ab	75.0ab	72.6abc
TGx 1987-10F(Check)	71.1a	74.4abcd	72.8abc
TGx 1835-10E(Check)	71.1a	70.2abcd	70.7abcd
TGx 1485-1D(Check)	68.3ab	71.2abcd	69.8abcd
±SE	5.7	4.6	5.3
Inoculation(I)			
Without inoculation	53.0b	56.2b	54.6b
NoduMax	72.2a	76.2a	74.2a
LegumeFix	73.9a	76.9a	75.4a
±SE	1.2	1.3	0.8
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.5: Chlorophyll content (%) of soybean leaves as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	43.9a	43.4a	43.7a
TGx 1990-110FN	43.2a	43.9a	43.6a

TGx 1989 -42FN	43.4a	43.7a	43.6a
TGx 1990 -95F	42.6a	44.4a	43.5a
TGx 1989-45F	45.1a	45.0a	45.1a
TGx 1990-114FN	44.9a	44.1a	44.5a
TGx 1989-53FN	46.0a	45.7a	45.8a
TGx 1993-4FN	43.9a	44.6a	44.2a
TGx 1989-75FN	43.6a	44.7a	44.1a
TGx 1990-78F	44.1a	45.1a	44.6a
TGx 1967-62F(Check)	45.1a	43.6a	44.3a
TGx 1448-2E(Check)	42.8a	44.6a	44.4a
TGx 1989-40F	45.2a	46.1a	45.7a
TGx 1990-52F	45.7a	45.1a	45.4a
TGx 1989-48FN	44.9a	46.6a	45.7a
TGx 1990-40F	44.9a	47.1a	46.0a
TGx 1989-49FN	43.2a	44.1a	43.7a
TGx 1990-57F	43.9a	43.8a	43.8a
TGx 1989-68FN	43.1a	42.7a	42.9a
TGx 1990-46F	43.8a	43.0a	43.4a
TGx 1990-55F	46.3a	44.7a	45.5a
TGx 1987-10F(Check)	47.1a	46.0a	46.6a
TGx 1835-10E(Check)	44.6a	45.2a	44.9a
TGx 1485-1D(Check)	44.6a	44.1a	44.3a
±SE	1.8	1.6	1.2
Inoculation(I)			
Without inoculation	40.2b	39.7b	39.9b
NoduMax	46.3a	47.2a	46.7a
LegumeFix	46.8a	47.1a	46.9a
±SE	0.4	0.2	0.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.6: Plant height (cm) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	56.6bcde	60.8bcd	58.7bcdef
TGx 1990-110FN	53.0cdef	58.1bcdef	55.6cdefgh

TGx 1989 -42FN	58.8bcd	60.9bcd	59.8bcd
TGx 1990 -95F	64.2ab	64.3ab	64.3bcd
TGx 1989-45F	66.7a	68.3a	67.5a
TGx 1990-114FN	51.4def	53.7defghi	52.6fgh
TGx 1989-53FN	56.8bcde	55.1cdefgh	55.9cdefgh
TGx 1993-4FN	60.2abc	61.0bcd	60.6bcd
TGx 1989-75FN	52.2cdef	53.8defgh	53.0efgh
TGx 1990-78F	48.0f	52.4fghi	50.2h
TGx 1967-62F(Check)	52.4cdef	50.8gh	51.6gh
TGx 1448-2E(Check)	54.2cdef	49.1i	51.7gh
TGx 1989-40F	50.4ef	53.3efghi	51.9gh
TGx 1990-52F	51.6def	49.9hi	50.7gh
TGx 1989-48FN	54.0cdef	55.8cdefghi	54.9defgh
TGx 1990-40F	57.4bcde	57.1bcdefgh	57.3cdefg
TGx 1989-49FN	54.7cdef	59.2bcdef	56.9cdefg
TGx 1990-57F	59.7abcd	63.9ab	61.8abc
TGx 1989-68FN	54.1cdef	55.3cdefghi	54.7defgh
TGx 1990-46F	50.6ef	52.8fghi	51.7gh
TGx 1990-55F	59.1abcd	62.7abc	60.9bcd
TGx 1987-10F(Check)	59.1abcd	59.6bcdef	59.3bcde
TGx 1835-10E(Check)	54.8cdef	56.8bcdefgh	55.8cdefgh
TGx 1485-1D(Check)	57.1cdef	61.3abcd	59.2bcde
±SE	3.4	4.2	3.1
Inoculation(I)			
Without inoculation	42.5b	44.7b	43.6b
NoduMax	61.3a	62.8a	62.1a
LegumeFix	63.3a	64.4a	63.8a
±SE	0.8	0.7	0.8
Interaction			
G x I	NS	*	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; *= Significant at P=0.05; SE = Standard error

Table 4.7: Interaction effects of genotypes and inoculation on plant height (cm) of soybean in 2016 cropping season in Abuja

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	50.7c	65.7b	66.0b
TGx 1990-110FN	45.7d	60.7b	68.0b

TGx 1989 -42FN	46.7d	68.3b	67.7b
TGx 1990 -95F	49.0d	69.7ab	74.3a
TGx 1989-45F	50.3c	77.0a	77.7a
TGx 1990-114FN	46.3d	57.3c	57.3c
TGx 1989-53FN	36.0e	64.7b	64.7b
TGx 1993-4FN	47.7d	66.7b	68.7b
TGx 1989-75FN	44.3d	59.0c	58.0c
TGx 1990-78F	45.7d	56.3c	55.3c
TGx 1967-62F(Check)	36.0e	58.0c	58.3c
TGx 1448-2E(Check)	30.0e	58.3c	59.0c
TGx 1989-40F	46.3d	56.0c	57.7c
TGx 1990-52F	32.7e	58.7c	58.3c
TGx 1989-48FN	37.3e	57.3c	72.7a
TGx 1990-40F	33.3e	69.0ab	69.0ab
TGx 1989-49FN	44.7d	67.7b	65.3b
TGx 1990-57F	54.3c	69.7ab	67.7b
TGx 1989-68FN	42.7d	55.3c	68.0b
TGx 1990-46F	42.7d	58.3c	57.3c
TGx 1990-55F	53.7c	65.7b	68.7b
TGx 1987-10F(Check)	49.7d	64.3b	64.7b
TGx 1835-10E(Check)	52.3c	59.0bc	60.0bc
TGx 1485-1D(Check)	55.3c	65.7b	63.0b
±SE		4.3	

Means followed by the same letters are not significantly different at P= 0.05 using DMRT; SE = Standard error

4.2.4 Number of leaves

Table 4.8 shows number of leaves of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons and the combined data at the Abuja site. The numbers of leaves among genotypes was generally similar in both cropping seasons. The numbers of leaves was significantly better in soybean inoculated with NoduMax and LegumeFix than in those without inoculation. The interaction between genotypes and inoculation was not significant (P=0.05) in both cropping seasons and the combined analysis.

4.2.5 Days to 50 % flowering

Table 4.9 shows the result of days to 50 % flowering of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Abuja site. Days to 50 % flowering for genotypes recorded no significant effect during the 2015 cropping season whereas in 2016 cropping season TGx 1989-45F, TGx 1989-68FN and TGx 1987-10F(Check) recorded significantly lower number of days to 50% flowering. In addition, combined data showed that TGx 1989-75FN, TGx 1989-68FN and TGx 1987-10F(Check) had significantly lower number of days to flowering. Also, there was no significant difference among plant inoculated with either NoduMax or LegumeFix for days to 50% flowering (Table 4.9). The interaction effects between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.2.6 Number of branches

Table 4.10 shows significant differences among genotypes and inoculation application during the two cropping seasons and the combined data analysis for number of branches per plant at the Abuja site. In 2015 cropping season, TGx 1989-11F and other eight entries produced significantly higher number of branches. Also, during the 2016 cropping season, TGx 1989-48FN had the highest number of branches per plant but not significantly different from other seven entries. In the combined analysis, TGx 1990-110FN and TGx 1990-52F recorded significantly lower value. Result of inoculation application revealed that plants without inoculation produced significantly lower branches per plant during the 2015 and 2016 cropping seasons and combined analysis. There was no significant interaction between soybean genotypes and inoculation in both two cropping seasons and the combined analysis.

Table 4.8: Number of leaves of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	25a	26a	26a
TGx 1990-110FN	26a	25a	25a
TGx 1989 -42FN	26a	26a	26a
TGx 1990 -95F	26a	26a	26a
TGx 1989-45F	26a	26a	26a
TGx 1990-114FN	25a	25a	25a
TGx 1989-53FN	25a	27a	26a
TGx 1993-4FN	26a	26a	26a
TGx 1989-75FN	24a	26a	25a
TGx 1990-78F	27a	29a	28a
TGx 1967-62F(Check)	26a	27a	27a
TGx 1448-2E(Check)	27a	26a	26a
TGx 1989-40F	26a	25a	26a
TGx 1990-52F	26a	27a	27a
TGx 1989-48FN	26a	26a	26a
TGx 1990-40F	27a	27a	27a
TGx 1989-49FN	27a	28a	27a
TGx 1990-57F	27a	28a	28a
TGx 1989-68FN	26a	27a	27a
TGx 1990-46F	26a	27a	27a
TGx 1990-55F	28a	26a	27a
TGx 1987-10F(Check)	26a	27a	27a
TGx 1835-10E(Check)	27a	26a	27a
TGx 1485-1D(Check)	27a	28a	28a
±SE	1.9	2.4	1.8
Inoculation(I)			
Without inoculation	19b	21b	20b
NoduMax	30a	29a	29a
LegumeFix	29a	30a	29a
±SE	0.2	0.3	0.2
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.9: Days to 50 % flowering of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	49a	50a	49ab
TGx 1990-110FN	48a	49a	48ab
TGx 1989 -42FN	48a	48ab	48ab
TGx 1990 -95F	47a	49a	48ab
TGx 1989-45F	48a	47bc	48ab
TGx 1990-114FN	48a	49ab	49ab
TGx 1989-53FN	49a	48ab	49ab
TGx 1993-4FN	48a	48ab	48ab
TGx 1989-75FN	47a	48ab	47bc
TGx 1990-78F	49a	48ab	49ab
TGx 1967-62F(Check)	49a	48ab	49ab
TGx 1448-2E(Check)	48a	49a	48ab
TGx 1989-40F	46a	50a	48ab
TGx 1990-52F	48a	49a	48ab
TGx 1989-48FN	47a	48ab	48ab
TGx 1990-40F	48a	48ab	48ab
TGx 1989-49FN	48a	48ab	48ab
TGx 1990-57F	49a	48ab	49ab
TGx 1989-68FN	47a	47bc	47bc
TGx 1990-46F	49a	48ab	49ab
TGx 1990-55F	47a	49a	48ab
TGx 1987-10F(Check)	48a	47bc	47bc
TGx 1835-10E(Check)	49a	51a	50a
TGx 1485-1D(Check)	49a	48ab	49ab
±SE	0.6	0.8	0.5
Inoculation(I)			
Without inoculation	49a	48a	48a
NoduMax	48a	48a	48a
LegumeFix	48a	49a	48a
±SE	0.3	0.2	0.2
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.10: Number of branches (per plant) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	5a	6ab	5ab
TGx 1990-110FN	4b	5b	4c
TGx 1989 -42FN	5a	5b	5ab
TGx 1990 -95F	5a	5b	5ab
TGx 1989-45F	5a	5b	5ab
TGx 1990-114FN	4b	5b	5ab
TGx 1989-53FN	5a	5b	5ab
TGx 1993-4FN	5a	5b	5ab
TGx 1989-75FN	5a	6ab	5ab
TGx 1990-78F	5a	6ab	5ab
TGx 1967-62F(Check)	4b	5b	5ab
TGx 1448-2E(Check)	4b	5b	5ab
TGx 1989-40F	4b	6ab	5ab
TGx 1990-52F	4b	5b	4c
TGx 1989-48FN	4b	7a	5ab
TGx 1990-40F	4b	6ab	5ab
TGx 1989-49FN	4b	6ab	5ab
TGx 1990-57F	4b	6ab	5ab
TGx 1989-68FN	4b	5b	5ab
TGx 1990-46F	4b	5b	5ab
TGx 1990-55F	4b	5b	5ab
TGx 1987-10F(Check)	5a	5b	6a
TGx 1835-10E(Check)	4b	5b	5ab
TGx 1485-1D(Check)	4b	5b	5ab
±SE	0.4	0.3	0.3
Inoculation(I)			
Without inoculation	4b	4b	4b
NoduMax	5a	6a	5a
LegumeFix	5a	6a	5a
±SE	0.1	0.1	0.1
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.2.7 Number of pods per plant

Table 4.11 shows the number of pods per plant of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons and the combined data analysis at the Abuja site. The variation of genotypes on number of pods per plant of soybean was significant (P=0.05) in both 2015 and 2016 cropping seasons and the combined data. TGx 1990-78F produced the highest number of pods per plant, but not significantly different from other four entries during the 2015 cropping season. Furthermore, during the 2016 cropping season, TGx 1990-78F had more pods per plant but not significantly different from other seven entries. The combined data revealed that TGx 1990-114FN had significantly lower number of pods per plant compared to other genotypes. Also, the results of inoculation application indicated that uninoculated plants produced significantly fewer pods per plant in both cropping seasons and the combined data. Genotypes by inoculation interaction was significant during the 2015, 2016 cropping seasons and the combined data (Table 4.11).

Table 4.12 shows the interaction effect of genotypes and inoculation on the number of pods per plant of soybean in 2015 cropping season at the Abuja site. The table shows that unmber of pods per plant were generally higher under NoduMax and LegumeFix than uninoculated treatments. TGx 1989-11F, TGx 1990-78F, TGx 1989-40F and TGx 1990-40F under NoduMax and TGx 1990-95F under LegumeFix gave significantly more pods per plant than others genotypes.

Table 4.13 shows the interaction effect of genotypes and inoculation on the number of pods per plant of soybean during the 2016 cropping seasons in Abuja. Without inoculation, the plants recorded significantly lower number of pods compared to those treated with NoduMax and LegumeFix inoculation irrespective of the genotype. Among the inoculated plants, irrespective of the inoculants type, TGx 1990-95F, TGx 1989-45F and TGx 1990-40F produced the highest number of pods per plant, similar to those produced by NoduMax-inoculated TGx 1990-57F and the LegumeFix-inoculated TGx 1989- plants.

Table 4.14 shows the combined analysis for the interaction effect of genotypes and inoculation on the number of pods per plant of soybean during the 2015 and 2016 cropping seasons at the Abuja site. The Table indicated that number of pods per plant were generally higher under plants treated with NoduMax and LegumeFix than those without inoculation treatments. TGx 1989-11F, TGx 1989-53FN, TGx 1990-78F, TGx 1989-40F, TGx 1990-40F and TGx 1989-68FN (under NoduMax) and TGx 1990-95F under LegumeFix gave significantly higher number of pods per plant than other genotypes.

Table 4.11: Number of pods per plant of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	81ab	81ab	81ab
TGx 1990-110FN	72bc	75bc	74bc
TGx 1989 -42FN	72bc	75bc	74bc
TGx 1990 -95F	84ab	84ab	84ab
TGx 1989-45F	72bc	69cd	71bc
TGx 1990-114FN	64e	65d	64e
TGx 1989-53FN	77bc	80ab	79bc
TGx 1993-4FN	73bc	79abc	76bc
TGx 1989-75FN	70bc	73bc	72bc
TGx 1990-78F	88a	92a	90a
TGx 1967-62F(Check)	72bc	74bc	73bc
TGx 1448-2E(Check)	67cd	68cd	67cd
TGx 1989-40F	80ab	83ab	81ab
TGx 1990-52F	67cd	68cd	68cd
TGx 1989-48FN	71bc	72bc	71ab
TGx 1990-40F	85ab	80ab	82ab
TGx 1989-49FN	64e	66cd	65cd
TGx 1990-57F	66de	70bc	68cd
TGx 1989-68FN	73bc	72bc	73bc
TGx 1990-46F	67cd	74bc	71bc
TGx 1990-55F	75bc	71bc	73bc
TGx 1987-10F(Check)	79bc	82ab	81ab
TGx 1835-10E(Check)	66de	69bc	67cd
TGx 1485-1D(Check)	72bc	71bc	72bc
±SE	7.3	8.4	6.2
Inoculation(I)			
Without inoculation	48b	57b	53b
NoduMax	88a	91a	89a
LegumeFix	83a	85a	84a
±SE	1.5	1.6	1.6
Interaction			
G x I	*	*	*

Means followed by the same letter (s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant;
*= Significant at P=0.05; SE = Standard error

Table 4.12: Interaction effect of genotypes and inoculation on the number of pods per plant of soybean during the 2015 cropping season in Abuja

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	49g	110a	84c
TGx 1990-110FN	52f	77d	87c
TGx 1989 -42FN	46g	85c	85c
TGx 1990 -95F	55f	91b	106a
TGx 1989-45F	50f	80c	87c
TGx 1990-114FN	43g	64e	83c
TGx 1989-53FN	42g	99b	91b
TGx 1993-4FN	38h	91b	91b
TGx 1989-75FN	39h	82c	90b
TGx 1990-78F	46g	125a	94b
TGx 1967-62F(Check)	48g	82c	88c
TGx 1448-2E(Check)	44g	78d	80c
TGx 1989-40F	47g	120a	73d
TGx 1990-52F	42g	83c	76d
TGx 1989-48FN	46g	81c	87c
TGx 1990-40F	56f	117a	82c
TGx 1989-49FN	43g	78d	71d
TGx 1990-57F	45g	79cd	75d
TGx 1989-68FN	41g	99b	80c
TGx 1990-46F	42g	81c	79cd
TGx 1990-55F	67e	84c	74d
TGx 1987-10F(Check)	57f	91b	89bc
TGx 1835-10E(Check)	51f	76d	71d
TGx 1485-1D(Check)	59f	77d	82c
±SE		6.8	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

Table 4.13: Interaction effect of genotypes and inoculation on the number of pods per plant of soybean during the 2016 cropping season in Abuja

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	47g	112a	86c
TGx 1990-110FN	47g	90b	89c
TGx 1989 -42FN	52f	87c	87c
TGx 1990 -95F	51f	93b	108a
TGx 1989-45F	49g	82c	76d
TGx 1990-114FN	44g	66e	85c
TGx 1989-53FN	47g	101a	93b
TGx 1993-4FN	52f	93b	93b
TGx 1989-75FN	43g	84c	92b
TGx 1990-78F	54f	127a	96b
TGx 1967-62F(Check)	49g	84c	90b
TGx 1448-2E(Check)	41g	80c	82c
TGx 1989-40F	50f	122a	75d
TGx 1990-52F	41g	85c	78d
TGx 1989-48FN	43g	83c	89c
TGx 1990-40F	36h	119a	84c
TGx 1989-49FN	45g	80c	73d
TGx 1990-57F	51f	81c	77d
TGx 1989-68FN	34h	101a	82c
TGx 1990-46F	57f	83c	81c
TGx 1990-55F	50f	86c	76d
TGx 1987-10F(Check)	63e	93b	91b
TGx 1835-10E(Check)	55f	78d	73d
TGx 1485-1D(Check)	50f	79d	84c
±SE		8.3	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

Table 4.14: Combined analysis for the interaction effect of genotypes and inoculation on the number of pods per plant of soybean in 2015 and 2016 cropping seasons in Abuja

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	48g	111a	85c
TGx 1990-110FN	50f	83c	88c
TGx 1989 -42FN	49g	86c	86c
TGx 1990 -95F	53f	92b	107a
TGx 1989-45F	50f	81c	82c
TGx 1990-114FN	44g	65e	84c
TGx 1989-53FN	44g	100ab	92b
TGx 1993-4FN	45g	92b	92b
TGx 1989-75FN	41g	83c	91b
TGx 1990-78F	50f	126a	95b
TGx 1967-62F(Check)	48g	83c	89c
TGx 1448-2E(Check)	43g	79d	81c
TGx 1989-40F	49g	121a	74d
TGx 1990-52F	42g	84c	77d
TGx 1989-48FN	44g	82c	88c
TGx 1990-40F	46g	118a	83b
TGx 1989-49FN	44g	79d	72d
TGx 1990-57F	48g	80c	76d
TGx 1989-68FN	38h	100ab	81c
TGx 1990-46F	50f	82c	80c
TGx 1990-55F	58f	85c	75d
TGx 1987-10F(Check)	60e	92b	90b
TGx 1835-10E(Check)	53f	77d	72d
TGx 1485-1D(Check)	54f	78d	83c
±SE		7.1	

Means followed by the same letter are not significantly different at P=0.05 using DMRT; SE = Standard error

4.2.8 Total biomass yield

The total biomass yield of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Abuja site is presented in Table 4.15. There were significant differences among the genotypes and inoculation during the two cropping seasons and the combined. In 2015, TGx 1989-49FN produced the highest biomass but not significantly different from other eleven entries. Similarly, in 2016, TGx 1989-49FN produced the highest biomass but not significantly different from other eight entries. Combined data recorded a similar trend. Result of inoculation application showed that plants without inoculation had significantly lower biomass during the 2015, 2016 cropping seasons and the combined data when compared to those inoculated with NoduMax and LegumeFix (Table 4.15). Furthermore, the interaction between genotype and inoculation was not significant in both cropping seasons and the combined data.

4.2.9 Above ground biomass yield

Table 4.16 shows above ground biomass of soybean as affected by genotype and inoculation during the 2015 and 2016 cropping seasons and the combined data at the Abuja site. Above ground biomass were significant among genotypes and inoculation in the two cropping seasons and the combined data. TGx 1989-49FN recorded the highest biomass during the 2015 and 2016 cropping seasons but not significantly different from other seven entries. Combined data recorded similar trend while TGx 1990-95F, TGx 1989-40F recorded the least biomass during the same periods but not significantly different from other two entries. The result of inoculation revealed that plants without inoculation produced significantly fewer biomass than those inoculated with NoduMax and LegumeFix during the two cropping seasons and the combined data. Also, there was no significant difference in the interaction between genotype and inoculation in both cropping seasons and the combined data.

4.2.10 Seed yield

Table 4.17 shows seed yield of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons and the combined data at the Abuja site. Seed yield was significant among the genotypes and the inoculation applications at both cropping seasons and their combined data. TGx 1990-110FN, TGx 1990-46F, TGx 1989-45F, TGx 1989-49FN and TGx 1990-55F recorded significantly higher seed yield during the 2015 cropping season while TGx 1990-95F had the least yield during the same cropping season. In 2016 cropping season, TGx 1990-46F produced the highest yield but not significantly different from four other entries. Also, the combined data revealed that TGx 1990-46F and TGx 1984-49FN had significantly higer yield compared to other entries. The result of inoculation indicated that plants without inoculation produced significantly lower yield at both cropping seasons and the combined data. Furthermore, the interaction between genotypes and inoculation was not significant except during the 2016 cropping season.

Table 4.18 shows that seed yield were generally higher in plants inoculated with either NoduMax or LegumeFix compared to those plants without inoculation. Among the inoculated plants, irrespective of the inoculants, TGx 1990-110FN, TGx 1989-49FN and TGx 1990-46F produced higher yield, similar to those produced by NoduMax-inoculated TGx 1989-48FN, TGx 1990-40F and the LegumeFix-inoculated TGx 1989-42FN, TGx 1989-68FN and TGx 1990-55F plants. These were similar in yield as the checks TGx 1835-10E(CK), TGx 1835-10E(CK), TGx 1967-62F(CK) and TGx 1987-10F(CK).

Table 4.15: Total biomass yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	3869.2bc	3948.1bc	3908.6bc
TGx 1990-110FN	3958.7bc	4048.7bc	4003.7bc
TGx 1989 -42FN	4161.2ab	4206.8ab	4184.0ab
TGx 1990 -95F	3861.2c	3884.5cd	3872.9d
TGx 1989-45F	4051.4ab	4141.4ab	4096.4bc
TGx 1990-114FN	4144.9ab	4012.7bc	4078.8bc
TGx 1989-53FN	3959.8bc	3916.5bc	3938.1bc
TGx 1993-4FN	3927.8bc	4062.3bc	3995.1bc
TGx 1989-75FN	3913.5bc	3803.5d	3858.5c
TGx 1990-78F	3835.6c	3892.3cd	3864.0c
TGx 1967-62F(Check)	4044.2ab	4134.2ab	4089.2bc
TGx 1448-2E(Check)	3950.8bc	4040.8bc	3995.8bc
TGx 1989-40F	3874.9bc	3853.8cd	3864.3cd
TGx 1990-52F	3960.1bc	3939.0bcd	3949.5bc
TGx 1989-48FN	4104.6ab	4083.5bc	4094.0bc
TGx 1990-40F	3907.4bc	3997.4bcd	3952.4bc
TGx 1989-49FN	4378.8a	4468.8a	4423.8a
TGx 1990-57F	4155.7ab	4245.7ab	4200.7ab
TGx 1989-68FN	3977.9bc	4001.2bc	3989.6bc
TGx 1990-46F	4118.4ab	4097.3bc	4107.9ab
TGx 1990-55F	4171.0ab	4149.9ab	4160.5ab
TGx 1987-10F(Check)	4204.2ab	4294.2ab	4249.2ab
TGx 1835-10E(Check)	4168.0ab	4146.9ab	4157.4ab
TGx 1485-1D(Check)	4154.6ab	4244.6ab	4199.6ab
±SE	156.7	173.3	155.4
Inoculation(I)			
Without inoculation	3380.2b	3439.7b	3410.0b
NoduMax	4340.7a	4350.1a	4345.4a
LegumeFix	4385.1a	4411.8a	4398.7a
±SE	28.5	36.4	32.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.16: Above ground biomass (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	3117.2bc	3190.1bc	3153.6cd
TGx 1990-110FN	3206.7bc	3290.7bc	3248.7bc
TGx 1989 -42FN	3409.2ab	3448.8ab	3429.0ab
TGx 1990 -95F	3109.2c	3126.5c	3117.9d
TGx 1989-45F	3299.4ab	3383.4ab	3341.4bc
TGx 1990-114FN	3392.9ab	3254.7bc	3323.8bc
TGx 1989-53FN	3207.8bc	3158.5bc	3183.1bc
TGx 1993-4FN	3175.8bc	3304.3bc	3240.1bc
TGx 1989-75FN	3161.5bc	3045.5d	3103.5e
TGx 1990-78F	3083.6c	3134.3cd	3109.0d
TGx 1967-62F(Check)	3292.2bc	3376.2ab	3334.2bc
TGx 1448-2E(Check)	3198.8bc	3282.8bc	3240.8bc
TGx 1989-40F	3122.9bc	3095.8cd	3109.3d
TGx 1990-52F	3208.1bc	3181.0bc	3194.5bc
TGx 1989-48FN	3352.6ab	3325.5bc	3339.0bc
TGx 1990-40F	3155.4bc	3239.4bc	3197.4bc
TGx 1989-49FN	3626.8a	3710.8a	3668.8a
TGx 1990-57F	3403.7ab	3487.7ab	3445.7ab
TGx 1989-68FN	3225.9bc	3243.2bc	3234.6bc
TGx 1990-46F	3366.4ab	3339.3ab	3352.9bc
TGx 1990-55F	3419.0ab	3391.9ab	3405.5ab
TGx 1987-10F(Check)	3452.2ab	3536.2ab	3494.2ab
TGx 1835-10E(Check)	3416.0ab	3388.9ab	3402.4ab
TGx 1485-1D(Check)	3402.6ab	3486.6ab	3444.6ab
±SE	138.6	101.8	105.3
Inoculation(I)			
Without inoculation	2628.2b	2681.7b	2655.0b
NoduMax	3588.7a	3592.1a	3590.4a
LegumeFix	3633.7a	3653.8a	3643.7a
±SE	36.7	47.6	38.4
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.17: Seed yield (kg ha^{-1}) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	1659.2cd	1545.1dc	1602.1c
TGx 1990-110FN	2717.5ab	1839.0ab	2278.3a
TGx 1989 -42FN	1590.6cd	1676.5bc	1633.6c
TGx 1990 -95F	1514.2d	1544.6cd	1529.4c
TGx 1989-45F	1989.8ab	1820.1ab	1905.0ab
TGx 1990-114FN	1558.8cd	1611.3cd	1585.0c
TGx 1989-53FN	1613.0cd	1498.9d	1556.0c
TGx 1993-4FN	1581.8cd	1601.0cd	1591.4c
TGx 1989-75FN	1573.1cd	1592.3cd	1582.7c
TGx 1990-78F	1563.6cd	1582.8cd	1573.2c
TGx 1967-62F(Check)	1722.7bc	1738.6bc	1730.7bc
TGx 1448-2E(Check)	1658.7cd	1655.7bc	1657.2c
TGx 1989-40F	1583.3cd	1647.0bc	1615.2c
TGx 1990-52F	1657.3cd	1693.2bc	1675.3c
TGx 1989-48FN	1752.9bc	1816.5bc	1784.7bc
TGx 1990-40F	1699.1bc	1762.7bc	1730.9bc
TGx 1989-49FN	1996.4ab	1982.3ab	1989.4ab
TGx 1990-57F	1707.4bc	1771.1bc	1739.2bc
TGx 1989-68FN	1696.7bc	1727.0bc	1711.9bc
TGx 1990-46F	2060.0a	2145.9a	2102.9a
TGx 1990-55F	1859.5ab	1801.0bc	1830.2bc
TGx 1987-10F(Check)	1741.8bc	1794.4bc	1768.1bc
TGx 1835-10E(Check)	1743.7bc	1851.9ab	1797.8bc
TGx 1485-1D(Check)	1753.0bc	1872.2ab	1812.6bc
±SE	112.7	109.3	122.2
Inoculation(I)			
Without inoculation	1204.0c	1250.2b	1239.7c
NoduMax	1882.1b	1912.8a	1892.0b
LegumeFix	1988.1a	2008.3a	1991.0a
±SE	38.3	42.0	39.5
Interaction			
G x I	NS	*	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; *= Significant at P=0.05; SE = Standard error

Table 4.18: Interaction effect of genotypes and inoculation on the seed yield (kg ha^{-1}) of soybean during the 2016 cropping season in Abuja

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	1189.1j	1530.9f	1915.2b
TGx 1990-110FN	1299.4i	2118.3a	2099.3a
TGx 1989 -42FN	1236.1i	1777.5d	2016.0a
TGx 1990 -95F	1185.6j	1836.3c	1611.8e
TGx 1989-45F	1122.7j	1965.6b	1772.1d
TGx 1990-114FN	1172.6j	1746.4d	1915.0b
TGx 1989-53FN	1158.9j	1701.9d	1636.0e
TGx 1993-4FN	1197.9j	1828.7c	1776.4d
TGx 1989-75FN	1270.5i	1743.7d	1762.6d
TGx 1990-78F	1181.5i	1696.4e	1870.7c
TGx 1967-62F(Check)	1238.1i	1814.3c	2163.5a
TGx 1448-2E(Check)	1317.6h	1734.7d	1914.9b
TGx 1989-40F	1317.8h	1874.3c	1748.8d
TGx 1990-52F	1244.3i	1931.3b	1904.0b
TGx 1989-48FN	1345.6h	2125.2a	1978.7b
TGx 1990-40F	1212.7i	2148.9a	1926.5b
TGx 1989-49FN	1168.3j	2229.3a	2549.3a
TGx 1990-57F	1329.9h	1904.0b	2079.1a
TGx 1989-68FN	1341.6h	1759.0d	2080.3a
TGx 1990-46F	1326.8h	2588.8a	2521.9a
TGx 1990-55F	1144.8i	1911.6b	2346.3a
TGx 1987-10F(Check)	1314.1h	1987.0b	2081.8a
TGx 1835-10E(Check)	1245.0i	2025.7a	2284.7a
TGx 1485-1D(Check)	1443.7g	1929.2b	2243.7a
±SE		88.2	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

4.2.11 Harvest index

Harvest index of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons and the combined data at the Abuja site is shown in Table 4.19. The variations in genotypes during the 2015 cropping season revealed that TGx 1990-46F recorded the highest harvest index but not significantly different from three other entries. In 2016 cropping season, TGx 1990-46F had significantly higher harvest index with similar trend in the combined data. Application of inoculation showed that plant without inoculation had significantly lower harvest index compared to plants treated with either NoduMax or LegumeFix at both cropping seasons and the combined data. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.2.12 One hundred-seed weight

Table 4.20 shows one hundred-seed weight of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data in Abuja. Genotype effect had no significant variation during the 2015 cropping season, whereas in 2016 cropping season and combined data, TGx 1989-53FN and TGx 1993-4FN produced significantly lower seed weight. The result of inoculation applications indicated that inoculated plants had significantly highest seed weight at both cropping seasons and combined data. In addition, there were no significant differences in the interaction between the genotypes and inoculation in both cropping seasons and the combined data.

Table 4.19: Harvest index of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	0.43ab	0.39b	0.41b
TGx 1990-110FN	0.43ab	0.45b	0.44b
TGx 1989 -42FN	0.38bc	0.40b	0.39b
TGx 1990 -95F	0.39bc	0.40b	0.39b
TGx 1989-45F	0.39bc	0.39b	0.39b
TGx 1990-114FN	0.37c	0.40b	0.39b
TGx 1989-53FN	0.40bc	0.38b	0.39b
TGx 1993-4FN	0.40bc	0.39b	0.40b
TGx 1989-75FN	0.40bc	0.42b	0.41b
TGx 1990-78F	0.40bc	0.41b	0.41b
TGx 1967-62F(Check)	0.42bc	0.42b	0.42b
TGx 1448-2E(Check)	0.42bc	0.41b	0.41b
TGx 1989-40F	0.41bc	0.42b	0.42b
TGx 1990-52F	0.42bc	0.43b	0.42b
TGx 1989-48FN	0.42bc	0.44b	0.43b
TGx 1990-40F	0.43ab	0.43b	0.43b
TGx 1989-49FN	0.45ab	0.43b	0.44b
TGx 1990-57F	0.41bc	0.41b	0.41b
TGx 1989-68FN	0.42bc	0.43b	0.43b
TGx 1990-46F	0.49a	0.52a	0.50a
TGx 1990-55F	0.44ab	0.43b	0.43b
TGx 1987-10F(Check)	0.41bc	0.41b	0.41b
TGx 1835-10E(Check)	0.41bc	0.44b	0.42b
TGx 1485-1D(Check)	0.42bc	0.44b	0.43b
±SE	0.01	0.02	0.01
Inoculation(I)			
Without inoculation	0.35b	0.36b	0.36b
NoduMax	0.43a	0.44a	0.43a
LegumeFix	0.45a	0.45a	0.45a
±SE	0.01	0.01	0.01
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.20: One hundred-seed weight (g) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Abuja

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	11.16a	12.15a	11.66ab
TGx 1990-110FN	11.99a	12.91a	12.49a
TGx 1989 -42FN	11.19a	12.69a	11.69ab
TGx 1990 -95F	11.38a	12.76a	11.77ab
TGx 1989-45F	11.26a	12.16a	11.76ab
TGx 1990-114FN	11.43a	12.20a	11.82ab
TGx 1989-53FN	11.17a	10.18b	10.67d
TGx 1993-4FN	11.37a	10.32b	10.87c
TGx 1989-75FN	11.41a	12.42a	11.91ab
TGx 1990-78F	10.97a	11.77a	11.47ab
TGx 1967-62F(Check)	11.66a	10.16b	11.16bc
TGx 1448-2E(Check)	11.29a	12.99a	11.79ab
TGx 1989-40F	11.03a	12.53a	11.53ab
TGx 1990-52F	11.30a	12.30a	11.80ab
TGx 1989-48FN	11.02a	12.62a	11.52ab
TGx 1990-40F	11.36a	12.76a	11.86ab
TGx 1989-49FN	11.65a	12.45a	12.15ab
TGx 1990-57F	11.34a	12.44a	11.84ab
TGx 1989-68FN	11.20a	12.90a	11.70ab
TGx 1990-46F	11.53a	12.33a	12.03ab
TGx 1990-55F	11.60a	12.60a	12.10ab
TGx 1987-10F(Check)	11.11a	12.11a	11.61ab
TGx 1835-10E(Check)	11.80a	12.20a	12.30a
TGx 1485-1D(Check)	11.60a	12.10a	12.10a
±SE	0.2	0.3	0.2
Inoculation(I)			
Without inoculation	10.72b	11.54b	11.17b
NoduMax	11.69a	12.37a	11.99a
LegumeFix	11.68a	12.37a	12.02a
±SE	0.1	0.1	0.1
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.3 Growth and Yield Attributes in Igabi

4.3.1 Emergence percentage

Table 4.21 shows emergence percentage of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. Genotypes had significant differences in 2015 cropping season and the combined data whereas in 2016 cropping season, the variation of genotypes on emergence percentage was not significant. TGx 1989-45F had significantly poorer emergence during the 2015 cropping season and the combined data. The result of inoculation revealed, that plant without inoculation recorded significantly poorer emergence percentage compared to plants inoculated with either NoduMax or LegumeFix. The interaction between genotypes and inoculation was not significant.

4.3.2 Chlorophyll content

Table 4.22 shows chlorophyll content of soybean leaves as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons and the combined data in Igabi. Genotypes variations had significant differences in both cropping seasons and the combined data. In 2015 cropping season, TGx 1989-45F recorded the lowest chlorophyll content but not significantly different from other twenty-two entries. Also, in 2016 cropping season and the combined data, TGx 1989-45F had the lowest chlorophyll content that was significantly different from other genotypes. In addition, inoculation applications indicated that plants without inoculation recorded lower chlorophyll content significantly in both cropping seasons and the combined data. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

Table 4.21: Emergence percentage of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	76.0ab	78.0a	77.0ab
TGx 1990-110FN	72.6ab	75.3a	73.9bc
TGx 1989 -42FN	75.1ab	76.0a	75.6ab
TGx 1990 -95F	75.9ab	83.3a	79.6ab
TGx 1989-45F	71.3c	74.1a	72.7c
TGx 1990-114FN	78.7ab	80.7a	79.7ab
TGx 1989-53FN	76.2ab	78.2a	77.2ab
TGx 1993-4FN	72.2bc	74.2a	73.2bc
TGx 1989-75FN	81.0ab	79.1a	80.1ab
TGx 1990-78F	82.2ab	82.3a	82.3ab
TGx 1967-62F(Check)	78.1ab	80.1a	79.1ab
TGx 1448-2E(Check)	77.2ab	75.6a	76.4ab
TGx 1989-40F	81.6ab	77.4a	79.5ab
TGx 1990-52F	79.4ab	78.3a	78.9ab
TGx 1989-48FN	79.7ab	77.9a	78.8ab
TGx 1990-40F	84.8ab	80.7a	82.7ab
TGx 1989-49FN	79.9ab	78.8a	79.3ab
TGx 1990-57F	84.8ab	81.9a	83.3ab
TGx 1989-68FN	86.6a	84.1a	85.3ab
TGx 1990-46F	80.1ab	82.7a	81.4a
TGx 1990-55F	76.2ab	80.3a	78.3ab
TGx 1987-10F(Check)	81.8ab	82.1a	81.9ab
TGx 1835-10E(Check)	78.2ab	76.8a	77.5ab
TGx 1485-1D(Check)	76.9ab	80.8a	78.8ab
±SE	6.4	5.8	5.7
Inoculation(I)			
Without inoculation	64.9b	62.8b	63.8b
NoduMax	85.7a	87.4a	86.5a
LegumeFix	85.1a	87.1a	86.1a
±SE	1.7	1.2	1.4
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.22: Chlorophyll content (%) of soybean leaves as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	44.2ab	45.2ab	44.7ab
TGx 1990-110FN	43.1ab	44.8bc	43.9ab
TGx 1989 -42FN	44.3ab	45.0ab	44.7ab
TGx 1990 -95F	43.2ab	43.1cd	43.2abc
TGx 1989-45F	41.3b	40.3e	40.8d
TGx 1990-114FN	46.2ab	45.0ab	45.6ab
TGx 1989-53FN	45.7ab	44.7bc	45.2ab
TGx 1993-4FN	44.4ab	43.4cd	43.9ab
TGx 1989-75FN	44.8ab	45.8ab	45.3ab
TGx 1990-78F	43.2ab	42.2d	42.7cd
TGx 1967-62F(Check)	45.4ab	44.3bc	44.9ab
TGx 1448-2E(Check)	44.6ab	46.4ab	45.5ab
TGx 1989-40F	44.9ab	45.9ab	45.4ab
TGx 1990-52F	44.7ab	46.7ab	45.7ab
TGx 1989-48FN	46.8ab	49.1ab	47.9ab
TGx 1990-40F	44.6ab	47.1ab	45.8ab
TGx 1989-49FN	46.6ab	49.4ab	48.0a
TGx 1990-57F	45.7ab	50.3a	48.0a
TGx 1989-68FN	45.0ab	49.8ab	47.4ab
TGx 1990-46F	44.4ab	46.6ab	45.5ab
TGx 1990-55F	43.4ab	48.3ab	45.9ab
TGx 1987-10F(Check)	45.8ab	49.1ab	47.4ab
TGx 1835-10E(Check)	47.2a	49.7ab	48.4a
TGx 1485-1D(Check)	44.7ab	46.4ab	45.6ab
±SE	2.1	1.8	1.3
Inoculation(I)			
Without inoculation	40.6b	41.2b	40.9c
NoduMax	46.0a	48.0a	47.0b
LegumeFix	47.5a	49.4a	48.5a
±SE	0.4	0.5	0.5
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.3.3 Plant height

Plant height of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons and the combined data at the Igabi site is shown in Table 4.23. During the 2015 cropping season, TGx 1989-11F, TGx 1989-53FN and other three entries had shorter height that were significantly different from other genotypes. In 2016 cropping season, TGx 1989-11F, TGx 1989-45F, TGx 1989-53FN and TGx 1990-55F had significantly shorter height compared to other genotypes. Also, combined data revealed that, there were no significant differences in height except with TGx 1989-11F and TGx 1989-53FN plants. The effect of inoculation indicated that plants without inoculation produced significantly shorter height compared to plants treated with either NoduMax or LegumeFix in both cropping seasons and the combined data. The interaction between genotypes and inoculation was significant in both cropping seasons and the combined data.

Table 4.24 shows the interaction effect of genotypes and inoculation on the plant height of soybean in 2015 cropping season at the Igabi site. The Table shows that plants treated with either NoduMax or LegumeFix were generally taller compared to plants without inoculation. TGx 1989-11F, TGx 1990-110FN, TGx 1989-53FN, TGx 1993-4FN, TGx 1989-75FN, TGx 1967-62F(Check), TGx 1989-48FN, TGx 1990-57F and TGx 1990-46F (under NoduMax and LegumeFix) and TGx 1989-40F, TGx 1990-52F, TGx 1987-10F(Check) under NoduMax gave significantly taller height than others. Table 4.25 revealed that plants were generally taller under NoduMax and LegumeFix inoculation. Although, TGx 1989-75FN under LegumeFix recorded the highest height, it was not significantly different from other 18 genotypes treated with either NoduMax or LegumeFix inoculation. Similar trends were also recorded in Table 4.26.

Table 4.23: Plant height (cm) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	58.4c	59.4d	58.9d
TGx 1990-110FN	61.7ac	64.8ab	63.2ab
TGx 1989 -42FN	60.1bc	61.1bc	60.6ab
TGx 1990 -95F	61.2ab	62.2ab	61.7ab
TGx 1989-45F	59.7bc	60.7cd	60.2bc
TGx 1990-114FN	62.2ab	63.2ab	62.7ab
TGx 1989-53FN	59.2c	60.2cd	59.7cd
TGx 1993-4FN	64.2ab	65.2ab	64.7ab
TGx 1989-75FN	64.9ab	65.9ab	65.4ab
TGx 1990-78F	63.1ab	64.1ab	63.6ab
TGx 1967-62F(Check)	65.6ab	69.2a	67.4ab
TGx 1448-2E(Check)	63.4ab	66.0ab	64.7ab
TGx 1989-40F	65.3ab	68.8ab	67.1ab
TGx 1990-52F	67.3ab	66.3ab	66.8ab
TGx 1989-48FN	63.9ab	62.3ab	63.1ab
TGx 1990-40F	63.6ab	66.1ab	64.8ab
TGx 1989-49FN	65.1ab	69.6a	67.3ab
TGx 1990-57F	64.6ab	66.2ab	65.4ab
TGx 1989-68FN	65.9ab	65.6ab	65.7ab
TGx 1990-46F	68.8a	64.8ab	66.8ab
TGx 1990-55F	61.1ab	59.8d	60.4abc
TGx 1987-10F(Check)	68.9a	62.8ab	65.8ab
TGx 1835-10E(Check)	65.8ab	65.4ab	65.6ab
TGx 1485-1D(Check)	65.4ab	67.7ab	66.6ab
±SE	3.6	2.8	4.2
Inoculation(I)			
Without inoculation	52.7b	53.3b	53.0a
NoduMax	69.1a	71.0a	70.5b
LegumeFix	69.4a	70.2a	69.8b
±SE	0.4	0.3	0.5
Interaction			
G x I	*	*	*

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant;
*= Significant at P=0.05; SE = Standard error

Table 4.24: Interaction effect of genotypes and inoculation on the plant height (cm) of soybean in 2015 cropping season in Igabi

Treatment	Without inoculation	NoduMax	LegumeFix
Genotypes			
TGx 1989-11F	35.3e	70.3a	69.7ab
TGx 1990-110FN	44.0d	70.3a	70.7a
TGx 1989 -42FN	44.3d	66.7b	69.3ab
TGx 1990 -95F	44.7d	69.7b	69.3b
TGx 1989-45F	44.0d	68.0b	67.0b
TGx 1990-114FN	48.0d	68.7b	70.0a
TGx 1989-53FN	34.3e	70.7a	72.7a
TGx 1993-4FN	45.7d	70.0a	77.0a
TGx 1989-75FN	55.3c	70.0a	69.3ab
TGx 1990-78F	55.3c	66.3b	67.7b
TGx 1967-62F(Check)	55.3c	70.3a	71.0a
TGx 1448-2E(Check)	56.3c	66.3b	67.7b
TGx 1989-40F	56.7c	71.7a	67.7b
TGx 1990-52F	64.7b	69.0ab	68.3b
TGx 1989-48FN	50.3c	70.0a	71.3a
TGx 1990-40F	59.3bc	66.7b	64.7b
TGx 1989-49FN	58.7c	68.3b	68.3b
TGx 1990-57F	53.3c	70.0a	70.3a
TGx 1989-68FN	56.7c	69.7b	71.3a
TGx 1990-46F	64.3b	70.7a	71.3a
TGx 1990-55F	51.3c	64.0b	68.0b
TGx 1987-10F(Check)	63.7b	74.3a	68.7b
TGx 1835-10E(Check)	62.0b	67.3b	68.0b
TGx 1485-1D(Check)	61.0b	68.3b	67.0b
±SE		3.8	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

Table 4.25: Interaction effect of genotypes and inoculation on the plant height (cm) of soybean in 2016 cropping season in Igabi

Treatment	Without inoculation	NoduMax	LegumeFix
Genotypes			
TGx 1989-11F	36.3e	71.3a	70.7a
TGx 1990-110FN	51.3c	78.3a	71.7a
TGx 1989 -42FN	45.3d	77.7a	70.3a
TGx 1990 -95F	45.7d	70.7a	70.3a
TGx 1989-45F	45.0d	79.0a	68.0b
TGx 1990-114FN	49.0d	69.7ab	71.0a
TGx 1989-53FN	35.3e	71.7a	73.7a
TGx 1993-4FN	36.7e	71.0a	78.0a
TGx 1989-75FN	56.3c	71.0a	80.3a
TGx 1990-78F	56.3c	57.3c	68.7b
TGx 1967-62F(Check)	56.3c	75.3a	76.0a
TGx 1448-2E(Check)	60.0b	69.7ab	68.3b
TGx 1989-40F	63.3b	68.0b	75.0a
TGx 1990-52F	58.0c	73.0a	68.0b
TGx 1989-48FN	49.0d	72.0a	66.0b
TGx 1990-40F	63.3b	67.3b	67.7b
TGx 1989-49FN	65.7b	70.3a	72.7a
TGx 1990-57F	58.3c	70.7a	69.7ab
TGx 1989-68FN	53.0c	74.3a	69.3ab
TGx 1990-46F	61.0b	68.0b	65.3b
TGx 1990-55F	47.7d	63.7b	68.0b
TGx 1987-10F(Check)	53.3c	68.7b	66.3b
TGx 1835-10E(Check)	58.7c	69.3ab	68.3b
TGx 1485-1D(Check)	63.0b	68.7b	71.3a
±SE		2.7	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

Table 4.26: Combined analysis for the interaction effect of genotypes and inoculation on the plant height (cm) of soybean in 2015 and 2016 cropping seasons in Igabi

Treatment	Without inoculation	NoduMax	LegumeFix
Genotypes			
TGx 1989-11F	35.8e	70.8a	70.2a
TGx 1990-110FN	47.7d	70.8a	71.2a
TGx 1989 -42FN	44.8d	67.2b	69.8b
TGx 1990 -95F	45.2d	70.2a	69.8ab
TGx 1989-45F	44.5d	68.5b	67.5b
TGx 1990-114FN	48.5d	69.2b	70.5a
TGx 1989-53FN	34.8e	71.2a	73.2a
TGx 1993-4FN	46.2d	70.5a	77.5a
TGx 1989-75FN	55.8c	70.5a	75.8a
TGx 1990-78F	55.8c	66.8b	68.2b
TGx 1967-62F(Check)	55.8c	72.8a	73.5a
TGx 1448-2E(Check)	58.2c	68.0b	68.0b
TGx 1989-40F	60.0b	69.8ab	71.3a
TGx 1990-52F	61.3b	71.0a	68.2b
TGx 1989-48FN	49.7d	71.0a	68.7ab
TGx 1990-40F	61.3b	67.0b	66.2b
TGx 1989-49FN	62.2b	69.3ab	70.5a
TGx 1990-57F	55.8c	70.3a	70.0a
TGx 1989-68FN	54.8c	72.0a	70.3a
TGx 1990-46F	62.7b	69.3ab	68.3b
TGx 1990-55F	49.5d	63.8b	68.0b
TGx 1987-10F(Check)	58.5c	71.5a	67.5b
TGx 1835-10E(Check)	60.3b	68.3b	68.2b
TGx 1485-1D(Check)	62.0b	68.5b	69.2ab
±SE		3.1	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

4.3.4 Number of leaves

Table 4.27 shows the number of leaves of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. There were no significant differences in genotypes leaves number except TGx 1990-40F and TGx 1989-53FN in both 2015, 2016 cropping seasons and the combined data. Also, result of inoculation applications revealed that plants without inoculation recorded significantly lower leaves number compared to plants inoculated with either NoduMax or LegumeFix in both cropping seasons and the combined data. Furthermore, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.3.5 Days to 50 % flowering

Table 4.28 showed days to 50 % flowering of soybean as affected by genotypes and inoculation in the 2015, 2016 cropping seasons and the combined data at the Igabi site. Days to 50 % flowering had no significant variations during the 2015 cropping season. Also, in 2016 cropping season, there were no significant variations among the genotypes except TGx 1990-110FN and other four entries. The result of the combined data revealed that, there were no significant variations among the genotypes except TGx 1990-52F and TGx 1835-10E(Check). Also, the result of inoculation applications recorded non significant differences. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.3.6 Number of branches

Table 4.29 shows that number of branches per plant was non significant among genotypes in both 2015, 2016 cropping seasons and the combined data. Whereas the result of inoculation indicated that plant without inoculation recorded significantly lower branches per plant during the 2016 cropping season and the combined data. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.3.7 Number of pods per plant

Table 4.30 shows the number of pods per plant of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. Genotypes pods number per plant recorded similar values during the 2015 croppin season except TGx 1989-45F with the least pods per plant but not significantly different from 23 other entries. Similar trends were recorded in both 2016 cropping season and the combined data. The result of inoculation revealed that plants without inoculation recorded significantly lower pods compared to plants inoculated with either NoduMax or LegumeFix in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.3.8 Total biomass yield

Table 4.31 shows the total biomass yield of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. In 2015 cropping season, there was no significant difference among genotypes except TGx 1990-110FN and TGx 1989-49FN that recorded significantly lower biomass yield. Similar trends were recorded during the 2016 cropping season and the combined data. The result of inoculation revealed that, uninoculated plants recorded significantly lower biomass compared to plants treated with either NoduMax or LegumeFix. The interaction between the genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.3.9 Above ground biomass yield

Table 4.32 shows above ground biomass yield of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data in Igabi. The table revealed that, TGx 1990-110FN and TGx 1989-49FN recorded the least above ground biomass and was significantly different from other genotypes during the 2015 cropping season. Also, similar trends were recorded in 2016 cropping season and the combined data analysis. Inoculation result revealed that, plant without inoculation produced significantly lower above ground biomass compared to plant treated with either NoduMax or LegumeFix. The interaction between the genotypes and inoculation was not significant in both cropping seasons and the combined data.

Table 4.27: Number of leaves of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	28a	29a	28a
TGx 1990-110FN	28a	29a	28a
TGx 1989 -42FN	26a	27a	27a
TGx 1990 -95F	27a	28a	27a
TGx 1989-45F	29a	29a	29a
TGx 1990-114FN	27a	29a	28a
TGx 1989-53FN	16b	17b	16b
TGx 1993-4FN	28a	29a	28a
TGx 1989-75FN	29a	30a	29a
TGx 1990-78F	27a	29a	28a
TGx 1967-62F(Check)	27a	29a	28a
TGx 1448-2E(Check)	27a	29a	28a
TGx 1989-40F	27a	26a	27a
TGx 1990-52F	26a	29a	28a
TGx 1989-48FN	27a	27a	27a
TGx 1990-40F	14b	15b	15b
TGx 1989-49FN	28a	27a	27a
TGx 1990-57F	27a	29a	28a
TGx 1989-68FN	26a	26a	26a
TGx 1990-46F	26a	26a	26a
TGx 1990-55F	26a	26a	26a
TGx 1987-10F(Check)	26a	28a	27a
TGx 1835-10E(Check)	28a	29a	28a
TGx 1485-1D(Check)	27a	28a	27a
±SE	1.6	1.9	1.7
Inoculation(I)			
Without inoculation	19b	21b	20b
NoduMax	30a	30a	30a
LegumeFix	29a	30a	30a
±SE	0.6	0.5	0.4
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.28: Days to 50 % flowering of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	48a	49ab	48ab
TGx 1990-110FN	47a	48b	48ab
TGx 1989 -42FN	47a	48ab	48ab
TGx 1990 -95F	48a	49ab	48ab
TGx 1989-45F	49a	50ab	49ab
TGx 1990-114FN	49a	50ab	49ab
TGx 1989-53FN	47a	48b	48ab
TGx 1993-4FN	49a	50ab	49ab
TGx 1989-75FN	48a	49ab	48ab
TGx 1990-78F	48a	50ab	49ab
TGx 1967-62F(Check)	49a	49ab	49ab
TGx 1448-2E(Check)	47a	49ab	48ab
TGx 1989-40F	47a	48b	48ab
TGx 1990-52F	46a	47b	47b
TGx 1989-48FN	50a	53a	51a
TGx 1990-40F	47a	48b	48ab
TGx 1989-49FN	50a	51ab	51a
TGx 1990-57F	48a	49ab	49ab
TGx 1989-68FN	50a	51ab	50ab
TGx 1990-46F	48a	51ab	49ab
TGx 1990-55F	49a	51ab	50ab
TGx 1987-10F(Check)	49a	51ab	50ab
TGx 1835-10E(Check)	46a	47b	47b
TGx 1485-1D(Check)	49a	51ab	50ab
±SE	0.8	1.3	0.6
Inoculation(I)			
Without inoculation	48a	50a	49a
NoduMax	48a	50a	49a
LegumeFix	48a	50a	49a
±SE	0.3	0.4	0.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.29: Number of branches per plant of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	5a	5a	5a
TGx 1990-110FN	5a	5a	5a
TGx 1989 -42FN	4a	5a	5a
TGx 1990 -95F	4a	5a	5a
TGx 1989-45F	5a	5a	5a
TGx 1990-114FN	5a	6a	5a
TGx 1989-53FN	4a	5a	5a
TGx 1993-4FN	4a	5a	5a
TGx 1989-75FN	5a	5a	5a
TGx 1990-78F	4a	5a	5a
TGx 1967-62F(Check)	5a	5a	5a
TGx 1448-2E(Check)	5a	5a	5a
TGx 1989-40F	4a	5a	5a
TGx 1990-52F	5a	5a	5a
TGx 1989-48FN	5a	6a	5a
TGx 1990-40F	5a	5a	5a
TGx 1989-49FN	4a	5a	5a
TGx 1990-57F	4a	5a	5a
TGx 1989-68FN	4a	5a	5a
TGx 1990-46F	5a	6a	5a
TGx 1990-55F	5a	6a	5a
TGx 1987-10F(Check)	5a	6a	5a
TGx 1835-10E(Check)	5a	5a	5a
TGx 1485-1D(Check)	4a	5a	5a
±SE	0.4	0.1	0.3
Inoculation(I)			
Without inoculation	4a	4b	4b
NoduMax	5a	6a	6a
LegumeFix	5a	6a	6a
±SE	0.1	0.1	0.1
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.30: Number of pods per plant of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	81ab	83ab	82ab
TGx 1990-110FN	95a	97a	96a
TGx 1989 -42FN	77ab	79ab	78ab
TGx 1990 -95F	69ab	71b	70b
TGx 1989-45F	68b	70b	69b
TGx 1990-114FN	74ab	78ab	76ab
TGx 1989-53FN	74ab	76ab	75ab
TGx 1993-4FN	78ab	78ab	78ab
TGx 1989-75FN	83ab	82ab	82ab
TGx 1990-78F	83ab	85ab	84ab
TGx 1967-62F(Check)	71ab	73ab	72ab
TGx 1448-2E(Check)	82ab	79ab	80ab
TGx 1989-40F	76ab	75ab	75ab
TGx 1990-52F	81ab	82ab	81ab
TGx 1989-48FN	84ab	83ab	83ab
TGx 1990-40F	85ab	83ab	84ab
TGx 1989-49FN	86ab	85ab	86ab
TGx 1990-57F	78ab	77ab	77ab
TGx 1989-68FN	81ab	74ab	78ab
TGx 1990-46F	88ab	84ab	86ab
TGx 1990-55F	78ab	74ab	76ab
TGx 1987-10F(Check)	84ab	80ab	82ab
TGx 1835-10E(Check)	84ab	76ab	80ab
TGx 1485-1D(Check)	83ab	75ab	79ab
±SE	6.4	5.8	7.2
Inoculation(I)			
Without inoculation	61b	59b	60b
NoduMax	89a	88a	88a
LegumeFix	90a	90a	90a
±SE	2.5	2.8	1.9
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.31: Total biomass yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	4012.3ab	4100.3ab	4056.3ab
TGx 1990-110FN	3654.9c	3742.9c	3698.9d
TGx 1989 -42FN	4049.3ab	4137.3ab	4093.3ab
TGx 1990 -95F	4030.9ab	4118.9ab	4074.9ab
TGx 1989-45F	3823.8ab	3911.8ab	3867.8ab
TGx 1990-114FN	3796.4ab	3884.4bc	3840.4bc
TGx 1989-53FN	3822.7ab	3910.7ab	3866.7ab
TGx 1993-4FN	4193.9ab	4281.9ab	4237.9ab
TGx 1989-75FN	4171.4ab	4259.4ab	4215.4ab
TGx 1990-78F	3992.1ab	4080.1ab	4036.1ab
TGx 1967-62F(Check)	4043.9ab	4131.9ab	4087.9ab
TGx 1448-2E(Check)	4315.4ab	4403.4ab	4359.4ab
TGx 1989-40F	4136.9ab	4224.9ab	4180.9ab
TGx 1990-52F	4276.6ab	4364.6ab	4320.6ab
TGx 1989-48FN	4390.9a	4480.4ab	4435.7ab
TGx 1990-40F	4022.7ab	4123.7ab	4073.2ab
TGx 1989-49FN	3672.2c	3773.2c	3722.7cd
TGx 1990-57F	3804.5ab	3905.5ab	3855.0ab
TGx 1989-68FN	4060.8ab	4161.8ab	4111.3ab
TGx 1990-46F	3802.4ab	3903.4ab	3852.9ab
TGx 1990-55F	4409.5a	4510.5a	4460.0a
TGx 1987-10F(Check)	4215.5ab	4316.5ab	4266.0ab
TGx 1835-10E(Check)	3746.9bc	3847.9ab	3797.4cd
TGx 1485-1D(Check)	4143.7ab	4244.7ab	4194.2ab
±SE	223.1	242.6	147.4
Inoculation(I)			
Without inoculation	3188.9b	3281.8b	3235.4b
NoduMax	4383.9a	4476.8a	4430.3a
LegumeFix	4500.7a	4593.8a	4547.3a
±SE	76.8	85.3	79.6
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.32: Above ground biomass yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	3262.3bc	3400.3bc	3331.3bc
TGx 1990-110FN	3204.9d	3342.9d	3273.9d
TGx 1989 -42FN	3499.3ab	3637.3ab	3568.3ab
TGx 1990 -95F	3558.7ab	3696.7ab	3627.7ab
TGx 1989-45F	3373.8ab	3511.8ab	3442.8ab
TGx 1990-114FN	3346.4bc	3484.4bc	3415.4bc
TGx 1989-53FN	3372.7bc	3510.7ab	3441.7ab
TGx 1993-4FN	3743.9ab	3881.9ab	3812.9ab
TGx 1989-75FN	3721.4ab	3859.4ab	3790.4ab
TGx 1990-78F	3542.1ab	3680.1ab	3611.1ab
TGx 1967-62F(Check)	3593.9ab	3731.9ab	3662.9ab
TGx 1448-2E(Check)	3865.4ab	4003.4a	3934.4ab
TGx 1989-40F	3686.9ab	3824.9ab	3755.9ab
TGx 1990-52F	3826.6ab	3964.6ab	3895.6ab
TGx 1989-48FN	3740.9ab	3878.9ab	3809.9ab
TGx 1990-40F	3572.7ab	3710.7ab	3641.7ab
TGx 1989-49FN	3222.2c	3360.2cd	3291.2cd
TGx 1990-57F	3354.5ab	3492.5ab	3423.5ab
TGx 1989-68FN	3610.8ab	3748.8ab	3679.8ab
TGx 1990-46F	3352.4ab	3490.4ab	3421.4ab
TGx 1990-55F	3959.5a	4097.5a	4028.5a
TGx 1987-10F(Check)	3765.5ab	3903.5ab	3834.5ab
TGx 1835-10E(Check)	3296.9bc	3434.9bc	3365.9bc
TGx 1485-1D(Check)	3693.7bc	3831.7ab	3762.7ab
±SE	235.4	185.3	247.8
Inoculation(I)			
Without inoculation	2702.8b	2840.8b	2771.8b
NoduMax	3913.1a	4051.1a	3982.1a
LegumeFix	4029.9a	4167.9a	4098.9a
±SE	64.8	75.9	69.6
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.3.10 Seed yield

Table 4.33 shows the seed yield of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. There were no significant differences among genotypes during the 2015, 2016 cropping seasons and the combined data, whereas the result of inoculation revealed that plant without inoculation recorded significantly lower seed yield compared to plant inoculated with either NoduMax or LegumeFix in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was only significant in 2016 cropping season.

Table 4.34 shows the interaction effect of genotypes and inoculation on seed yield of soybean during the 2016 cropping season at the Igabi site. The table indicated that, seed yield were generally higher among the inoculated plants, irrespective of the inoculants type compared plant without inoculation. Except the checks TGx 1835-10E and TGx 1483-ID under NoduMax and LegumeFix, other genotype plants gave significantly higher seed yield.

4.3.11 Harvest index

Table 4.35 shows harvest index of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Igabi site. In 2015 cropping season, TGx 1989-49FN recorded the highest harvest index but not significantly different from other three entries. Similar performance was also recorded for 2016 cropping season and the combined data. The result of inoculation showed that, plant without inoculation had significantly lower index compared to plants treated with either NoduMax or LegumeFix. In addition, the interaction between the genotypes and inoculation on the harvest index in Igabi was not signification (Table 4.36).

4.3.12 One hundred-seed weight

Table 4.36 shows one hundred-seed weight of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons at the Igabi site. Genotypes variation was not significant during the 2015 cropping season whereas in 2016 cropping season and combined data, significant variations were recorded. Also, the result of inoculation revealed that, plants without inoculation recorded significantly lower seed weight compared to plant treated with either NoduMax or LegumeFix in both cropping seasons and the combined data. The interaction between genotypes and inoculation was not significant during the 2015, 2016 cropping seasons and the combined data analysis.

Table 4.33: Seed yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation in 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	1903.2a	1991.2a	1947.2a
TGx 1990-110FN	2073.6a	1961.6a	2017.6a
TGx 1989 -42FN	1810.7a	1898.7a	1854.7a
TGx 1990 -95F	1972.5a	2060.5a	2016.5a
TGx 1989-45F	2154.5a	2242.5a	2198.5a
TGx 1990-114FN	1752.3a	1840.3a	1796.3a
TGx 1989-53FN	1661.5a	1749.5a	1705.5a
TGx 1993-4FN	1853.7a	1941.7a	1897.7a
TGx 1989-75FN	1811.1a	1899.1a	1855.1a
TGx 1990-78F	1707.8a	1795.8a	1751.8a
TGx 1967-62F(Check)	1766.1a	1854.1a	1810.1a
TGx 1448-2E(Check)	1901.0a	1989.0a	1945.0a
TGx 1989-40F	1808.0a	1896.0a	1852.0a
TGx 1990-52F	1864.3a	1952.3a	1908.3a
TGx 1989-48FN	1940.7a	2028.7a	1984.7a
TGx 1990-40F	1810.7a	1898.7a	1854.7a
TGx 1989-49FN	2025.0a	2113.0a	2069.0a
TGx 1990-57F	1968.1a	2056.1a	2012.1a
TGx 1989-68FN	1683.3a	1771.3a	1727.3a
TGx 1990-46F	1868.9a	1956.9a	1912.9a
TGx 1990-55F	1834.7a	1922.7a	1878.7a
TGx 1987-10F(Check)	1868.0a	1956.0a	1912.0a
TGx 1835-10E(Check)	1688.0a	1776.0a	1732.0a
TGx 1485-1D(Check)	1642.9a	1730.9a	1686.9a
±SE	203.4	175.2	183.5
Inoculation(I)			
Without inoculation	1213.7b	1301.7b	1257.7b
NoduMax	2058.0a	2146.0a	2102.0a
LegumeFix	2174.5a	2262.5a	2218.5a
±SE	48.7	56.8	47.6
Interaction			
G x I	NS	*	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant;
*= Significant at P=0.05; SE = Standard error

Table 4.34: Interaction effects of genotypes and inoculation on seed yield (kg ha^{-1}) of soybean in 2016 cropping season in Igabi

Genotypes	Without inoculation	NoduMax	LegumeFix
TGx 1989-11F	1238.4j	2287.9ab	2447.5ab
TGx 1990-110FN	1195.7k	1947.4bc	2141.6ab
TGx 1989 -42FN	1251.1j	2164.9ab	2280.0ab
TGx 1990 -95F	1250.9j	2611.5a	2319.1ab
TGx 1989-45F	1242.7i	2184.8ab	2100.0ab
TGx 1990-114FN	1180.2k	2270.4ab	2070.3ab
TGx 1989-53FN	1404.7h	1939.7bc	1904.0bc
TGx 1993-4FN	1245.7j	2164.1ab	2415.2ab
TGx 1989-75FN	1283.7j	2239.9ab	2173.6ab
TGx 1990-78F	1237.9j	2132.9ab	2016.6ab
TGx 1967-62F(Check)	1187.7k	2214.9ab	2159.6ab
TGx 1448-2E(Check)	1238.8j	1937.6bc	2790.7a
TGx 1989-40F	1287.5j	2164.4ab	2236.0ab
TGx 1990-52F	1244.3j	2359.3ab	2253.4ab
TGx 1989-48FN	1417.3h	2101.6ab	2567.2a
TGx 1990-40F	1323.0ij	2060.7ab	2312.2ab
TGx 1989-49FN	1359.2ij	2651.7a	2328.2ab
TGx 1990-57F	1420.5h	2231.8ab	2516.2a
TGx 1989-68FN	1342.8ij	1812.1cd	2159.1ab
TGx 1990-46F	1293.2ij	1814.7bc	2762.8a
TGx 1990-55F	1296.1ij	2025.4ab	2456.6ab
TGx 1987-10F(Check)	1230.7ij	2241.7ab	2395.6ab
TGx 1835-10E(Check)	1333.4ij	1734.0e	1760.7e
TGx 1485-1D(Check)	1736.6e	1721.5e	1734.6e
±SE		146.3	

Means followed by the same letters are not significantly different at P=0.05 using DMRT; SE = Standard error

Table 4.35: Harvest index of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	0.46bc	0.48bc	0.47bc
TGx 1990-110FN	0.46bc	0.47bc	0.46bc
TGx 1989 -42FN	0.44bc	0.45bc	0.44bc
TGx 1990 -95F	0.48ab	0.49ab	0.49ab
TGx 1989-45F	0.46bc	0.47bc	0.47bc
TGx 1990-114FN	0.46bc	0.47bc	0.46bc
TGx 1989-53FN	0.43bc	0.45bc	0.44bc
TGx 1993-4FN	0.43bc	0.45bc	0.44bc
TGx 1989-75FN	0.43bc	0.44bc	0.43bc
TGx 1990-78F	0.42bc	0.44bc	0.43bc
TGx 1967-62F(Check)	0.43bc	0.44bc	0.44bc
TGx 1448-2E(Check)	0.43bc	0.45bc	0.44bc
TGx 1989-40F	0.43bc	0.44bc	0.44bc
TGx 1990-52F	0.43bc	0.44bc	0.44bc
TGx 1989-48FN	0.44bc	0.45bc	0.44bc
TGx 1990-40F	0.44bc	0.46bc	0.45bc
TGx 1989-49FN	0.55a	0.56a	0.56a
TGx 1990-57F	0.51ab	0.52ab	0.52ab
TGx 1989-68FN	0.41cd	0.42cd	0.42cd
TGx 1990-46F	0.48ab	0.49ab	0.49ab
TGx 1990-55F	0.41cd	0.42cd	0.42cd
TGx 1987-10F(Check)	0.43bc	0.45bc	0.44bc
TGx 1835-10E(Check)	0.46bc	0.47bc	0.46bc
TGx 1485-1D(Check)	0.39d	0.40d	0.40d
±SE	0.03	0.01	0.02
Inoculation(I)			
Without inoculation	0.38b	0.40b	0.39b
NoduMax	0.47a	0.48a	0.48a
LegumeFix	0.49a	0.50a	0.49a
±SE	0.01	0.01	0.01
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.36: One hundred-seed weight (g) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Igabi

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	11.70a	10.70d	11.20cd
TGx 1990-110FN	11.92a	10.92d	11.42bc
TGx 1989 -42FN	11.54a	10.54d	11.04d
TGx 1990 -95F	11.82a	11.26cd	11.54ab
TGx 1989-45F	11.64a	10.64d	11.14d
TGx 1990-114FN	11.59a	11.92bc	11.76ab
TGx 1989-53FN	11.93a	10.93d	11.43bc
TGx 1993-4FN	11.73a	10.73d	11.23cd
TGx 1989-75FN	12.02a	11.02d	11.52ab
TGx 1990-78F	11.64a	10.99d	11.31cd
TGx 1967-62F(Check)	11.60a	12.37ab	11.98ab
TGx 1448-2E(Check)	11.70a	12.70ab	12.20ab
TGx 1989-40F	11.45a	12.45ab	11.95ab
TGx 1990-52F	11.67a	12.67ab	12.17ab
TGx 1989-48FN	11.91a	12.91ab	12.41ab
TGx 1990-40F	11.31a	12.31ab	11.81ab
TGx 1989-49FN	12.00a	13.00a	12.50a
TGx 1990-57F	11.66a	12.66ab	12.16ab
TGx 1989-68FN	11.66a	12.66ab	12.16ab
TGx 1990-46F	11.64a	12.64ab	12.14ab
TGx 1990-55F	11.37a	12.37ab	11.87ab
TGx 1987-10F(Check)	11.51a	12.51ab	12.01ab
TGx 1835-10E(Check)	11.49a	12.49ab	11.99ab
TGx 1485-1D(Check)	12.08a	12.87ab	12.48ab
±SE	0.32	0.46	0.48
Inoculation(I)			
Without inoculation	11.02b	11.24b	11.13b
NoduMax	12.02a	12.27a	12.16a
LegumeFix	12.02a	12.26a	12.14a
±SE	0.13	0.15	0.13
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.4 Growth and Yield Attributes in Gwarzo

4.4.1 Emergence percentage

Table 4.37 shows the emergence percentage of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data in Gwarzo. Genotypes variation was not significant during the 2015 cropping season whereas in 2016 cropping season and the combined data analysis, there were significant differences among genotypes. TGx 1989-48FN plants had significantly lower emergence in the 2016 cropping season and the combined compared to other genotypes. Also, inoculation result indicated that, plants without inoculation had significantly lower emergence in both cropping seasons and the combined data. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.4.2 Chlorophyll content

Table 4.38 shows chlorophyll content of soybean leaves as affected by genotypes and inoculation in the 2015, 2016 cropping seasons and the combined data at the Gwarzo site. Genotypes variation was significant in both cropping seasons and the combined data. TGx 1989-40F recorded significantly lower chlorophyll content in both cropping seasons and the combined data. Result of inoculation indicated that, plant without inoculation recorded significantly lower chlorophyll content in both cropping seasons and the combined data. The interaction was not significant between the genotypes and inoculation at both cropping seasons and the combined data.

4.4.3 Plant height

Table 4.39 shows plant height of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data in Gwarzo. In 2015 cropping season, there were no significant differences in plant height among genotypes except TGx 1967-62F(CK). Also, in 2016 cropping season, TGx 1967-62F(CK) recorded the least height but not significantly different from other seven entries. Similar trends were recorded in the combined data. Inoculation result revealed that, plants without inoculation recorded significantly lower height in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined analysis.

4.4.4 Number of leaves

Table 4.40 shows the number of leaves as affected by genotypes and inoculation during the 2015, 2016 cropping seasons in Gwarzo. During the 2015 cropping seasons, TGx 1989-42FN had the least number of leaves but was not significantly different from other twenty genotypes. In 2016, there were no statistical differences among the genotypes. Combined data showed that, only TGx 1989-42FN plants had significantly lower leaf number but not significantly different from other twenty genotypes. Inoculation result revealed that, plants without inoculation produced the least number of leaves in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.4.5 Days to 50 % flowering

Table 4.41 showed days to 50 % flowering of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data in Gwarzo. Genotypes variation was not significant in 2015 cropping season, except TGx 1989-40F and TGx 1989-48FN. The same trends were recorded during the 2016 cropping season and the combined data. Inoculation result revealed that, there were no significant differences in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was not significant at both cropping seasons and the combined data.

4.4.6 Number of branches

Table 4.42 shows the number of branches per plant of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Gwarzo site. The variation of genotypes on number of branches per plant was not significant during the 2015 cropping season. In 2016 cropping season, TGx 1990-110FN recorded the least branches but not significantly different from other seventeen entries. Combined data analysis recorded a similar trend. Furthermore, result of inoculation revealed that, plants without inoculation recorded significantly fewer branches in both cropping seasons and the combined data analysis. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

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4.4.7 Number of pods per plant

Table 4.43 shows number of pods per plant of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data in Gwarzo. Genotypes variation was not significant in the 2015 cropping season whereas in 2016 and the combined analysis, there were significant variations. Inoculation result revealed that, plants without inoculation produced significantly fewer pods in both cropping seasons and the combined data compared to plants treated with either NoduMax or LegumeFix. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

Table 4.37: Emergence percentage of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	83.8a	80.6ab	82.2a
TGx 1990-110FN	80.2a	75.0ab	77.6ab
TGx 1989 -42FN	76.6a	73.4bc	75.0ab
TGx 1990 -95F	77.8a	80.3ab	79.1ab
TGx 1989-45F	74.9a	74.8ab	74.8ab
TGx 1990-114FN	73.8a	79.2ab	76.5ab
TGx 1989-53FN	79.1a	75.4ab	77.3ab
TGx 1993-4FN	74.8a	78.6ab	76.7ab
TGx 1989-75FN	76.0a	74.1ab	75.1ab
TGx 1990-78F	77.4a	74.1ab	75.8ab
TGx 1967-62F(Check)	80.8a	74.0ab	77.4ab
TGx 1448-2E(Check)	76.6a	73.0bc	74.8ab
TGx 1989-40F	83.4a	86.4a	84.9a
TGx 1990-52F	77.4a	71.3bc	74.4ab
TGx 1989-48FN	70.3a	66.2c	68.3c
TGx 1990-40F	70.3a	70.2bc	70.3bc
TGx 1989-49FN	80.6a	82.0ab	81.3ab
TGx 1990-57F	76.6a	76.0ab	76.3ab
TGx 1989-68FN	77.7a	80.2ab	78.9ab
TGx 1990-46F	76.7a	75.0ab	75.8ab
TGx 1990-55F	77.9a	75.9ab	76.9ab
TGx 1987-10F(Check)	78.1a	77.2ab	77.7ab
TGx 1835-10E(Check)	77.8a	78.9ab	78.3ab
TGx 1485-1D(Check)	77.0a	75.6ab	76.3ab
±SE	5.3	4.8	5.4
Inoculation(I)			
Without inoculation	64.5b	60.3b	62.4b
NoduMax	82.9a	83.3a	83.1a
LegumeFix	84.4a	84.6a	84.5a
±SE	1.4	1.2	1.0
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.38: Chlorophyll content (%) of soybean leaves as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	46.4ab	49.4ab	47.9ab
TGx 1990-110FN	43.9b	46.4ab	45.2bc
TGx 1989 -42FN	43.7b	46.7ab	45.2bc
TGx 1990 -95F	46.9ab	47.3ab	47.1ab
TGx 1989-45F	46.6ab	51.0a	48.8ab
TGx 1990-114FN	47.8ab	48.8ab	48.3ab
TGx 1989-53FN	46.3ab	46.7ab	46.5ab
TGx 1993-4FN	48.7ab	49.2ab	48.9ab
TGx 1989-75FN	45.6ab	47.8ab	46.7ab
TGx 1990-78F	43.6b	45.9ab	44.7bc
TGx 1967-62F(Check)	44.7ab	48.9ab	46.8ab
TGx 1448-2E(Check)	45.7ab	44.0bc	44.8bc
TGx 1989-40F	43.7b	42.7c	43.2c
TGx 1990-52F	50.3ab	48.4ab	49.4ab
TGx 1989-48FN	46.4ab	45.4ab	45.9ab
TGx 1990-40F	47.2ab	45.6ab	46.4ab
TGx 1989-49FN	46.7ab	47.2ab	46.9ab
TGx 1990-57F	44.0b	46.3ab	45.2bc
TGx 1989-68FN	47.2ab	49.9a	48.6ab
TGx 1990-46F	47.9ab	47.8ab	47.8ab
TGx 1990-55F	46.9ab	47.0ab	46.9ab
TGx 1987-10F(Check)	46.8ab	47.3ab	47.1ab
TGx 1835-10E(Check)	51.3a	50.0a	50.7a
TGx 1485-1D(Check)	46.2ab	47.2ab	46.7ab
±SE	2.2	2.1	2.4
Inoculation(I)			
Without inoculation	40.6b	40.0b	40.3b
NoduMax	48.4a	50.4a	49.4a
LegumeFix	50.1a	51.5a	50.8a
±SE	0.7	0.6	0.6
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.39: Plant height (cm) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	65.4ab	68.1ab	66.8ab
TGx 1990-110FN	60.9ab	61.9cd	61.4bc
TGx 1989 -42FN	61.1ab	64.0ab	62.6bc
TGx 1990 -95F	62.7ab	61.2cd	61.9bc
TGx 1989-45F	61.1ab	60.2cd	60.7cd
TGx 1990-114FN	67.8a	71.2a	69.5a
TGx 1989-53FN	65.8a	64.6ab	65.2ab
TGx 1993-4FN	64.2ab	66.4ab	65.3ab
TGx 1989-75FN	61.1ab	61.0cd	61.1cd
TGx 1990-78F	63.0ab	61.7cd	62.3bc
TGx 1967-62F(Check)	56.7b	55.8d	56.2d
TGx 1448-2E(Check)	63.0ab	60.0cd	61.5bc
TGx 1989-40F	64.8ab	62.7bc	63.7ab
TGx 1990-52F	61.0ab	62.4bc	61.7bc
TGx 1989-48FN	66.0a	70.0ab	68.0ab
TGx 1990-40F	62.4ab	65.0ab	63.7ab
TGx 1989-49FN	63.7ab	61.1cd	62.4bc
TGx 1990-57F	63.7ab	62.9bc	63.3ab
TGx 1989-68FN	63.6ab	64.2ab	63.9ab
TGx 1990-46F	62.1ab	61.6cd	61.8bc
TGx 1990-55F	59.3ab	60.9cd	60.1cd
TGx 1987-10F(Check)	62.3ab	62.8bc	62.6bc
TGx 1835-10E(Check)	63.0ab	64.0ab	63.5ab
TGx 1485-1D(Check)	61.6ab	61.3cd	61.4bc
±SE	2.8	3.2	3.1
Inoculation(I)			
Without inoculation	53.5b	51.4b	52.4b
NoduMax	67.5a	69.3a	68.4a
LegumeFix	67.2a	68.5a	67.8a
±SE	0.6	0.5	0.6
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.40: Number of leaves of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	27ab	29a	28ab
TGx 1990-110FN	28ab	28a	28ab
TGx 1989 -42FN	24b	26a	25b
TGx 1990 -95F	27ab	28a	27ab
TGx 1989-45F	27ab	28a	27ab
TGx 1990-114FN	27ab	29a	29a
TGx 1989-53FN	26ab	27a	27ab
TGx 1993-4FN	29a	28a	28ab
TGx 1989-75FN	29a	29a	29a
TGx 1990-78F	26ab	27a	26ab
TGx 1967-62F(Check)	28ab	29a	29a
TGx 1448-2E(Check)	28ab	28a	28ab
TGx 1989-40F	27ab	30a	28ab
TGx 1990-52F	29a	29a	29a
TGx 1989-48FN	28ab	29a	28a
TGx 1990-40F	28ab	29a	29a
TGx 1989-49FN	27ab	29a	28ab
TGx 1990-57F	27ab	29a	28ab
TGx 1989-68FN	28ab	28a	28ab
TGx 1990-46F	28ab	29a	28ab
TGx 1990-55F	28ab	30a	29a
TGx 1987-10F(Check)	27ab	29a	28ab
TGx 1835-10E(Check)	27ab	28a	28ab
TGx 1485-1D(Check)	28ab	28a	28ab
±SE	2.1	1.7	1.9
Inoculation(I)			
Without inoculation	19b	21b	20b
NoduMax	31a	31a	31a
LegumeFix	31b	29a	30a
±SE	0.3	0.4	0.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.41: Days to 50 % flowering of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	49.1a	50.9a	50a
TGx 1990-110FN	47.8ab	48.8ab	48ab
TGx 1989 -42FN	48.6ab	50.4a	50a
TGx 1990 -95F	49.8a	50.8a	50a
TGx 1989-45F	48.6ab	49.6ab	49ab
TGx 1990-114FN	47.2ab	48.2ab	48ab
TGx 1989-53FN	48.7ab	49.7ab	49ab
TGx 1993-4FN	45.7ab	46.7ab	46abc
TGx 1989-75FN	48.6ab	49.2ab	49ab
TGx 1990-78F	46.6ab	47.6ab	47abc
TGx 1967-62F(Check)	48.3ab	49.3ab	49ab
TGx 1448-2E(Check)	47.2ab	48.2ab	48ab
TGx 1989-40F	44.6bc	45.6b	45bc
TGx 1990-52F	49.2a	50.2a	50a
TGx 1989-48FN	44.4c	45.4b	45c
TGx 1990-40F	46.9ab	47.9ab	47abc
TGx 1989-49FN	47.9ab	48.9ab	48ab
TGx 1990-57F	47.1ab	48.9ab	48ab
TGx 1989-68FN	48.1ab	49.1ab	49ab
TGx 1990-46F	47.4ab	48.4ab	48ab
TGx 1990-55F	47.8ab	48.8ab	48ab
TGx 1987-10F(Check)	48.4ab	49.4ab	49ab
TGx 1835-10E(Check)	48.3ab	49.3ab	49ab
TGx 1485-1D(Check)	48.9a	49.9ab	49ab
±SE	1.4	0.9	1.1
Inoculation(I)			
Without inoculation	47.4a	48.3a	48.4a
NoduMax	48.0a	49.2a	49.3a
LegumeFix	47.8a	48.9a	48.3a
±SE	0.3	0.3	0.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.42: Number of branches (per plant) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	4a	5ab	5ab
TGx 1990-110FN	4a	4b	4b
TGx 1989 -42FN	5a	5ab	5ab
TGx 1990 -95F	5a	5ab	5ab
TGx 1989-45F	4a	5ab	4b
TGx 1990-114FN	5a	6a	5ab
TGx 1989-53FN	5a	5ab	5ab
TGx 1993-4FN	5a	6a	5ab
TGx 1989-75FN	5a	5ab	5ab
TGx 1990-78F	5a	5ab	5ab
TGx 1967-62F(Check)	5a	6a	6a
TGx 1448-2E(Check)	5a	6a	5ab
TGx 1989-40F	5a	5ab	5ab
TGx 1990-52F	4a	5ab	5ab
TGx 1989-48FN	5a	5ab	5ab
TGx 1990-40F	5a	5ab	5ab
TGx 1989-49FN	5a	5ab	5ab
TGx 1990-57F	5a	5ab	5ab
TGx 1989-68FN	5a	6a	6a
TGx 1990-46F	4a	5ab	5ab
TGx 1990-55F	5a	6a	5ab
TGx 1987-10F(Check)	5a	5ab	5ab
TGx 1835-10E(Check)	5a	5ab	5ab
TGx 1485-1D(Check)	5a	5ab	5ab
±SE	0.3	0.2	0.1
Inoculation(I)			
Without inoculation	4b	4b	4b
NoduMax	5a	6a	5a
LegumeFix	5a	6a	5a
±SE	0.2	0.1	0.1
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.43: Number of pods per plant of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	66a	65ab	65ab
TGx 1990-110FN	60a	58d	59c
TGx 1989 -42FN	71a	61cd	61bc
TGx 1990 -95F	63a	67ab	65ab
TGx 1989-45F	64a	71ab	67ab
TGx 1990-114FN	66a	69ab	68ab
TGx 1989-53FN	67a	74ab	71a
TGx 1993-4FN	60a	63cd	62bc
TGx 1989-75FN	63a	69ab	66ab
TGx 1990-78F	62a	68ab	65ab
TGx 1967-62F(Check)	66a	69ab	67ab
TGx 1448-2E(Check)	65a	65bc	65ab
TGx 1989-40F	66a	68ab	67ab
TGx 1990-52F	62a	69ab	66ab
TGx 1989-48FN	65a	66ab	65ab
TGx 1990-40F	61a	62cd	62bc
TGx 1989-49FN	62a	62cd	62bc
TGx 1990-57F	68a	75a	71a
TGx 1989-68FN	66a	70ab	68ab
TGx 1990-46F	67a	74ab	71a
TGx 1990-55F	61a	66ab	64ab
TGx 1987-10F(Check)	61a	63cd	62bc
TGx 1835-10E(Check)	62a	61cd	62bc
TGx 1485-1D(Check)	67a	74ab	71a
±SE	3.1	2.3	2.8
Inoculation(I)			
Without inoculation	58b	60b	59b
NoduMax	66a	72a	70a
LegumeFix	67a	70a	68a
±SE	1.3	1.2	0.7
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.4.8 Total biomass yield

The effect of genotypes and inoculation on the total biomass yield of soybean during the 2015, 2016 cropping seasons and the combined data in Gwarzo is presented in Table 4.44. Genotypes in both cropping seasons and the combined data recorded significant variation (P=0.05) on the total biomass yield. TGx 1989-11F, TGx 1990-110FN, TGx 1989-42FN, TGx 1990-95F and TGx 1990-114FN plants produced significantly higher biomass compared to other genotypes in 2015 cropping season. Similar trends were recorded in 2016 croppin season and the combined data. Also, inoculation result revealed that, plants without inoculation produced significantly lower biomass in both cropping seasons and the combined data. The interaction between the genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.4.9 Above ground biomass yield

Table 4.45 shows the above ground biomass yield of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data in Gwarzo. The genotypes variations were significant in both cropping seasons and the combined data. However, TGx 1989-11F, TGx 1990-110FN, TGx 1989-42FN, TGx 1990-95F plants, produced significantly higher above ground biomass compared to other genotypes in 2015 cropping season. Similar trends were recorded in 2016 cropping season and the combined data. In addition, inoculation result showed that, plants without inoculation were significantly lower in biomass compared to plants treated with either NoduMax or LegumeFix in both cropping seasons and the combined data. The interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data analysis.

4.4.10 Seed yield

Table 4.46 shows seed yield of soybean as affected by genotype and inoculation during the 2015, 2016 cropping seasons and the combined data at the Gwarzo site. Genotypes variation was not significant except TGX 1990-78F which was not significantly different from other twenty-two entries in 2015 cropping season, with similar trends been observed in 2016 cropping season and the combined data. Inoculation result revealed that, uninoculated plants produced significantly lower seed yield in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation had no significant variation in both cropping seasons and the combined data.

4.4.11 Harvest index

Table 4.47 Shows harvest index of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Gwarzo site. The genotype variation on harvest index was significant at both cropping seasons and the combined data. TGx 1989-53FN plants recorded significantly higher harvest index in 2015 cropping season compared to other genotypes. In 2016 cropping season, TGx 1989-40F and TGx 1990-57F plants had the highest index but not significantly different from nineteen entries, with similar trend been recorded in the combined data. Inoculation result indicated that, plants without inoculation recorded significantly lower index in both cropping seasons and the combined data. Also, the interaction between genotypes and inoculation was not significant in both cropping seasons and the combined data.

4.4.12 One hundred-seed weight

Table 4.48 shows one hundred-seed weight of soybean as affected by genotypes and inoculation during the 2015, 2016 cropping seasons and the combined data at the Gwarzo site. In 2015 cropping season, there were no significant variations among genotypes except TGx 1990-78F, which was not significantly different from other twenty-two genotypes. In 2016 cropping season, TGx 1990-57F and TGx 1990-46F plants produced the higher weight but not significantly different from other seven genotypes. The combined data was not statistically different except TGx 1989-49FN which was not different from other twenty-two entries. Inoculation result indicated that, plants without inoculation had significantly smaller seeds in both cropping seasons and the combined data compared to plants inoculated with either NoduMax or LegumeFix. The interaction between genotypes and inoculation on one hundred-seed weight was not significant in both cropping seasons and the combined data analysis.

Table 4.44: Total biomass yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	3455.7a	3427.7bc	3441.7a
TGx 1990-110FN	3501.5a	3673.5ab	3587.5a
TGx 1989 -42FN	3647.7a	3819.7a	3733.7a
TGx 1990 -95F	3649.4a	3821.4aa	3735.4a
TGx 1989-45F	3510.4a	3682.4ab	3596.4a
TGx 1990-114FN	3437.9a	3609.9ab	3523.9a
TGx 1989-53FN	2390.7e	3262.7cd	2826.7bc
TGx 1993-4FN	3022.4b	3194.4cd	3108.4b
TGx 1989-75FN	2958.3b	3130.3cd	3044.3bc
TGx 1990-78F	2591.2cd	2763.2cd	2677.2de
TGx 1967-62F(Check)	3037.5b	3109.5cd	3073.5bc
TGx 1448-2E(Check)	2613.9cd	2885.9e	2749.9cd
TGx 1989-40F	2697.1bc	2769.1f	2733.1cd
TGx 1990-52F	2765.8bc	2937.8de	2851.8bc
TGx 1989-48FN	2874.6bc	3146.6cd	3010.6bc
TGx 1990-40F	2601.0cd	2973.0de	2787.0bc
TGx 1989-49FN	2742.4bc	3014.4de	2878.4bc
TGx 1990-57F	2710.5bc	2882.5e	2796.5bc
TGx 1989-68FN	2504.6de	2776.6f	2640.6e
TGx 1990-46F	2883.0bc	3155.0cd	3019.0bc
TGx 1990-55F	2880.8bc	3152.8cd	3016.8bc
TGx 1987-10F(Check)	2887.0bc	2959.0de	2923.0bc
TGx 1835-10E(Check)	2731.5bc	2903.5ef	2817.5bc
TGx 1485-1D(Check)	2860.8bc	2932.8de	2896.8bc
±SE	113.8	185.7	177.2
Inoculation(I)			
Without inoculation	2674.7b	2884.2b	2779.4b
NoduMax	3058.4a	3267.9a	3163.2a
LegumeFix	3136.3a	3345.8a	3241.0a
±SE	58.2	54.1	56.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.45: Above ground biomass yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	2674.7a	2843.7a	2759.2a
TGx 1990-110FN	2720.5a	2889.5a	2805.0a
TGx 1989 -42FN	2466.7ab	2635.7ab	2551.2ab
TGx 1990 -95F	2468.4ab	2637.4ab	2552.9ab
TGx 1989-45F	2329.4bc	2498.4bc	2413.9bc
TGx 1990-114FN	2256.9bc	2425.9bc	2341.4cd
TGx 1989-53FN	2309.7bc	2478.7bc	2394.2cd
TGx 1993-4FN	1841.4d	2010.4fg	1925.9fg
TGx 1989-75FN	2077.3cd	2246.3cde	2161.8cd
TGx 1990-78F	1710.2g	1879.2g	1794.7g
TGx 1967-62F(Check)	2056.5cd	2225.5cd	2141.0cd
TGx 1448-2E(Check)	1832.9fd	2001.9fg	1917.4fg
TGx 1989-40F	1816.1fg	1985.1fg	1900.6fg
TGx 1990-52F	1984.8de	2153.8de	2069.3ef
TGx 1989-48FN	2093.6cd	2262.6cd	2178.1cd
TGx 1990-40F	1920.0ef	2089.0ef	2004.5ef
TGx 1989-49FN	1961.4ef	2130.4ef	2045.9ef
TGx 1990-57F	1829.5fg	1998.5fg	1914.0efg
TGx 1989-68FN	1823.6fg	1992.6fg	1908.1fg
TGx 1990-46F	2102.0cd	2271.0cd	2186.5cd
TGx 1990-55F	2099.8cd	2268.8cd	2184.3cd
TGx 1987-10F(Check)	2006.0cd	2175.0cd	2090.5cd
TGx 1835-10E(Check)	1950.5ef	2119.5efg	2035.0ef
TGx 1485-1D(Check)	1879.8fg	2048.8fg	1964.3fg
±SE	97.8	101.5	88.7
Inoculation(I)			
Without inoculation	1810.3b	1979.3b	1894.8b
NoduMax	2194.1a	2363.1a	2278.6a
LegumeFix	2271.9a	2440.9a	2356.4a
±SE	35.7	48.2	40.3
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.46: Seed yield (kg ha $^{-1}$) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	1144.7ab	1229.7ab	1187.2ab
TGx 1990-110FN	1152.6ab	1237.1ab	1195.1ab
TGx 1989 -42FN	1174.2ab	1259.2ab	1216.7ab
TGx 1990 -95F	1232.2ab	1317.2ab	1274.7ab
TGx 1989-45F	1252.6a	1337.9a	1295.4a
TGx 1990-114FN	1193.7ab	1278.7ab	1236.2ab
TGx 1989-53FN	1173.4ab	1258.4ab	1216.2ab
TGx 1993-4FN	1249.3a	1334.6a	1292.1a
TGx 1989-75FN	1233.2ab	1318.2ab	1276.4ab
TGx 1990-78F	1097.3b	1182.8b	1139.9b
TGx 1967-62F(Check)	1170.8ab	1255.8ab	1212.9ab
TGx 1448-2E(Check)	1144.7ab	1229.7ab	1186.7ab
TGx 1989-40F	1130.6ab	1215.6ab	1173.4ab
TGx 1990-52F	1135.4ab	1220.4ab	1177.5ab
TGx 1989-48FN	1146.9ab	1231.9ab	1188.6ab
TGx 1990-40F	1148.6ab	1233.6ab	1190.9ab
TGx 1989-49FN	1197.7ab	1282.7ab	1240.4ab
TGx 1990-57F	1178.7ab	1263.7ab	1220.6ab
TGx 1989-68FN	1128.7ab	1213.7ab	1171.1ab
TGx 1990-46F	1169.2ab	1254.2ab	1212.3ab
TGx 1990-55F	1144.9ab	1229.9ab	1186.7ab
TGx 1987-10F(Check)	1170.2ab	1255.2ab	1212.9ab
TGx 1835-10E(Check)	1128.4ab	1213.4ab	1171.1ab
TGx 1485-1D(Check)	1169.5ab	1254.5ab	1211.9ab
±SE	63.5	56.8	59.7
Inoculation(I)			
Without inoculation	952.2b	1037.0b	994.5b
NoduMax	1266.3a	1351.3a	1308.8a
LegumeFix	1290.1a	1375.1a	1332.6a
±SE	16.5	18.6	14.2
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.47: Harvest index of soybean as affected by genotypes and inoculation duing the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	0.34fg	0.37bcd	0.35cd
TGx 1990-110FN	0.33g	0.34ef	0.33d
TGx 1989 -42FN	0.32g	0.33f	0.33d
TGx 1990 -95F	0.34fg	0.35de	0.34d
TGx 1989-45F	0.36defg	0.37bcd	0.36cd
TGx 1990-114FN	0.35efg	0.35cde	0.35cd
TGx 1989-53FN	0.50a	0.39abc	0.44a
TGx 1993-4FN	0.41bcd	0.41ab	0.41ab
TGx 1989-75FN	0.42bc	0.42a	0.42a
TGx 1990-78F	0.42bc	0.43ab	0.43a
TGx 1967-62F(Check)	0.39cde	0.40ab	0.40ab
TGx 1448-2E(Check)	0.44bc	0.42a	0.43a
TGx 1989-40F	0.42bcd	0.44a	0.43a
TGx 1990-52F	0.41bcd	0.41ab	0.41ab
TGx 1989-48FN	0.40bcd	0.39abc	0.40ab
TGx 1990-40F	0.44bc	0.41ab	0.43a
TGx 1989-49FN	0.43bc	0.42a	0.43a
TGx 1990-57F	0.43bc	0.44a	0.43a
TGx 1989-68FN	0.45b	0.43a	0.44a
TGx 1990-46F	0.41bcd	0.40ab	0.40ab
TGx 1990-55F	0.40bcd	0.39ab	0.40ab
TGx 1987-10F(Check)	0.41bcd	0.42a	0.42ab
TGx 1835-10E(Check)	0.41bcd	0.42ab	0.42ab
TGx 1485-1D(Check)	0.41bcd	0.43a	0.42ab
±SE	0.02	0.01	0.01
Inoculation(I)			
Without inoculation	0.36b	0.36b	0.36b
NoduMax	0.42a	0.42a	0.42a
LegumeFix	0.42a	0.42a	0.42a
±SE	0.01	0.01	0.01
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

Table 4.48: One hundred-seed weight (g) of soybean as affected by genotypes and inoculation during the 2015 and 2016 cropping seasons in Gwarzo

Treatment	2015	2016	Combined
Genotypes (G)			
TGx 1989-11F	11.40ab	12.49bc	11.99ab
TGx 1990-110FN	11.27ab	12.27d	11.77ab
TGx 1989 -42FN	11.27ab	12.27d	11.77ab
TGx 1990 -95F	11.52ab	12.52bc	12.02ab
TGx 1989-45F	11.48ab	12.48bc	11.98ab
TGx 1990-114FN	11.29ab	12.29d	11.79ab
TGx 1989-53FN	11.81a	12.81ab	12.31ab
TGx 1993-4FN	11.48ab	12.48bc	11.98ab
TGx 1989-75FN	11.67ab	12.90ab	12.28ab
TGx 1990-78F	10.84b	12.84ab	11.84ab
TGx 1967-62F(Check)	11.23ab	13.23ab	12.23ab
TGx 1448-2E(Check)	11.29ab	13.06ab	12.18ab
TGx 1989-40F	11.19ab	13.19ab	12.19ab
TGx 1990-52F	11.14ab	13.14ab	12.14ab
TGx 1989-48FN	11.33ab	12.33cd	11.83ab
TGx 1990-40F	11.58ab	12.58cd	12.08ab
TGx 1989-49FN	11.09ab	12.09e	11.59b
TGx 1990-57F	11.50ab	13.50a	12.50a
TGx 1989-68FN	11.36ab	13.36ab	12.36ab
TGx 1990-46F	11.59ab	13.59a	12.59a
TGx 1990-55F	11.53ab	12.53bc	12.03ab
TGx 1987-10F(Check)	11.30ab	12.30cd	11.80ab
TGx 1835-10E(Check)	11.11ab	13.11ab	12.11ab
TGx 1485-1D(Check)	11.27ab	12.27de	11.77ab
±SE	0.23	0.31	0.24
Inoculation(I)			
Without inoculation	10.89b	12.26b	11.58b
NoduMax	11.54a	12.92a	12.23a
LegumeFix	11.63a	13.01a	12.32a
±SE	0.34	0.13	0.17
Interaction			
G x I	NS	NS	NS

Means followed by the same letter(s) within a set of treatment column are not significantly different at P=0.05 using DMRT; NS= Not significant; SE = Standard error

4.5 Correlation Analysis

4.5.1 Correlation matrix at the Abuja site

The result of correlation analysis between growth and yield attributes of some soybean genotypes as influenced by inoculation in 2015, 2016 and combined data at Abuja are shown in Tables 4.49, 4.50 and 4.51, respectively. In 2015, with the exception of number of leaves and branches per plant which were positive and not significant, all the growth and yield attributes correlated positively and significantly with seed yield. The strongest relationship between a growth attribute and the seed yield was that recorded between harvest index and seed yield (r = 0.886*), which in turn was also the strongest relationship between any two growth and yield parameters recorded in this year in this study.

In 2016, all the growth and yield attributes measured correlated positively and significantly with the seed yield, with the exception of branches per plant which was positive and not significant (Table 4.50). The strongest relationship between a growth parameter and seed yield in 2016 was that recorded by harvest index and seed yield (r = 0.864*), which in turn was also the strongest relationship between any two parameters in the year.

In the combined data, all the growth and yield attributes measured correlated positively and significantly with the seed yield (Table 4.51). The strongest relationship between any two growth parameters and seed yield in the combined data, was that between 100-seed weight and seed yield (r = 0.889*). This was in turn also the strongest relationship between any two growth parameters recorded.

Table 4.49: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2015 in Abuja

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.349*	1								
3	0.514*	0.664*	1							
4	0.471*	0.553*	0.661	1						
5	0.045	0.021	0.025	0.213	1					
6	0.497*	0.653*	0.736	0.569*	0.085	1				
7	0.498*	0.653*	0.736	0.569*	0.854	1.000*	1			
8	0.430*	0.421*	0.509	0.388*	0.026	0.406*	0.406*	1		
9	0.236*	0.348*	0.359	0.328*	0.123	0.376*	0.376*	0.138	1	
10	0.532*	0.594*	0.694	0.5298*	0.029	0.777*	0.777*	0.886*	0.276*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.50: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2016 in Abuja

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.538*	1								
3	0.527*	0.613*	1							
4	0.584*	0.572*	0.643*	1						
5	0.178*	0.139*	0.064*	0.123	1					
6	0.550*	0.631*	0.635*	0.557*	0.146*	1				
7	0.550*	0.631*	0.635*	0.557*	0.146*	1.000*	1			
8	0.413*	0.354*	0.411*	0.340*	0.014	0.337*	0.337*	1		
9	0.191*	0.289*	0.242*	0.245*	0.002	0.251*	0.251*	0.237*	1	
10	0.556*	0.551*	0.589*	0.497*	0.084	0.757*	0.757*	0.864*	0.283*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.51: Combined analysis for correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type during the 2015 and 2016 cropping seasons in Abuja

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.564*	1								
3	0.621*	0.719*	1							
4	0.581*	0.603*	0.709*	1						
5	0.156*	0.298*	0.253*	0.186*	1					
6	0.599*	0.696*	0.752*	0.589*	0.240*	1				
7	0.599*	0.696*	0.752*	0.589*	0.240*	0.000*	1			
8	0.242*	0.335*	0.340*	0.307*	0.145*	0.333*	0.333*	1		
9	0.478*	0.424*	0.539*	0.393*	0.177*	0.455*	0.455*	0.199*	1	
10	0.591*	0.597*	0.696*	0.509*	0.234*	0.789*	0.789*	0.264*	0.889*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

4.5.2 Correlation matrix at the Igabi site

Table 4.52 shows the correlation matrix of parameters for 2015 cropping season at the Igabi site. A strong positive and significant correlation was observed between chlorophyll content and plant height. The correlation of number of branches per plant with other parameters was not significant, although positive. The strongest relationship between any two parameters was that recorded between above ground biomass and total biomass yield (r = 0.995*). Also, the strongest relationship between a growth growth attribute and the seed yield was that recorded between harvest index and seed yield (r = 0.789*). The parameters observed except number of branches per plant recorded positive and significant correlation with seed yield.

Table 4.53 shows the correlation matrix of parameters for the 2016 cropping season in Igabi. Chlorophyll content had strong positive and significant correlation with plant height, number of leaves, and number of pods per plant, above ground biomass yield, total biomass yield, harvest index, one hundred-seed weight and seed yield. The strongest relationship between any two parameters was that recorded between above ground biomass and total biomass yield (r = 0.996*). In addition, the strongest relationship between a growth growth attribute and the seed yield was that recorded between harvest index and seed yield (r = 0.774*).

Table 4.54 shows the combined data correlation matrix of parameters for the 2015, 2016 cropping seasons in Igabi. Chlorophyll content recorded positive and significant correlation with all the other parameters except number of branches per plant. The strongest relationship between any two parameters was that recorded between above ground biomass and total biomass yield (r = 0.995*). In addition, the strongest relationship between a growth growth attribute and the seed yield was that recorded between harvest index and seed yield (r = 0.782*) Also, the traits observed recorded positive and significant correlation with seed yield.

Table 4.52: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2015 in Igabi

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.421*	1								
3	0.381*	0.528*	1							
4	0.395*	0.389*	0.376*	1						
5	0.027	0.048	0.017	0.022	1					
6	0.376*	0.574*	0.540*	0.399*	0.096	1				
7	0.375*	0.558*	0.542*	0.398*	0.091	0.995*	1			
8	0.283*	0.387*	0.382*	0.294*	0.037	0.209*	0.206*	1		
9	0.333*	0.400*	0.366*	0.285*	0.073	0.376*	0.376*	0.351*	1	
10	0.407*	0.592*	0.569*	0.422*	0.031	0.755*	0.757*	0.789*	0.458*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.53: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2016 in Igabi

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.481*	1								
3	0.374*	0.535*	1							
4	0.379*	0.396*	0.408*	1						
5	0.044	0.088	0.120	0.189	1					
6	0.447*	0.575*	0.512*	0.456*	0.171	1				
7	0.449*	0.559*	0.511*	0.458*	0.167	0.996*	1			
8	0.295*	0.345*	0.361*	0.335*	0.104	0.186*	0.183*	1		
9	0.423*	0.410*	0.240*	0.228*	0.014	0.333*	0.322*	0.249*	1	
10	0.468*	0.569*	0.552*	0.488*	0.168	0.755*	0.757*	0.774*	0.358*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.54: Combined analysis for correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type during the 2015 and 2016 cropping seasons in Igabi

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.505*	1								
3	0.419*	0.568*	1							
4	0.423*	0.413*	0.412*	1						
5	0.109	0.159	0.063	0.074	1					
6	0.445*	0.595*	0.541*	0.438*	0.163	1				
7	0.445*	0.578*	0.542*	0.438*	0.157	0.995*	1			
8	0.313*	0.379*	0.382*	0.322*	0.092	0.198*	0.195*	1		
9	0.412*	0.470*	0.332*	0.302*	0.219*	0.384*	0.376*	0.321*	1	
10	0.472*	0.601*	0.576*	0.465*	0.159*	0.755*	0.757*	0.782*	0.438*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

4.5.3 Correlation matrix at the Gwarzo site

Table 4.55 shows the correlation matrix of parameters for the 2015 cropping season at the Gwarzo site. Number of branches had positive correlation with other traits, but not significantly correlated. The strongest relationship between any two parameters was that recorded between above ground biomass yield and total biomass yield (r = 0.889*). In addition, the strongest relationship between a growth growth attribute and the seed yield was that recorded between number of leaves and seed yield (r = 0.710*). The parameters except number of branches per plant recorded positive and significant correlation with seed yield.

Table 4.56 shows the correlation matrix of parameters for the 2016 cropping season at the Gwarzo site. Chlorophyll content had positive and significant correlation with plant height, number of leaves, and number of pods per plant, above ground biomass, total biomass yield and seed yield. Although, the number of branches per plant was positively correlated with chlorophyll content, number of leaves, above ground biomass yield, total biomass yield, harvest index and seed yield, the correlation was not significant. The strongest relationship between any two parameters was that recorded between above ground biomass yield and total biomass yield (r = 0.943**). In addition, the strongest relationship between a growth growth attribute and the seed yield was that recorded between number of leaves and seed yield (r = 0.630**). The traits except number of pods, branches per plant recorded positive and highly significant correlation with seed yield.

Table 4.57 shows the combined data for the correlation matrix of parameters for the 2015 and 2016 cropping seasons at Gwarzo. The correlation between chlorophyll content with other traits recorded positive and significant correlation. Also, number of branches per plant had positive but not significant correlation with plant height, number of pods per plant, above ground biomass yield, total biomass yield, harvest index and one hundred-seed weight. The strongest relationship between any two parameters was that recorded between above ground biomass yield and total biomass yield (r = 0.928**). In addition, the strongest relationship between a growth growth attribute and the seed yield was that recorded between number of leaves and seed yield (r = 0.710**). Furthermore, chlorophyll content, plant height, number of leaves, number of pods per plant, number of branches per plant, above ground biomass yield, total biomass yield, harvest index and one hundred-seed weight recorded positive and highly significant correlation with seed yield.

Table 4.55: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2015 in Gwarzo

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.346*	1								
3	0.491*	0.636*	1							
4	0.202*	0.340*	0.431*	1						
5	0.052	0.119	0.100	0.085	1					
6	0.229*	0.299*	0.393*	0.145*	0.036	1				
7	0.190*	0.241*	0.338*	0.094	0.053	0.889*	1			
8	0.334*	0.339*	0.383*	0.239*	0.064	0.323*	0.470*	1		
9	0.239*	0.271*	0.368*	0.221*	0.019	0.320*	0.244*	0.183*	1	
10	0.539*	0.557*	0.710*	0.302*	0.103	0.471*	0.453*	0.559*	0.407*	1

*= Significant at 5%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.56: Correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2016 in Gwarzo

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.542**	1								
3	0.639**	0.612*	1							
4	0.348**	0.409**	0.455**	1						
5	0.084	0.163*	0.135	0.156*	1					
6	0.343**	0.356**	0.348**	0.154*	0.044	1				
7	0.332**	0.334**	0.299**	0.141*	0.059	0.943**	1			
8	0.328*	0.317**	0.388**	0.265*	0.033	0.359**	0.406*	1		
9	0.209*	0.242*	0.265**	0.265**	0.158*	0.106	0.046	0.285**	1	
10	0.600**	0.579**	0.630**	0.362**	0.073	0.471**	0.479**	0.600**	0.309**	1

*= Significant at 5%, **= Significant at 1%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

Table 4.57: Combined analysis for correlation matrix between growth and yield attributes against seed yield of some soybean genotypes as influenced by inoculation type in 2015 and 2016 cropping season in Gwarzo

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.510**	1								
3	0.626**	0.722**	1							
4	0.318**	0.448**	0.533**	1						
5	0.182*	0.123	0.175*	0.084	1					
6	0.309**	0.357**	0.390**	0.163*	0.019	1				
7	0.289**	0.319**	0.346**	0.124	0.021	0.928**	1			
8	0.358**	0.358**	0.412**	0.286**	0.227	0.347**	0.423**	1		
9	0.254**	0.301**	0.337**	0.274**	0.045	0.215*	0.157**	0.239*	1	
10	0.614**	0.615**	0.710**	0.364**	0.248*	0.471**	0.472**	0.590**	0.371**	1

*= Significant at 5%, **= Significant at 1%, ns= not significant, 1= Chlorophyll content, 2= Plant height, 3= Number of leaves, 4= Number of pods per plant, 5= Number of branches per plant, 6= Above ground biomass yield, 7= Total biomass yield, 8= Harvest index, 9= 100-seed weight, 10= Seed yield

4.6 Path Analysis

4.6.1 Direct and indirect contributions of some selected traits to seed yield in Abuja

The direct and indirect effects of some growth and yield attributes to seed yield of soybean genotypes at Abuja in 2015 are shown in Table 4.58. In this year, the direct and indirect contribution of all the growth and yield attributes to seed yield were positive, with the exception of indirect contribution via plant height, which was negative. Plant height made the greatest direct effect on seed yield of soybean (0.41). The weakest direct effect was from branches per plant (0.15), while the weakest indirect effect was via plant height (-0.28) in this year.

Plant height also made the highest percentage contribution to seed yield (16.81 %) in 2015 (Table 4.59). This was followed by total biomass (4.84 %) and number of leaves (2.89 %), respectively. However, the greatest and positive combined contribution of 10.82 % was made by plant height via total biomass yield, followed by number of leaves via total biomass yield (7.10 %).

Table 4.60 shows direct, indirect and total contribution of some selected traits to seed yield during the 2016 cropping season at the Abuja site. The direct and indirect contribution of plant height to seed yield was found to be 0.67. It was observed that 0.37 was contributed directly while 0.01, 0.10 and 0.19 were contributed indirectly via number of leaves, branches per plant and total biomass yield respectively. Also, out of the total contribution of 0.10 by number of leaves to seed yield, -0.22, 0.10 and 0.19 were contributed via plant height, branches per plant and total biomass. The association between branches per plant and seed yield recorded 0.19, out of which 0.16 was contributed directly, -0.23, 0.01 and 0.22 were contributed indirectly via plant height number of leaves and total biomass respectively. In addition, the direct contribution of total biomass yield was found to be 0.30 and indirect contributions via plant height, number of leaves and branches per plant were -0.23, 0.01 and 0.12. The total contribution of total biomass yield was found to be 0.21.

Table 4.61 shows direct and combined contributions (percent) of some selected traits to seed yield during the 2016 cropping season at the Abuja site. The traits plant height, branches per plant and total biomass directly contributed 13.69, 2.56 and 9.00 percent. The contribution of number of leaves was only 0.04 percent. The contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were 0.52, 3.62 and 6.73 percent. Also, the contribution of number of leaves in combination with branches per plant and total biomass yield were 0.42 and 0.79 percent. 7.08 percent was recorded as the combined contribution of branches per plant and total biomass yield. Residual effect recorded for about 55.5 percent.

The combined data for direct, indirect and total contributions of some selected traits to seed yield at the Abuja site are shown in Table 4.62. It was observed that out of the total contribution of 0.80 by plant height to seed yield, the direct contribution was 0.32 while the indirect contributions via number of leaves, branches per plant and total biomass yield were 0.12, 0.22 and 0.14 respectively. Number of leaves was also observed to have contributed 0.16 directly to seed yield as against its indirect contributions of -0.41, 0.22 and 0.15 via plant height, branches per plant and total biomass respectively. The total contribution was 0.13. The direct contribution of branches per plant was found to be 0.13 while its indirect contributions via plant height, number of leaves and total biomass were -0.40, 0.11 and 0.16 respectively. The branches per plant total contribution were

0.19. Furthermore, the total association between total biomass yield and seed yield was found to be 0.19, out of which 0.20 was contributed directly and -0.38, 0.12 and 0.24 were contributed indirectly via plant height, number of leaves and branches per plant.

Table 4.63 shows the combined data for direct and combined contributions (percent) of some selected traits to seed yield at the Abuja site. In quantifying the traits in terms of percentage, the plant height, number of leaves, branches per plant and total biomass recorded a direct contribution of 10.24, 2.56, 9.61 and 4.00 percent respectively. The contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were 0.20, 1.21 and 1.08 percent. Also, the contribution of number of leaves in combination with branches per plant and total biomass yield recorded 7.38 and 5.00 percent. A combined contribution of branches per plant and total biomass yield was found to be 10.04 percent. 48.77 percent of the seed yield contribution was recorded as the residual effect.

Table 4.58: Direct, indirect and total contributions of some selected traits to seed yield of soybean during the 2015 cropping season in Abuja

Traits	Contributions

1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.41
	b	Indirect contribution via number of leaves	0.12
	c	Indirect contribution via branches per plant	0.10
	d	Indirect contribution via total biomass yield	0.15
		Total contribution (direct and indirect)	0.78
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.17
	b	Indirect contribution via plant height	-0.28
	c	Indirect contribution via branches per plant	0.11
	d	Indirect contribution via total biomass	0.16
		Total contribution (direct and indirect)	0.16
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.15
	b	Indirect contribution via plant height	-0.27
	c	Indirect contribution via number of leaves	0.12
	d	Indirect contribution via total biomass	0.18
		Total contribution (direct and indirect)	0.18
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.22
	b	Indirect contribution via plant height	-0.27
	c	Indirect contribution via number of leaves	0.12
	d	Indirect contribution via branches per plant	0.12
		Total contribution (direct and indirect)	0.19

Table 4.59: Direct and combined contributions (percent) of some selected traits to yield during the 2015 cropping season in Abuja

Yield Component	Percentage
Direct Contribution	
Plant height	16.81
Number of leaves	2.89
Branches per plant	2.25
Total biomass	4.84
Combined Contribution	
Plant height and number of leaves	9.01
Plant height and branches per plant	3.45
Plant height and total biomass yield	10.82
Number of leaves and branches per plant	3.87
Number of leaves and total biomass yield	7.10
Branches per plant and total biomass yield	2.16
Residual effect	51.0
Total	100

Table 4.60: Direct, indirect and total contributions of some selected traits to seed yield during the 2016 cropping season in Abuja

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.37
	b	Indirect contribution via number of leaves	0.01
	c	Indirect contribution via branches per plant	0.10
	d	Indirect contribution via total biomass yield	0.19
		Total contribution (direct and indirect)	0.67
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.02
	b	Indirect contribution via plant height	-0.22
	c	Indirect contribution via branches per plant	0.10
	d	Indirect contribution via total biomass	0.19
		Total contribution (direct and indirect)	0.10
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.16
	b	Indirect contribution via plant height	-0.23
	c	Indirect contribution via number of leaves	0.01
	d	Indirect contribution via total biomass	0.22
		Total contribution (direct and indirect)	0.19
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.30
	b	Indirect contribution via plant height	-0.23
	c	Indirect contribution via number of leaves	0.01
	d	Indirect contribution via branches per plant	0.12
		Total contribution (direct and indirect)	0.21

Table 4.61: Direct and combined contributions (percent) of some selected traits to seed yield during the 2016 cropping season in Abuja

Yield Component	Percentage
Direct Contribution	
Plant height	13.69
Number of leaves	0.04
Branches per plant	2.56
Total biomass	9.00
Combined Contribution	
Plant height and number of leaves	0.52
Plant height and branches per plant	3.62
Plant height and total biomass yield	6.73
Number of leaves and branches per plant	0.42
Number of leaves and total biomass yield	0.79
Branches per plant and total biomass yield	7.08
Residual effect	55.5
Total	100

Table 4.62: Combined analysis for direct, indirect and total contributions of some selected traits to seed yield in Abuja

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.32
	b	Indirect contribution via number of leaves	0.12
	c	Indirect contribution via branches per plant	0.22
	d	Indirect contribution via total biomass yield	0.14
		Total contribution (direct and indirect)	0.80
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.16
	b	Indirect contribution via plant height	-0.41
	c	Indirect contribution via branches per plant	0.22
	d	Indirect contribution via total biomass	0.15
		Total contribution (direct and indirect)	0.13
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.31
	b	Indirect contribution via plant height	-0.40
	c	Indirect contribution via number of leaves	0.11
	d	Indirect contribution via total biomass	0.16
		Total contribution (direct and indirect)	0.19
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.20
	b	Indirect contribution via plant height	-0.38
	c	Indirect contribution via number of leaves	0.12
	d	Indirect contribution via branches per plant	0.24
		Total contribution (direct and indirect)	0.19

Table 4.63: Combined analysis for direct and combine contributions (percent) of some selected traits to seed yield in Abuja

Yield Component	Percentage
Direct Contribution	
Plant height	10.24
Number of leaves	2.56
Branches per plant	9.61
Total biomass	4.00
Combined Contribution	
Plant height and number of leaves	0.20
Plant height and branches per plant	1.12
Plant height and total biomass yield	1.08
Number of leaves and branches per plant	7.38
Number of leaves and total biomass yield	5.00
Branches per plant and total biomass yield	10.04
Residual effect	48.77
Total	100

4.6.2 Direct and indirect contributions of some selected traits to seed yield in Igabi

Table 4.64 shows direct, indirect and total contribution of some selected traits to seed yield during the 2015 cropping season in Igabi. It was observed that out of the total contribution of 0.22 by plant height to seed yield, 0.30 was contributed directly and 0.17 indirectly via branches per plant. The indirect contribution via number of leaves and total biomass yield were small and negative (-0.40 and -0.23). Out of the total association between number of leaves and seed yield (0.03), the direct contribution was negative (-0.08) as against its indirect contributions via plant height, branches per plant and total biomass which were 0.16, 0.18 and -0.22 respectively. The direct contribution of branches per plant was found to be 0.34 and indirect contributions via plant height, number of leaves and total biomass were 0.15, -0.04 and -0.32. The total contribution of branches per plant to seed yield was found to be 0.14. Furthermore, it was observed that total biomass yield recorded a negative total contribution (-0.01), out of which -0.41 was contributed directly while 0.17, 0.05 and 0.27 were contributed through plant height, number of leaves and branches per plant.

Direct and combined contributions (percent) of some selected traits to seed yield during the 2015 cropping season in Igabi are shown in Table 4.65. The traits plant height, number of leaves, branches per plant and total biomass directly contributed 9.00, 0.64, 11.56 and 16.81 percent respectively. The contribution of plant height in combination with number of leaves and total biomass were negative (-8.40 and -16.21) while with branches per plant recorded 12.75 percent. Also, the contribution of number of leaves in combination with branches per plant and total biomass yield were -3.44 and 4.38 percent. A combined contribution of branches per plant and total biomass yield was found to be 22.58 percent. 50.32 percent of the seed yield contribution was considered residual effect.

Table 4.66 shows direct, indirect and total contribution of some selected traits to seed yield during the 2016 cropping season at the Igabi site. The direct contribution of plant height was found to be 0.02 and the indirect contribution via number of leaves, branches per plant and total biomass yield were -0.04, 0.19 and -0.21 respectively. The direct and indirect contributions of plant height to seed yield was found to be 0.14. In addition, it was observed that out of the total contribution of -0.01 by number of leaves to seed yield, -0.09 was contributed directly while 0.10, 0.18 and -0.20 were contribution through plant height, branches per plant and total biomass respectively. Out of a total association between branches per plant and seed yield (0.14), the direct contribution was 0.37 as against its indirect contributions via plant height, number of leaves and total biomass which were 0.10, -0.04 and -0.30 respectively. The total biomass yield recorded its total contribution of 0.01, out of which direct contribution recorded a negative value (-0.38) and the indirect contributions of 0.11, -0.05 and 0.29 through plant height number of leaves and branches per plant.

Direct and combined contributions (percent) of some selected traits to seed yield during the 2016 cropping seasons in Igabi are shown in Table 4.67. The table shows that when the contribution of traits were quantified in terms percentage, the three traits plant height, branches per plant and total biomass directly contributed 4.00, 13.69 and 14.44 percent respectively. The contribution of number of leaves was only 0.81 percent. The contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were 2.20, 9.30 and -9.70 percent.

Also, the contribution of number of leaves in combination with branches per plant and total biomass yield were -0.05 and 4.42 percent respectively. The combined contribution of branches per plant and total biomass yield was found to be 4.22 percent while 65.89 percent was recorded as the residual effect.

Table 4.68 shows the combined data for direct, indirect and total contributions of some selected traits to seed yield at Igabi. Out of a total relationship between plant height and seed yield (0.17), the direct contribution was 0.23 as against its indirect contributions via number of leaves, branches per plant and total biomass yield which were -0.05, 0.17 and -0.19 respectively. It was also observed that out of the total contribution of 0.48 by number of leaves to yield, a negative (-0.09) was contributed directly as against 0.12, 0.17 and 0.18 contributed indirectly via plant height, branches per plant and total biomass respectively. The direct contribution of branches per plant to seed yield was found to be 0.32 and indirect contribution via plant height was 0.12. Its indirect contribution via number of leaves and total biomass were negative and very small (-0.05 and -0.26 respectively). Furthermore, the direct contribution of total biomass yield was a negative value (-0.33), while the indirect contribution via plant height, number of leaves and branches per plant were 0.13, -0.05 and 0.25 respectively. 0.01 was recorded as the total contribution of total biomass yield to seed yield.

Table 4.69 shows the combined data for direct, indirect and combined contributions (percent) of some selected traits to seed yield in Igabi. Plant height, branches per plant and total biomass directly contributed 5.29, 10.24 and 10.89 percent. The contribution of number of leaves was only

0.81 percent. Also, the contribution of plant height in combination with number of leaves and total biomass yield were negative (-2.67 and -10.06) as against branches per plant (9.40). The contribution of number of leaves in combination with branches per plant and total biomass yield were positive (2.03 and 3.87 respectively). A combined contribution of branches per plant and total biomass yield was found to be 17.06 percent. 53.14 percent was recorded as the residual effect.

Table 4.64: Direct, indirect and total contributions of some selected traits to seed yield during the 2015 cropping season in Igabi

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.30
	b	Indirect contribution via number of leaves	-0.40
	c	Indirect contribution via branches per plant	0.17
	d	Indirect contribution via total biomass yield	-0.23
		Total contribution (direct and indirect)	0.22
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	-0.08
	b	Indirect contribution via plant height	0.16
	c	Indirect contribution via branches per plant	0.18
	d	Indirect contribution via total biomass	-0.22
		Total contribution (direct and indirect)	0.03
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.34
	b	Indirect contribution via plant height	0.15
	c	Indirect contribution via number of leaves	-0.04
	d	Indirect contribution via total biomass	-0.32
		Total contribution (direct and indirect)	0.14
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	-0.41
	b	Indirect contribution via plant height	0.17
	c	Indirect contribution via number of leaves	0.05
	d	Indirect contribution via branches per plant	0.27
		Total contribution (direct and indirect)	-0.01

Table 4.65: Direct and combined contributions (percent) of some selected traits to seed yield during the 2015 cropping season in Igabi

Yield Component	Percentage
Direct Contribution	
Plant height	9.00
Number of leaves	0.64
Branches per plant	11.56
Total biomass	16.81
Combined Contribution	
Plant height and number of leaves	-8.40
Plant height and branches per plant	12.75
Plant height and total biomass yield	-16.21
Number of leaves and branches per plant	-3.44
Number of leaves and total biomass yield	4.38
Branches per plant and total biomass yield	22.58
Residual effect	50.32
Total	100

Table 4.66: Direct, indirect and total contributions of some selected traits to seed yield during the 2016 cropping season in Igabi

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.20
	b	Indirect contribution via number of leaves	-0.04
	c	Indirect contribution via branches per plant	0.19
	d	Indirect contribution via total biomass yield	-0.21
		Total contribution (direct and indirect)	0.14
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	-0.09
	b	Indirect contribution via plant height	0.10
	c	Indirect contribution via branches per plant	0.18
	d	Indirect contribution via total biomass	-0.20
		Total contribution (direct and indirect)	-0.01
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.37
	b	Indirect contribution via plant height	0.10
	c	Indirect contribution via number of leaves	-0.04
	d	Indirect contribution via total biomass	-0.30
		Total contribution (direct and indirect)	0.14
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	-0.38
	b	Indirect contribution via plant height	0.11
	c	Indirect contribution via number of leaves	-0.05
	d	Indirect contribution via branches per plant	0.29
		Total contribution (direct and indirect)	0.01

Table 4.67: Direct and combined contributions (percent) of some selected traits to yield during the 2016 cropping season in Igabi

Yield Component	Percentage
Direct Contribution	
Plant height	4.00
Number of leaves	0.81
Branches per plant	13.69
Total biomass	14.44
Combined Contribution	
Plant height and number of leaves	2.20
Plant height and branches per plant	9.30
Plant height and total biomass yield	-9.70
Number of leaves and branches per plant	-4.05
Number of leaves and total biomass yield	4.42
Branches per plant and total biomass yield	4.22
Residual effect	64.89
Total	100

Table 4.68: Combine analysis for direct, indirect and total contributions of some selected traits to seed yield in Igabi

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.23
	b	Indirect contribution via number of leaves	-0.05
	c	Indirect contribution via branches per plant	0.17
	d	Indirect contribution via total biomass yield	-0.19
		Total contribution (direct and indirect)	0.17
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	-0.09
	b	Indirect contribution via plant height	0.12
	c	Indirect contribution via branches per plant	0.17
	d	Indirect contribution via total biomass	0.18
		Total contribution (direct and indirect)	0.02
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.32
	b	Indirect contribution via plant height	0.12
	c	Indirect contribution via number of leaves	-0.05
	d	Indirect contribution via total biomass	-0.26
		Total contribution (direct and indirect)	0.14
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	-0.33
	b	Indirect contribution via plant height	0.13
	c	Indirect contribution via number of leaves	-0.05
	d	Indirect contribution via branches per plant	0.25
		Total contribution (direct and indirect)	0.01

Table 4.69: Combined analysis for direct and combined contributions (percent) of some selected traits to yield in Igabi

Yield Component	Percentage
Direct Contribution	
Plant height	5.29
Number of leaves	0.81
Branches per plant	10.24
Total biomass	10.89
Combined Contribution	
Plant height and number of leaves	-2.67
Plant height and branches per plant	9.40
Plant height and total biomass yield	-10.06
Number of leaves and branches per plant	2.03
Number of leaves and total biomass yield	3.87
Branches per plant and total biomass yield	17.06
Residual effect	53.14
Total	100

4.6.3 Direct and indirect contributions of some selected traits to seed yield in Gwarzo

Table 4.70 shows the direct, indirect and total contributions of some selected traits to seed yield during the 2015 cropping season at the Gwarzo site. It was noted that out of the total negative contributions (-0.07) by plant height to seed yield, a negative value (-0.10) was contributed directly while 0.10, -0.20 and 0.13 were contributed indirectly via number of leaves, branches per plant and total biomass yield respectively. Out of a total contribution of 0.02 by number of leaves, 0.16 was contributed directly as against -0.06 and 0.28 contributed via plant height and branches per plant, 0.19 via total biomass. The direct contribution of branches per plant was found to be negative (-0.21) while the indirect contributions via plant height, number of leaves and total biomass were -0.03, 0.06 and 0.14 respectively. The direct and indirect contribution of branches per plant was found to be negative (-0.29). Also, it was observed that a negative value (-0.02) accounted for the total contributions of total biomass yield to seed yield, out of which 0.27 accounted for the direct contributions while -0.05, 0.12 and -0.36 were contributed via plant height, number of leaves and branches per plant respectively.

The contributions of traits when quantified in terms of percentage revealed that plant height, number of leaves, branches per plant and total biomass contributed 1.00, 2.56, 4.41 and 7.29 percent, respectively (Table 4.71). Also, that the contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were 2.20, 2.70 and -3.35 percent. The contribution of number of leaves in combination with branches per plant and total biomass yield were 1.68 and 6.60 percent (Table 4.71). The combined contribution of branches per plant and total biomass yield was found to be 0.63 percent. About 47 percent of the seed yield contribution was not explained. Table 4.72 shows the direct, indirect and total contribution of some selected traits to seed yield during the 2016 cropping season in Gwarzo. The direct contribution of plant height was found to be 0.11 and indirect contributions via number of leaves, branches per plant and total biomass yield were 0.13, -0.34 and 0.10 respectively. The direct and indirect contributions of plant height to seed yield was found to be negative (-0.04). Also, it was observed that out of the total contribution of 0.10 by number of leaves to seed yield, 0.22 was contributed directly whereas 0.06, -0.26 and 0.11 were made available via plant height, branches per plant and total biomass respectively. Branches per plant contributed 0.54 in total, out of which 0.32 was made available directly and 0.05, 0.08, 0.09 indirectly via plant height, number of leaves and total biomass respectively. Furthermore, a negative value (-0.02) was the total contribution by total biomass yield, out of which 0.17 was made available directly and indirectly (0.06, 0.14, -0.37) via plant height number of leaves and branches per plant.

Direct and combined contributions (percent) of some selected traits to seed yield during the 2016 cropping season in Gwarzo are shown in Table 4.73. The four traits plant height, number of leaves, branches per plant and total biomass directly contributed 1.21, 4.85, 10.24 and 2.89 percent respectively. The contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were 3.20, 1.82 and 2.47 percent. Also, the contribution of number of leaves in combination with branches per plant and total biomass yield were 4.96 and 5.28 percent. A combined contribution of branches per plant and total biomass yield recorded 2.11 percent. Residual effect recorded 60.98 percent.

Table 4.74 shows the combined analysis for direct, indirect and total contributions of some selected traits to seed yield at the Gwarzo site. It was observed that a negative value (-0.06) accounted for the total contribution by plant height, out of which a negative value (-0.03) was contributed directly while 0.15, -0.29 and 0.08 were contributed indirectly via number of leaves, branches per plant and total biomass yield respectively. In addition, the direct contribution of number of leaves was found to be 0.21 and indirect contributions via plant height, branches per plant and total biomass were -0.02, -0.29 and 0.11 respectively. The direct and indirect contributions of number of leaves to seed yield was found to be 0.05. In the total contribution (-0.55) of branches per plant to seed yield, the direct contribution was negative (-0.72) and its indirect contributions via plant height, number of leaves and total biomass were -0.01, 0.09 and 0.07 respectively. Also, it was revealed that a negative value (-0.02) was the total contribution made by total biomass yield in which 0.15 accounted for it direct contributions while -0.02, 0.16 and -0.37 accounted for its indirect contributions via plant height, number of leaves and branches per plant respectively.

Table 4.75 shows the combined analysis for direct and combined contributions (percent) of some selected traits to seed yield in Gwarzo. Three traits; number of leaves, branches per plant and total biomass directly contributed 4.41, 51.84 and 2.25 percent. The contribution of plant height was only 0.09 percent. The contribution of plant height in combination with number of leaves, branches per plant and total biomass yield were -0.93, 2.74 and 0.61 percent. Furthermore, the contributions of number of leaves in combination with branches per plant were 17.73 and 4.91 percent respectively. The combined contribution of branches per plant and total biomass yield was found to be negative (-13.39). About 30 percent of the yield contribution was regarded as the residual effect.

Table 4.70: Direct, indirect and total contributions of some selected traits to seed yield during the 2015 cropping season in Gwarzo

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	-0.10
	b	Indirect contribution via number of leaves	0.10
	c	Indirect contribution via branches per plant	-0.20
	d	Indirect contribution via total biomass yield	0.13
		Total contribution (direct and indirect)	-0.07
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.16
	b	Indirect contribution via plant height	-0.06
	c	Indirect contribution via branches per plant	-0.28
	d	Indirect contribution via total biomass	0.19
		Total contribution (direct and indirect)	0.02
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	-0.21
	b	Indirect contribution via plant height	-0.03
	c	Indirect contribution via number of leaves	0.06
	d	Indirect contribution via total biomass	0.14
		Total contribution (direct and indirect)	-0.29
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.27
	b	Indirect contribution via plant height	-0.05
	c	Indirect contribution via number of leaves	0.12
	d	Indirect contribution via branches per plant	-0.36
		Total contribution (direct and indirect)	-0.02

Table 4.71: Direct and combined contributions (percent) of some selected traits to yield during the 2015 cropping season in Gwarzo

Yield Component	Percentage
Direct Contribution	
Plant height	1.00
Number of leaves	2.56
Branches per plant	4.41
Total biomass	7.29
Combined Contribution	
Plant height and number of leaves	2.20
Plant height and branches per plant	2.70
Plant height and total biomass yield	-3.35
Number of leaves and branches per plant	1.68
Number of leaves and total biomass yield	6.60
Branches per plant and total biomass yield	0.63
Residual effect	47.29
Total	100

Table 4.72: Direct, indirect and total contributions of some selected traits to yield during the 2016 cropping season in Gwarzo

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	0.11
	b	Indirect contribution via number of leaves	0.13
	c	Indirect contribution via branches per plant	-0.34
	d	Indirect contribution via total biomass yield	0.10
		Total contribution (direct and indirect)	-0.04
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.22
	b	Indirect contribution via plant height	0.06
	c	Indirect contribution via branches per plant	-0.26
	d	Indirect contribution via total biomass	0.11
		Total contribution (direct and indirect)	0.10
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	0.32
	b	Indirect contribution via plant height	0.05
	c	Indirect contribution via number of leaves	0.08
	d	Indirect contribution via total biomass	0.09
		Total contribution (direct and indirect)	0.54
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.17
	b	Indirect contribution via plant height	0.06
	c	Indirect contribution via number of leaves	0.14
	d	Indirect contribution via branches per plant	-0.37
		Total contribution (direct and indirect)	-0.02

Table 4.73: Direct and combined contributions (percent) of some selected traits to yield during the 2016 cropping season in Gwarzo

Yield Component	Percentage
Direct Contribution	
Plant height	1.21
Number of leaves	4.84
Branches per plant	10.24
Total biomass	2.89
Combined Contribution	
Plant height and number of leaves	3.20
Plant height and branches per plant	1.82
Plant height and total biomass yield	2.47
Number of leaves and branches per plant	4.96
Number of leaves and total biomass yield	5.28
Branches per plant and total biomass yield	2.11
Residual effect	60.98
Total	100

Table 4.74: Combined analysis for direct, indirect and total contributions of some selected traits to seed yield in Gwarzo

		Traits	Contributions
1		**Plant height and seed yield**	
	a	Direct contribution of plant height	-0.03
	b	Indirect contribution via number of leaves	0.15
	c	Indirect contribution via branches per plant	-0.29
	d	Indirect contribution via total biomass yield	0.08
		Total contribution (direct and indirect)	-0.06
2		**Number of leaves and seed yield**	
	a	Direct contribution of number of leaves	0.21
	b	Indirect contribution via plant height	-0.02
	c	Indirect contribution via branches per plant	-0.29
	d	Indirect contribution via total biomass	0.11
		Total contribution (direct and indirect)	0.05
3		**Branches per plant and seed yield**	
	a	Direct contribution of branches per plant	-0.72
	b	Indirect contribution via plant height	-0.01
	c	Indirect contribution via number of leaves	0.09
	d	Indirect contribution via total biomass	0.07
		Total contribution (direct and indirect)	-0.55
4		**Total biomass yield and seed yield**	
	a	Direct contribution of total biomass yield	0.15
	b	Indirect contribution via plant height	-0.02
	c	Indirect contribution via number of leaves	0.16
	d	Indirect contribution via branches per plant	-0.37
		Total contribution (direct and indirect)	-0.02

Table 4.75: Combined analysis for direct and combine contributions (percent) of some selected traits to seed yield in Gwarzo

Yield Component	Percentage
Direct Contribution	
Plant height	0.09
Number of leaves	4.41
Branches per plant	51.84
Total biomass	2.25
Combined Contribution	
Plant height and number of leaves	-0.93
Plant height and branches per plant	2.74
Plant height and total biomass yield	0.61
Number of leaves and branches per plant	17.73
Number of leaves and total biomass yield	4.91
Branches per plant and total biomass yield	-13.39
Residual effect	29.74
Total	100

4.7 Sensitivity and Stability across Environments

4.7.1 Sensitivity and stability coefficient of seed yield across environments in 2015 season

The sensitivity and stability coefficient for seed yield from soybean genotypes across three environments in 2015 cropping season are shown in Table 4.76. The mean values for yield and sensitivity coefficient (b) for genotypes of soybean over three environments revealed the genotypic sensitivity to changes in the environmental quality, where values of $b > 1$ means genotypes with a higher than average sensitivity and less stable, $b < 1$ means genotypes that are less sensitive and more stable and $b = 1$ means averagely stable genotype. The regression showed that TGx 1990-95F had mean seed yield (1573 kg ha $^{-1}$) greater than the average mean 1560 kg ha $^{-1}$ and showed average genotypic sensitivity based on the regression coefficient ($b = 1$) hence averagely stable. Five genotypes TGx 1990-52F, TGx 1989-48FN, TGx 1990-57F, TGx 1989-11F and TGx 1448-2E(CK) had more than average mean performance and above average sensitivity ($b > 1$, less stable). Three genotypes TGx 1990-110FN, TGx 1989-45F and TGx 1993-4FN recorded more than average mean performance and below average sensitivity ($b < 1$, more stable).

4.7.2 Sensitivity and stability coefficient of seed yield across environments in 2016 season

Table 4.77 shows the sensitivity and stability coefficients for seed yield from soybean genotypes across environments during the 2016 cropping season. The regression coefficient shows that TGx 1990-95F recorded mean seed yield (1641 kg ha $^{-1}$) greater than average mean 1604 kg ha $^{-1}$ and showed average genotypic sensitivity based on the regression coefficient ($b = 1$), it is therefore averagely stable. Also, five genotypes TGx 1990-40F, TGx 1987-10F(CK), TGx 1990-55F, TGx 1448-2E(CK) and TGx 1990-52F had more than average mean performance and above average sensitivity (b > 1) therefore less stable. In addition, eight genotypes TGx 1989-45F, TGx 1989-75FN, TGx 1485-1D(CK), TGx 1993-4FN, TGx 1990-110FN, TGx 1987-62F(CK), TGx 1989-42F and TGx 1835-10E(CK) recorded more than average mean performance and below average sensitivity (b < 1) therefore more stable.

4.7.3 Combined data sensitivity and stability coefficient of seed yield across environments in 2015, 2016 cropping seasons

Table 4.78 shows the combined analysis for sensitivity and stability coefficients for seed yield from soybean genotypes across environments during the 2015 and 2016 cropping seasons. TGx 1989-19F recorded mean seed yield (1577 kg ha $^{-1}$) greater than average mean 1570 kg ha $^{-1}$ and showed average genotypic sensitivity (b = 1) hence averagely stable. Also, five genotypes TGx 1990-40F, TGx 1989-11F, TGx 1990-52F, TGx 1448-2E(CK) and TGx 1990-55F recorded more than average mean performance and above average sensitivity, thus less stable. Furthermore, four genotypes, TGx 1989-45F, TGx 1989-75FN, TGx 1990-110FN and TGx 1990-95F had more than average mean performance and below average sensitivity (b < 1) making it more stable.

Table 4.76: Sensitivity and stability coefficients for seed yield from soybean genotypes across environments in 2015 cropping season

Genotype	Mean	Sensitivity (b value)	Static Stability	Mean square Deviation
TGx 1989-53FN	1532	0.7369	65355	3107
TGx 1989-45F	1613	0.7812	72198	991
TGx 1990-114FN	1502	0.8147	80440	4878
TGx 1989-75FN	1539	0.8199	84122	10266
TGx 1993-4FN	1562	0.8449	91520	15259
TGx 1485-ID(CK)	1522	0.8492	96139	22820
TGx 1990-110FN	1700	0.8897	98747	11449
TGx 1989-68FN	1503	0.9280	101672	7792
TGx 1989-42F	1525	0.9286	104460	6274
TGx 1990-78F	1456	0.9288	105079	6124
TGx 1835-10E(CK)	1520	0.9603	110262	14745
TGx 1987-62F(CK)	1553	0.9631	115726	2558
TGx 1990-95F	1573	0.9632	118901	61139
TGx 1448-2E(CK)	1568	1.0000	149338	6297
TGx 1989-11F	1569	1.1174	149943	6470
TGx 1990-55F	1502	1.1598	162017	13493
TGx 1990-57F	1618	1.1598	164809	7887
TGx 1989-48FN	1613	1.2095	172422	1040
TGx 1990-46F	1515	1.2703	219598	59972
TGx 1990-52F	1740	1.3556	220396	8918
Grand mean	**1560**			

CK= Check

Table 4.77: Sensitivity and stability coefficients for seed yield from soybean genotypes across environments in 2016 cropping season

Genotype	Mean	Sensitivity (b value)	Static Stability	Mean square Deviation
TGx 1989-53FN	1502	0.7051	60209	8775
TGx 1989-45F	1622	0.7406	63939	4696
TGx 1989-75FN	1603	0.8289	79724	14184
TGx 1990-114FN	1577	0.8325	84231	3803
TGx 1485-ID(CK)	1619	0.8557	92586	45125
TGx 1993-4FN	1626	0.8586	96080	19638
TGx 1990-110FN	1613	0.9063	97071	29600
TGx 1989-68FN	1571	0.9082	100840	6918
TGx 1990-78F	1520	0.9263	104774	1444
TGx 1987-62F(CK)	1616	0.9447	105376	1278
TGx 1989-42F	1611	0.9651	107030	1583
TGx 1835-10E(CK)	1614	0.9695	118359	32023
TGx 1990-95F	1641	1.0000	121555	62251
TGx 1989-40F	1586	1.0207	123515	2740
TGx 1990-40F	1632	1.0464	134565	1136
TGx 1989-11F	1589	1.0687	137078	36333
TGx 1987-10F(CK)	1600	1.0939	137883	438
TGx 1990-55F	1651	1.0997	145027	2586
TGx 1990-52F	1669	1.1033	145046	2428
TGx 1448-2E(CK)	1625	1.1159	146413	10399
Grand mean	**1604**			

CK= Check

Table 4.78: Combined analysis for sensitivity and stability coefficients for seed yield from soybean genotypes across environments during the 2015 and 2016 cropping seasons

Genotype	Mean	Sensitivity (b value)	Static Stability	Mean square Deviation
TGx 1989-53FN	1493	0.7377	62849	909
TGx 1989-45F	1631	0.7381	64383	3846
TGx 1989-75FN	1571	0.8235	79986	12118
TGx 1990-114FN	1539	0.8239	83799	4325
TGx 1990-110FN	1594	0.8509	91675	17353
TGx 1485-ID(CK)	1570	0.8553	98997	32982
TGx 1993-4FN	1564	0.9010	100316	19412
TGx 1989-68FN	1537	0.9180	100367	7392
TGx 1990-78F	1488	0.9270	102786	973
TGx 1989-42F	1568	0.9485	104917	3565
TGx 1987-62F(CK)	1585	0.9533	105135	1887
TGx 1835-10E(CK)	1567	0.9676	118586	22522
TGx 1990-95F	1607	0.9848	118601	61738
TGx 1989-40F	1577	1.0000	124557	4196
TGx 1990-40F	1592	1.0414	136271	426
TGx 1989-11F	1579	1.0881	139353	18149
TGx 1987-10F(CK)	1566	1.0900	142051	125
TGx 1990-52F	1587	1.0970	144824	2772
TGx 1448-2E(CK)	1596	1.1146	146514	8178
TGx 1990-55F	1632	1.1271	149189	7093
Grand mean	**1570**			

CK= Check

4.8 Boxplot across Environments

4.8.1 Boxplot for seed yield from soybean genotypes across the environments

The boxplot for seed yield during the 2015 cropping season across the three environments is shown in Figure 4.1. Igabi environment recorded the highest mean performance than Abuja and Gwarzo environments. However, the soybean genotypes showed wider variability in Igabi and Abuja environments. The boxplot encloses observations between the 25th (lower quartile) and 75th (upper quartiles) with the lines extending to the minimum and maximum of observed values. Figure 4.2 shows the boxplot for seed yield during the 2016 cropping season across the three environments. Although Igabi environment had the highest mean performance, the genotypes recorded wider variability in Abuja environment. The boxplot showed observations between 25th lower quartiles and 75th upper quartiles with the lines extending to the minimum and maximum observed values.

The combined analysis of boxplot for seed yield during the 2015 and 2016 cropping seasons across the three environments revealed Igabi environment recording the highest mean performance than other environments (Figure 4.3). However, Abuja environment showed wider soybean genotype variability. The boxplot indicates observations between 25th and 75 quartiles, showing lines extending to the minimum and maximum values.

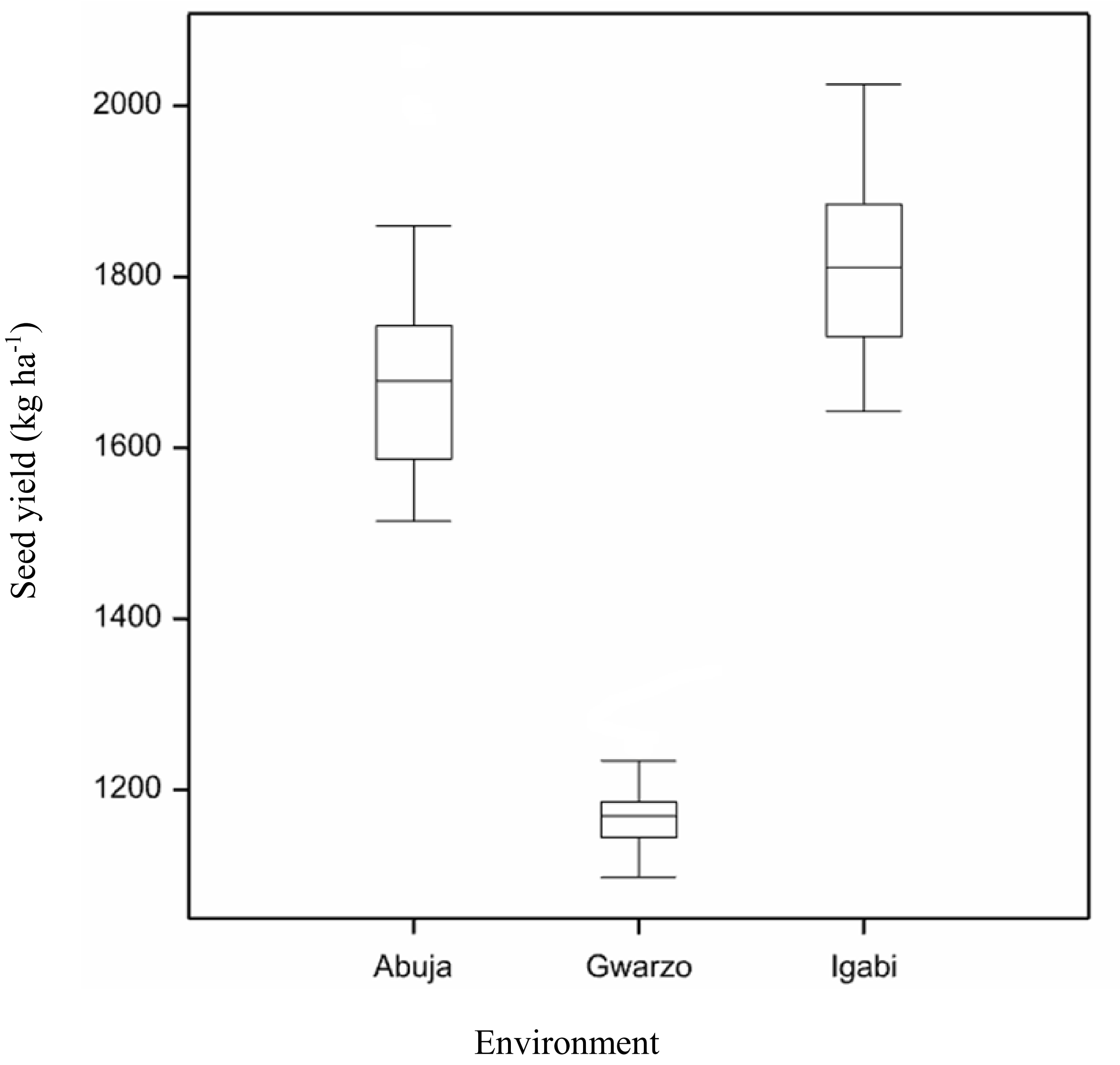

Figure 4.1: Boxplot for seed yield (kg ha^{-1}) in 2015 cropping season across environments

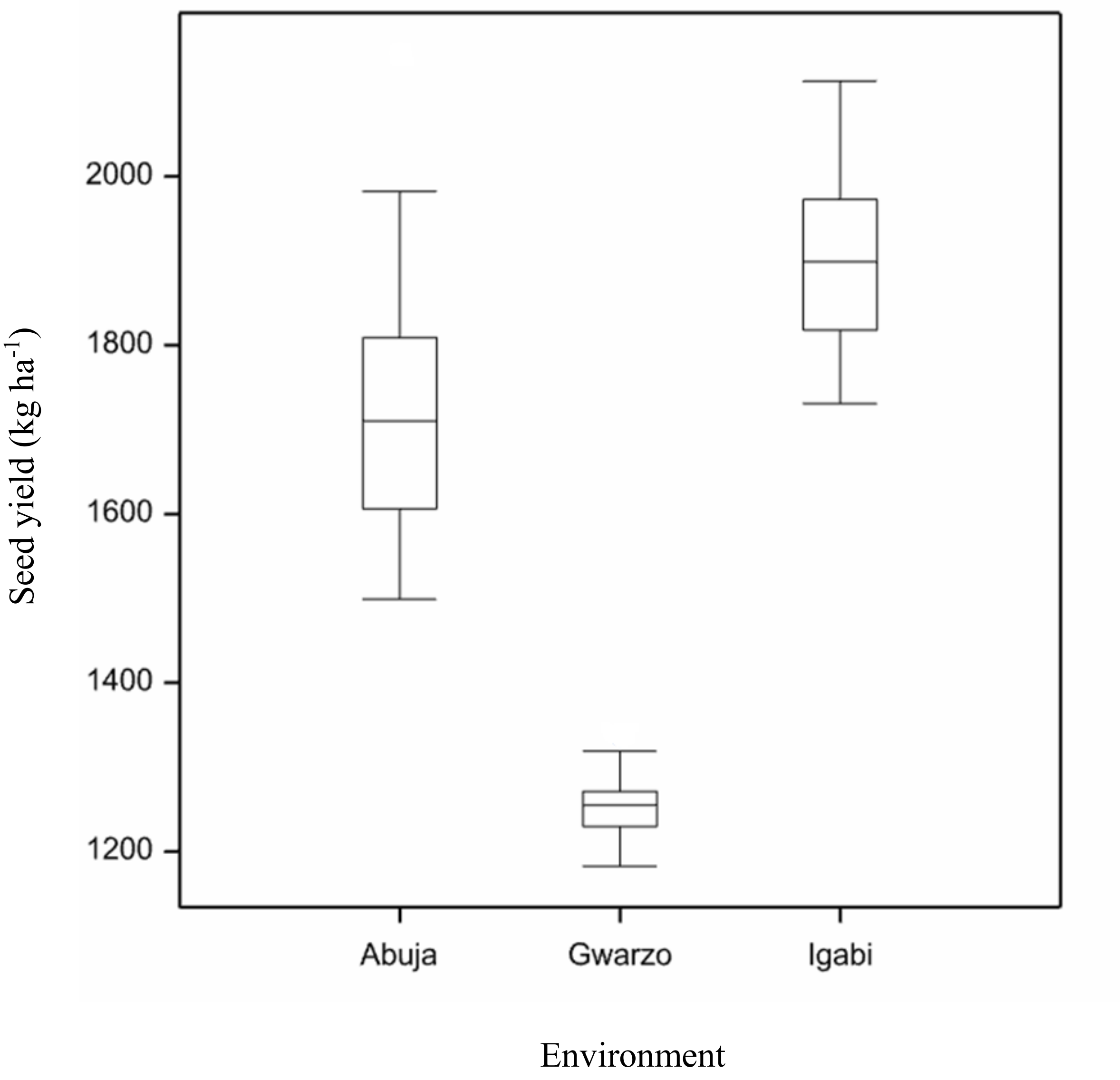

Figure 4.2: Boxplot for seed yield (kg ha^{-1}) in 2016 cropping season across environments

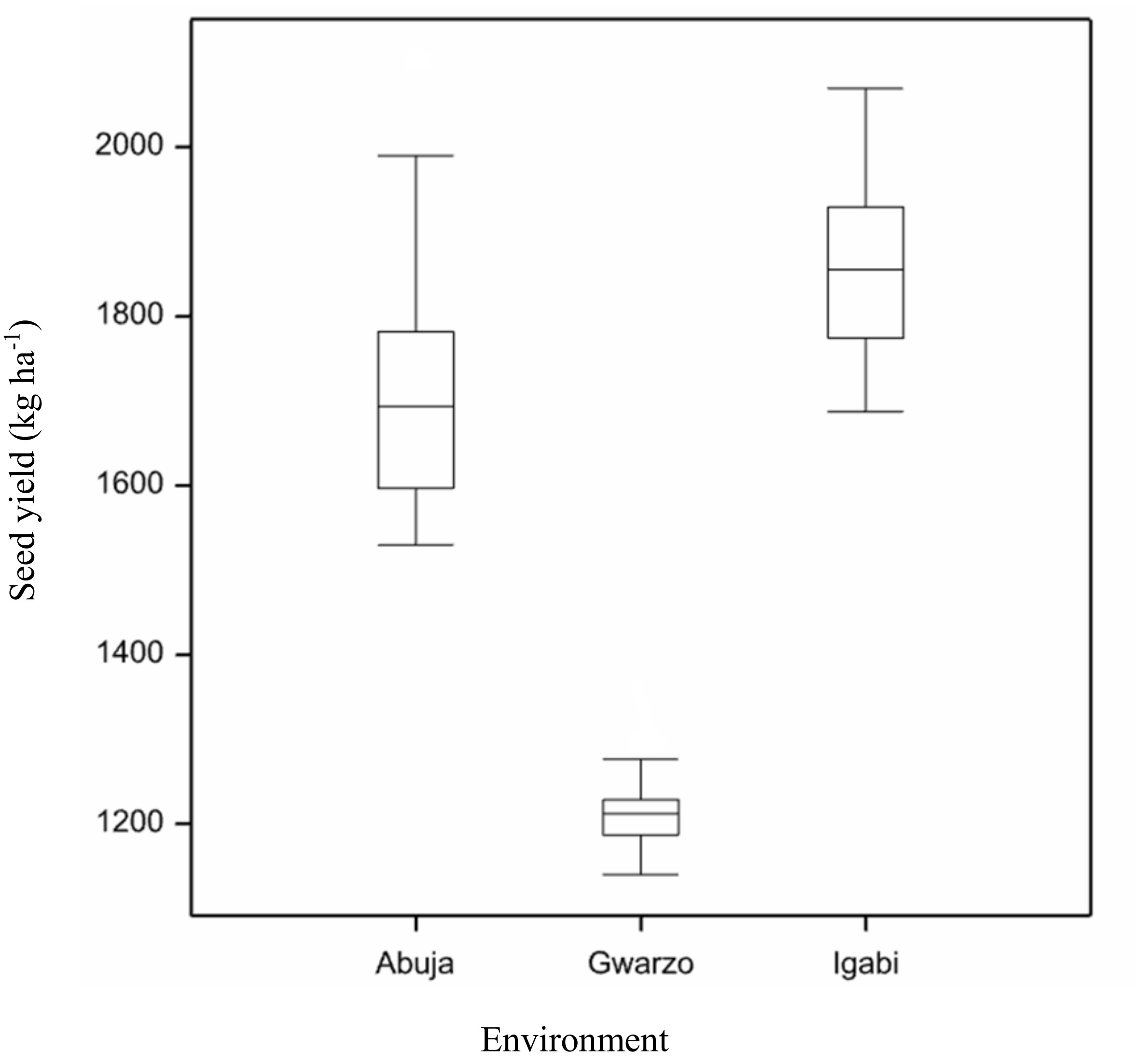

Figure 4.3: Combined analysis of boxplot for seed yield (kg ha^{-1}) during the 2015 and 2016 cropping seasons across environments

4.8.2 Boxplot for seed yield from soybean genotypes inoculation across the environments

Figure 4.4 shows the boxplots for seed yield from soybean genotypes inoculation in 2015 cropping season across the environments. LegumeFix inoculants recorded the highest mean performance, followed by NoduMax as revealed in the figures. The boxplot encloses observations between the 25th lower quartile and 75th upper quartile with the lines extending to the minimum and maximum observed values. The boxplot for seed yield from soybean genotypes inoculation in the 2016 cropping season is revealed in Figure 4.5. The figure showed that LegumeFix inoculants had the highest mean performance, while without inoculation recorded the least value. The boxplot observations are between 25th lower quartile and 75th upper quartile with a line extending between the minimum and the maximum values. Figure 4.6 recorded similar trends.

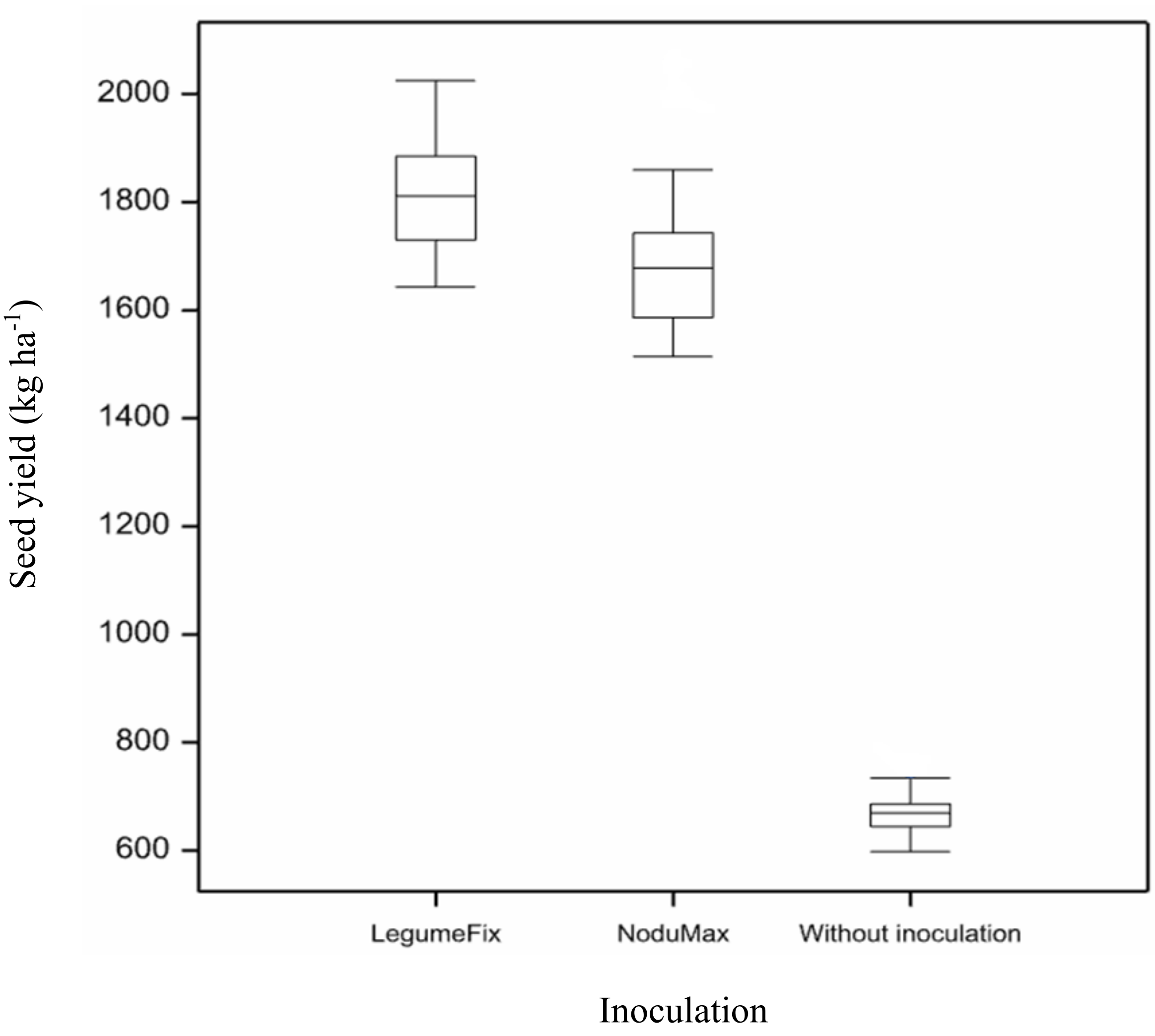

Figure 4.4: Boxplot for seed yield (kg ha^{-1}) from soybean genotypes inoculation in 2015 cropping season across environments

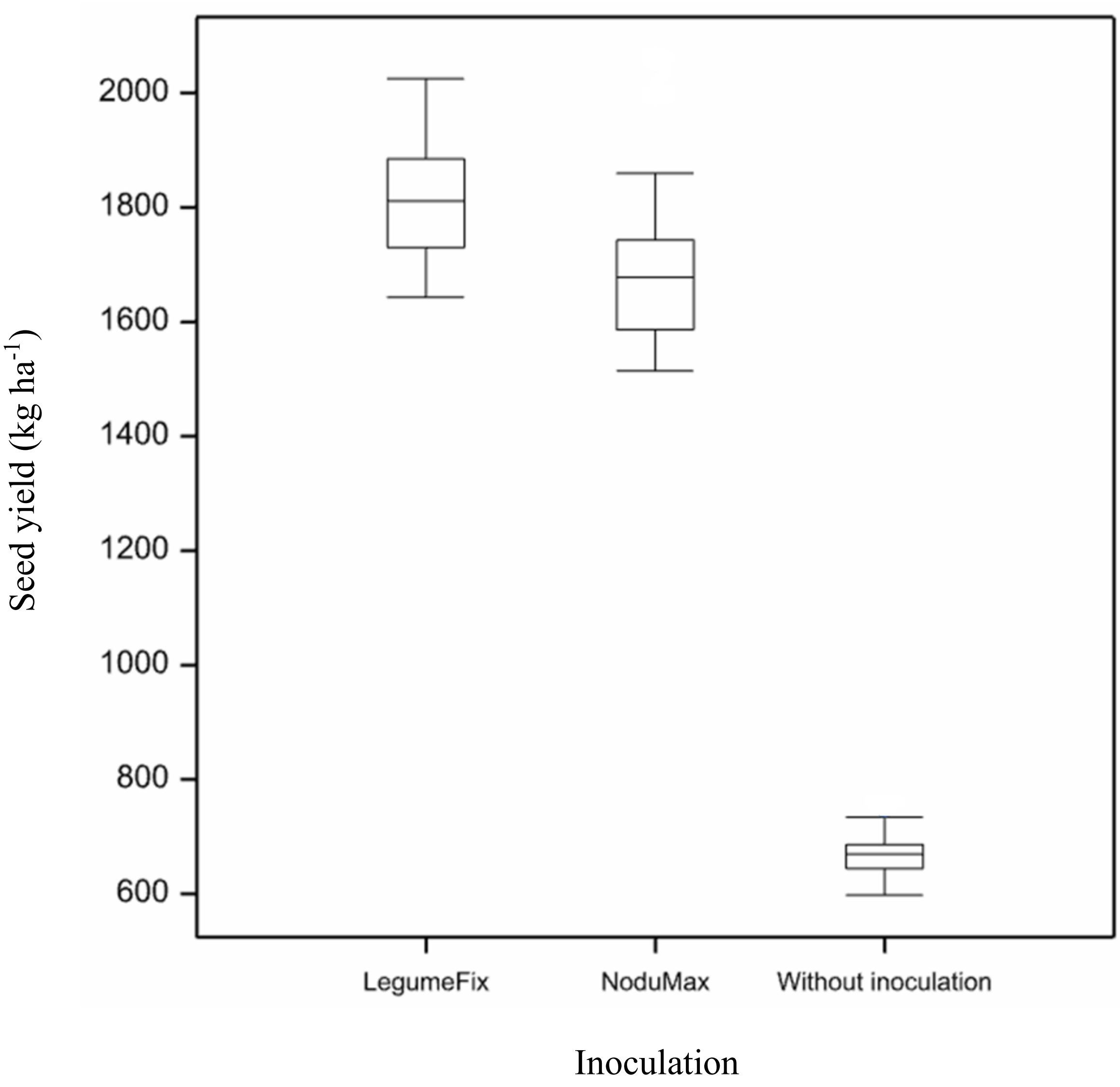

Figure 4.5: Boxplot for seed yield (kg ha^{-1}) from soybean genotypes inoculation in 2016 cropping season across environments

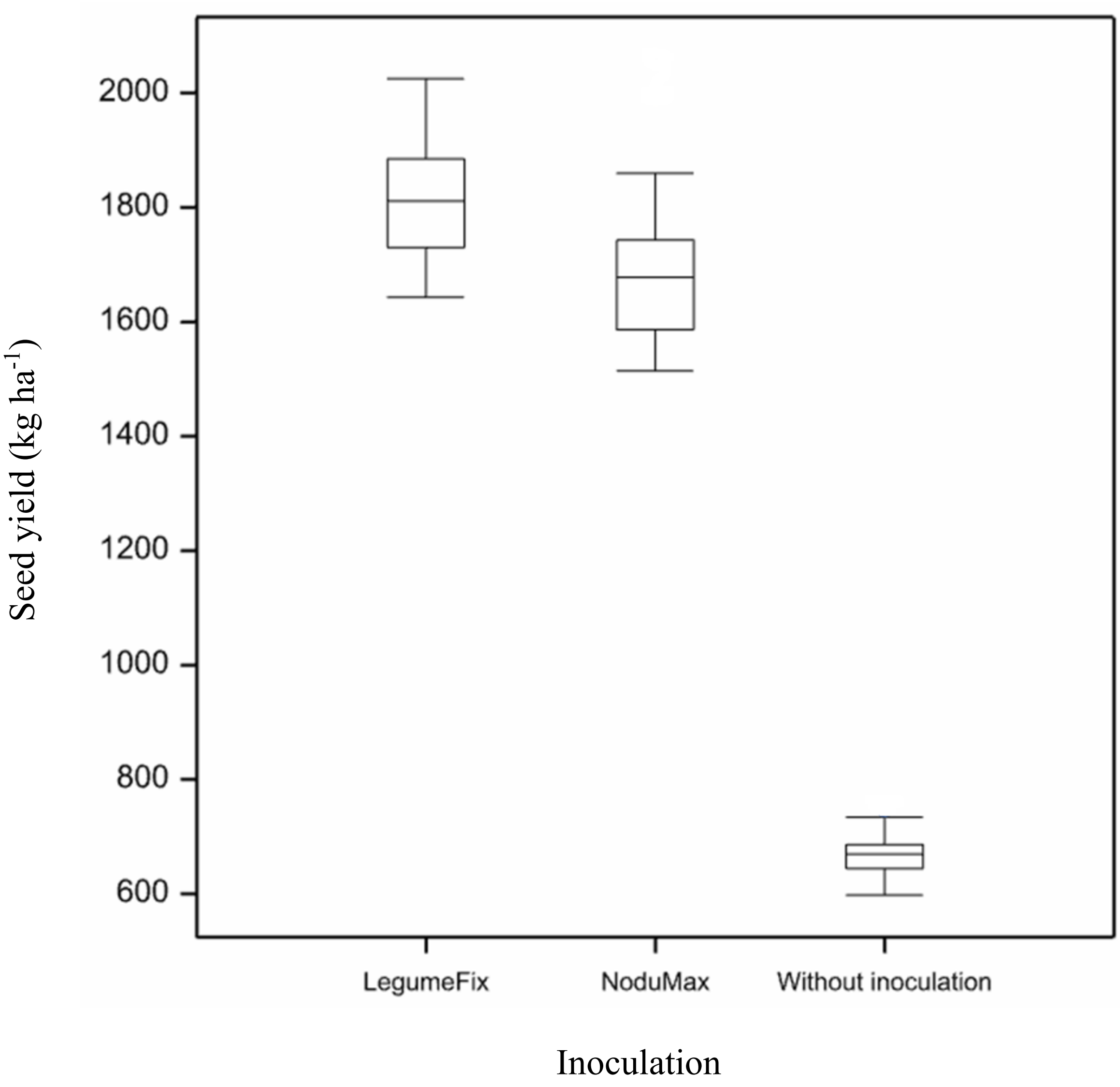

Figure 4.6: Combined data boxplot for seed yield (kg ha^{-1}) from soybean genotypes inoculation during the 2015 and 2016 cropping seasons across environments

4.9 AMMI and GGE Biplots

4.9.1 AMMI and GGE biplots for seed yield from soybean genotypes across the environments

Figure 4.7 shows the Additive Main Effect Multiplicative Interaction (AMMI) biplot for seed yield across the environments during the 2015 cropping season. The presence of genotype by environment interaction was demonstrated by the AMMI model. The Interaction Principal Component Analysis (IPCA1) explained 69.95 % genotype by environment interaction. This implied that, the interaction of the genotypes with three environments was predicted by the first principal components of genotype and environment. The differences among genotypes in terms of direction and magnitude along the X-axis (yield) and Y-axis (IPCA1 scores) were provided by AMMI biplot using the main effect and the first principal component scores of interaction (IPCA1) of both genotypes and environment (Figure 4.7). In the biplot, genotypes or environments that appear almost on a perpendicular line of the graph have similar mean seed yields and those that fall almost on a horizontal line have similar interaction. Hence the variability due to environment was greater than that due to genotype differences. Genotypes or environments on the right side of the midpoint of the perpendicular line have higher yields than those on the left side. The genotypes TGx 1989-49FN, TGx 1990-46F, TGx 1990-55F, TGx 1989-48FN and TGx 1990-57F were high yielding. In contrast TGx 1990-78F, TGx 1989-53FN, TGx 1989-68FN and TGx 1990-110F were low yielding.

Genotypes or environments with large negative or positive IPCA1 scores have high interactions, while those with IPCA1 scores near zero (close to the horizontal line) have little interaction across environment and are considered more stable than those further away from the horizontal line. In the biplot, TGx 1989-53FN and TGx 1989-48FN fell almost on the horizontal line near the zero point on IPCA1. This implies that these genotypes showed high and stable yield. Genotypes TGx 1987-10F, TGx 1448-2E and TGx 1990-57F were a little far away from the horizontal line and implies that the genotypes are high yielding but relatively unstable. The genotypes TGx 1990-78F, TGx 1990-52F and TGx 1989-68FN were close to the horizontal line but at the left side of the perpendicular line. This means that the genotypes are relatively stable but produce below average yield. The poorest of the genotypes due to instability and lowest yield were TGx 1990-114FN and TGx 1989-40F. In terms of the environments, Igabi is the most yielding while Gwarzo recorded the least yielding but most stable.

The biplot for the best genotypes in each of the environment for seed yield during the 2015 cropping season is presented in Figure 4.8. The polygon view of the Genotype plus Genotype by Environment interaction (GGE) biplot displays the best genotypes in each environment and it is a summary of the genotype by environment pattern of a multi-environment yield trial. The polygon is formed by connecting the genotypes that are further away from the biplot origin such that all other genotypes are contained within the polygon. To each side of the polygon, a perpendicular line starting from the origin is drawn and extended beyond the polygon so that the biplot is divided into several sectors and the different environments were separated into different sectors. The genotypes at the vertices of each sector are the best performers at the environment included in that sector, provided that GGE is sufficiently approximated by PC1 and PC2. Although, there were six sectors in all, the three mega environments were identified. Abuja was one mega environment with TGx 1990-40F, TGx 1990-46F and TGx 1990-55F as the best genotypes in this environment. The best genotypes for the second mega environment Igabi were TGx 1989-49FN, TGx 1989-48FN and TGx 1987-10F-check, while the last mega environment Gwarzo had TGx 1993-4FN, TGx 1989-75FN, TGx 1448-2E-check, TGx 1989-40F and TGx 1990-52F as the best. The remaining sectors without environment within them contained the following genotypes TGx 1989-45F, TGx 1990-114FN, TGx 1989-53FN, TGx 1990-78F, TGx 1990-110FN, TGx 1989-68FN, TGx 1835-10E-check and TGx 1485-1D-check. These genotypes were not the highest yielding genotype at any environment.

Figure 4.9 shows the AMMI biplot for seed yield across the environments during the 2016 cropping season. Genotypes or environments with large negative or positive IPCA1 scores have high interactions, while those with IPCA1 scores near zero have little interaction across environments and are more stable. Genotypes TGx 1989-48FN, TGx 1987-10F-check, TGx 1990-52F and TGx 1990-57F were a little far away from the horizontal line and implies that the genotypes are high yielding but relatively unstable. The genotype TGx 1990-78F and TGx 1990-114FN were close to the horizontal line but on the left side of the perpendicular line implies that the genotypes are relatively stable but produced below average yield.

Figure 4.10 shows GGE biplot sectors for seed yield during the 2016 cropping season. The polygon view showed the best genotypes in each environment. To each side of the polygon, a perpendicular line from the origin extended beyond the polygon dividing it into several sectors. The genotypes at the vertices of each sector are presented as the best performance at each environment. Although, there were five sectors in all, three mega environments were identified. Abuja mega environment recorded TGx 1990-40F, TGx 1990-46F and TGx 1990-55F as the best genotypes, Igabi environment recorded TGx 1989-48FN, TGx 1989-49FN and TGx 1990-57F were recorded as the best genotypes. The third mega environment Gwarzo had TGx 1989-11F, TGx 1993-4FN and TGx 1989-75FN as the best genotypes. The sectors without environment within them contain genotypes that were not the highest yielding at any environment. Figure 4.11 shows AMMI biplot for seed yield across environments during the 2015 and 2016 cropping seasons combined data. In the biplot, TGx 1989-48FN fell almost on the horizontal line near zero point of IPCA1. This revealed that this genotype showed high and stable yield. Genotypes TGx 1987-10F-check, TGx 1990-40F, TGx 1990-52F and TGx 1990-57F were a little distance from the horizontal line which implies that the genotypes were high yielding but relatively stable.

The biplot of the best genotypes in each environment for seed yield in 2015 and 2016 cropping seasons combined data is presented in Figure 4.12. The polygon revealed the outstanding genotypes in each environment and a summary of the genotype by environment interaction pattern of multi-location trials. There were five sectors in the polygon, three environments were identified. Abuja had TGx 1990-40F, TGx 1990-46F and TGx 1990-55F as the best genotypes. Igabi showed TGx 1989-48FN, TGx 1990-57F and TGx 1987-10F-check as the best genotypes and Gwarzo environment had TGx 1989-11F, TGx 1993-4FN, TGx 1989-75FN and TGx 1448-2E-check as the best genotypes. The remaining sectors without environment showed that the genotypes were not highest yielding genotypes at any environment.

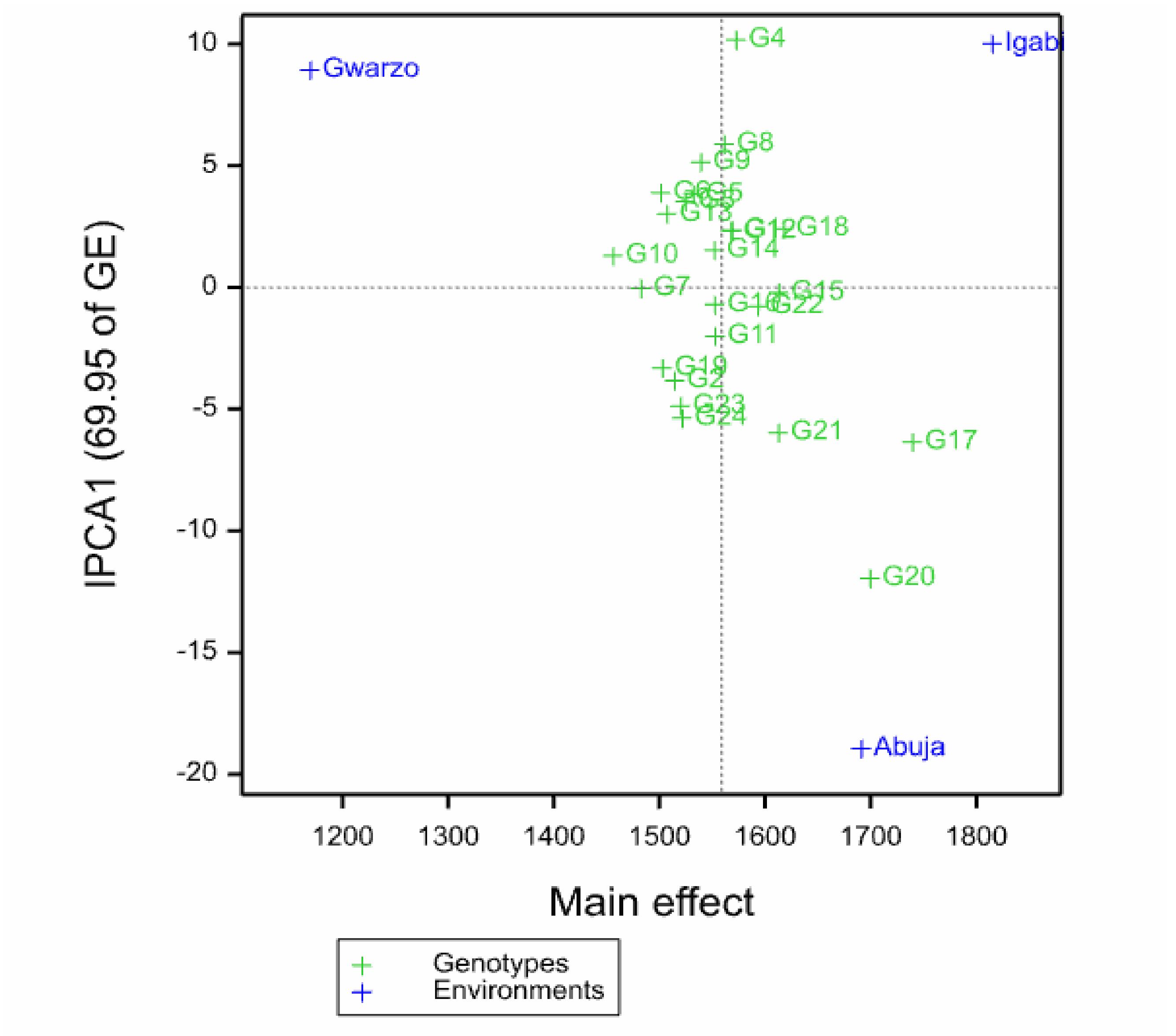

Figure 4.7: Additive Main Effect Multiplicative Interactions (AMMI) biplot for seed yield across environments in 2015 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

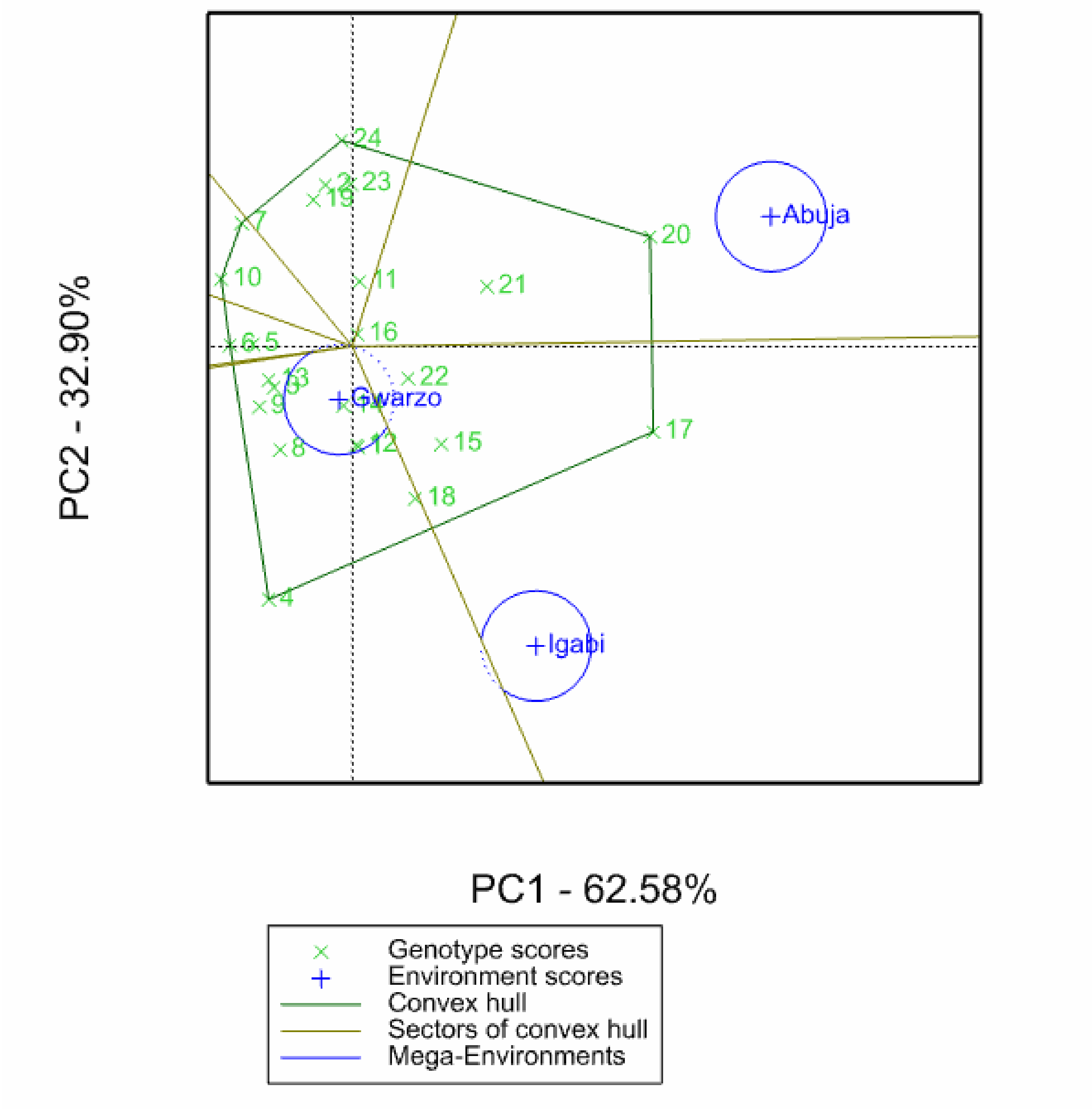

Figure 4.8: Genotype plus genotype-by-environment interaction (GGE) biplot sectors for seed yield (environment scaling) in 2015 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

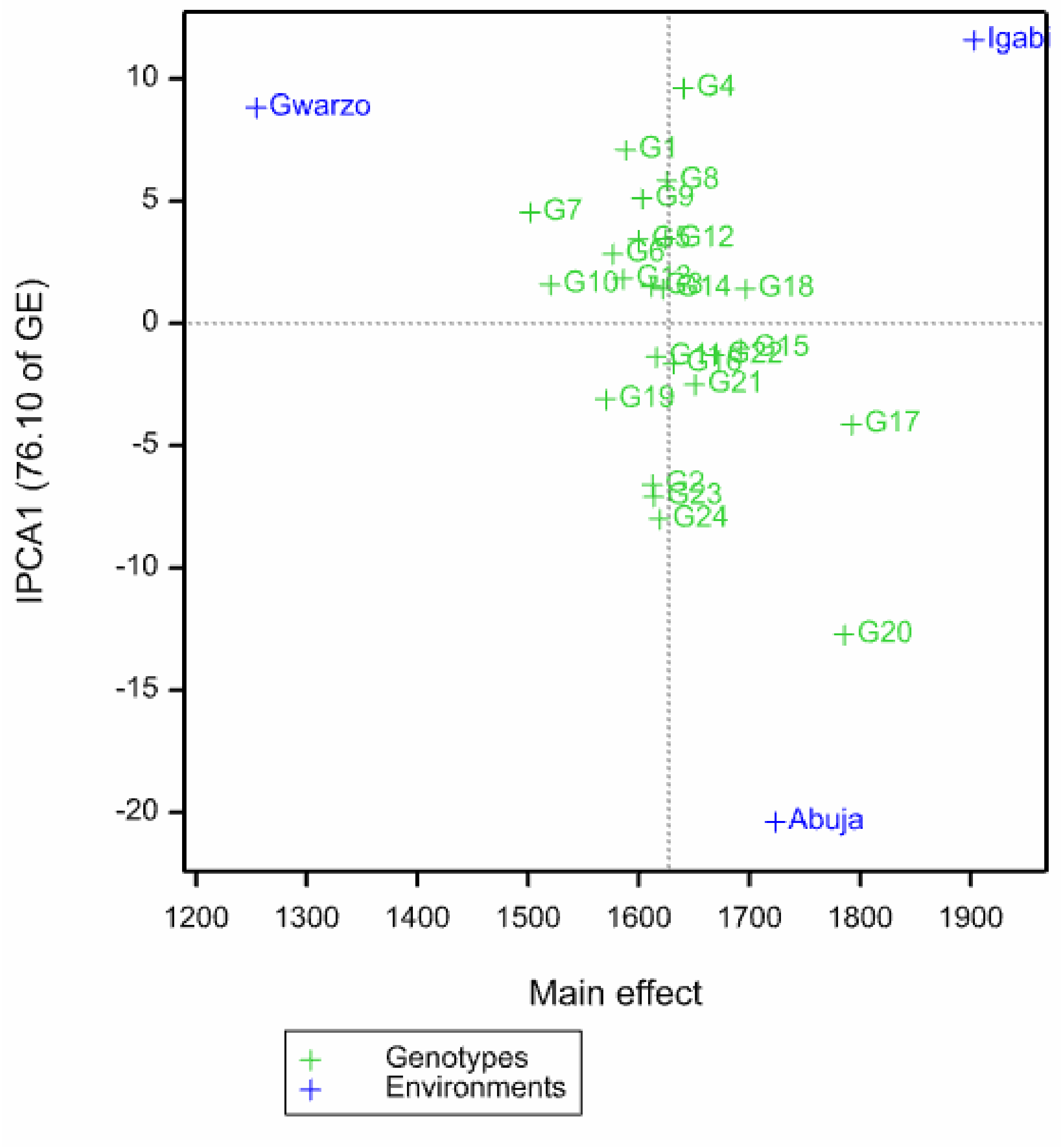

Figure 4.9: Additive Main Effect Multiplicative Interactions (AMMI) biplot for seed yield across environments in 2016 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

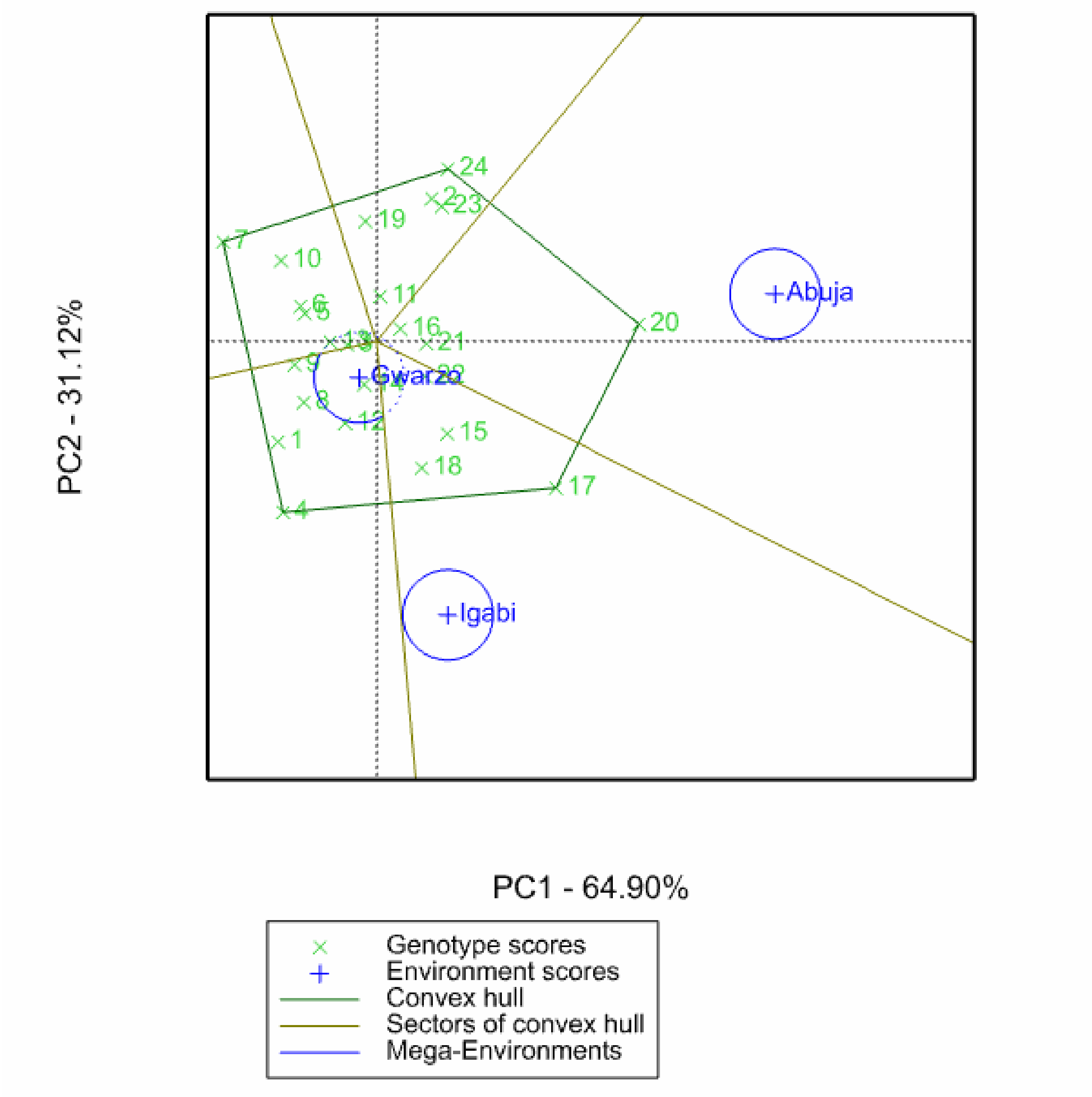

Figure 4.10: Genotype plus genotype-by-environment interaction (GGE) biplot sectors for seed yield (environment scaling) in 2016 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

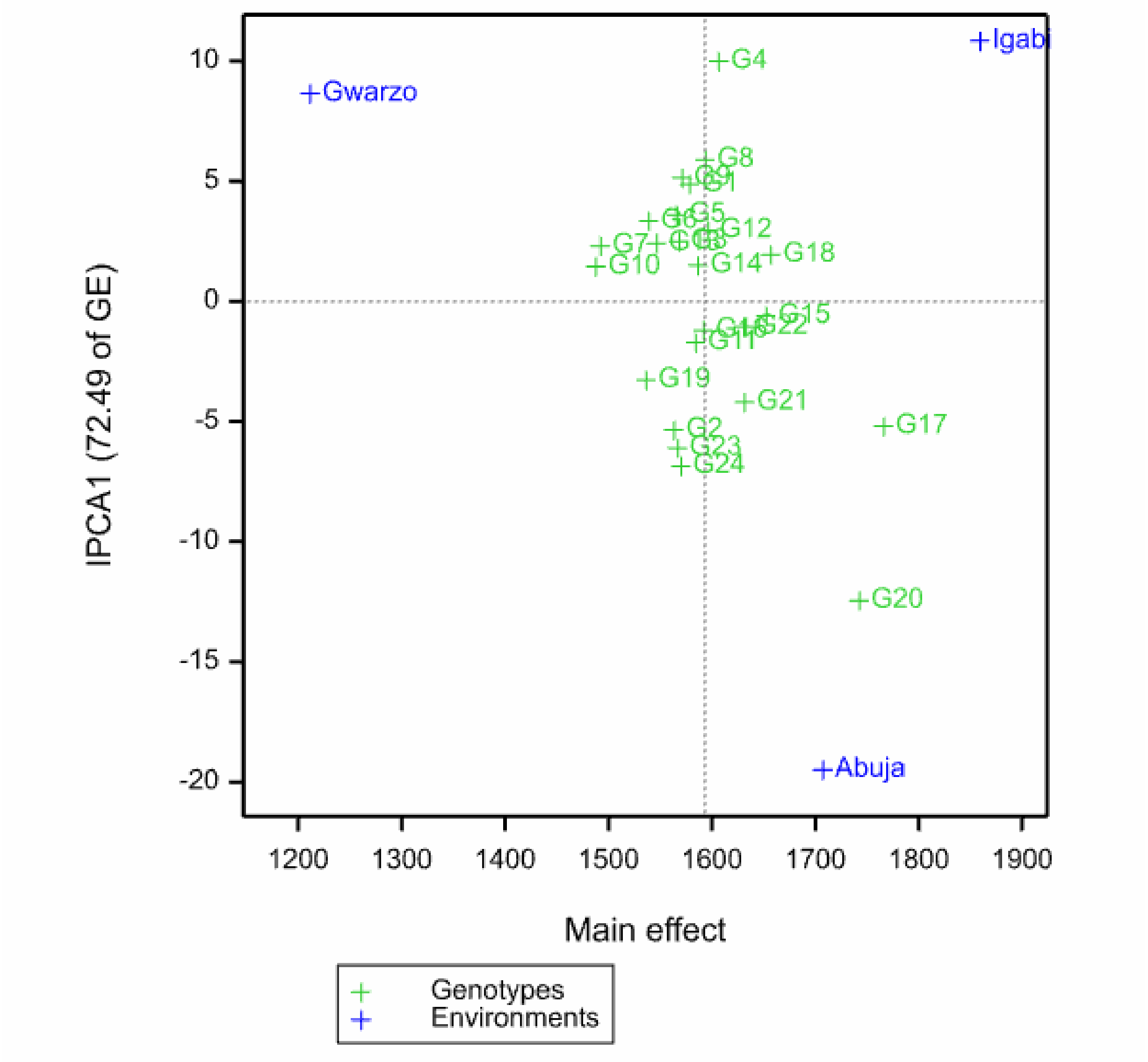

Figure 4.11: Additive Main Effect Multiplicative Interactions (AMMI) biplot for seed yield across environments in 2015 and 2016 cropping seasons combined analysis. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

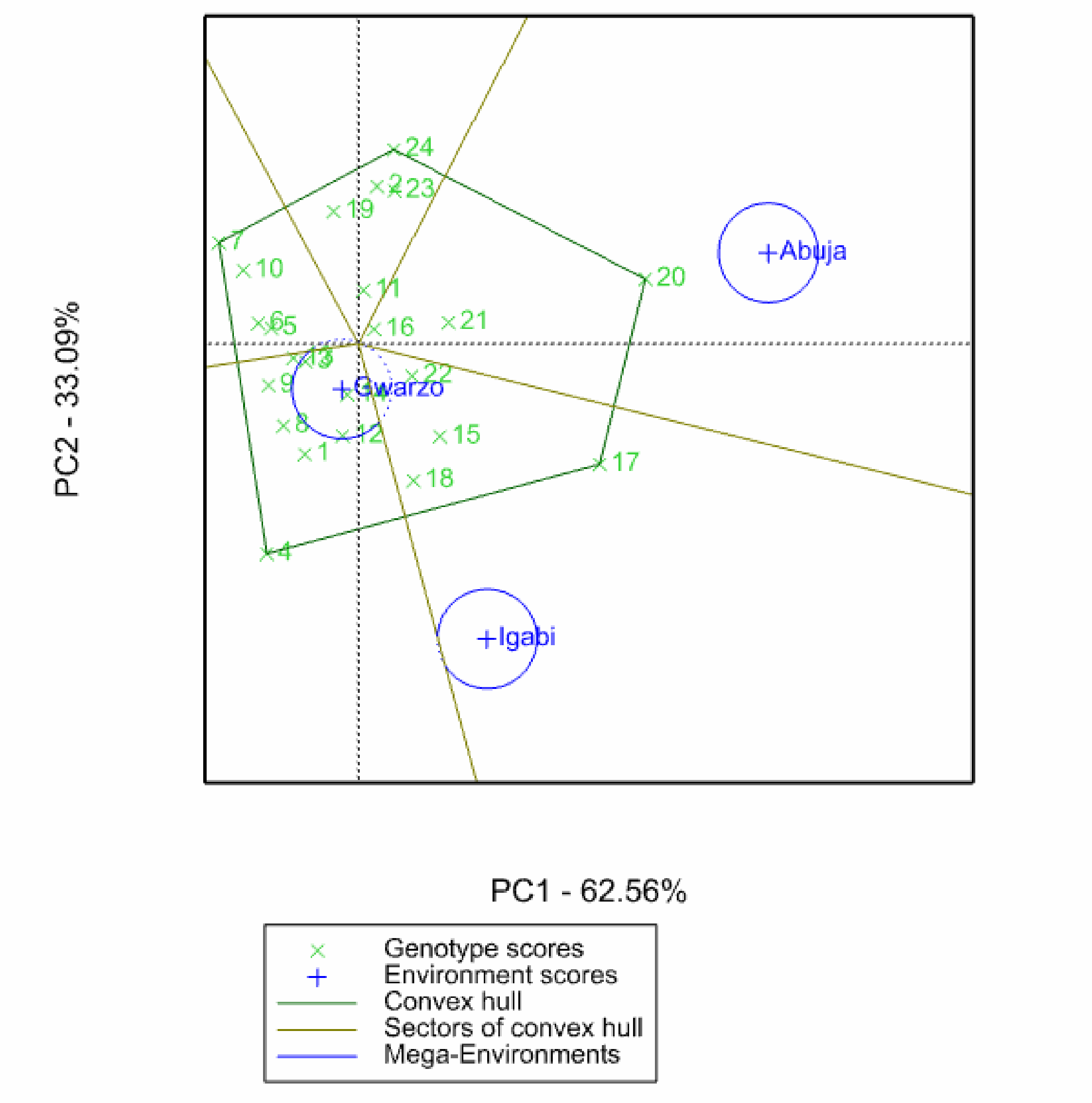

Figure 4.12: Genotype plus genotype-by-environment interaction (GGE) biplot sectors for seed yield (environment scaling) in 2015 and 2016 cropping seasons combined analysis. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

4.9.2 AMMI biplots for seed yield from soybean genotypes inoculation across the environments

Figure 4.13, 4.14 and 4.15 shows Additive Main Effect Multiplicative Interaction (AMMI) biplot for inoculation across the environments. The model demonstrated the presence of genotype by inoculation interaction. The Interaction Principal Component Analysis (IPCA1) explained 69.95 % genotype by inoculation interaction. The interaction of genotypes with inoculation was predicted by the first principal components.

The differences among genotypes in terms of direction and magnitude along X-axis (yield) and Y-axis (IPCA1 scores) are provided by the biplots using the main effect and the first principal component scores interaction of both genotypes and inoculation. In the biplot, genotypes or inoculants that appear almost on a perdicular line of thr graph have similar yields and those that fall almost on a horizontal line have similar interactions. Therefore, the variability due to inoculation was greater than that due to genotypes differences. Genotypes or inoculants on the right side of the midpoint of the perpendicular line have higher yields than those on the left.

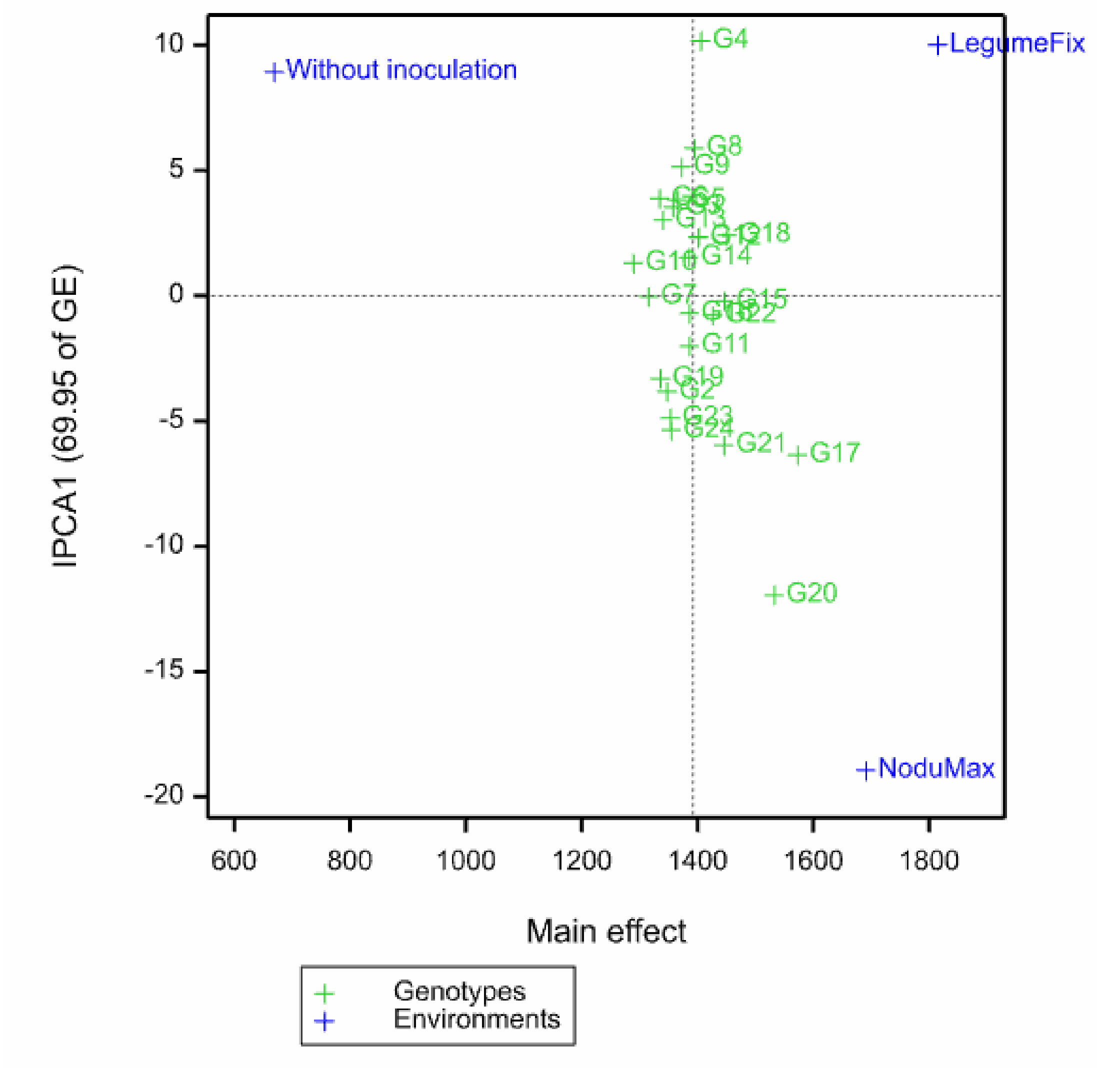

Figure 4.13: Additive Main Effect Multiplicative Interactions (AMMI) biplot for inoculation across environments in 2015 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

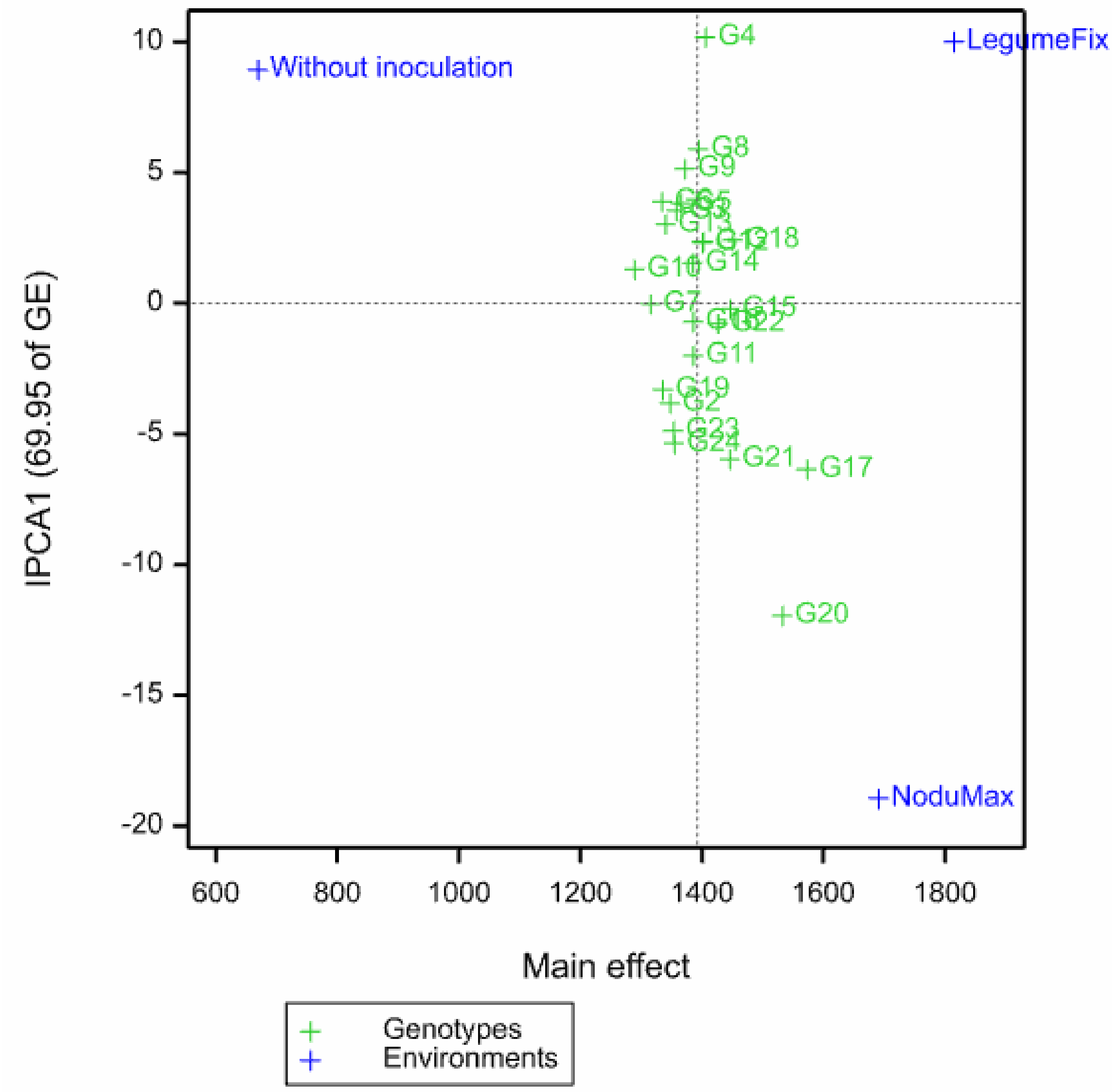

Figure 4.14: Additive Main Effect Multiplicative Interactions (AMMI) biplot for inoculation across environments in 2016 cropping season. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

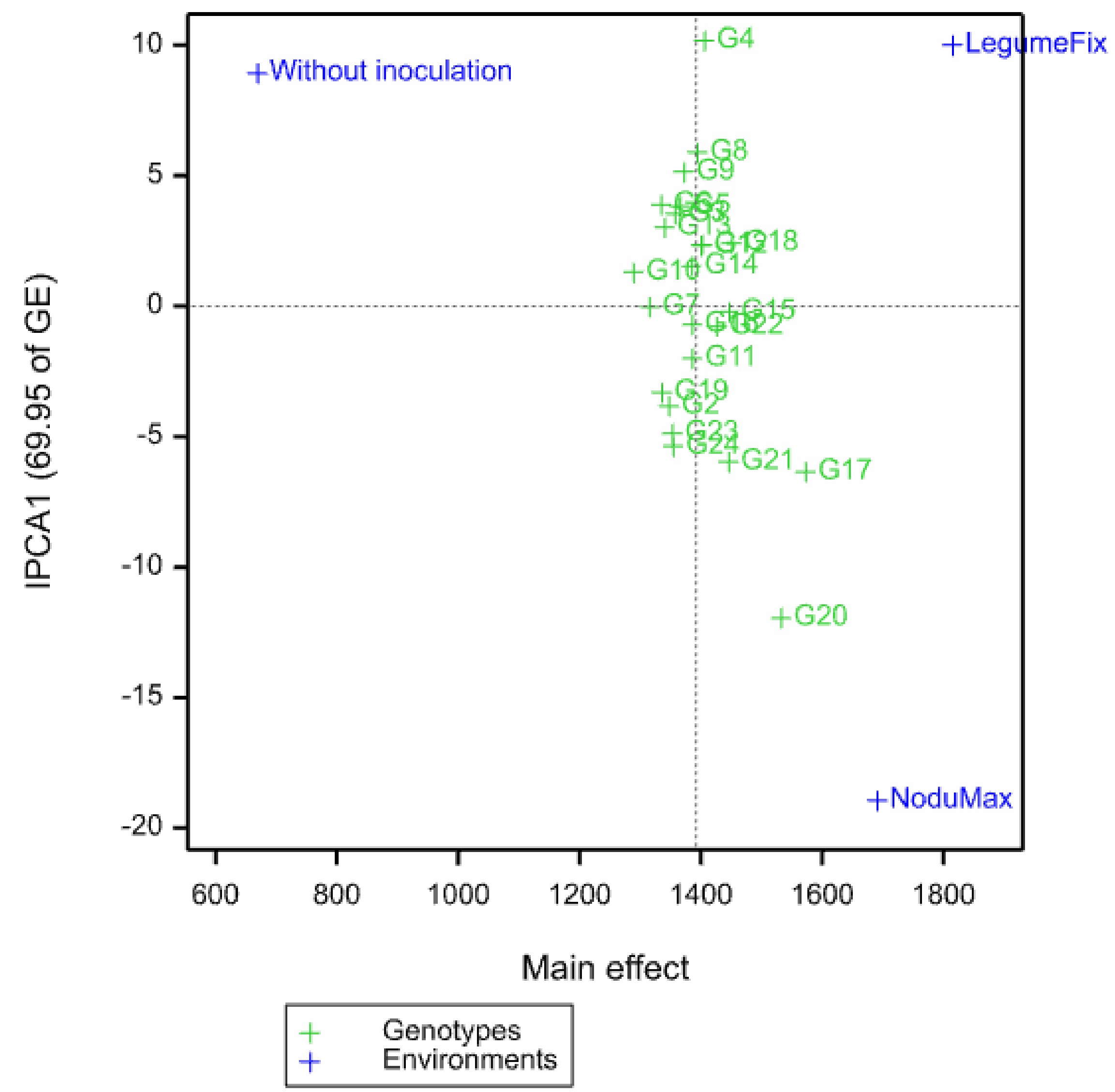

Figure 4.15: Additive Main Effect Multiplicative Interactions (AMMI) biplot for inoculation across environments in 2015 and 2016 cropping seasons combined analysis. 1= TGx 1989-11F; 2= TGx 1990-110FN; 3= TGx 1989-42FN; 4= TGx 1990-95F; 5= TGx 1989-45F; 6= TGx 1990-114FN; 7= TGx 1989-53FN; 8= TGx 1993-4FN; 9= TGx 1989-75FN; 10= TGx 1990-78F; 11= TGx 1967-62F-Check; 12= TGx 1448-2E-Check; 13= TGx 1989 -40F; 14= TGx 1990-52F; 15= TGx 1989-48FN; 16= TGx 1990-40F; 17= TGx 1989-49FN; 18= TGx 1990-57F; 19= TGx 1989-68FN; 20= TGx 1990-46F; 21= TGx 1990-55F; 22= TGx 1987-10F-Check; 23= TGx 1835-10E-Check; 24= TGx 1485-1D- Check

CHAPTER FIVE

5.0 DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion

The poor emergence (percentage) of seeds planted without inoculation relative to seeds treated with either NoduMax or LegumeFix confirmed the existence of *Rhizobium* activities with the seeds. Dorivar *et al*. (2010), Macak and Candrakova (2013) and Rasaei *et al*. (2013) showed that *Bradyrhizobium japonicum* inoculants have activities that promote seed germination and early seedling growth in soybean. However, differences in emergence among genotypes may be due to genetic variability, seed handling, seed storage methodology and the soil moisture content.

The genotypes that recorded above average yield performance, in the different environments had taller plants, more of pods, heavier biomass yield and seeds. Nevertheless, some other genotypes exhibited similar attributes but recorded yields close to average. These suggests that the high yielding genotypes utilized better, the environmental conditions available to accumulate adequate biomass before the initiation of reproductive phase.

The yield variations expressed by the environments showed that environments were diverse. Although temperature distribution was relatively uniform and favourable across the three environments during the production period, rainfall pattern varied, this could be the major cause of yield variations across the environments. Similarly the high mean performance of genotypes in Igabi and Abuja environments could be traced to the similar favourable rainfall pattern exhibited by the two environments. On the contrary, the lower yield experienced in Gwarzo may be attributed to the decline in rainfall during the seed filling stage of the genotypes. This might have eventually caused seed maturation to occur too early, thereby lowering their weight and resulted in yield reduction.

The genotype and environment interaction clearly plays a significant role in breeding adaptable genotypes to the wide environment. This interaction was validated by the highly significant difference for seed yield. These results relate the findings of Gebeyehu and Assefa (2003) who reported that selections based on the highest yielding genotypes appeared less stable than the average of all genotypes. Furthermore, Gebeyehu and Assefa (2003) stated that selection solely for seed yield could result in rejection of several stable genotypes. TGx 1989-45F and TGx 1990-110FN out yielded others because of its yield components such as plant height, number of leaves, number of pods per plant and some other growth traits that have contributed to the high yield. In contrast, Arslanglu and Aytac (2010) reported contrary finding on the effect of genotype, environment and genotype by environment interaction on soybean pod number per plant, whereby plant height, seed yield and one hundred-seed weight were found to be significant at (P=0.01).

From the findings of this study, it was evident that total biomass yield and seed yield declined in the same trend. The mean performance analysis revealed that high yielding genotypes across the environments over the two years were TGx 1989-45F, TGX 1990-110FN and TGx 1989-53FN. Thus, the outstanding performance by TGx 1989-45F in terms of yield and yield related traits made it the best performer across the three environments over two years. These conform to Egli (1998) explanation for soybean performance that yield variation across environments and years was associated with changes in number of seeds per unit area. A contrary explanation is that an ideal soybean cultivar is one that achieves the greatest yield across many environments (Fasoula and Fasoula, 2002).

The exhibited non-significance by these traits, number of branches per plant, number of pods per plant and one hundred-seed weight was confirmed by Baker (1988) who defined the non-significant difference as failure of genotypes to achieve the same relative performance in different environment. Thus, the genotype by environment interaction might have made it difficult for breeders to identify the best genotypes, during selection and recommendation. The positive and significant correlation estimated between seed yield and other traits agreed with the findings of Malik *et al*. (2006). This implies that selections aimed at increasing seed yield would invariably select for higher plant height, higher leaf number and earliness to flower and as against one hundred-seed weight, number of branches per plant and number of pod per plant. This finding was in agreement with Karasu *et al*. (2002) who revealed that crop yield variations are stronghly influenced by growth and yield parameters. Th positive correlation reported agrees with Maesri *et al*. (1998) whereas, Rajanna *et al*. (2000) were of the view that one hundred-seed weight had negative association with seed yield. The positive correlation of number of pods per plant with seed yield obtained conformed to Karasu *et al*. (2002) study in Turkey. But Haliloglu *et al*. (2007) reported a contradictory result that the number of pods per plant indicated a positive association with seed yield. On the other hand, the positive correlation estimated between number of branches per plant and seed yield, total biomass yield, number of pods per plant agrees with Malik *et al*. (2007). Thus the correlation estimation in this study clearly defines the contribution of various other traits such as plant height, number of leaves, branches per plant and total biomass yield to seed yield through path analysis. The highest and the lowest seed yields level attained by the genotypes were mostly due to plant height, number of leaves, number of branches per plant and number of pods per plant.

In this study, it could be cited that the correlation coefficient of the genotypes across the environments in two years indicated that plant height had significant correlation with seed yield. This finding conformed to the report of Rajanna *et al*. (2000). Although number of branches per plant correlated non-significantly with other traits, positive trend was recorded. The chlorophyll content was significantly associated with seed yield. This indicated that with the greenish nature of the leaves more efficient utilization of solar radiation could be achieved. The finding was in agreement with Kumudini *et al*. (2001) who explained that the higher the chlorophyll content, the more improved the yield due to increased intercepted solar radiation and enhanced carbon exchange rate. The little variability recorded among genotypes was due to their response to climate changes in the three environments. This agrees with Kang (1998) findings that environment played major role in phenotypic expressions of agronomic traits. To overcome genotype by environment effect, Cucolotto *et al*. (2007) partitioned genotype by environment interaction into two; adaptability and phenotypic stability. These researchers defined adaptability as the capability that a genotype has to make use of the environmental effects that warrants a high yield level and phenotypic stability was related to yield maintenance or yield predictability in diverse environment. However, in the present study, genotype by environment was not partitioned. Phenotypically, all the studied genotypes followed similar trend of performance over two years. The non-significant differences posed by genotype by environment were confirmed by Faisal (1986) who reported that traits do influence performance and seed yield. The yield variations explained by environments indicates that the environments were diverse, with large differences between environmental means contributing most of the variations in yield. According to Eberhart and Russell (1996), an ideal cultivar would have both a high average performance over a wide range of environments plus stability. Although genotypic main effect was highly significant this shows difference in genotypic performance across environments resulting in genotype by environment interaction. The existence of genotype by environment interaction raised the need to identify stable and high yielding genotypes.

The additive main effect multiplicative interaction analysis of variance revealed that the environmental variance was significant and higher than both the genotype and genotype by environment interaction variance. The result revealed that the environment main effect was the most important source of variation, due to its large contribution to the total sum of squares for yield. Variations due to genotype were larger than that due to genotype by environment interaction, meaning that differences among genotype vary across environments. Similar observations were obtained by Kaya *et al*. (2002) and Admassu *et al*. (2008) in their studies. The observed differential genotypic responses can be traceable also to differences in inherent genetic composition. Such responses had been reported by Sanginga *et al*. (2000) and Osodeke (2001). This observation is also consistent with the findings of Aduloju *et al*. (2009) for the savanna region of Nigeria.

5.2 Conclusion

The performance of inoculated seeds by B. *japonicum* was statistically higher than that without inoculation seeds. Therefore, symbiotic N_2 requirement and optimum yield potential of soybean genotypes grown in the savanna region of Nigeria may be met by rhizobia population. Also, from the results of this study, it can be concluded that the genotypic and phenotypic correlations were consistent and hence, there was little intervention of environment effects in expression of characters. Traits such as plant height, number of leaves, number of pods per plant, above ground biomass yield, total biomass yield, harvest index and one hundred-seed weight which showed significant correlation with seed yield, can be used as selection indices in seed yield improvement. Except number of branches per plant, all the traits affected seed yield directly or indirectly, mainly through impact on total biomass production. Therefore, selection for biomass will possibly improve other component characters thereby improving seed yield.

Out of the twenty-four genotypes evaluated for genotype by environment interaction and yield stability, two (TGx 1989-45F and TGx 1990-110FN) were identified by the analytical tools used as the overall best in relation to seed yield and stability as compared to the checks an grand mean performance of the genotypes. In terms of the environment, Gwarzo produced the least interaction scores, while Abuja and Igabi produced the highest interaction scores. Therefore, Gwarzo was most stable than Abuja and Igabi. However, the average yield performance of Gwarzo was poor when compared with the yield performance of the other two environments.

5.3 Recommendations

Based on the result of the study, it is recommended that;

i. Appropriate soybean inoculation with LegumeFix and or NoduMax should be adopted in order to enhance soybean yield and productivity in farmer's field.

ii. The two genotypes (TGx 1989-45F and TGx 1990-110FN) that were identified as the overall best in relation to seed yield and stability could be nominated into yield evaluation trials for subsequent release as soybean varieties in Nigeria.

iii. Gwarzo can be considered for soybean evaluation as effective selection will be obtained due to relatively uniform performance of the genotypes.

iv. For large scale soybean production, environments like Abuja and Igabi may be considered in order to ensure high yield, effective production and food security.

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