INFLUENCE OF STARTER NITROGEN APPLICATION ON YIELDS OF TWO SOYA BEAN VARIETIES GROWN ON FERRIC LUVISOL IN OYO STATE, NIGERIA

BY

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ABSTRACT.

Nitrogen is a major soil nutrient for the growth and development of crops. Nitrogen deficiency in-between pre-nodulation and nodulation in soya bean is critical to enhancing its growth and yield. Decision Support Systems for Agro-technology Transfer (DSSAT) model like CROPGRO-soya bean could be a useful tool for predicting starter nitrogen requirement in soya bean. However, information on starter nitrogen application to overcome N-deficiency-induced-stress during early seedling growth and prediction using CROPGRO-soya bean is limited. This study was undertaken to investigate the effect of starter nitrogen on soya bean yield grown on ferric luvisol in Oyo State, Nigeria.

Field experiment involving two soya bean varieties (TGx1485-1D and TGx1448-2E) and five starter nitrogen rates (0, 5, 15, 25 and 35 kg/ha) was carried out for two seasons at Ipapo and Gbonran in Itesiwaju Local Government Area of Oyo State. The experiment was laid out as split-plot in a randomised complete block design with three replications. Nitrogen rate and soya bean variety were main and sub-plot factors, respectively. Shoot Dry Weight (SDW, t/ha), Grain Yield (GY, t/ha), Harvest Index (HI) and Shoot Nitrogen Content (SNC, g/kg) were measured. In screenhouse, soil from each location was filled into pots (5 kg) and each variety was planted under optimum management practices in a completely randomised design with three replications. Data on days to seedling emergence, days to first pod appearance and days to physiological maturity were obtained, fitted and used to calibrate CROPGRO-soya bean model. Data on weather parameters, soil description and characterisation (pH, field capacity, permanent wilting point, bulk density and hydraulic conductivity) were used for predicting phenology and yield. Data were analysed using ANOVA at $\alpha_{0.05}$, and model outputs were evaluated with percentage error (PE).

Nitrogen rate had no significant effect on SDW, while variety TGx1448-2E had significantly higher SDW (2.9±0.3) and GY (1.5±0.1) than TGx1485-1D (2.3±0.3 and 1.3±0.1, respectively) at both locations. Nitrogen rate had no significant effects on GY and HI at Gbonran. However, 15 kgN/ha produced a significantly highest GY (1.4±0.1) than the control (1.2±0.1), while HI at 5 kgN/ha (0.60±0.02) was highest at Ipapo. Variety TGx1485-1D had significantly higher HI (0.58±0.05) than TGx1448-2E (0.52±0.05) at both locations. Nitrogen rate had no significant effect on SNC at both locations. Variety TGx1485-1D had significantly higher SNC (33.0±1.5) than TGx1448-2E (26.0±1.5) at Ipapo. CROPGRO-Soya bean model predicted soya bean phenology across nitrogen rates within 0 – 1 day of the observed values at both locations. Predicted yield of TGx1485-1D was 1.5 t/ha across N rates with PE < 15%, while that of TGx1448-2E was 2.6 t/ha with PE > 30%.

Application of starter nitrogen had no effect on yields of soya bean at Gbonran but 15 kgN/ha enhanced grain yield of soya bean at Ipapo. Variety TGx1448-2E had better biomass yield, while TGx1485-1D had better nitrogen content on ferric luvisol. Prediction of CROPGRO-soya bean model was reliable for phenology and yield of TGx1485-1D but not reliable for yield of TGx1448-2E.

Keywords: Starter nitrogen rate, Soya bean grain yield, CROPGRO-soya bean model, Soya bean phenology.

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CERTIFICATION

We certify that this work was carried out by Mr. Olukayode Stephen OYATOKUN of the Department of Agronomy, University of Ibadan, Ibadan, Nigeria.

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DEDICATION

This work is dedicated to the Glory of God and to the fond memories of the following people:

1. My sweet parents, Late (Mr) R. O. Oyatokun and Late (Mrs) F. B. Oyatokun

and

2. My first supervisor, Late (Dr) J. A. Okogun

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CHAPTER ONE

INTRODUCTION

Nitrogen (N) is a major and the most limiting plant nutrient to crop production in Sub-Saharan Africa (SSA). The low N status of soils in the SSA is due to poor nutrient holding capacity occasioned by the inherent nature of the soils. The reasons for this are the dominance of kaolinitic clay type, as well as the climatic factors of very high torrential rainfall and high temperature regimes, which influence N availability. Despite its crop-limiting attribute to crop production in this region, N requirement for soya bean is usually met by a combination of soil-derived nitrogen and nitrogen provided through the process of symbiotic fixation from *Rhizobia* bacteria in root nodules (Sanginga *et al*., 2001). The relative nitrogen supply from these two sources can change widely depending on soil nitrogen supply and conditions for nodule development (Varco, 1999; Gan *et al*., 2003). Increase in human population, resulting in high demand for food, has necessitated the intensification of land use and continuous cropping with attendant soil fertility reduction, thereby, resulting in declining crop yields (Padwick, 1983).

Production of soya bean is taking a central place in the production of cereals and grain legumes in the moist savanna zone of Nigeria. This stems from the fact that it is fast becoming a major food as well as an industrial crop in Nigeria (Brader, 1998). The increase in area of cultivation and yield has been linked to farmers' adoption of newly bred soya bean varieties from the International Institute for Tropical Agriculture (IITA). These varieties store well and do not require expensive inputs such as high N supply needed by maize or pesticide spraying as required by cowpea to sustain production (IITA, 1993). The bulk of soya bean production in Nigeria occurs in the southern Guinea savanna agro-ecological zone, although production has extended to the northern Guinea savanna and rain forest agro-ecological zones (Okpara and Ibiam, 2000; Chiezey *et al*., 2001). In the Guinea savanna zone of Nigeria, adoption of soya bean has had a clear positive impact on household socio-economic status of rural communities by enhancing better nutritional status of children and income across gender (Sanginga *et al*., 1999). Intensive research following the growing importance of soya bean has also resulted in the development of improved varieties with increased resistance to diseases (Leleji and Adedzwa, 1983; Dashiell *et al*., 1987; IITA, 1992).

Worldwide, interest and attention in soya bean have mainly been due to its high nutritional value and seed protein content (Tiamigu and Idowu, 2001). Soya bean is widely distributed in most parts of the world; the crop has a lot of potential in Africa (Adamu and Amatobi, 2001; Steve and Jonathan, 2001). Soya bean had been successfully used to increase the protein content of traditional foods. New products such as flour, milk, baby food and many others had been developed and introduced. Some IITA-bred tropical soya bean varieties have also been released by National Agricultural Research and Extension Systems (NARES) of several West and Central African countries (Nigeria, Benin, Ghana, Democratic Republic of Congo, Togo), and Uganda (Research for Development Review, 2008). These varieties show considerable increases in grain and fodder yields, improving soil fertility in the savannas and enhancing the yields of subsequent crops such as maize and sorghum. Producing enough in the region and adding value can save millions spent on imports for other development activities. In spite of this great potential, soya bean production is still low in Nigeria owing to various limitations which result in low yield per unit area. Yield on farmers' fields in Nigeria is often lower than 1000 kg ha^{-1} compared to yields greater than 2500 kg ha^{-1} in the USA (Modali, 2004), 2869 kg ha^{-1} in Brazil and above 4000 kg ha^{-1} in Turkey (FAOSTAT, 2014). There is therefore the need to improve soya bean production in order to bridge the gap between production and domestic / industrial demand. Increasing soya bean production to meet this demand can best be achieved through an increase in yield per unit area, which can partly be achieved by the cultivation of high-yielding improved varieties and improved agronomic practices.

Application of nitrogen fertilizer to soya bean is not a common practice, but there is a speculation that the ability of soya bean to fix atmospheric N is not always adequate for maximum yield (Wesley *et al*., 1998; Okogun *et al*., 2005). Several studies evaluating the response of soya bean to N fertilizer application showed conflicting results that make it difficult to draw a general conclusion about soya bean response to N fertilizer. Applications were mainly during the growing season. Many studies have shown an increase in yield and associated dry matter accumulation as a result of nitrogen application to soya bean (Afza *et al*., 1987; Wood *et al*., 1993; Michael *et al*., 2001; Osborne and Riedell, 2006). These have been application of low rates of "starter N". Conversely, other research reports have indicated that soya bean grown on most soils does not respond to low rates (25 – 35 Kg N /ha) of pre-plant N fertilizer application (Hoeft *et al*., 2000; Heatherly *et al*., 2003).

There are a number of factors influencing N fixation by the crop and its response to applied nitrogen (Sanginga *et al.,* 2001). Factors like soil temperature, moisture and pH can affect soya bean response to applied nitrogen. On the other hand, nitrogen fixation begins 14 days after planting, only when plants are grown under optimum moisture and temperature conditions. Nitrogen applied before planting could be beneficial to soya bean for early growth, given that nodules would not be present until at least 9 days after soya bean emergence (Osborne and Riedell, 2006). A starter dose of fertilizer nitrogen could be used to stimulate early growth of leguminous crops and to induce the activity of nitrogen-fixing bacteria in most legumes (Jefing *et al*., 1992; Ali *et al*., 1998). There is therefore a dearth of information on the suitable starter N rate that would enhance soya bean growth and development to improve soil N status and grain yield in SSA. High N application to crops could be leached, leading to pollution of underground water or surface water, causing eutrophication and health hazards (Vanlauwe *et al*., 2001).

The variability in rainfall pattern especially rainfall distribution/amount is a critical factor influencing soil N availability and in essence the performance of crops, soya bean inclusive. This variability could be assessed with the aid of crop growth models. The Cropping System Model (CSM)-CROPGRO-Soya bean was developed to simulate vegetative and reproductive development, growth and yield of soya bean as a function of crop characteristics, weather, soil conditions and crop management options (Jones *et al*., 2003). This model is part of a suite of crop growth models that comprise the Decision Support System for Agrotechnology Transfer (DSSAT) (Hoogenboom *et al*., 2003). The model simulates the productivity of soya bean cultivars under various management and environmental conditions (Singh *et al*., 1994, Boote *et al*., 1998). CROPGRO – Soya bean model is a process-oriented model that can be used to study soya bean response to management (Egli and Bruening, 1992), environmental conditions (Curry *et al*., 1995) and genetic yield potential (Boote and Tollenaar, 1994). It has also been used to study causes of spatial yield variability (Allen *et al*., 1996; Paz *et al*., 1998).

Itesiwaju Local Government Area of Oyo State falls within the southern Guinea savanna agro-ecological zone of Nigeria, a humid savvana area where soya bean is extensively cultivated. The soils are derived from basement complex which is at an advanced weathering form and characterized by low cation exchange capacity. This low capacity has marked consequences for fertilizer application and soil fertility management due to its poor ability to supply nutrients to the plant and/or retain nutrients. This inherently low fertility is compounded by intensive cultivation of the soil leading to annual yield decline.

The enrichment of soil with nutrients, especially application of fertilizer nitrogen, is therefore required to ameliorate leaching losses resulting from high intensity of rainfall in this area. The sustenance of land productivity requires the availability of plant nutrients, principal among which is nitrogen. Information on adequate starter dose to enhance soya bean production is relatively scanty in sub Sahara Africa. Crop simulation models such as CROPGRO-soya bean are useful tools for optimizing fertilizer management in order to estimate soya bean yields under different N applications and have not been effectively utilised in soil fertility studies for soya bean production. There is therefore need to investigate the effect of starter N on soya bean yield in this area in order to sustain crop production.

This study thus sought to evaluate the influence of starter-dose of nitrogen on the performances of two soya bean varieties grown on ferric luvisols (Arenic and Plinthic Kanduistalf) in Oyo State, Nigeria. The objectives of this investigation were to:

1. determine the optimum N fertilizer rate that enhances growth and development in two soya bean varieties,
2. assess CROPGRO-Soya bean crop simulation model for the humid agroecological zone of Nigeria, and
3. validate the reliability of data measured and project soya bean yield under different N use regimes.

CHAPTER TWO

LITERATURE REVIEW

2.1 Nitrogen

Nitrogen is an essential building block of amino and nucleic acids, essential to life on earth. Elemental nitrogen in the atmosphere cannot be used directly by either plants or animals, and must be converted to a reduced (or 'fixed') state to be useful. Precipitation often contains substantial quantities of ammonium and nitrate, thought to result from nitrogen fixation by lightning and other atmospheric electric phenomena (Rakov and Uman, 2007). However, because ammonium is preferentially retained by the forest canopy relative to atmospheric nitrate, most fixed nitrogen reaches the soil surface under trees as nitrate. Specific bacteria (e.g. *Rhizobium trifolium*) possess nitrogenase enzymes that can fix atmospheric nitrogen into a form (ammonium ion) that is chemically useful to higher organisms. This process requires a large amount of energy and anaerobic conditions. Such bacteria may live freely in soil (e.g. *Azotobacter*), but they normally exist in a symbiotic relationship in root nodules of some leguminous plants (e.g. clover, cowpea, *Trifolium*, soya bean. Nitrogen-fixing bacteria are also symbiotic with a number of unrelated plant species such as alders (*Alnus*) spp., lichens, *Casuarina*, *Myrica*, liverworts and *Gunnera* (Bothe *et al*., 2007). They are also found in the rhizosphere of some grasses in the order *Andrpogonae* e.g. *Andropogon tectorum*, *A.savanus* etc.

As part of the symbiotic relationship, plant converts 'fixed' ammonium ion to nitrogen oxides and amino acids to form proteins and other molecules (e.g. alkaloids) and in return for the 'fixed' nitrogen; plant secretes sugars to the symbiotic bacteria (Bothe *et al*., 2007). Legumes maintain an anaerobic environment for their nitrogen-fixing bacteria which enable such plants to assimilate nitrogen directly in the form of nitrates that may be present in soil from natural mineral deposits, artificial fertilizers, animal waste, or organic decay. Nitrates absorbed in this fashion are converted to nitrites by the enzyme *nitrate* reductase, and then converted to ammonia by another enzyme called *nitrite* reductase (Bothe *et al.,* 2007).

Nitrogen compounds are basic building blocks in animal biology as well. Animals use nitrogen-containing amino acids from plant sources as starting materials for all nitrogen-compound animal biochemistry, including the manufacture of proteins and nucleic acids. Plant-feeding insects are dependent on nitrogen in their diet, such that varying the amount of nitrogen fertilizer applied to a plant can affect the reproduction rate of insects feeding on fertilized plants (Jahn *et al.*, 2005).

Of all mineral nutrients, nitrogen (N) is quantitatively the most important for plant growth. Nitrogen nutrition influences leaf growth, leaf area duration and carbohydrate source size (Wullschleger and Oosterhuis, 1990), the photosynthetic rate per unit leaf area and source activity (Lawlor *et al.,* 1989), as well as the number of vegetative and generative storage organs and sink capacity (Hageman and Below, 1990). Nitrogen deficiency may depress plant growth not only by reduced synthesis of enzyme proteins and membrane constituents, but also via an altered transport of water (Radin and Boyer, 1982; Chapin *et al.*, 1988) or phytohormones (Chapin *et al.*, 1988; Kniper, 1988) from roots. Nitrogen has also been reported as one of the most important nutrient elements affecting the yield of soya bean (Penas and Wiese, 1987). Nitrogen requirement for soya bean are typically met by a combination of soil-derived nitrogen and nitrogen provided through the process of symbiotic fixation from Rhizobia bacteria in root nodules. The relative nitrogen supply from these two sources can change widely depending on soil nitrogen supply and conditions for nodule development (Varco, 1999; Gan *et al.*, 2003).

Field studies measuring soya bean response to applied N have been conducted by several researchers (Hoeft *et al*., 2000; Scharf and Wiebold, 2003; Salvagiotti *et al*., 2008). Nitrogen fixation alone cannot meet the N requirement for maximizing soya bean yield. Best timing for N top-dressing during reproduction is at the flowering stage, which increased seed yield by 19 and 21%, compared to the treatment without N top dressing (Gan *et al*., 2003). Nitrogen increases yield by influencing a variety of agronomic and quality parameters. In general, there was an increase in plant height and dry matter accumulation per plant in soya bean (Manral and Saxena, 2003). Varon *et al*. (1984) reported an increase in plant height with the application of nitrogen fertilizer. Grain yield response of soya bean to nitrogen application may be because the nutrient plays an important role in the synthesis of chlorophyll and amino-acids which are indispensable ingredients of the process of autotrophization. Nitrogen influenced grain yield through source-sink relationships resulting in higher production of photosynthates and their increased translocation to reproductive parts (Tripathi *et al*., 1992).

2.2 The Nitrogen Cycle

Nitrogen is present in the environment in a wide variety of chemical forms including organic, ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), nitrous oxide (N_2O), nitric oxide (NO) or inorganic gas (N_2). Organic nitrogen may be in form of a living organism, humus or in the intermediate products of organic matter decomposition. The processes of the nitrogen cycle transforms nitrogen from one form to another. Many of those processes are carried out by microbes, either in their efforts to harvest energy or to accumulate nitrogen in a form needed for their growth. Figure 2.1 shows how these processes fit together to form the nitrogen cycle. Five main processes cycle nitrogen through the biosphere, atmosphere, and geosphere: nitrogen fixation, nitrogen uptake (assimilation), nitrogen mineralization (ammonification), nitrification, and denitrification. Microorganisms, particularly bacteria, play major roles in all of the principal nitrogen transformations. As microbially mediated processes, these nitrogen transformations tend to occur faster than geological processes like plate motion, a very slow, purely physical process that is a part of the carbon cycle. Instead, rates are affected by environmental factors that influence microbial activity, such as temperature, moisture, and resource availability.

2.2.1 Nitrogen fixation

Atmospheric nitrogen must be processed, or "fixed" to be used by plants. Some fixation occurs in lightening strikes, but most fixations are done by free-living or symbiotic bacteria. These bacteria have the nitrogenase enzyme that combines gaseous nitrogen with hydrogen to produce ammonia which is then further converted by the bacteria to make their own organic compounds. Most biological nitrogen fixation occurs by the activity of Mo-nitrogenase, found in a wide variety of bacteria and some Archeae. Mo-nitrogenase is a complex two component enzyme that has multiple metal-containing prosthetic groups (Moir, 2011). Some nitrogen fixing bacteria, such as *Rhizobium*, live in the root nodules of some legumes (such as peas or beans) where they form a mutualistic relationship with the plant, producing ammonia in exchange for carbohydrates. Nutrient-poor soils can be planted with such legumes to enrich them with nitrogen. A few other plants can form such symbiosis.

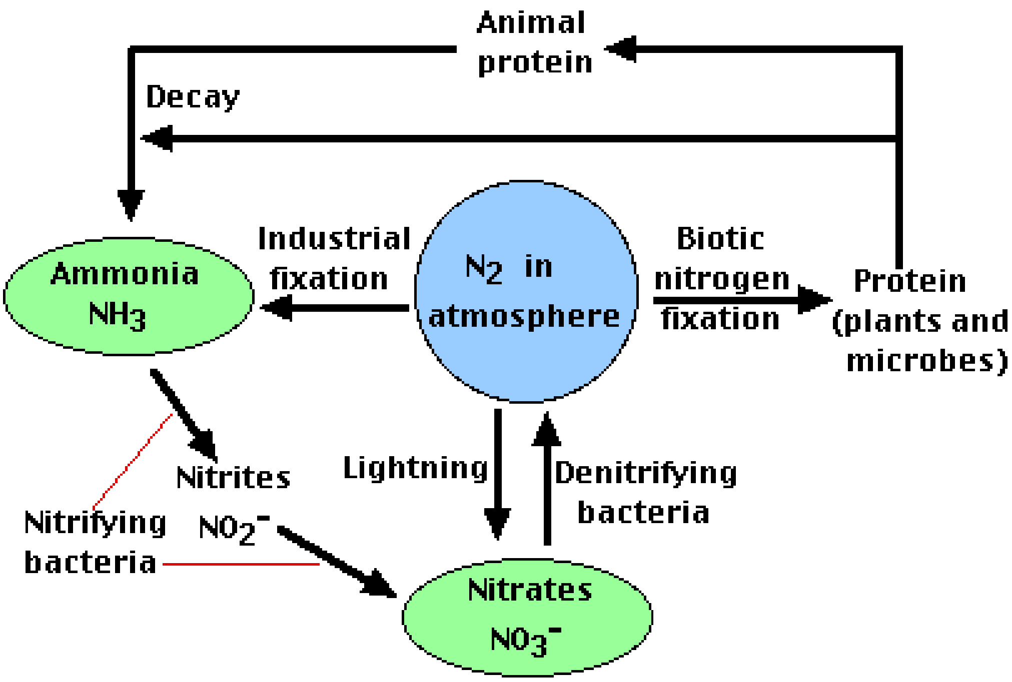

Figure 2.1: The Nitrogen Cycle

(Source: Moir, 2011)

2.2.2 Assimilation

Plants take nitrogen from the soil, by absorption through their roots in the form of either nitrate ions or ammonium ions. All nitrogen obtained by animals can be traced back to the eating of plants at different stages of the food chain. Plants can absorb nitrate or ammonium ions from the soil via their root hairs. If nitrate is absorbed, it is first reduced to nitrite ions and then ammonium ions for incorporation into amino acids, nucleic acids, and chlorophyll (Smil, 2000). In plants that have a symbiotic relationship with *rhizobia*, some nitrogen is assimilated in the form of ammonium ions directly from the nodules.

2.2.3 Ammonification

When a plant or animal dies, or an animal expels waste, the initial form of nitrogen is organic. Bacteria, or fungi in some cases, convert the organic nitrogen within the remains back into ammonium (NH_4^+), a process called ammonification or mineralization (Vance and Griffith, 1990).

2.2.4 Nitrification

The conversion of ammonium to nitrate is performed primarily by soil-living bacteria and other nitrifying bacteria. In the primary stage of nitrification, the oxidation of ammonium (NH_4^+) is performed by bacteria such as the *Nitrosomonas* species, which converts ammonia to nitrites (NO_2^-). Other bacterial species, such as the *Nitrobacter*, are responsible for the oxidation of the nitrites into nitrates (NO_3^-) (Smil, 2000). It is important for the ammonia to be converted to nitrates because accumulated nitrites are toxic to plant life. Due to their very high solubility, and because soils are largely unable to retain anions, nitrates can enter groundwater. Elevated nitrate in groundwater is a concern for drinking water use because nitrate can interfere with blood-oxygen levels in infants and cause *methemoglobinemia* or blue-baby syndrome (Vitousek *et al.*, 1997). In places where groundwater recharges stream flow, nitrate-enriched groundwater can contribute to eutrophication, a process that leads to high algal, especially blue-green algal populations. While not directly toxic to fish life, like ammonia, nitrate can have indirect effects on fish if it contributes to this eutrophication. Nitrogen has contributed to severe eutrophication problems in some water bodies. Since 2006, the application of nitrogen fertilizer has been increasingly controlled in Britain and the United States. This is occurring along the same lines as control of phosphorus fertilizer, restriction of which is normally considered essential to the recovery of eutrophied water bodies.

2.2.5 Denitrification

Denitrification is the reduction of nitrates back into the largely inert nitrogen gas (N_2), completing the nitrogen cycle. This process is performed by bacterial species such as *Pseudomonas* and *Clostridium* in anaerobic conditions (Smil, 2000). They use the nitrate as an electron acceptor in the place of oxygen during respiration. These facultatively anaerobic bacteria can also live in aerobic conditions.

2.3 Soya bean (*Glycine max* (L) Merril) Taxa

Kingdom:	Plantae
Order:	Fabales
Family:	Fabacea
Sub-family:	Papilionaceae
Genus:	*Glycine*
Species:	*max*
Normal:	*Glycine max* (L.) Merril

2.3.1 Origin and Classification

The word *glycine* is derived from the Greek - *glykys* (sweet) and likely refers to the sweetness of the pear-shaped (*apios* in Greek) edible tubers produced by the native North American twining or climbing herbaceous legume, *Glycine apios*, now known as *Apios americana* (Newell and Hymowitz, 1983). The cultivated soya bean first appeared in *Species Plantarum*, by Linnaeus, under the name *Phaseolus max* L. The combination *Glycine max* (L.) Merr. as proposed by Merrill in 1917, has become the valid name for this useful plant. The genus *Glycine* Wild is divided into two subgenera, *Glycine* and *Soja*. The subgenus *Soja* (Moench) F.J. Herm. includes the cultivated soya bean, *Glycine max* (L.) Merr., and the wild soya bean, *Glycine soja* Sieb. and Zucc. Both species are annuals. *Glycine soja* is the wild ancestor of *Glycine max*, and grows wild in China, Japan, Korea, Taiwan and Russia (Singh *et al*., 2006). The subgenus *Glycine* consists of at least 16 wild perennial species: for example, *Glycine canescens* F.J. Herm. and *G. tomentella* Hayata are both found in Australia and Papua New Guinea (Newell and Hymowitz, 1983; Hymowitz, 1995). Like some other crops of long domestication, the relationship of the modern soya bean to wild-growing species can no longer be traced with any degree of certainty. It is a cultural variety with a very large number of cultivars.

2.3.2 Description and Physical Characteristics of soya bean

Soya bean varies in growth and habit. The height of the plant varies from below 20 cm up to 2 meters. The pods, stems, and leaves are covered with fine brown or gray hairs. The leaves are trifoliolate, having three leaflets per leaf, and each leaflet is 6–15 cm long and 2–7 cm broad. The leaves fall before the seeds are mature. The inconspicuous, self-fertile flowers are borne in the axils of the leaves and are white, pink or purple. The flower is vexillary, which promotes self pollination. 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 (rarely more) seeds and 5 – 11 mm in diameter. Soya beans occur in various sizes, and in many hull or seed coat colors, including black, brown, blue, yellow, green and mottled (Singh *et al*., 2006). The hull of the mature bean is hard, water resistant, and protects the cotyledon and hypocotyls (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. Remarkably, seeds such as soya beans containing very high levels of protein can undergo desiccation, yet survive and revive after water absorption. Carl Leopold began studying this capability at the Boyce Thompson Institute for Plant Research at Cornell University in the mid 1980s. He found soya beans and corn to have a range of soluble carbohydrates protecting the seed's cell viability (Blackman *et al*., 1992).

The plant of the cultivated soya bean is an erect, bushy annual which if given space, branches profusely (Poehlman, 1987). Soya bean varieties have a tawny or gray-coloured pubescence on the stems, leaves and pods; the seed size varies from 5-55 g per 100 seeds; and the colour of the seed coat is generally yellow, but may be green, black, brown or variegated (Poehlman 1987; IITA, 1984). Like many other legumes, soya bean can symbiose with nodule bacteria (rhizobia) present in most soils. This attribute allows adequate yields in N-deficient soils where non-nodulated crop such as cereals fail.

Figure 2.2: Picture showing a cross section of young soya bean plants on a field

(Source: *http://www.picsearch.com/Soybean-pictures.html)*

2.3.3 Global Production of Soya bean

More than 216 million tons of soya beans were produced worldwide in 2007, of which 1.5 million were in Africa. Africa imports nearly as much soya bean as it produces. Africa exports about 20,000 tons annually. Nigeria is the largest producer of soya bean in sub-Saharan Africa (SSA), followed by South Africa. Low yields (<1 t/ha in tropical Africa) and a shortage of fertilizer constrain the ability of some countries to increase production. In Nigeria the haulms and post-processed pulp (soya bean meal) serve as important sources of animal feed. A 30% annual growth in the poultry industry from 2003 to 2008 fuelled such a demand for soya bean meal that an increase in imports was required. Commercial soya bean production on large farms takes place in Zambia, Zimbabwe and South Africa. However, it is mostly cultivated by small-scale farmers in other parts of Africa where it is planted as a minor food crop among sorghum, maize, or cassava. Nigeria is the largest producer of soya bean in Africa with the Southern Guinea savanna as the centre of production (Anon, 1992; Olufajo, 1992). Annual soya bean cultivation in Nigeria is estimated at 200,000 hectares with Benue State accounting for nearly 90 percent of the national total annual soya bean grain production and with Kaduna, Kwara, Niger States and Federal Capital Territory accounting for the remaining 10 percent (Abimbola, 1986; Root *et al*., 1987). Based on the area under soya bean cultivation and the average grain yield production of 400-1500 kg/ha at the farmgate (Ashaye *et al*., 1975; Woodworth *et al*., 1992), the annual soya bean grain production in Nigeria is estimated at 80,000-300,000 tonnes.

2.3.4 Soya bean Production in Nigeria

Soya bean (*Glucine max* (L.) Merril), a legume, occupies a premier position among grain legume crops because of its high and virtually unrivalled, protein content (40%) and the rich source of high quality edible oil (20%) which makes it a food crop with great potential to improve the diet of millions of people in developing counties (Carrao and Gontijo, 1994).

It is one of the most important oil seed crops in the world. The crop has gained popularity in Nigeria, outranking cowpea [*Vigna unguiculata* (L) Walp], because of its potential to supply high quality protein (Akande *et al*., 2007). In spite of its great potential, soya bean production is still on a small scale in Nigeria owing to various limitations which result in low yield per unit area. Grain yields of soya bean cultivars are generally low in Nigeria compared to other places in the world. Yield on growers' farms is often lower than 1000 $kgha^{-1}$ compared to yields greater than 2500 $kgha^{-1}$ in the USA (Modali, 2004), 2869 $kgha^{-1}$ in Brazil and greater than 4000 $kgha^{-1}$ in Turkey (FAOSTAT, 2014).

There is therefore a wide gap between what is currently being produced and what is needed. Increasing soya bean production to meet the required quantities can best be achieved through an increase in yield per unit area, which can partly be achieved by the cultivation of high-yielding improved varieties and improved agronomic practices. Consequently, new genotypes are being developed through breeding and selection (IITA, 1993). Over the past decades, IITA working with other several national research institutes in Nigeria have popularized soya bean production and consumption using acceptable recipes for the incorporation of soya bean into local dishes. In the Guinea savanna zone of Nigeria, adoption of soya bean has had a clear positive impact on household socio-economic status of rural communities by enhancing better nutritional status of children and income of both men and women (Sanginga *et al*., 1999). Because of the aforementioned importance of soya bean in the diet of man, intensive research into its improvement began, thus resulting in improved varieties with increased resistance to diseases (Leleji and Adedzwa, 1983; Dashiell *et al*., 1987; IITA, 1992). The bulk of soya bean production in Nigeria is in the southern Guinea savanna agro-ecology, though production has extended to the northern Guinea savanna and rain forest ecologies (Okpara and Ibiam, 2000; Chiezey *et al*., 2001).

2.3.5 Economic Importance of Soya bean

It is generally known that the seed of soya bean contains the highest and richest protein among all cultivated legumes (FAO, 1989; IITA, 1993). Worldwide interest and attention in soya bean is mainly due to its high nutritional value and seed protein content (Tiamigu and Idowu, 2001). Soya bean has a composition of protein content of over 40%, edible vegetable oil content of 20%, carbohydrates content of about 30%, a total sugar content of about 10% and an ash content of about 5% (IITA, 1993). Soya beans are the only legume from which a liquid can be extracted, "soya milk" (or "soya drink"), which is used to make tofu, among other purposes. Soya bean can also be pressed for oil and fermented and made into textured protein products.

Processed soya bean products (*miso, tamari, soy milk and tofu*) are especially consumed in Asian cultures. Soya granules are soya bean seeds whose outer husk has been removed before being milled. Soya bean sprouts are also ready to eat after germinating for a few days. They are used in the same way as mung bean sprouts. Soya flour is gluten-free (non-rising) flour. It contains 2-3 times more protein than wheat flour and 10 times more fat in the case of full-fat soy flour (which must be kept in the fridge). Soya bean contains more protein and calories than other legumes. Its proteins are of excellent quality and serve as an ideal complement to grain foods. The fats are 78% unsaturated, with no cholesterol, and contain lecithin. Soya bean is beneficial for the liver, mineralizing and energizing. It contains several potentially anti-cancerous compounds.

Economically the world's most important bean, soya bean provides vegetable protein for millions of people and ingredients for hundreds of chemical products, including paints, adhesives, fertilizers, insect sprays, and fire-extinguisher fluids. Soya beans contain no starch; hence, they are a good source of protein for diabetics (Adamu and Amatobi, 2001). The importance of soya bean is predicated on its high nutritional quality with respect to its protein and oils from the nutritional standpoint. It ranked high in the protein quality index pattern of amino acid (FAO, 1989). More than 90% of the soya bean oil produced is used in edible products such as margarine, salad and cooking oils. The remains are used industrially in paints, vanishes, linoleum, printing, ink, soap and rubber substitute (Metcalf and Elkins, 1980). Beside its importance as a source of protein for the formulation of low-cost nutritionally balanced food, soya bean is also widely used as a soil enriching crop because of its ability to fix N.

2.3.6 Soya bean Cultivation

Conditions necessary for soya bean production

Soya bean growth is influenced by climate and soil characteristics and it performs well in the southern and northern Guinea savannas of Nigeria where rainfall is more than 700 mm. However, short-duration varieties can thrive in the much drier Sudan savanna when sown early and with an even distribution of rainfall throughout the growing period (Dugje *et al*., 2009). The time for planting soya bean depends upon temperature and day length. Soya bean is a short-day plant and flowers in response to shortening days. It can be grown on a wide range of soils with pH ranging from 5.5 to 8.5. Soya bean should not be planted in sandy, gravelly, or shallow soils to avoid drought stress. It should not be grown in waterlogged soils or soils with surfaces that can crust, as this will lead to poor seedling emergence.

Land preparation

Land clearing precedes land preparation. The seedbed can be prepared manually with a hoe or animal-drawn implement or tractor. Well-prepared land ensures good germination and reduces weed infestation. Planting can be done on ridges or on a flat seedbed.

Choice of Variety

Some selected soya bean varieties grown in Nigeria are presented in Table 2.1 below. A variety that is suited to the agro-ecological zone is usually chosen. Soya bean variety selection should be based on maturity period, yield potential, lodging, drought tolerance, and resistance to pests and diseases (IITA, 1993). The maturity period should be the first consideration when choosing a variety. Earlier maturing varieties are considered rather than late maturing in areas with low rainfall. Although later maturity increases the yield potential, it is risky to grow late-maturing varieties in drier environments because of late-season drought.

Seed Cleaning and Preparation

High quality seeds of the selected variety should be used. Soya bean seeds easily lose their viability. It is common for soya bean, even when stored properly, not to germinate after 12 –15 months in storage. Therefore, seeds of not more than 12 months in storage should be planted to ensure good germination. Good seeds are sorted for planting to ensure that they are free from insects, disease infestation, and weed seeds. Planting of poor quality seeds will not produce a good yield.

Soya bean Germination Test

Soya bean seeds should be tested for germination before planting. The germination percentage should be 85% or more to obtain a good stand. In order to conduct a quick seed germination test, 400 seeds are randomly selected and sown, 100 seeds each in four wooden or plastic boxes or a prepared seedbed at a rate of one seed/hole at a distance of 10 cm between the seeds. Cloth- or paper-lined germination boxes or the seedbed are well soaked with water before sowing and provide water every morning and evening (Dugje *et al*., 2009). Seedling counting is done 5 days after sowing and completed within 10 days. A total count of 320 germinated seeds or more indicates a germination rate of 80% and above. When the percentage germination is 80% or less, the seed rate has to be increased accordingly to achieve 100% germination.

Table 2.1: Recommended soya bean varieties for Guinea savanna ecological zone in Nigeria

Variety	**Ecology**	**Characteristics**	***Sriga* control**
TGX 1448-2E	Southern and northern Guinea savannas	Medium maturing, high yield, low shattering, high oil content**,** excellent grain colour	Good
TGX 1835-10E	Guinea savanna	Early maturing, rust resistant, pustule resistant	Not known
TGX 1485-1D	Guinea savanna	Early maturing, pustule resistant, rust susceptible	Not known

(Source: Dugje *et al*., 2009).

Planting

Date of Planting

Soya bean produces well over a wide range of planting dates, if moisture is available. The recommended dates for planting soya bean in different ecological zones in Nigeria are presented in Table 2.2. When soya bean is planted too early, a prolonged dry spell after planting may result in permanent wilting of the crop, hence, there may be need for replanting (Dugje *et al*., 2009). Late planting, on the other hand, may expose the crop to attack by some late season pests and also deprive the crop of sufficient moisture if the rains stop early. Soya bean is best planted when the rains are well established.

Seed Rate

About 50–70 kg (20–28 standard *mudus*) are required to obtain a population of 444,444 plants/ha for soya bean varieties. Since soya bean seed size varies among varieties, it is essential to consider planting in terms of seeds/unit area. It is not uncommon to see sizes ranging from 12.6 to 18.9 g/100 seeds

Seed Dressing

Soya bean seeds are usually treated with fungicides, such as Captan, Apron Plus, or Thiram at the rate of 1 sachet/8 kg of seeds before planting for protection against soil-borne fungal diseases.

Plant Spacing and Sowing

Soya bean can be sown by hand, planter, or by drilling at the rate of 3 to 4 seeds/per hole and at a spacing of 75 cm between rows and 10 cm between stands. Alternatively, seeds are drilled at 50–75 cm between rows and 5 cm within rows. For the early maturing varieties, a spacing of 50 cm between rows and 5–10 cm within rows is recommended because they respond better to narrow spacing than the late-maturing varieties. Seeds are usually sown at between 2 and 5 cm depth. Deeper planting may result in loss of vigor or failure of seedlings to emerge.

2.3.7 Fertilizer recommendation for soya bean

A good fertilizer recommendation for soya bean production depends on a good soil test. Under normal conditions, soya bean as a nitrogen-fixing legume should provide itself with nitrogen through biological nitrogen fixation. Until nodulation occurs, the soya bean plant depends on soil nitrogen for growth.

Table 2.2: Recommended dates for planting soya bean in Nigeria.

Ecological zone	**Suggested time of planting**
Moist savannas/Southern Guinea savanna	Early June–early July
Northern Guinea savannah–Sudan savanna	Mid-June–early July
Sudan savanna	July, weeks 1–2

(Source: Dugje *et al*., 2009).

Phosphorus is often the most deficient nutrient; therefore, optimum phosphorous fertilizer should be applied for a good yield, usually at the rate of 30 kg P/ha in the form of single super phosphate fertilizer (3 × 50 kg bags) in addition to 2½ × 50 kg bags of compound fertilizer NPK 15:15:15 (Dugje, *et al*., 2009). Nitrogen and potassium fertilizers are needed only when there are obvious deficiencies. Fertilizer materials are incorporated into the soil at land preparation during harrowing and leveling of the field.

2.3.8 Soil Fertility Enhancement

Like most legumes, soya bean improves soil fertility and fixes nitrogen in the soil (Pueppke, 1986) for the succeeding maize. When grown in rotation with maize, it serves as a catch crop in controlling *Striga hermonthica*, a parasitic weed that attacks maize, by causing suicidal germination of *Striga* (Carsky *et al*., 2000).

2.3.9 Weeds and their Control

Perennial and most annual weeds are a problem in soya bean in its early growth stages. A properly timed weed control program can minimize the effects of weeds. Weed control in soya bean could be manual or chemical or both.

Manual Weed Control: First weeding should be carried out at 2 weeks after planting and the second at 5–6 weeks after planting. Weeding immediately after a rainfall should be avoided as this would lead to transplanting the weeds. Poor hoe weeding or delay in weeding could cause significant reductions in soya bean yields.

Chemical Weed Control: Herbicides, if used properly, are safe and effective in controlling weeds in soya bean. The choice of herbicide, however, depends on the predominant weed species and the availability of the herbicide. Herbicides are available for pre-emergence or post-emergence weed control in soya bean. If herbicide is applied at planting, one weeding may be required at 5–6 weeks after planting. Herbicides could be used as presented in Table 2.3.

2.3.10 Pests and Diseases

Insect pests and their control

Several different insects occur in soya bean fields but few are normally of any economic importance, and the species that cause damage are usually not abundant enough to warrant control measures. In the vegetative stage, the crop is very tolerant of caterpillars but

Table 2.3: Recommended herbicide rates for weed control in soya bean

Product	Product rate/ha (L)	Time of application	Remarks
Paraquat plus Pendimethalin (50EC)	3 L of Paraquat plus 3 L of Pendimethalin (250 ml of each/20-L sprayer)	Applied within 2 days of planting	Where grasses, e.g., *Rottboellia* are common
Paraquat plus Dual Gold	3 L of Paraquat plus 2 L of Dual Gold (= 250 ml of Paraquat plus 200 ml of Dual Gold in 15 L sprayer (= 1½ milk tins of Paraquat plus 3/4 milk tins of Dual Gold)	Applied within 2 days of planting	Controls most grasses and broadleaf weeds. Where sowing is done after 1 week of land preparation, application must be within 12 h after planting.
Paraquat plus Butachlor	3 L of Paraquat plus 4 L of Butachlor (= 250 ml of Paraquat plus 350 ml of Butachlor in 15-L sprayer) (= 1½ milk tins of Paraquat plus 2½ milk tins of Butachlor)	Applied within 2 days of planting	Controls most grasses and broadleaf weeds and sedges
Fusilade forte	1–1½ L (150 ml = 1 milk tin)/15-L Sprayer	Post-emergence Apply 21–28 days after sowing	For grass weed Control
Round-up or other Glyphosate Products	4 L (= 350 ml/15-L sprayer)	Pre-emergence (before land preparation)	Used under no-tillage system, applied at least 2 weeks before sowing also to control perennial weeds

(Source: Dugje *et al*., 2009).

very susceptible to silver-leaf whitefly attack. Soya bean becomes attractive to pod-sucking bugs that can seriously reduce seed quality from the onset of flowering. Insect pests can be controlled with a single spray of Cypermethrin + Dimethoate 10 EC at the rate of 100 ml in 15 L of water.

Diseases and their control

Soya bean diseases normally result in major yield losses in Nigeria. Some of these common diseases are caused by fungi, bacteria, and viruses.

These diseases can be controlled by one or more of the following:

1. Use of resistant varieties. This is the best option to control disease.
2. Preparation of a good seedbed. Avoid poorly drained or compacted soil.
3. Use of seeds treated with fungicides as mentioned earlier under 'seed dressing'.
4. Rotation of crops with maize to prevent the increase in inoculum levels in a field.
5. Application of a foliar fungicide is seldom warranted, except on high-value fields (e.g., seed production fields) or in years when the weather is especially favorable for disease development.

2.3.11 Harvesting Soya bean

Soya bean matures within 3–4 months after planting and requires timely harvesting to check excessive yield losses. At maturity, the pod is straw-colored. It is recommended that soya bean be harvested when about 85% of the pods have turned brown for a non-shattering variety but 80% for shattering varieties. Alternatively, the crop can be harvested when the seeds are at the hard-dough stage, when the seed moisture content is between 14 and 16%.

Newer varieties are resistant to shattering but losses in yield may occur from other causes if harvesting is delayed. Harvesting can be done with a cutlass, a hoe, or sickles. Mature plants are cut at the ground level, stack them loosely on tarpaulin and allow them to dry in the open for 2 weeks before threshing. Hand pulling as a means of harvesting is undesirable because this may remove the nutrient that the soya bean has added to the soil (Salisbury and Ross, 1986).

2.3.12 Postharvest Operations

Threshing Soya bean

Soya bean can be threshed manually or mechanically when the plants are properly dried. Manual threshing is mainly recommended for small-scale production. It involves piling soya bean plants on tarpaulin or putting dry soya bean pods in sacks and beating them with a stick. The material is then winnowed to remove the seeds from the debris. Mechanical threshers are used in large-scale production. Such threshers are equipped with blowers that separate the grains from the chaff.

Storage

Soya bean should be stored at a moisture content of 10 % or less. A soya bean seed is sufficiently dry when it cannot be dented with the teeth or fingernails. At harvest, the grains usually contain about 14 % moisture. High moisture content in stored soya bean encourages the development of various agents of deterioration, such as insects and microorganisms. Good storage management can greatly influence the storability of soya bean and subsequent germination when planted in the field. Soya bean seeds exposed to high temperatures during storage will deteriorate and hence, the seed viability will be reduced.

2.4 N-Fixation in Legumes

Biological N-fixation is recognized as fundamental process in some leguminous plants and for that reason, the association between legumes and their appropriate rhizobia has been the focus of intensive investigation (Robertson and Farden, 1980; Yates, 1980; Pueppke, 1986). Like many other legumes, soya bean can symbiose with indigenous nodule bacteria (rhizobia) present in most soils. The rhizobia possess the nitrogenase complex, an enzyme, capable of reducing atmospheric nitrogen into compounds assimilable by host plant. Effective cowpea-rhizobium symbioses has been reported to fix more than 150 kg//ha and supply 80-90 percent of the host plant N- requirement (Summerfied *et al*, 1977; Eaglesham *et al*, 1983). This attribute allows adequate yields in N-deficient soil where non-nodulated crops such as cereals fail. Maximizing N-fixation is an economic way to cope with the shortage of expensive nitrogenous fertilizers in the tropical countries.

Symbiotic N-fixation in legume root nodules is the result of complex biological and biochemical interaction between the host legume and the rhizobia endophyte. Nodules appear to be formed by two plant-specific patterns of infection of the host cell by the rhizobia. In some legumes, such as clovers, infection threads develop in the root hair and grow into the root cortex to initiate the nodule. Further dissemination of the rhizobia within the nodule may be entirely via infection threads or also partly by the host- cell division as in soya bean and cowpea (Pueppke, 1984). Alternatively, infection occurs without obvious infection thread formation in some legumes, such as peanut and lupine. Infection occurs usually in the axils of lateral roots, and the initial entry into host cells, rhizobia are spread by the host cell division. Little is known of the factors influencing this process. Availability of rhizobia to the host root is of a significant importance in infection initiation (Dazzo, 1980; Pueppke, 1984). This pattern is affected by the number of rhizobia in the soil, soil pH and calcium levels.

Rhizobia in the soil compete in nodule formation with those added by inoculation and may virtually prevent nodule formation by inoculum strain (Sanginga *et al*., 1997). In the presence of the host legume, soil rhizobia population usually increases rapidly. New methods of inoculation may also increase the competitiveness of the inoculum strains used (Nour, *et al*., 1994). Perhaps, host and rhizobium genomes may be modified to increase the host specificity in nodule formation, the rhizobium strain selected must also be generally stable in the soil and be able to persist there in sufficient high numbers (Sinclair and Eaglesham, 1984). The effectiveness of a nodule in N-fixation and the extent of a nodulation are determined by the compatibility of the host and rhizobium strain. For soya bean, nodule number and the specific activity of the nodule nitrogenase are root-determined while the shoots influence nodule tissue production and total nitrogenase activity per plant (Bothe *et al*., 2007).

2.5 Nitrogen Application in Legumes

Subhan (1991) studied the effect of sowing time and method of nitrogen fertilizer application on peas. He stated that a single application at sowing or split application, which included one at sowing time, increased the total number of pods per plant. Shah *et al* (2002) also found that N applied through broadcast method either in single or split doses gave statistically similar grain yield in mungbean. Amjad *et al.* (2004) stated that seed yield and 1000 seed weight were significantly increased with increased level of P_2O_5 and K_2O applications up to the dose of 69 and 100 kg ha^{-1}, respectively. Although, significant positive response of nitrogen fertilizer on the growth, yield and yield components of other legume crops has been thoroughly studied by many researchers (Ashraf *et al.*, 2003; Achakzai *et al.*, 2002a, b; Mahboob and Asghar, 2002; Toğay *et al.*, 2005), very little is known about the influence of nitrogen on the yield and yield attributes of pea (*Pisum sativum* L.) under field conditions. However, maximum number of fresh pods per plant (33.10), pod length

(8.49 cm), pod yield plant^{-1} (188.43 g) and total marketable green pod yield ha^{-1} (5.01 tons) were recorded in plots which received 75+120+120 or 75+120+0 kg NPK ha^{-1}, respectively (Kakar *et al.,* 2002), while no advantage was observed in pea plant stand on seed yield, or seed quality resulted from application of N and P fertilizers (Carr *et al.,* 2000) and K_2O combined with P_2O_5 (Silva *et al.*, 1984).

Several other researchers also revealed that combined application of NPK fertilizers have marked and significant effect on growth, yield and yield attributes of most of the crops than individual application of each nutrient. Prasad *et al.* (1989), Brovkin and Bulato (1990) and Pochauri *et al.* (1991) reported that combined application of NPK fertilizers gave significantly positive results of peas yield. The plant yield is a dependent variable, depends upon all other growth and yield contributing traits. Therefore, it is generally correlated with all other components of yield. A highly significant and positive correlation ($P<0.01$) were found between fresh pod yield per plant, number of pods per plant and average pod weight, length and width of eight local cowpea genotypes (Peksen, 2004). Vahdettin *et al.* (2004) also recorded positive and significant relationships ($P<0.05$) among seed yield, biological yield, harvest index, number of pods per plant and number of seeds per plant, but negative and non-significant relationship was determined between seed yield and seed weight. Many other researchers also noted significant and positive correlation among seed yield of other legume crops with most of their growth and yield contributing parameters (Khan *et al*., 1983; Khan *et al*., 2000a, b; Achakzai and Kayani, 2004).

2.6 Nitrogen Application in Soya bean

Nitrogen fertilization of soya bean is not a common practice, although, there is speculation that the ability of soya bean to fix atmospheric N is not always adequate for maximum yield (Wesley, 1998; Okogun *et al*., 2005). Many researchers have investigated the effect of nitrogen fertilizer on soya bean yield and quality; there are a number of factors influencing soya bean nitrogen fixation and the response to applied nitrogen. Factors such as soil temperature, moisture and pH affect soya bean response to applied nitrogen (Sanginga *et al*., 2001). On the other hand, nitrogen fixation begins 14 days after planting only when plants were grown under optimum moisture and temperature conditions, thus a small amount of nitrogen at planting could be beneficial to early growth (Jefing *et al.,* 1992). Therefore, nitrogen applied before planting could be beneficial to soya bean, given that nodules were not present until at least 9 days after soya bean emergence (Osborne and Riedell, 2006).

Broadcast nitrogen (50 kg ha^{-1}) applied at planting increased seed yield of determinate and indeterminate stem-termination type of soya bean by at least 8% (Starling *et al*., 1998).

Greenhouse studies have also shown an increase in early soya bean plant growth as a result of applied nitrogen (Eaglesham *et al*., 1983). However, results from field studies on the effect of nitrogen fertilizer on soya bean yield have been mixed. Over the years, numerous studies have been conducted to examine the application of N to soya bean. Many studies have shown an increase in yield and associated dry matter accumulation as a result of nitrogen application to soya bean (Afza *et al*., 1987; Wood *et al*., 1993; Michael *et al*., 2001; Osborne and Riedell, 2006). In most cases, these have been application of low rates of "starter N". However, soya bean grown on most soils does not respond to low rates (25 – 35 Kg N /ha) of pre-plant N fertilization (Hoeft *et al*., 2000; Heatherly *et al*., 2003). Soya bean response to N fertilization has been evaluated extensively (Salvagiotti *et al*., 2008). In an effort to improve soya bean grain yield with N fertilizer application, two general timings of N application have been studied. One is N application at reproductive stages. Reports have indicated that nitrogen-fixing capacity begins to decline after the beginning of seed (R5) growth stage (Fehr and Caviness, 1977), which also coincides with the time of peak N demand (Shibles, 1998).

Studies with N applied during reproductive stages have generated inconsistent results. Nitrogen applied at the beginning of pod to full pod stages was suggested to significantly increase grain yield with high-yield-potential irrigated soya bean (Gascho, 1993; Wesley *et al*., 1998). However, other rain-fed studies have shown no significant effect on grain yield from fertilizer N applied at those growth stages (Freeborn *et al*., 2001; Schmitt *et al*., 2001; Gutiérrez-Boem *et al*., 2004). Barker and Sawyer (2005) evaluated the effect of in-season (R3) N application to soya bean in Iowa, USA and showed that soya bean grain yield was not affected by fertilizer N application. However, plant N concentration and plant dry matter were increased.

The other potential times for N application to soya bean are either pre-plant or during early vegetative growth. Soya bean yield increases have also been inconsistent with N application at those times (Oplinger and Bundy, 1998; Randall and Schmitt, 1998). Measured yield response has varied with location, soil type, inorganic soil N level, soya bean variety, growing season, and disease presence. Generally, opinions have suggested that soya bean yield response has not been of sufficient magnitude or consistency for early-season N application to be economical. Early-season N application can also result in temporary suppression of nodule formation due to increased nitrate in the soil (Hungria *et al*., 2005).

Conversely, early-season N deficiency due to inadequate soil inorganic N or symbiotic fixation can delay crop growth and the development of an efficient nodulation system.

2.7 Starter N application to Soya bean

The use of starter fertilizer is not a routine practice for many soya bean producers. While the limited use of starter fertilizer in soya bean may be due, in part, to equipment limitation, it is instead most likely the result of mixed yield responses realized by the practice and the high sensitivity of soya bean germination when placing fertilizers in the seed furrow. Starter fertilizer is typically a relatively small amount of plant nutrients placed near the seed during the planting operation. Actual placement can vary, including in the furrow, or below and to the side of the seed. The objective is to place a concentrated band of plant nutrients in an area where young roots can easily reach them and promote early seedling development.

Bergersen (1958) concluded that N fertilization before planting gave plants a better start, considering nodules were not present until nine days after planting. Sij *et al*. (1979) postulated that a small amount of N applied at planting ("starter N") would stimulate early vegetative growth. However, research conducted in Texas concluded that N applied at planting had no effect on leaf area, plant height, shoot fresh weight or yield (Sij *et al*., 1979). Studies conducted in Alabama found that broadcast N increased early soya bean vegetative growth by 20%, but had no subsequent effect on yield (Terman, 1977). A similar work by Starling *et al*. (1998) in southern Alabama showed that soya bean growth and grain yield were higher when fertilizer N was applied as starter.

Field research in South Dakota found that N broadcast on the soil surface at planting or at soya bean emergence increased yield, while N applied at mid pod fill did not increase yield (Bly *et al*., 1998; Riedell *et al*., 1998). Additional works in the northern Great Plains found that low rates (15 kg N ha) of starter N increased soya bean yield compared with no N applied at planting in 9 out of 11 years (Pikul *et al*., 2001). In a similar work, 16 kg/ha rate gave an increase of 6% in yield over a 3-year period (Osborne and Riedell, 2006). They concluded that additional research is needed to be conducted to investigate the reason for the increase in yield.

A similar study in Iran recommended 32 kg N/ha as the starter dose (Valinejad *et al.*, 2013). In Brazil, a study by Mendes *et al*. (2003) revealed that it is not necessary to apply starter N rates on soya bean. In China, 10 kg/ha starter N is the recommendation for soya bean farmers (Ecological Agriculture Project, 2002). A recommended N rate for soya bean production in Nigeria is 20 kg/ha (Dugje *et al*., 2009).

2.8 Contribution of Soya bean N to Subsequent Crop

Numerous reports have been published on rotating corn and soya bean and its use as a management tool to increase crop yield (Crookston *et al.*, 1991; Messe *et al*., 1991; Pederson and Lauer, 2002). Such studies have also shown that N fertilizer requirement for economically optimum yields are less for maize following soya bean than for maize following maize (Heichel and Barnes, 1984; Peterson and Varvel, 1988). Also, Kinloch (1983) found that yields of soya bean varieties both resistant and susceptible to southern root knot nematodes were increased when grown in rotation with corn, however, yields of susceptible varieties declined with reduced length of rotation. Bundy *et al* (1993) showed that maize following soya bean produced a higher yield and had greater plant N accumulation on silt loam soils, but not on irrigated sands.

Agronomic work conducted in the Guinea savanna zones of Nigeria showed that the yield of maize improves in a rotation system with soya bean (Kaleem, 1993; Carsky *et al*., 1997). Sanaratne and Hardason (1988) reported that the N benefit to subsequent crops after grain legumes was due to a lower uptake of soil N by legumes relative to cereals, and a carry-over of N from the legume residue, both leading to a greater uptake of residual soil N by the subsequent crop compared to crops grown after non-legumes. Many factors have been hypothesized to influence the increase of maize grain yield when grown in rotation with soya bean. These include enhanced N availability following soya bean and other rotation effect such as the reduction of the diseases. For example, Carsky *et al*. (2000) reported reduced *Striga hermonthica* parasitism on maize after soya bean compared with a sorghum control.

2.9 Model: Definition and Concept

Agricultural production is primarily dependent on crop variety, soil, weather and management practices. Crop weather models are useful in quantifying response of specific production factor simply or in combinations on crop growth and development (Huda, 1988).
A model is a schematic representation of the conception of a system or an act of mimicry or a set of equations, which represents the behaviour of a system. Its purpose is usually to aid in explaining, understanding or improving performance of a system. A model is, by definition "a simplified version of a part of reality, not a one to one copy". This simplification makes models useful because it offers a comprehensive description of a problem situation, however, the simplification is, at the same time, the greatest drawback of the process. It is a difficult task to produce a comprehensible, operational representation of a part of reality, which grasps

the essential elements and mechanisms of that real world system and even more demanding, when the complex systems encountered in environmental management (Murthy, 2002).

A crop model can therefore be defined as a quantitative means of predicting the growth, development and the yield of a crop, given a set of genetic coefficients and relevant environmental variables (Monteith, 1996). Model algorithms express the relationship between plant processes, including phenological development, photosynthesis, respiration, plant water uptake, biomass growth and partitioning and environmental variables such as daily temperature, photoperiod and soil water availability. It also incorporates knowledge of cultivar-specific trait to predict daily growth and development as the plant responds to weather, soil characteristics and management practices (Boote *et al.*, 1998).

Crop growth models allow evaluation of one or more options that are available with respect to one or more agronomic management decisions like the determination of optimum planting date, determine best choice of cultivars and the evaluation of weather risk and investment decisions (Bouman et al.1996). In agro-meteorological research, crop models basically help in testing scientific hypothesis, highlight where information is missing, organize data and integrate across disciplines. They can be used to predict crop performance in regions where the crop has not been grown before or not grown under optimal conditions. Such applications are of value for regional development and agricultural planning in developing countries (Kiniry and Bockholt, 1998). It can be developed at various levels of complexity. The level of complexity required depends on the objective of the modeling exercise.

Although the crop simulation models can synthesize information quickly and inexpensively, the reliability/consistency of the model is based on the degree to which the model accurately reflects the natural process. More significantly, even in the presence of such data these models can be very difficult to calibrate because of a large numbers of uncertain parameters. Often this parameter uncertainty is ignored and a subjective decision is made to proceed with a single set of parameter values that produces acceptable agreement with observations. When uncertainties in parameter values are explicitly considered, however, the uncertainty estimates for model projections can widen substantially.

Among the numerous crop growth models, the most widely used models are the Decision Support for Agro-technology Transfer (DSSAT), Agricultural Production System Simulator (APSIM) and Aqua crop models. CSMs (APSIM and DSSAT) play important roles as decision support systems in crop growth, development and yield as a function of complex interaction of soil, plant and atmosphere.

2.9.1 Weather Data for Modeling

The national meteorological organizations provide weather data for crop modeling purposes through observatories across the globe (Sivakumar *et al*., 2000). In many European countries, weather records are available for over 50 years. In crop modeling, the use of meteorological data has assumed a paramount importance. There is a need for high precision and accuracy of the data. The data obtained from surface observatories has proved to be excellent. It gained the confidence of the people across the globe for decades. These data are being used daily by people from all walks of life. But, the automated stations are yet to gain popularity in the under-developed and developing countries. There is a huge gap between the old time surface observatories and present generation of automated stations with reference to measurement of rainfall. The principles involved in the construction and working of different sensors for measuring rainfall are not commonly followed in automated stations across the globe. As of now, solar radiation, temperature and precipitation are used as inputs in DSSAT.

2.9.2 Weather as an Input in Models

In crop modeling, weather is used as an input. The available data ranges from one second to one month at different sites where crop-modeling work in the world is going on. Different curve fitting techniques, interpolation, extrapolation functions etc., are being followed to use weather data in the model operation. Agro-meteorological variables are especially subject to variations in space. It is reported that, as of now, anything beyond daily data proved unworthy as they are either over-estimating or under-estimating the yield in simulation. Stochastic weather models can be used as random number generators whose input resembles the weather data to which they have been fit. These models are convenient and computationally fast, and are useful in a number of applications where the observed climate record is inadequate with respect to length, completeness, or spatial coverage. These applications include simulation of crop growth, development and impacts of climate change.

The present generations of crop simulation models, particularly DSSAT suite of models, have proved their superiority over analytical, statistical, empirical, combination of two or all etc., models so far available. In the earliest crop simulation models, only photosynthesis and carbon balance were simulated. Other processes such as vegetative and reproductive development, plant water balance, micronutrients, pest and disease, etc., are not accounted for as the statistical models use correlative approach and make large area yield prediction and only final yield data are correlated with the regional mean weather variables.

2.9.3 Role of Weather in Decision Making

Decisions based solely upon mean climatic data are likely to be of limited use for at least two reasons. The first is concerned with definition of success and the second with averaging and time scale. In planning and analyzing agricultural systems, it is essential not only to consider variability, but also to think of it in terms directly relevant to components of the system. Such analyses may be relatively straightforward probabilistic analyses of particular events, such as the start of cropping seasons in West Africa and India. The principal effects of weather on crop growth and development are well understood and are predictable. Crop simulation models can predict responses to large variations in weather. At every point of application, weather data are the most important input. The main goal of most applications of crop models is to predict commercial out-put (grain yield, fruits, root, biomass for fodder etc.). In general the management applications of crop simulation models can be defined as:

i) strategic applications (crop models are run prior to planting);

ii) practical applications (crop models are run prior to and during crop growth); and

iii) forecasting applications (models are run to predict yield both prior to and during crop growth).

2.9.4 Purposes of Use of Models

Crop models have been widely used over the years by many researchers for different applications. Many of these applications have been done to study management options at study sites including fertilizer application, irrigation, pest management and site-specific farming. These applications have been conducted by agricultural researchers from different disciplines, frequently working in teams to integrate cropping systems analysis using models with field agronomic research and socio-economic information to answer complex questions about production, economics, and the environment. An important aspect of many of these studies is a consideration that weather influences the performance of crops, interacting in complex ways with soil and management. Researchers have thus applied these models for, but not limited to, the following purposes:

1. To understand and interpret experimental results.
2. To enhance quality of field research and the result that is derived from it.
3. To diagnose yield gaps by looking at the differences between potential, attainable and actual yield from on-station and on-farm research, and to help develop technologies to test these under field conditions.

4. To estimate impact on production, water use, nitrogen use, and other inputs and determine various resource use efficiencies at scales from field to farm to watershed to region and higher.
5. To estimate the impact of climate change and climatic variability on crop production and develop adaptation scenarios.

2.9.5 IBSNAT and DSSAT Models

In many countries of the world, agriculture is the primary economic activity. Great numbers of the people depend on agriculture for their livelihood or to meet their daily needs, such as food. There is a continuous pressure to improve agricultural production due to staggering increase in human population. Agriculture is very much influenced by the prevailing weather and climate. The goal of the International Benchmark Site Network for Agrotechnology Transfer (IBSNAT) project is to accelerate flow of technology and increase success rate of technology transfer from agricultural research centers to farmers' fields. In order to achieve this, IBSNAT developed a computer software, which helps match crop requirements to land characteristics using crop simulation models, database and strategy evaluation programs. The resulting system is called "Decision Support System for Agrotechnology Transfer" (DSSAT) (IBSNAT, 1998). This demands a systematic appraisal of climatic and soil resources to forecast an effective land use plan. More than ever, farmers across the globe want access to options such as the management options or new commercial crops. Often, the goal is to obtain higher yields from the crops that they have been growing for a long time. The DSSAT products enable users to match the biological requirements of crops to the physical characteristics of land to provide them with management options for improved land use planning. The DSSAT is being used as a business tool to enhance profitability and to improve input marketing.

The traditional experimentation is time consuming and costly. So, systems analysis and simulation have an important role to play in fostering this understanding of options. DSSAT has the potential to reduce substantially the time and cost of field experimentation necessary for adequate evaluation of new cultivars and new management systems. Several crop growth and yield models built on a framework similar in structure were developed as part of DSSAT package. The package consists of:

a) Data base management system for soil, weather, genetic coefficients, and management inputs

b) Crop simulation models

c) Series of utility programs

d) Series of weather generation programs

e) Strategy evaluation program to evaluate options including choice of variety, planting date, plant population density, row spacing, soil type, irrigation, fertilizer application, initial conditions on yields, water stress in the vegetative or reproductive stages of development, and net returns (IBSNAT, 1998; Hoogenboom *et al.*, 2003).

The Decision Support System for Agrotechnology Transfer (DSSAT) is a suite of crop models integrated into a single software package in order to facilitate the application of crop simulation in research and decision-making. These models share a common input and output file format. The DSSAT-CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The DSSAT-CSM is structured using the modular approach described by Jones *et al.* (2001) and Porter *et al.* (2000). The DSSAT-CSM has a main driver program, a land unit module, and modules for the primary components that make up a land unit in a cropping system. The primary modules are for weather, soil, plant, soil-plant-atmosphere interface, and management components. Collectively, these components describe the time changes in the soil and plants that occur on a single land unit in response to weather and management. In contrast to earlier versions of DSSAT and its crop models, the DSSAT-CSM incorporates models of all crops within one set of code allowing all crops to utilize the same soil model components. This design feature greatly simplifies the simulation of crop rotations since soil processes operate continuously, and different crops are planted, managed, and harvested according to cropping system information provided as inputs to the model. Each module has six operational steps (run initialization, season initialization, rate calculations, integration, daily output, and summary output). The main program controls when each of these steps is active, and when each module performs the task that is called for. This feature, an adaptation of van Kraalingen's (1995) work, allows each module to read its own inputs, initialize itself, compute rates, integrate its own state variables, and write outputs completely independent from the operation of other modules. Only a few interface-variables are communicated to and from each module. This allows one to 'unplug' a module and replace it with a different one as long as it communicates the same variables to the rest of the modules, even if the parameters, state variables, and module input files are different. State variables are written after integration to represent the state of the system at the end of the day, and initial values are written during initialization for day 0. More details of this modular design can be found in Porter *et al*. (2000).

Different types of applications are accomplished in DSSAT-CSM by using different modes to call the land unit module on a daily basis; the mode is specified as a command line argument when the model is run. The basic mode provides for interactive sensitivity analysis and comparison of simulated versus observed field data. A second mode of operation simulates crops over a number of years of weather using the same soil initial conditions. This mode allows one to evaluate the effects of uncertain future weather conditions on decisions made when all soil initial conditions are known. A third mode operates the cropping system modules to simulate crop rotations over a number of years, and soil conditions are initialized only at the very start of the simulation. A fourth mode operates the CSM to simulate one or more crops over space (i.e. for precision agriculture, land use management or other spatial-based applications). One can also completely replace the main driver for other applications, thereby providing a highly flexible approach for development of additional applications and user interfaces without having to modify code for any other module. The application driver communicates with only one module – which is the Land Unit Module. The land unit module provides the interface between the application driver (main program) and all of the components that interact in a uniform area of land.

2.9.6 CROPGRO – Soya bean model

The CROPGRO is one of the crop simulation models that is included in the DSSAT (Tsuji *et al*., 1994; Hoogenboom *et al*., 1999; Jones *et al*., 2001) and has been used in many applications around the world (Tsuji *et al*., 1994; Boote *et al*., 1998). The model is physiologically based and simulates the productivity of soya bean cultivars under various management and environmental conditions (Singh *et al*., 1994, Boote *et al*., 1998). CROPGRO – Soya bean model is a process-oriented model that can be used to study soya bean response to management (Egli and Bruening, 1992), environmental conditions (Curry *et al*., 1995) and genetic yield potential (Boote and Tollenaar, 1994). It has also been used to study causes of spatial yield variability (Allen *et al*., 1996; Paz *et al*., 1998). The CROPGRO-Soya bean model requires inputs of management practices and environmental conditions, and incorporates knowledge of cultivar specific traits (genetic coefficients) to predict growth and development as the plant responds to weather, soil characteristics and management practices (Boote *et al*., 1998; Paz *et al*., 1998). The CROPGRO-Soya bean model is generic and has a species and a cultivar data file. The species file describes the species characteristics such as tissue composition and partitioning traits, and include sensitivity of processes to temperature, light, plant water deficit and plant N deficiency. The cultivar data file includes information on life cycle phases, vegetative traits, leaf traits, potential seed fill duration, seed size and seed composition (Jones, 1993; Hoogenboom *et al*., 1994; Boote *et al*., 1998).

2.9.7 Soil water sub module

The soil water balance model developed for CERES-Wheat by Ritchie and Otter (1985) was adapted for use by all of the DSSAT v3.5 crop models (Jones and Ritchie, 1991; Jones, 1993; Ritchie, 1998). This one-dimensional model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and irrigation, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes. In the new DSSAT-CSM, soil evaporation, plant transpiration, and root water uptake processes were separated out into a soil-plant-atmosphere module (SPAM) to create more flexibility for expanding and maintaining the model. Otherwise, the water balance model in DSSAT-CSM is the same as in DSSAT v3.5 individual crop models, and individual processes are modeled using the same logic and equations. The soil has parameters that describe its surface conditions and layer-by-layer soil water holding and conductivity characteristics. The model uses a ‘tipping bucket’ approach for computing soil water drainage when a layer’s water content is above a drained upper limit parameter. Upward unsaturated flow is also computed using a conservative estimate of the soil water diffusivity and differences in volumetric soil water content of adjacent layers (Ritchie, 1998). Soil water infiltration during a day is computed by subtracting surface runoff from rainfall that occurs on that day.

The SCS method (Soil Conservations Service, 1972) is used to partition rainfall into runoff and infiltration, based on a ‘curve number’ that attempts to account for texture, slope, and tillage. The modification to this method that was developed by Williams *et al*. (1984) is used in the model; it accounts for layered soils and soil water content at the time when rainfall occurs. When irrigation is applied, the amount applied is added to the amount of rainfall for the day to compute infiltration and runoff. Drainage of liquid water through the profile is first calculated based on an overall soil drainage parameter assumed to be constant with depth. The amount of water passing through any layer is then compared with the saturated hydraulic conductivity of that layer, if this parameter is provided. If the saturated hydraulic conductivity of any layer is less than computed vertical drainage through that layer, actual drainage is limited to the conductivity value, and water accumulates above that layer. This feature allows the model to simulate poorly drained soils and perched water tables. For example, a soil may have a layer with very low or no drainage at the bottom of the profile. Vertical drainage from the profile would not occur or it would be very low, limited by the saturated hydraulic conductivity value of the bottom layer. Evaporation of water from the soil surface and root water uptake (transpiration) from each layer are computed in the SPAM and communicated to this soil water balance module. Each day, the soil water content of each layer is updated by adding or subtracting daily flows of water to or from the layer due to each process.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Location

Field trials were carried out at two locations namely: Ipapo (Latitude 8° 08' N; Longitude 03° 30' E; 353 m asl) and Gbonran (Latitude 8° 06' N; Longitude 03° 30' E; 379 m asl) both situated in Itesiwaju Local Government Area of Oyo State (Figure 3.1) in the Southern Guinea Savanna agro-ecology of Nigeria.

Based on the history of the lands, the land-use was arable farming, where maize and cassava were the major crops, while natural fallow was the means of land regeneration. The fields at both locations were never planted to soya bean or any legume in the past 55 years of land use for agricultural activities (Personal communication). However, nomads usually graze their cattle on the fields during fallow periods.

3.2 Soil Profile Description

Profile pits of 1m x 1m x 2m depth were dug and soil sampled according to the generic horizons interval for the two locations (Ipapo and Gbonran), described and classified (Appendix V). The soil profiles were described according to FAO guidelines (2006). The soil characteristics and morphological properties were described for each of the identified horizons in the profiles. Soil colour was evaluated using Munsell Soil Colour Charts and texture determined on the field by the hand-feel method at moist state. Structure, concretions, roots and boundary forms were also described using visual assessment. The soil consistence was determined at dry, moist and wet states on the field. Replicate soil core samples for bulk density determination were taken from each of the horizons of the soil profiles using Anderson and Ingram (1993) method. Replicate core samples were also taken for the

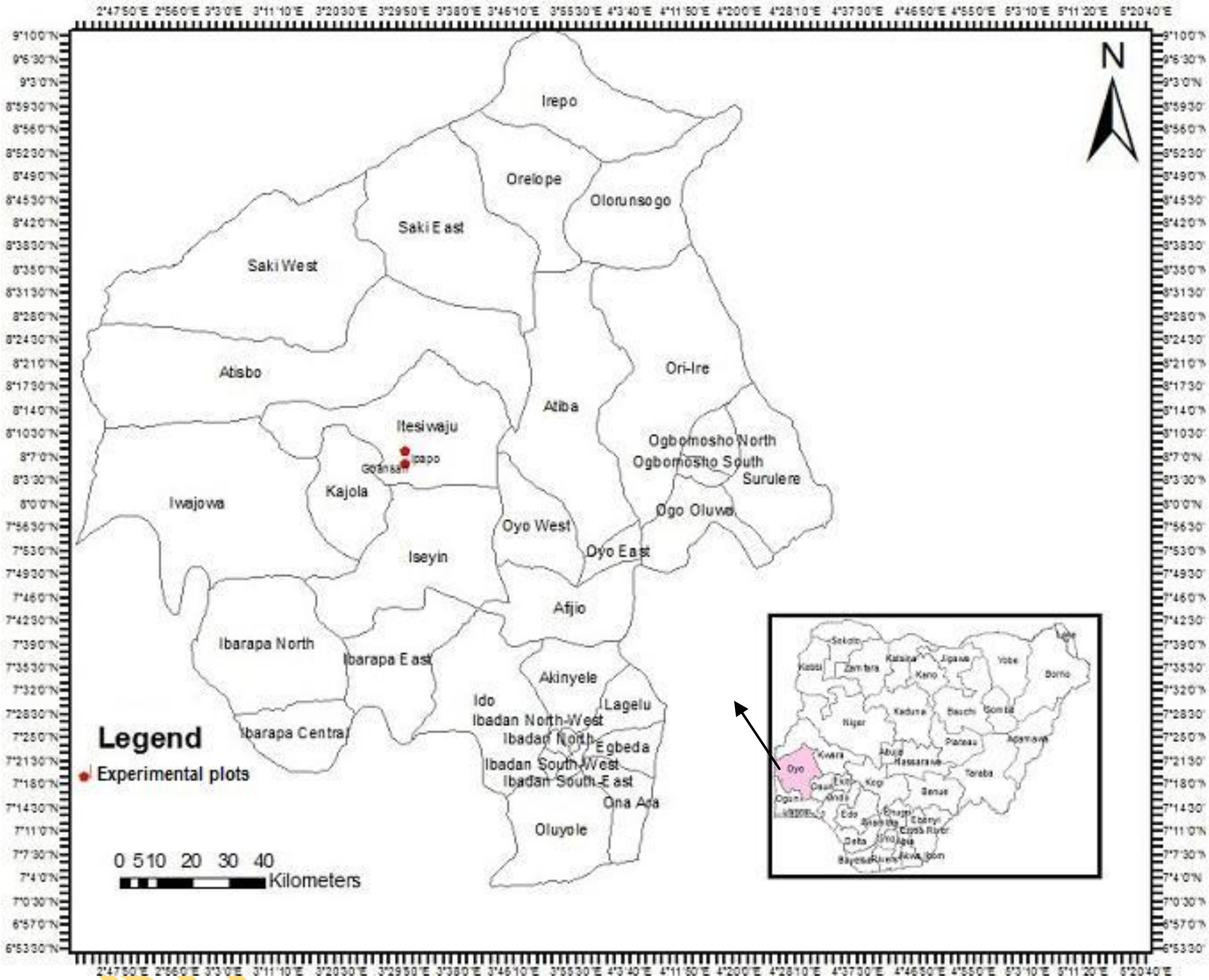

Figure 3.1. Map showing the relative position of the experimental sites

hydraulic conductivity from each of the horizons of the soil profile pits. After the description of the site and soil profiles, samples were taken from each of the soil profiles, starting from the lowest horizon upward, put into polythene bags and appropriately labeled for laboratory analysis. Water retention ability of the soils was evaluated gravimetrically using the method of Landon (1984). Soils were classified at series level according to Murdoch *et al.* (1976) while higher level of soil classification was based on USDA soil taxonomy (2010) and FAO (2006).

3.3 Climate, Geology and Soils of the locations

The mean annual rainfall of the areas varies from 1000 – 1400 mm. Most of the rainfall is concentrated between April and October. The wet and dry seasons are well marked. In August, there is a short dry spell in between the rainy months. Temperatures are usually high throughout the year with an annual mean of 27°C. Relative humidity is high and varies from 60 – 80%. The rocks underlying 95% of the area are ancient crystalline basement complex formations which are generally acidic in composition (Oyewoye, 1967; Rahaman, 1972). The basement complex consists mainly of gneiss, schist, quartzite, magmatite and marble but granite or syenite and intrusions of amphibolites and olivine-rich dykes are also found. Basement complex rocks give rise to a wide variety of soils.

According to FAO-UNESCO World soil map, luvisols are the most prevalent (about 70%) in the area. Arenosols, fluvisols, lithosols and nitosols are also found. Most of the soils vary in texture with depth, and have sandy topsoil over more clayey subsoil (FAO, 1988). Acidity also increases with depth but never reaches extreme values. Cation Exchange Capacity (CEC), organic carbon, total nitrogen and available P are low. Although base saturation is often high, low colloidal activity reduces the significance of this derived parameter as a guide to pedogenesis or fertility (Murdoch *et al*., 1976). Iron concretions and quartz gravels are also common features of the soils (Gbadegesin and Akinbola, 1995).

3.4 Meteorological data acquisition

Daily data for precipitation, evapo-transpiration, minimum and maximum temperatures spanning a period of thirty years from 1981 – 2010 were obtained from the observation station of the Nigerian Meteorological Agency (NIMET), Iseyin zonal office which is a distance of about 10 km to the two fields. Monthly and annual totals were computed for precipitation and evapo-transpiration while the mean monthly temperature values were computed as: $[\sum 1/2(D_{max} + D_{min})] / N$ days, where D_{max} = Daily maximum temperature, D_{min} = Daily minimum temperature and N days = Number of days in the specific month.

3.5 Test crop and its characteristics

Seeds of two promiscuous soya bean varieties TGx1448–2E and TGx1485–1D obtained from IITA were used for this study. Variety TGx1448–2E is a medium to late maturing cultivar which matures between 105-110 days after planting, while TGx1485-1D is an early maturing type that reaches maturity in 90-100 days after planting. The two varieties were reported to be very efficient in nitrogen fixation (IITA, 1984).

3.6 Pre-planting Soil Analysis

Surface soil (0-15 cm) samples were randomly collected from 15 spots on each field with a soil auger, mixed thoroughly and bulked to form a composite sample. The samples from the two locations were air dried and passed through 2 mm-sieve. A sub-sample of each composite sample was taken for the following analysis:

1. Determination of pH: The pH was determined in distilled water using 10 g of soil sample in 10 ml of distilled water and allowed to equilibrate after shaking on a mechanical shaker for 5 minutes (Okalebo *et al.*, 1993). The pH was thereafter determined with the aid of a glass electrode pH meter.
2. Determination of available phosphorus (P) using Bray-1 method: Two (2) g of soil sample was weighed into the shaking bottle and 20 ml of the extractant (1.056 g of ascorbic acid salt dissolved in 200 ml of Riley and Murphy reagent) added. This was shaken with a mechanical stirrer for 5 minutes and thereafter filtered with Whatman No. 42 filter paper into a clean beaker for P determination. The phosphorus content was later read on Bausche and Lomb Spectronic 20 at 882 nm (Bray and Kurtz, 1945).
3. Soil total N was determined using Kjedhal analytical method (Bremmer and Mulvaney, 1982)
4. Soil organic carbon was determined using wet dichromate acid oxidation method (Walkey and Black, 1934).
5. Exchangeable bases (Mg, Ca, K and Na) were determined using neutral 1M ammonium acetate (Okalebo *et al.*, 1993).

6. Extractable micronutrients: Copper, Fe, Zn and Mn were determined with the aid of atomic absorption spectrophotometer (AAS) after extraction with 0.1N HCl (Okalebo *et al.*, 1993).
7. Soil particle size distribution was determined using Bouyoucus hydrometer method (Okalebo *et al.*, 1993).

3.7 Laboratory analysis of profile samples

Ten (10) soil samples were taken from the soil profile pits for chemical properties and particle size analysis. These were taken to the laboratory, air-dried, crushed and sieved through a 2 mm mesh. The gravel portion (>2 mm diameter), of the soil samples were weighed and the ratio of gravel to fine earth calculated. Thus, the gravel content was calculated as a percentage of total air-dried soil. Particle size fractions were determined by Bouyoucos (1951) hydrometer method. Soil pH was determined in 1:1 soil-water ratio, and by KCl media using a glass electrode pH-meter with calomel electrode (Bates, 1954). Organic carbon was estimated by Dichromate wet oxidation method of Walkey and Black (1934). Total nitrogen was determined by micro-Kjedhal method of Jackson (1962). Available phosphorus was evaluated by Bray - P1 method of Bray and Kurtz (1945); while exchangeable cations [Ca, Mg, K, and Na] were extracted by neutral NH_4OAC. Calcium, K and Na were measured through a flame photometer, while Mg was determined by atomic absorption spectrophotometer (Rhoades, 1982). Exchangeable acidity was determined by 1 N KCl extraction and titrated with 0.5N NaO_4 solution (Black, 1975). Effective Cation Exchange Capacity (ECEC) was calculated as the summation of the values of exchangeable cations and exchangeable acidity. The micronutrients (Fe, Mn, Zn and Cu) were determined in 0.1N HCl extract and evaluated using the atomic absorption spectrophotometer (Jackson, 1962).

Soil moisture characteristics

1. Soil moisture content at saturation (SSAT) was determined by weighing the soil samples after saturating them for 24 hours by placing them in a water-bath.
2. Moisture content at field capacity (FC or SDUL) was determined by placing the soil samples in the tension-table for 24 hours and taking their respective weights thereafter.

3. Moisture content at permanent wilting point (SLLL) was determined by placing the soil samples in the tension-table for 24 hours and taking their respective weights thereafter.
4. Bulk density – Soil core sample is obtained. The volume of the sample is equal to that of the cylinder (core) used. The weight of the soil samples is maintained at constant weight by oven-drying at 105°C, bulk density was calculated using the formula below:

$$\rho_b = \frac{M_s}{V_b}$$

Where ρ_b is bulk density, M_s is mass of oven-dry soil and V_b is soil bulk volume. For the purpose of the model, bulk density is expressed in g/cm^3.
5. Saturated hydraulic conductivity (SSKS) - A cylindrical metal core of 5 cm diameter and 5 cm height was used to take soil samples for saturated hydraulic conductivity (K_s) in the laboratory using a constant head permeameter as described by Reynolds and Elrick (2002). The K_s was calculated as described by Hillel (2003) in the equation below:

$$K_s = \frac{QL}{At\Delta H}$$

where: Q is volume of the water that flows through the soil column (cm^3); A is the cross-sectional area of flow (soil core) through the soil column (cm^2); t is time interval (h); L is the length of soil column (cm); ΔH is hydraulic head drop (cm), equals the sum of the pressure head and gravitational head drops.

3.8 Screenhouse and Field Investigations

3.8.1 Experiment 1: Determination of optimum N–level for the growth and development of two soya bean varieties

This experiment was conducted at the screenhouse of the Department of Agronomy, University of Ibadan, Ibadan. It was separately conducted for the two locations.

Soil sample preparation and planting

Top soil (0 – 15 cm) samples from the two locations were separately collected, air-dried and passed through 2 mm sieve. Five kilograms (5 kg) of the soil from each location was weighed into each of the 42 pots for planting. All the pots except six (6) were planted to maize (quality protein maize hybrid, Oba 98, which has high nitrogen requirement) and uprooted 2 weeks after planting (WAP). The aim was to mop up some native nitrogen in the soil. All the pots were then planted to soya bean varieties treated with Apron plus. Planting was done at the rate of 4 seeds per pot.

Cultural practices

Soya bean seedlings were later thinned to 2 seeds per pot. Watering was done regularly on a daily basis and the pots were maintained weed-free. Fertilizer application was done 7 days after planting.

Experimental design and treatments

The experiment was a 2 x 7 factorial in a Completely Randomized Design (CRD). Nitrogen fertilizer, in the form of urea, was applied 1 WAP at two levels of control (mopped control and not mopped control), 5, 10, 15, 20 and 25 kg N/ha. Planting materials were seeds of two varieties of soya bean: TGx1448-2E and TGx1485-1D. These treatments were replicated three times.

Measurement of parameters

Weekly measurement of plant growth parameters commenced 2 WAP: plant height was determined by measuring the plant from the soil level to the top, number of leaves per plant were also counted and recorded.

Harvesting

At the end of the sixth week, harvesting was done. The plant was cut at soil level with the aid of a secateur. Leaves were detached from the stem; fresh weights of both the leaves and the stem were separately measured. The leaves and stem were also air-dried for 24 hours and later taken to the oven for drying at 70 ºC for 24 hours, after which dry weights were measured. Oven-dried shoots were also grinded and sieve with 1 mm sieve for nitrogen content determination.

Data Analysis

Data obtained were subjected to analysis of variance procedures using GENSTAT Discovery Edition 3 (Genstat, 1995). Standard error of the difference of means (s.e.d) was used for means comparison (Steel and Torie, 1987).

3.8.2 Experiment 2: Influence of N starter-dose on the yields of two soya bean varieties grown on ferric luvisol in Oyo state, Nigeria

The field trials were carried out at two selected locations where soils for the pot study were collected viz: Ipapo and Gbonran in Itesiwaju Local Government Area of Oyo State, Nigeria.

Land preparation

A total land area of 665 m^2 was allocated for the field trial in each of the locations. The land was cleared, plough-disked, harrowed, marked and pegged into 5 m x 4.5 m (22.5 m^2) plots. The land was divided into five (5) small plots with three replications (Figure 3.2). Oba 98 maize hybrid (quality maize with high nitrogen requirements) was used to mop up the native nitrogen and was uprooted 4 weeks after planting when signs of N deficiency were noticed.

Planting and cultural practices

Planting was done at the two locations on 28 June 2009 for the first year and on the 11 June 2010 for the second year, being the beginning of the growing season and the recommended planting period for soya bean in the southern Guinea savanna zone of Nigeria, at a planting distance of 75 cm x 5 cm, two soya bean seed was planted per hill at 3 - 4 cm planting depth and later thinned to one, to give a total plant population of 266,667 plants per hectare. Weeding was done once by hoeing at 6 WAP before canopy establishment.

Starter nitrogen fertilizer was applied in the form of urea by banding at 7 days after planting at the rate of 0 (control), 5, 15, 25 and 35 kg N/ha. Data collected were weight of 100 seeds, dry shoot weight, grain yield, harvest index and shoot N-content.

Treatment and experimental design

The experiment was laid out as a 5 x 2 split-plot arrangement with treatments replicated three times in a randomized complete block design. Nitrogen application doses of 0 (control), 5, 15, 25 and 35 kg N/ha were the main plot while soya bean varieties TGx1485-1D and TGx1448-2E constituted the sub-plot.

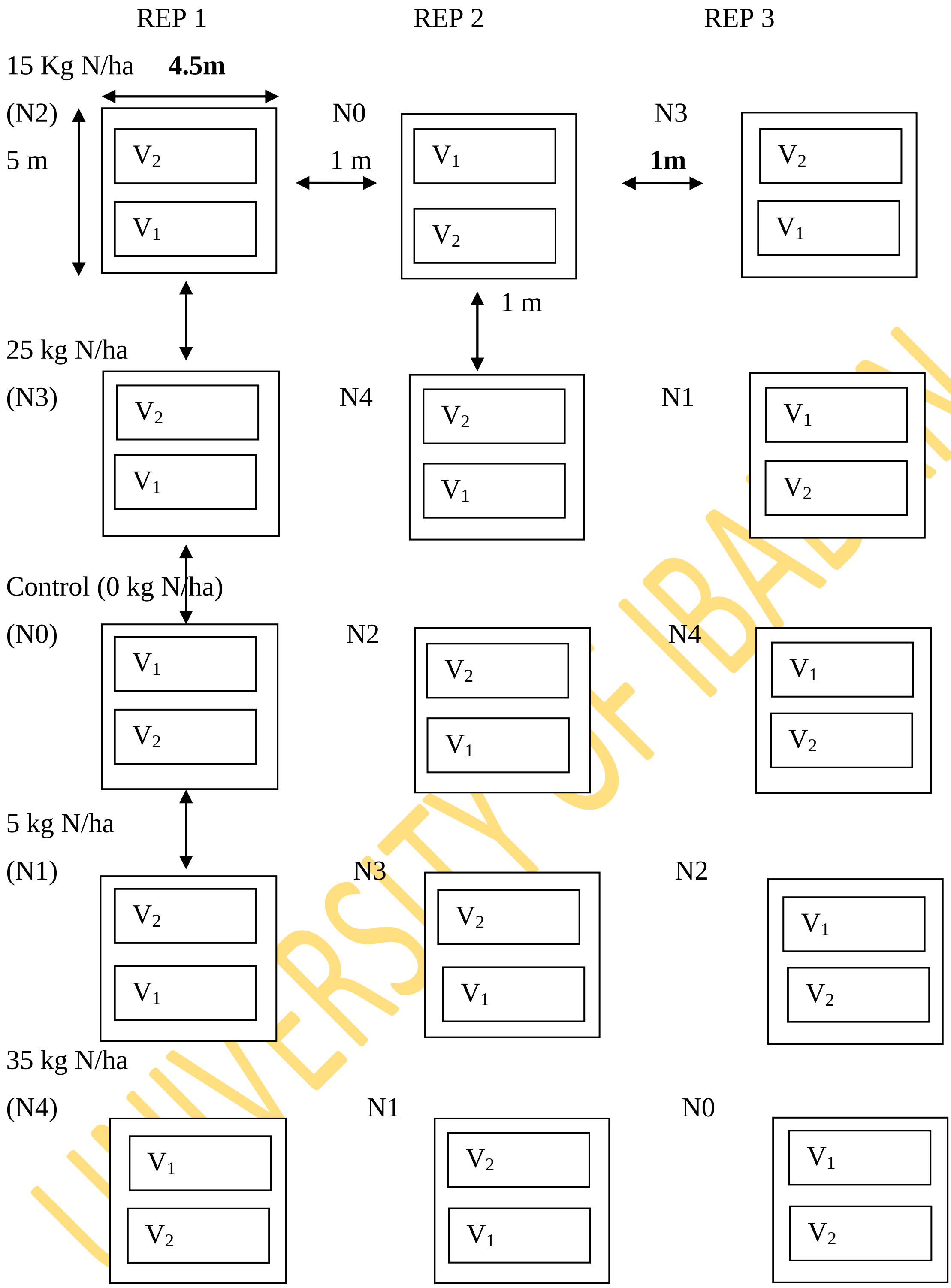

Figure 3.2: The layout of the field experiment.

V1 = Soya bean variety TGx1485-1D

V2 = Soya bean variety TGx1448-2E

Data collection

Harvesting of soya bean was done with sickles. A designated final harvest area (1.5 m x1.5 m) was marked on the third and fourth rows. Twenty plants were randomly selected in the designated harvest area. After harvesting, plants were left in the field for sun drying for two days, and then threshed. The harvested plants were used to determine harvest index, 100 seed weight and grain yield. Grain yield was calculated in kilograms per hectare.

Determination of shoot N-content

Plant shoots were oven -dried at 70℃ for 24 hours.The shoot materials were grinded with a steel grinder to pass 1.0 mm mesh. 0.3 g of the sample was transferred into the digestion tube, 4.4 ml of the digestion mixture was added. The digestion was done at 360 C, cooled and transferred to 50 ml volumetric flask fill to volume with distilled water. 5 ml of the sample solution was transferred to the reaction chamber of the still and 10 ml of 40% NaOH. The distill was immediately steamed into 5 ml of 1% boric acid containing 4 drops of the indicator. The distillation continued tor 2 minutes from the time the indicator turns green. The distillate was removed and titrated with N/70 HCl. A blank determination was also run.

$$\% \text{ N in sample is calculated thus: } \frac{(\text{Plant tissue titre value} - \text{Blank titre value}) \times 0.2}{\text{Weight of sample}}$$

Determination of Harvest Index

Harvest index was calculated as the ratio of grain yield to shoot dry weight.

Data analysis

Data analysis was done as in experiment 1. Means were also separated with least significant difference (LSD) at 5% probability level (Steel and Torrie, 1987).

3.9 CROPGRO-Soya bean Crop Model

3.9.1 Screen-house Model Calibration Experiment

Screen-house experiment was conducted for model calibration on the 3 May, 2011 at the screen-house, Department of Agronomy, University of Ibadan. Surface soils (0 – 15 cm) were randomly collected from 15 different points at Ipapo and Gbonran locations. The soils were bulked to form a composite, air-dried and passed through 2 mm sieve.

Experimental procedure

The soils were filled into 5 kg-pots. Each variety of soya bean was planted into twelve pots containing soil from each location and replicated three times. A total of 36 pots were used for each variety. The pots were watered on a daily basis. Cypermethrin EC was sprayed to avoid attacks from insect pests. The experiment was conducted under optimum management practices to avoid stresses from moisture, pests and diseases. Basal N.P.K. 15 – 15 -15 fertilizer application was made. Phenological data on emergence, anthesis and physiological maturity were collected. The number of days to first pod appearance, days to first seed and harvesting date were also recorded.

3.9.2 Model calibration

The CSM – CROPGRO - Soya bean model uses 15 genetic coefficients to define development and growth characteristics of a soya bean cultivar (Table 3.1). The calibration process is a systematic search of possible values that the model will use to predict accurately the observed parameters. Genetic coefficient for this study was obtained following the procedures described by Mavromatis *et al*. (2001). The photothermal units accumulated for different phenological stages such as emergence, anthesis and physiological maturity were used for the calibration of the genetic coefficients of the soya bean varieties used in this trial. The photothermal units are calculated as ½ (Daily maximum temperature + Daily minimum temperature) – Base temperature.

3.9.3 Model validation

Data collected on soya bean growth and developments were used as inputs for running the models. The data are organized to fit DSSAT file structures such as experimental data file (file X), yield and yield parameters data (file A), weather data (file WTH), and soil file (SOIL.sol) (Appendices I - IV) created from measurements or data from the field experiments located at both Ipapo and Gbonran in 2009 and 2010 cropping seasons.

3.9.4 Statistical analysis of model data

The predicted and observed values of soya bean phenological characteristics such as number of days to anthesis, first pod, first seed and physiological maturity were analyzed to test the reliability of data using root mean square error (RMSE) method (Wallach and Goffinet, 1987). A simple way of expressing error is to express root mean square error as percentage of means of observation i.e. percentage error (PE) otherwise referred to as normalized root mean

Table 3.1: Definition of genetic coefficients used in the CSM-CROPGRO – Soya bean model

Parameter	Definition	Units
EM-FL	Time between plant emergence and first flower emergence (R1)	PTD
FL-SH	Time between first flower and first pod (R3)	PTD
FL-SD	Time between first flower and first seed (R5)	PTD
SD-PM	Time between first seed (R5) and physiological maturity (R7)	PTD
FL-LF	Time between first flower (R1) and the end of leaf expansion	PTD
SLAVR	Specific leaf area of cultivar under standard growth conditions	cm^2g^{-1}
SIZLF	Maximum size of full leaf (three leaflets)	cm^2
WTPSD	Maximum weight per seed	g
The default DSSAT values were used for the following:		
CSDL	Critical Short Day Length below which reproductive development progresses with no day-length effect (for short day plant)	hr
PPSEN	Slope of the relative response of development to photoperiod with time (positive for short-day plants)	l/hr
LFMAX	Maximum leaf photosynthesis rate at 30°C, 350 vpm CO_2 and high light	mg $CO_2m^{-2}s^{-1}$
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell	
SFDUR	Seed filling duration for pod cohort at standard growth conditions	PTD
SDPDV	Average seed per pod under standard growth conditions	number/pod
PODUR	Time required for cultivar to reach final pod load under optimal conditions	PTD

PTD - Photo-thermal days (Mavromatis *et al.*, 2001) square errors ($RMSE_n$) calculated following Loague and Green (1991).

The equations are as written below:

$$RMSE = \sqrt{[\sum (Pi-Oi)^2/n]} \quad (1)$$

$$PE\ (RMSE_n) = RMSE/\bar{O} \times 100 \quad (2)$$

where RMSE = Root mean square error, Pi = predicted value, Oi = observed value, $\bar{O}$ = mean of observed value, n = number of replicates/locations, $\sum$ = Summation sign, and $\sqrt{}$ = Square root.

Normalized RMSE or PE values provide a measure (%) of relative differences between simulated and observed data. A simulation is considered to be excellent, good, fair, and poor if the normalized RMSE or PE is < 10%, $\geq$ 10% but less than 20%, $\geq$ 20% but less than 30%, and $\geq$ 30%, respectively (Jamieson *et al*., 1991).

3.9.5 Soil water balance

The soil water balance module of the DSSAT models computes, on a daily basis, all processes that directly affect water content in the soil profile throughout the seasonal simulation. Ritchie (1998) describes many of these algorithms in detail. The change in soil water content for the soil profile is calculated on a daily time step using the equation:

$$\Delta S = P + I - T - ES - R - D$$

Where ΔS = Change in soil water content, P = Precipitation, I = Irrigation, T = Transpiration, ES = Soil Evaporation, R = Surface Runoff and D = Drainage from Soil Profile.

The soil water content in each soil layer is updated sequentially throughout a day of simulation by each process affecting the soil profile. Drainage, root water uptake, soil evaporation, and plant transpiration each modified the soil water content sequentially and preferentially. With the modular structure, the various soil process rates are calculated using the value of soil water content at the end of the previous day. After all rates are calculated throughout the model and the rates are used to update the state variables. This one-dimensional model computes the daily changes in soil water content by soil layer due to infiltration of rainfall and/or irrigation, vertical drainage, unsaturated flow, soil evaporation, and root water uptake processes. In the model, soil evaporation, plant transpiration, and root water uptake processes are separated out into a soil-plant-atmosphere module (SPAM) to create more flexibility for expanding and maintaining the model (Ritchie and Otter, 1985).

CHAPTER FOUR

RESULTS

4.1 Soil characteristics

Some of the physico-chemical properties of the soils in both fields are: pH 6.4 showing that the soils were slightly acidic, which is within the optimum range of 5.8 to 7.0 recommended for soya bean production (PCARRD/USDA, 1986); Total N (g/kg) 0.7 and 1.0; organic C (g/kg) 8.6 and 12.1; available P (mg/kg) 6.3 and 7.3, and K (cmol/kg) 0.2 apiece for Ipapo and Gbonran respectively (Table 4.1). Thus, the soils in both locations are inherently low in fertility. Total N, available P and exchangeable K were very low before and after mopping. Organic matter content was also low. The soils' textural class is loamy sand.

4.2 Meteorological data

The annual rainfall values were 935.5 mm and 1475.8 mm in 2009 and 2010 respectively. Potential evapotranspiration (PET) values were 1676.5 mm and 1676.8 mm in 2009 and 2010 respectively (Table 4.2). This implies that an annual moisture deficit of 741 mm in 2009 and 219 mm in the 2010 were recorded. These deficits were however encountered for five months (November, December, January, February and March) in 2009, which are regarded as the dry season in the region. Temperature values ranged from 24 to 29.8 °C in both years and the mean monthly temperature for 2009 was 26.5 and 27.1 °C for 2010. The mean monthly temperature in the study period was within the 22 – 30 °C which is the recommended optimum temperature range for soya bean production (PCARRD/USDA, 1986). The relationships between environmental demand for water (evapotranspiration) and the decadal/monthly rainfall distribution in 2009 and 2010 cropping seasons are presented in figures 4.1 and 4.2 respectively.

Table 4.1: Soil physical and chemical properties of Ipapo and Gbonran experimental sites.

Parameters		Ipapo	Gbonran
pH(H_2O) (1:1)		6.4	6.4
Total Nitrogen	(g/kg)	0.7	1.0
Organic Carbon	(g/kg)	8.6	12.1
Avail. P (Bray – 1)	(mg/kg)	6.3	7.3
Exchangeable cations (c mol/kg)			
Ca		1.3	1.9
Mg		1.1	1.2
K		0.2	0.2
Na		0.3	0.3
Exch. Acidity ($H^+ + Al^{3+}$)	(c mol/kg)	0.2	0.3
Extractable micronutrients (mg/kg)			
Fe		27.0	29.8
Mn		98.2	130.3
Cu		2.1	2.6
Zn		1.3	1.5
Particle size distribution (g/kg)			
Clay		48	68
Silt		80	120
Sand		872	812
Textural Class (USDA)		Loamy Sand	Loamy Sand
Soil pH and N.P.K. levels following mopping			
PH(H_2O) (1:1)		6.1	6.0
Total Nitrogen	g/kg	0.25	0.26
Organic Carbon	g/kg	1.01	1.07
Avail P (Bray – 1)	mg/kg	3.87	3.33

Table 4.2: Monthly rainfall, potential evapotranspiration and mean monthly temperature for Iseyin (2009 – 2010).

Month	Rainfall (mm)		Potential Evapotranspiration (mm)		Mean Monthly Temperature (°C)	
	2009	2010	2009	2010	2009	2010
Jan	2.1	0.0	170.2	170.2	27.8	28.7
Feb	10.6	19.5	174.0	168.2	28.1	29.8
Mar	29.0	131.6	169.4	169.9	29.5	29.1
Apr	102.4	43.5	149.0	149.8	27.0	28.9
May	130.7	204.4	127.4	128.2	26.9	27.1
Jun	139.5	167.4	115.1	115.3	25.7	26.7
Jul	217.9	105.3	108.5	108.5	24.8	24.9
Aug	74.5	205.7	111.5	110.9	24.0	24.8
Sep	108.9	256.5	121.5	120.8	24.5	25.4
Oct	117.8	240.5	136.2	136.5	25.8	25.9
Nov	2.1	101.4	138.5	138.5	26.1	26.8
Dec	0.0	0.0	155.2	160.0	27.3	27.1
Total	935.5	1475.8	1676.5	1676.8	-	-
Mean	-	-	-	-	26.5	27.1

Source: NIMET, Iseyin Zonal Office.

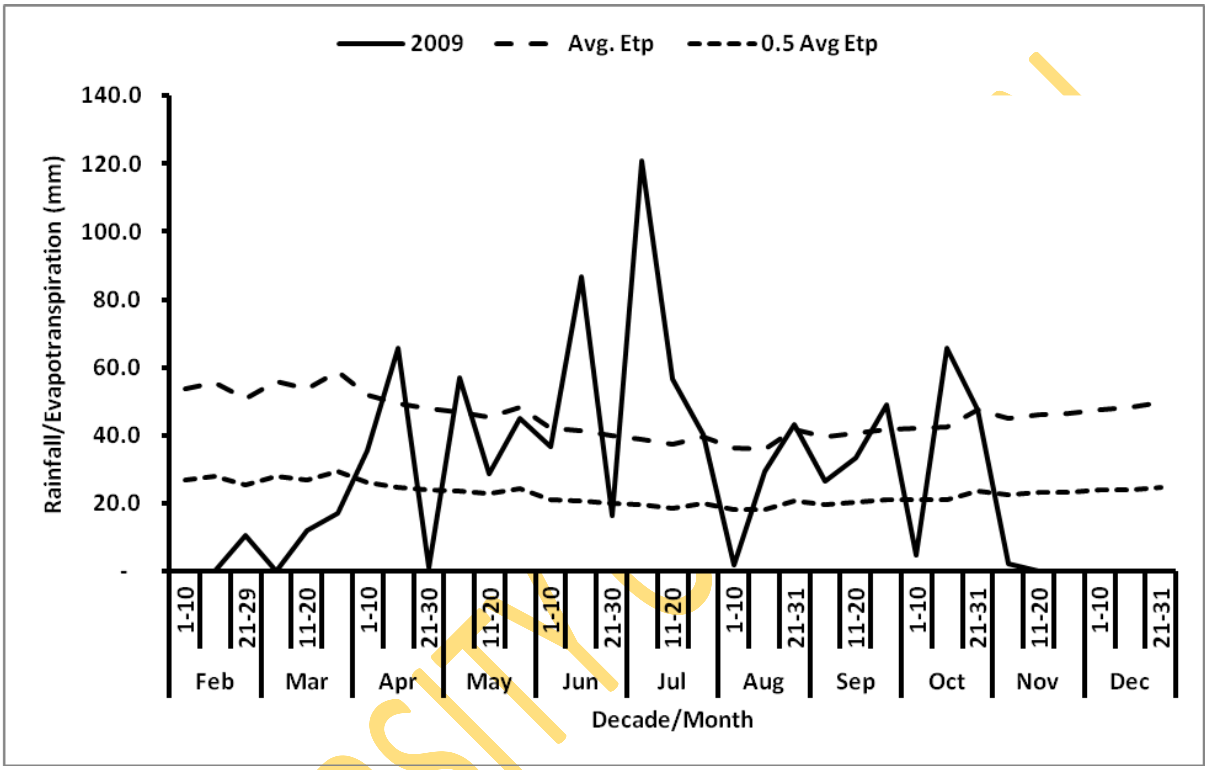

Figure 4.1: Relationship between environmental demand for water (Evapotranspiration) and decadal rainfall distribution during the 2009 rainy season at Iseyin.

Legend:
2009 = 2009 Rainfall
Avg.Etp = Average Evapotranspiration
0.5 Avg Etp = Half Average Evapotranspiration

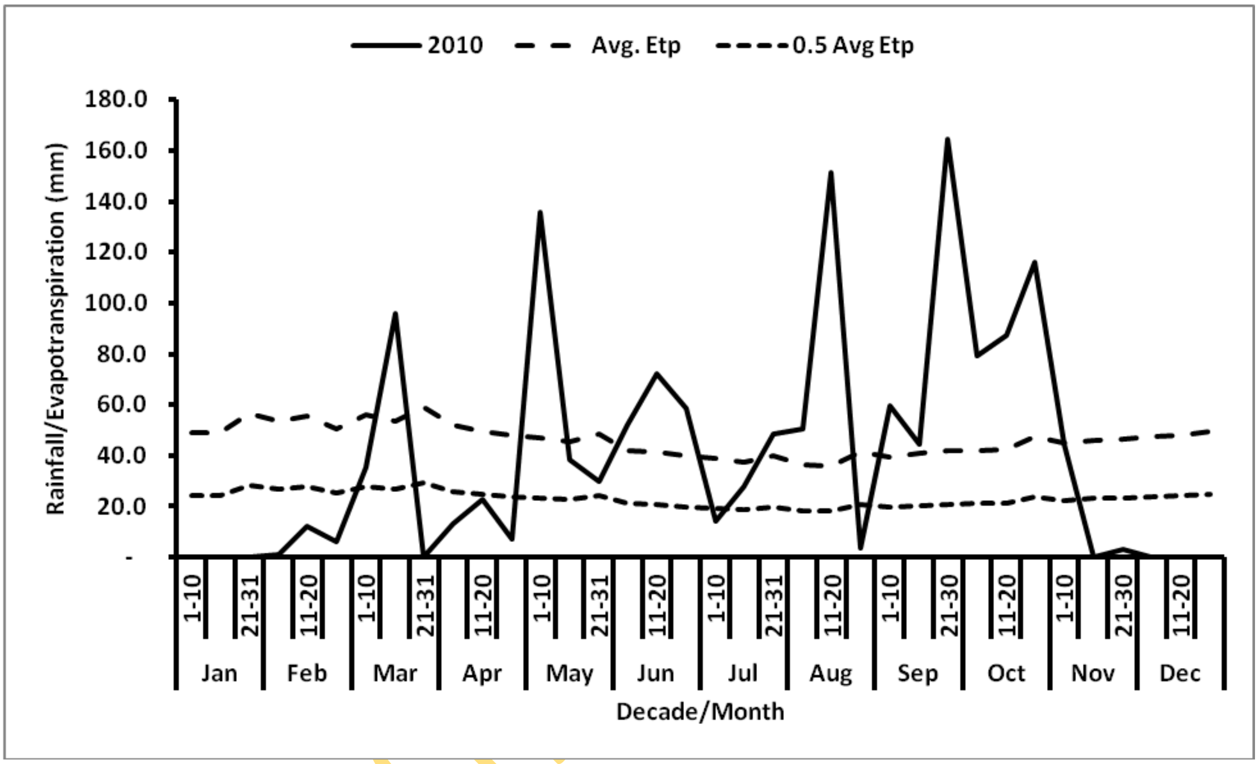

Figure 4.2: Relationship between environmental demand for water (Evapotranspiration) and decadal rainfall distribution during the 2010 rainy season at Iseyin.

Legend:
2010 = 2010 Rainfall
Avg. Etp = Average Evapotranspiration
0.5 Avg Etp = Half Average Evapotranspiration

4.3 Screen-house study 2008/2009

4.3.1 Effect of starter N on plant height of two soya bean varieties on Ipapo and Gbonran soils

Starter nitrogen rates had no significant effects on plant height of the two soya bean varieties grown on Ipapo soil at 2 and 4 WAP. However, at 5 WAP, variety TGx1448-2E produced significantly taller plants thatn variety TGx1485-1D (Table 4.3). Conversely, varietal responses were significantly different on Gbonran soil at 2 and 4 WAP, where variety TGx1485-1D plants were significantly taller than those of TGx1448-2E (Table 4.4). There was no significant difference in plant height of both varieties at 5 WAP. Application of starter nitrogen had no significant effects on plant height of the two soya bean varieties on Gbonran soil (Table 4.4). Significant N level x variety interaction was evident on plant height. At 2 WAP and with 10 kg N/ha application rate, variety TGx1485-1D plants showed a significantly higher plant height response in Gbonran soil (Figure 4.3). At 5 WAP, variety TGx1448-2E plants showed a significantly higher plant height in Ipapo soil with 15 kg N/ha application rate (Figure 4.4).

4.3.2 Effect of starter N on number of leaves of two soya bean varieties on Ipapo and Gbonran soils

There was no significant difference in the number of leaves as a result of nitrogen application rates on Ipapo soil, however, varietal response was significantly different at 4 WAP with variety TGx1448-2E producing more leaves on Ipapo location soil (Table 4.3). Conversely, the application of nitrogen rates only produced a significant difference in the number of leaves at 2 WAP on Gbonran soil with variety TGx1448-2E producing more leaves (Table 4.4). Varietal response to leaf production did not show any significant difference on Gbonran soil (Table 4.4). The effects of variety x N level interaction were significant on number of leaves produced at various stages of plant growth. At 2 WAP and 5 WAP, 10kg N/ha produced a significant response in terms of leaf production between the varieties in Gbonran soil (Figures 4.5 and 4. 6). At 4 WAP, 15kg N/ha application produced significantly different response in Ipapo soil (Figure 4.7).

Table 4.3: Nitrogen dose and variety effects on the growth and development of soya bean on soil from Ipapo in the screenhouse

Variable	Plant height (cm)			Number of leaves				Days to flowering	Stem weight (g/pot)	Leaf weight (g/pot)	Shoot weight (g/pot)	% N in shoot
	2WAP	4WAP	5WAP	2WAP	3WAP	4WAP	5WAP					
Variety												
TGx1485	21.6	36.4	44.3b	8.3	9.3	12.1b	20.2	33.0b	0.47b	0.42	0.89	5.18
TGx1448	21.0	38.3	56.5a	8.1	10.3	14.5a	20.5	34.1a	0.54a	0.44	0.98	5.06
N levels (kg/ha)												
M0	19.5	37.7	51.0	8.2	8.5	11.3	17.5	33.0	0.53	0.43	0.97	5.27
N0	21.3	35.7	43.7	8.2	9.0	12.3	19.7	33.7	0.48	0.42	0.91	4.78
5	20.0	35.5	46.3	7.7	10.0	12.5	19.8	34.0	0.47	0.39	0.87	5.13
10	20.3	36.3	46.7	7.5	10.5	12.8	20.2	33.3	0.47	0.44	0.92	5.02
15	22.4	37.3	51.7	8.8	10.5	13.3	20.3	33.7	0.53	0.45	0.98	5.20
20	23.1	41.5	56.3	8.7	10.5	15.5	21.7	33.3	0.54	0.39	0.93	5.17
25	22.7	37.5	57.0	8.5	11.2	15.3	23.5	33.8	0.49	0.47	0.96	5.25
s.e.d												
Variety	0.68	1.56	4.06*	0.33	0.55	0.93*	1.22	0.41*	0.04*	0.05	0.09	0.11
N levels	1.27	2.92	7.60	0.61	1.02	1.75	2.29	0.761	0.07	0.09	0.14	0.21

*Significant at $p \leq 0.05$

means followed by different letters are significantly different at $p \leq 0.05$

M0 = mopped control

N0 = not-mopped control

Table 4.4: N dose and varietal effects on the growth and development of soya bean on soil from Gbonran in the screenhouse

Variable	Plant height (cm) 2WAP	4WAP	5WAP	Number of leaves 2WAP	3WAP	4WAP	5WAP	Days to flowering	Stem weight (g/pot)	Leaf weight (g/pot)	Shoot weight (g/pot)	% N in shoot
Variety												
TGx1485	21.3a	44.9a	58.7	7.5	10.8	14.4	19.8	32.10b	0.55a	0.38b	0.85b	4.68a
TGx1448	17.1b	37.7b	58.0	7.9	10.5	14.4	20.6	34.12a	0.48b	0.48a	1.03a	4.12b
N levels (kg/ha)												
M0	20.8	41.5	59.6	5.2c	9.8	13.8	16.3	33.00	0.61	0.58	1.18	3.84
N0	23.2	52.2	77.3	7.8b	10.3	14.8	21.0	33.17	0.56	0.46	1.02	4.52
5	19.2	44.5	65.8	8.0b	11.8	15.0	19.8	32.00	0.55	0.43	0.94	4.67
10	17.0	37.4	50.1	6.8bc	10.3	13.4	17.0	33.50	0.49	0.39	0.88	4.24
15	21.0	42.5	66.8	8.2ab	10.3	15.0	20.7	33.17	0.52	0.43	0.95	4.25
20	19.4	35.2	40.7	8.8ab	10.5	15.2	21.9	33.17	0.47	0.37	0.83	4.42
25	13.8	35.8	48.2	9.3a	11.7	13.5	24.7	33.75	0.42	0.35	0.77	4.86
s.e.d.												
Variety	1.66*	3.15*	6.27	0.64	0.49	0.72	1.46	0.26*	0.05*	0.04*	0.08*	0.18*
N levels	3.11	5.89	11.72	1.20*	0.92	1.34	2.72	0.49	0.09	0.07	0.16	0.33

*Significant at $p \leq 0.05$

means followed by different letters are significantly different at $p \leq 0.05$

M0 = mopped control

N0 = not-mopped control

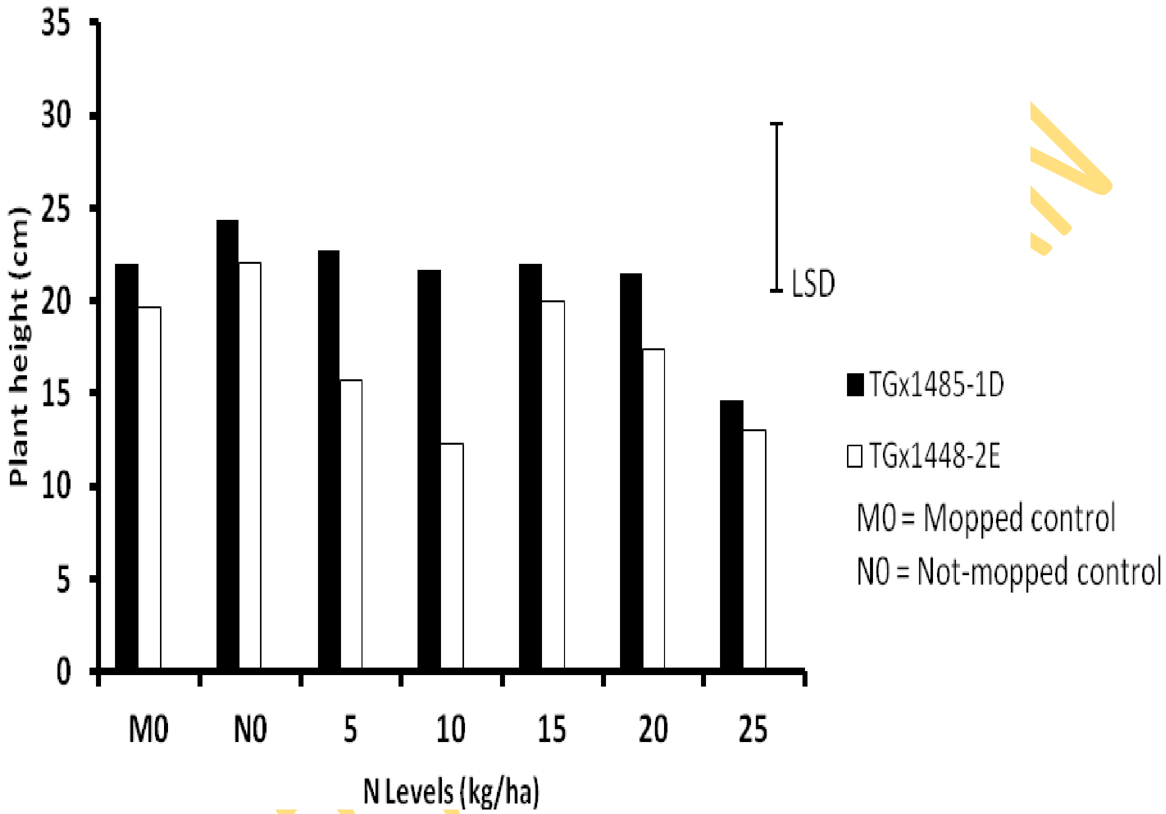

Figure 4.3: The effect of N levels on soya bean plant height at 2WAP on Gbonran soil.

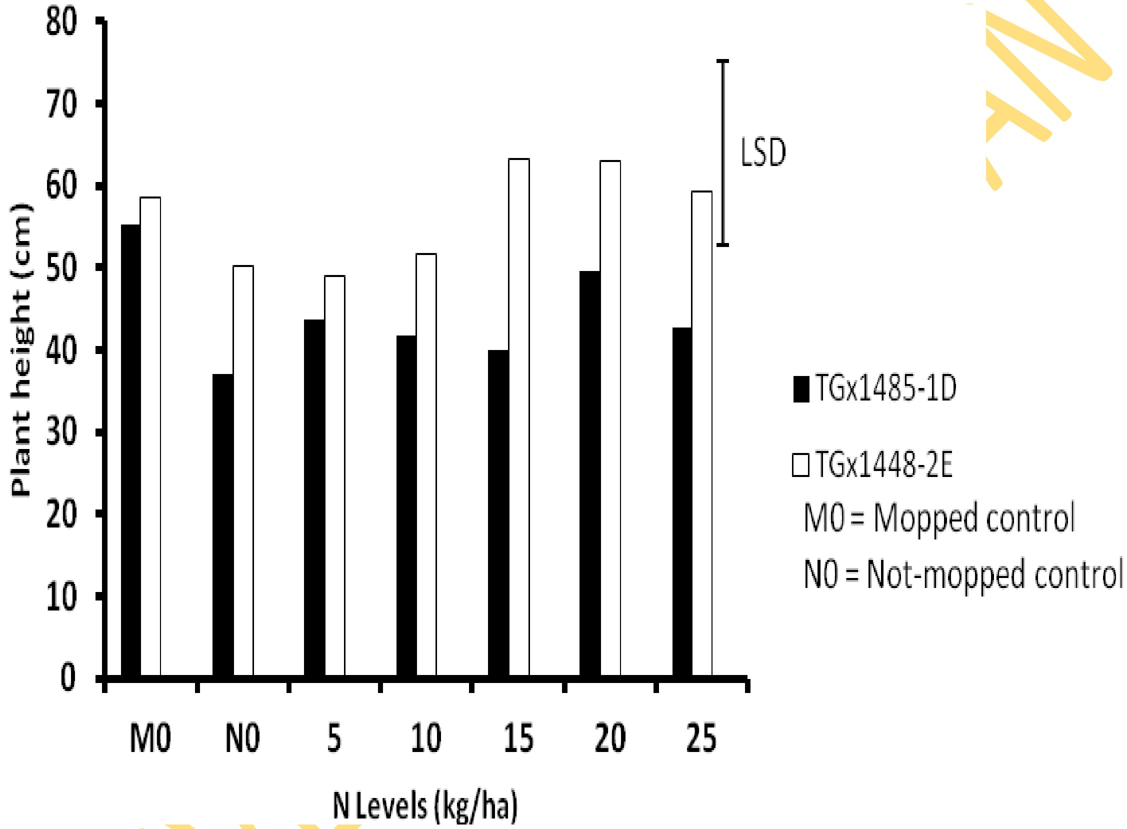

Figure 4.4: The effect of N-levels on soya bean plant height at 5WAP on Ipapo soil

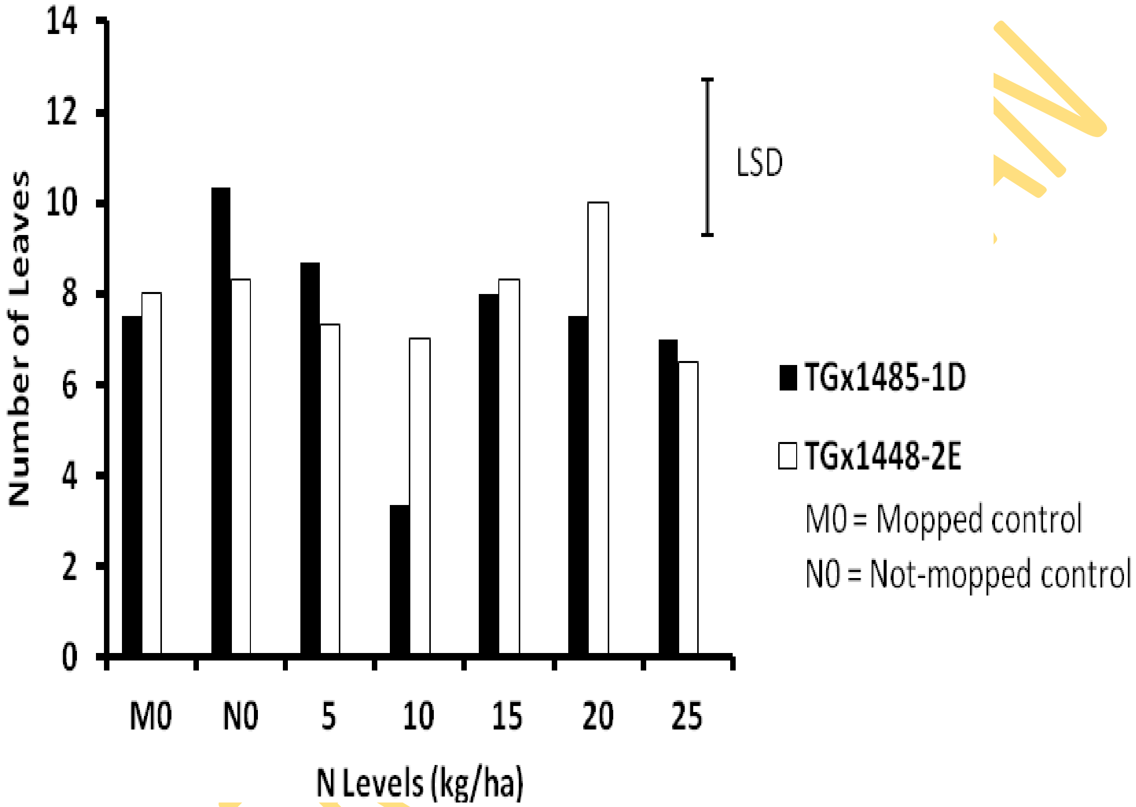

Figure 4.5: The effect of nitrogen levels on the number of leaves produced by soya bean at 2WAP on Gbonran soil

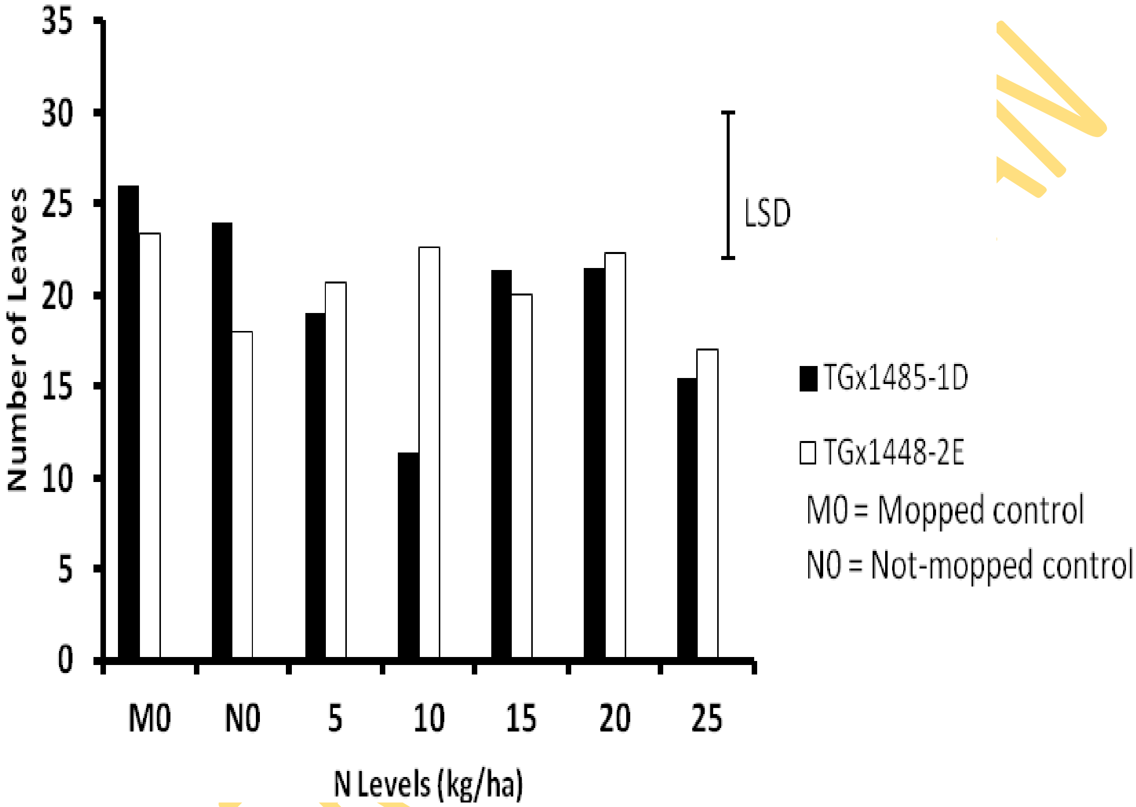

Figure 4.6: The effect of nitrogen levels on the number of leaves produced by soya bean at 5WAP on Gbonran soil.

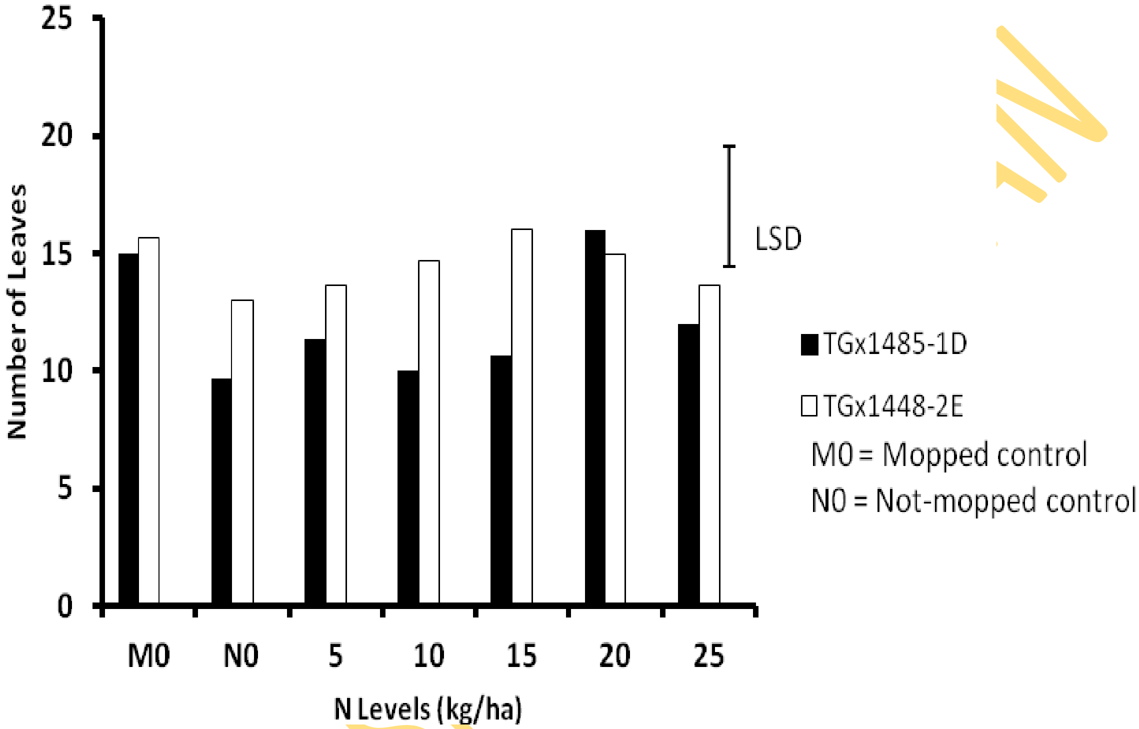

Figure 4.7: The effect of nitrogen levels on the number of leaves produced by soya bean at 4WAP on Ipapo soil.

4.3.3 Effect of starter N on days to flowering of two soya bean varieties on Ipapo and Gbonran soils

There was a significant difference in the number of days to flowering between the soyabean varieties, where variety TGx1485-1D flowered earlier than variety TGx1448-2E on both Ipapo and Gbonran soils (Tables 4.3 and 4.4). The application of N starter-dose did not give a remarkable difference in this attribute on soils from both locations.

4.3.4 Effect of starter N on shoot biomass of two soya bean varieties on Ipapo and Gbonran soils

The application of starter nitrogen had no significant effects on Ipapo soil in respect of shoot biomass production (Table 4.3). There was a significant difference in varietal response in terms of stem weight, however, leaf and shoot weights showed no significant response on Ipapo location soil (Table 4.3). Similarly, starter nitrogen had no significant effects soya bean shoot biomass production on Gbonran soil (Table 4.4). Although, varietal response was significantly different with variety TGx1448-2E producing higher leaf and shoot weights but lesser stem weight on Gbonran soil (Table 4.4).

4.3.5 Effect of starter N on shoot N accumulation of two soya bean varieties on Ipapo and Gbonran soils

The application of different starter nitrogen rates had no significant effect on soya bean shoot N accumulation in soils from both Ipapo and Gbonran locations (Table 4.3 and 4.4). The two soya bean varieties responded differently on Gbonran soil, where variety TGx1485-1D accumulated significantly higher % nitrogen in shoot (Table 4.4). However, responses of the two varieties were similar on Ipapo soil (Table 4.3). It is worthy of note that even in mopped-up control on Ipapo location soil, soya bean varieties accumulated the highest shoot N content than when 25 kg N/ha was applied (Table 4.3).

4.4 Field Experiments (2009 and 2010)

4.4.1 Effect of starter N on weight of 100 seeds of two soya bean at Ipapo and Gbonran

There was no marked difference in the effect of N starter doses on the weight of 100 seeds in Ipapo field of Iseyin soil series (Table 4.5). In Gbonran field of Sepeteri soil series, N dose produced a significantly different effect on the weight of 100 seeds. The control treatment (0 kg N/ha) produced the heaviest 100 seeds while 35 kg N/ha dose produced the least 100-seed weight (Table 4.6). Varietal responses were significantly differently at both fields with variety TGx1448-2E producing heavier 100 seeds than those of TGx1485-1D on the average (Tables 4.5 and 4.6).

Table 4.5: Effects of N Dose and Variety on Yield Parameters in Ipapo (2009-2010).

Treatment	100 seed weight (g)	Shoot N-content (g/kg)	Shoot dry weight (kg/ha)	Grain Yield (kg/ha)	Harvest Index
Nitrogen Dose (kg/ha)					
0	24.7	31.0	2103	1241	0.59
5	23.2	28.0	2145	1287	0.60
15	24.0	32.0	2372	1376	0.58
25	24.9	28.0	2398	1371	0.58
35	25.8	29.0	2530	1342	0.57
LSD (0.05)	Ns	Ns	ns	118.5	0.02
Soya bean variety					
TGx1485-1D	21.7	32.9	2322	1347	0.58
TGx1448-2E	27.3	25.6	2961	1540	0.52
LSD (0.05)	2.75	4.2	521.2	147.2	0.012

ns – not significant

Table 4.6: Effects of N Dose and Variety on Yield Parameters in Gbonran (2009-2010).

Treatment	100 seed weight (g)	Shoot N-content (g/kg)	Shoot dry weight (kg/ha)	Grain Yield (kg/ha)	Harvest Index
Nitrogen Dose (kg/ha)					
0	22.3	29.0	2441	1095	0.51
5	19.9	26.0	2560	1072	0.50
15	19.6	29.0	2919	1080	0.47
25	20.0	23.0	3100	1095	0.45
35	19.6	28.0	3064	1070	0.47
LSD (0.05)	1.67	Ns	ns	ns	Ns
Soya bean variety					
TGx1485-1D	16.7	28.0	2804	1346	0.58
TGx1448-2E	23.9	26.0	2903	1539	0.53
LSD (0.05)	1.48	Ns	93.4	136.9	0.03

ns – not significant

4.4.2 Effect of starter N on shoot N-content of soya bean at Ipapo and Gbonran

Starter N had no significant effect on shoot N content at both locations (Tables 4.5 and 4.6). However, TGx1485-1D accumulated significantly more N in its shoot than TGx1448-2E at Ipapo (Table 4.5). There was no significant difference in shoot N accumulation of both varieties at Gbonran (Table 4.6).

4.4.3 Effect of starter N on Shoot dry weight of soya bean at Ipapo and Gbonran

Nitrogen starter-doses did not significantly affect soya bean shoot dry weight at both locations. However, varietal effects on shoot dry weight was significantly different with variety TGx1448-2E plants having a significantly higher shoot dry weight than those of TGx1485-1D (Tables 4.5 and 4.6). The interaction of N level x variety showed significantly different responses at 0, 5 and 35 kg N/ha application rates with variety TGx1448-2E being more responsive in Ipapo field at harvest (Figure 4.8), Similarly, in Gbonran field, all N application rates except 5 kg N/ha produced significant factor interaction with TGx1448-2E showing better responsiveness (Figure 4.9).

4.4.4 Effect of starter N on grain yield of soya bean at Ipapo and Gbonran

Variety TGx1448-2E produced a significantly higher grain yield than variety TGx1485-1D at both locations (Tables 4.5 and 4.6). With respect to N application rates, 15 and 25 kg/ha produced significantly higher grain yield than the control (0 kg/ha); though not significantly different from all others in Ipapo field (Table 4.5). However, there was no significant response observed in Gbonran field (Table 4.6).

4.4.5 Effect of starter N on harvest index of soya bean at Ipapo and Gbonran

There was a significant difference in varietal effect on harvest index with variety TGx1485-1D having a significantly higher harvest index than variety TGx1448-2E across both fields (Tables 4.5 and 4.6). In terms of N application rates, 5 kg/ha dose produced the significantly highest harvest index and the lowest harvest index was produced by 35 kg/ha in Ipapo field (Table 4.5). In Gbonran field, N rate had no significant effects on harvest index (Table 4.6).

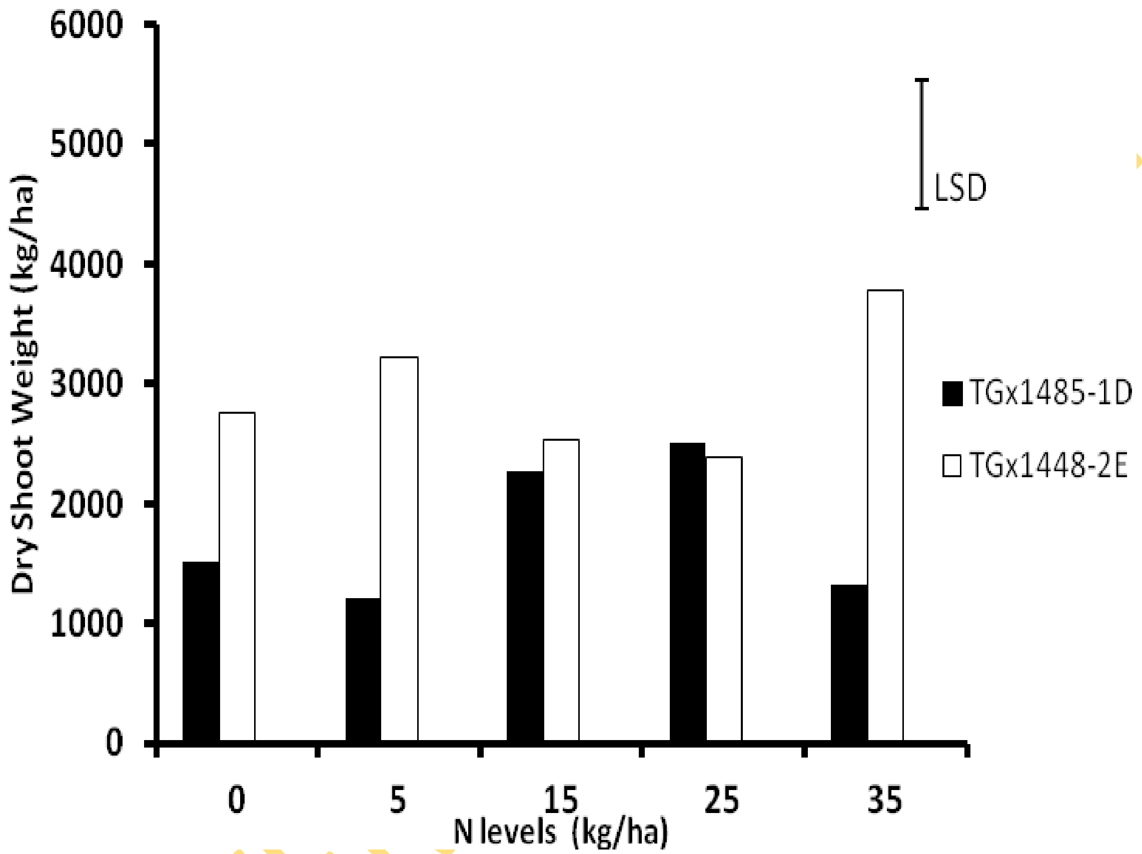

Figure 4.8: The effect of N levels on dry shoot weight of soya bean at harvest in Ipapo field

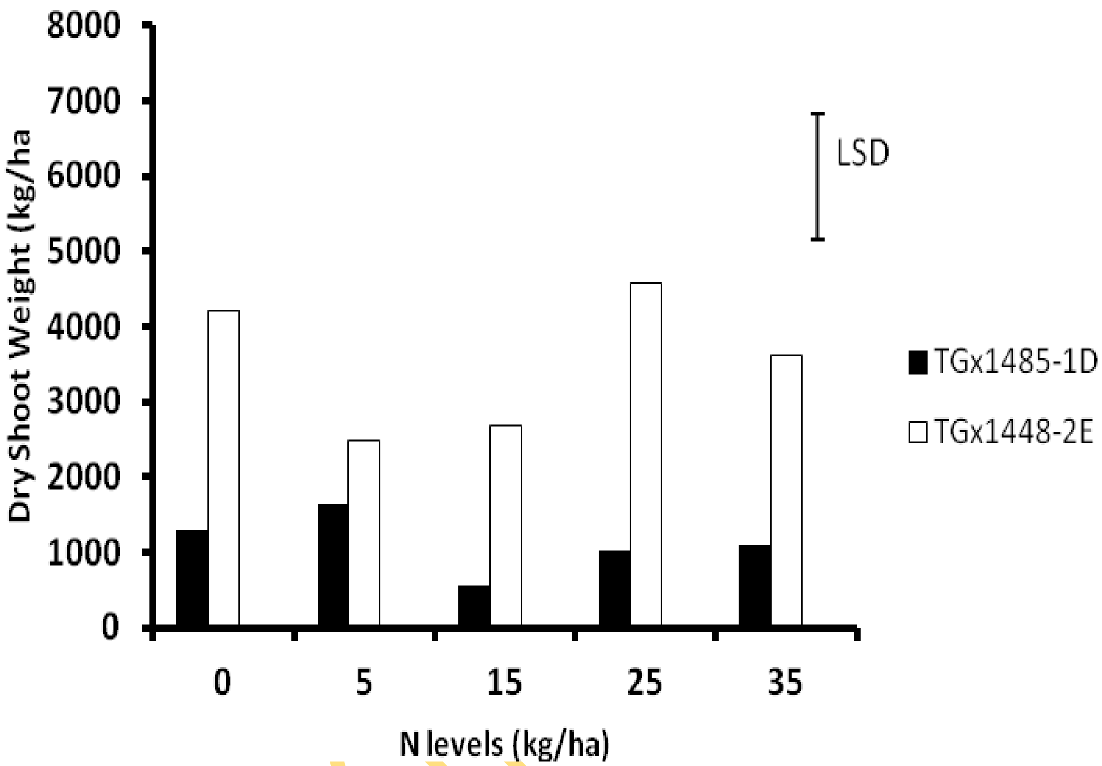

Figure 4.9: The effect of N levels on dry shoot weight of soya bean at harvest in Gbonran field

4.5 CROPGRO - Soya bean Model

4.5.1 Soil profile description and characterization

The texture of the soil ranges from loamy sand at the top becoming finer with depth to become sandy-clay loam (Table 4.7). The colour ranges from 7.5YR4/3 at the top to 2.5YR5/6 at the bottom of the profile. The bulk density of the soil is fairly normal, increasing from the top to the subsoil and later decreased down the profile. It ranges between 1.54 – 1.74g/cm^3. The saturated hydraulic conductivity of the horizons ranges from 0.264 – 0.469 cm^{3}cm^{-3}. The available moisture content generally increases with depth (Table 4.8). The slope ranges from 2 – 6 % at both locations. The soils have been classified as Iseyin and Sepeteri series (Moss 1975) for Ipapo and Gbonran locations respectively. The chemical characteristics (Table 4.9) of the horizons revealed that soil acidity increases with depth, organic C and total N decrease down the profile in an irregular pattern. The soils are generally classified at higher category as ferric luvisols / ferric luvisol (Eutric) (FAO, 2006) respectively for soils from Ipapo (Plate 1) and Gbonran (Plate 2) locations. The detailed soil description and characterization is given in Appendix V.

4.5.2: Soybean genetic coefficient determination

Genselect, a utility for selecting experiment and treatments for cultivar coefficient estimation was employed. The GenSelect wizard of the model software was used to generate genetic coefficients for the two soya bean varieties. The generated genetic coefficient is shown in Table 4.10.

4.5.3 Crop growth and development data

The model prediction of number of days to anthesis, first pod, first seed and physiological maturity was accurate for the two soya bean varieties and for all nitrogen rates applied during year 2009 cropping season in Ipapo field (Table 4.11). Difference of one (1) day was observed for soya bean phenological parameters with different nitrogen application rates. There were wide margins between the simulated and measured yield at harvest with variety TGx1485-1D showing wider margins in Ipapo field during 2009 cropping season (Table 4.11). Conversely, in Gbonran field, there was accurate prediction of soya bean phenology with difference of one (1) day observed with different nitrogen application rates (Table 4.12). The yield at harvest followed trend in Ipapo field but with wider margins between simulated and measured yield for variety TGx1485-1D and TGx1448-2E respectively (Table 4.12).

Table 4.7: Physical characteristics of the soil profile in Ipapo and Gbonran.

Depth (cm)	Clay	Silt	Sand	Textural Class (USDA)	Colour
	———	g / kg	———		
Ipapo					
0 -18	100	54	846	LS	7.5YR4/3
18 -66	460	54	486	SC	7.5YR5/6
66 -90	400	94	506	SC	7.5YR5/8
90 -128	320	74	606	SCL	7.5YR4/6
128 -150	320	74	606	SCL	2.5YR5/6
Gbonran					
0-26	80	34	846	LS	7.5YR4/3
26 -64	400	74	526	SC	7.5YR5/8
64 -118	280	74	646	SCL	7.5YR5/8, 7.5YR5/6
118 -134	180	274	546	SL	7.5YR4/6, 7.5YR6/8
134 170	360	94	546	SC	2.5YR4/3

Legend:

LS - Loamy sand

SC - Sandy clay

SL - Silty loam

SCL - Sandy clay loam

Table 4.8: Hydrological properties of the soil profile

Depth (cm)	SLMH	SLLL (cm^3/cm^3)	SDUL (cm^3/cm^3)	SSAT (cm^3/cm^3)	SRGF	SSKS cm hr^{-1}	SBDM (g/cm^3)
Ipapo							
18	AP	0.014	0.111	0.387	1.0	19.93	1.63
66	BW	0.017	0.110	0.295	1.0	6.31	1.74
90	BW	0.021	0.112	0.264	1.0	12.9	1.61
128	BW	0.016	0.113	0.407	0.6	2.01	1.64
150	BC	0.098	0.117	0.469	0.0	1.77	1.54
Gbonran							
26	AP	0.011	0.107	0.357	-99	0.69	1.59
64	BW	0.028	0.117	0.449	-99	3.00	1.49
118	BW	0.010	0.111	0.714	-99	2.14	1.51
134	BW	0.022	0.118	0.469	-99	4.81	1.49
170	BC	0.078	0.121	0.376	-99	54.4	1.24

Legend:

SLMH- Soil morphological horizon

SLLL - Lower limit of plant extractable soil water (permanent wilting point)

SDUL - Drained upper limit of soil (field capacity)

SSAT - Soil saturation

SRGF - Soil root growth factor

SSKS - Saturated hydraulic conductivity

SBDM- Soil bulk density

-99 - Data not available

Table 4.9: Chemical characteristics of the soil of the study area

						Exch. Cations (c mol/kg)						Extractable micronutrients (mg/kg)			
Profile depth (cm)	pH	TOC	TN	Avail. P	Ex. Acidity	Ca	Mg	Na	K	CEC	BS	Mn	Fe	Cu	Zn
Ipapo															
0 – 18	6.7	5.0	0.5	20.2	0.6	2.5	0.6	0.3	0.1	3.6	85.6	40.7	9.8	2.2	1.3
18 – 66	5.8	5.8	0.6	7.4	0.3	4.1	1.2	0.3	0.1	5.7	95.0	12.7	11.5	0.9	0.4
66 – 90	5.6	5.0	0.5	3.6	0.6	4.4	1.4	0.3	0.1	6.2	91.2	50.6	55.9	0.7	0.6
90 – 128	5.6	5.0	0.5	5.2	1.4	3.6	1.4	0.4	0.1	5.6	80.0	4.1	14.2	0.4	0.4
128 – 150	5.6	2.3	0.2	3.2	0.6	4.9	1.3	0.4	0.1	6.8	91.9	6.4	20.0	0.4	0.4
Gbonran															
0 – 26	6.7	20.9	2.2	17.7	0.3	7.7	1.0	0.4	0.3	9.4	97.0	76.1	9.1	1.1	1.3
26 – 64	6.0	10.5	1.1	11.1	0.3	4.4	1.2	0.3	0.2	6.1	95.3	38.6	9.6	1.1	0.5
64 – 118	5.7	1.6	0.2	5.6	0.3	3.4	1.2	0.3	0.2	5.2	94.5	19.9	12.5	0.3	1.0
118 – 134	5.6	5.0	0.5	1.5	1.6	4.2	1.1	0.3	0.2	5.8	78.4	11.8	11.7	0.2	0.6
134 – 170	5.6	5.0	0.5	2.2	0.4	3.1	1.1	0.3	0.1	4.6	91.9	3.6	12.7	0.4	0.4

Legend:

TOC - Total Organic Content

TN - Total Nitrogen

CEC - Cation Exchange Capacity

BS - Base saturation

Plate 1: Iseyin series (Ferric luvisol) found at Ipapo with sandy clay to sandy clay loam subsoil and dark red hue down the profile.

Plate 4.2: Sepeteri series [Ferric luvisol (Eutric)] found at Gbonran. Note the very coarse and stony topsoil and subsoil.

Table 4.10: Modified genetic coefficients for soya bean varieties.

Parameter	Unit	TGx1485-1D	TGx1448-2E
EM-FL	PTD	13.09	11.88
FL-SH	PTD	0.29	0.34
FL-SD	PTD	25.00	28.90
SD-PM	PTD	9.00	7.00
FL-LF	PTD	13.80	13.50
SLAVR	cm^2g-^{1}	30.00	31.50
SIZLF	cm^2	25.00	15.00
WTPSD	g	1.00	1.03
CSDL	hr	300.00	300.00
PPSEN	l/hr	190.00	180.00
LFMAX	mg $CO_2m^{-2}s^{-1}$	1.00	1.00
XFRT		0.19	0.18
SFDUR	PTD	25.50	22.00
SDPDV	number/pod	2.40	2.05
PODUR	PTD	10.50	10.00

PTD- Photothermal Days (= thermal time x maximum sunshine hour in a day)

Table 4.11: Comparison of selected field observation and their simulation in Ipapo, 2009

Variable	TGx1485-1D			TGx1448-2E		
	Simulated	Measured	Diff	Simulated	Measured	Diff
No N application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	55	1
First seed day (dap)	49	49	0	67	67	0
Physiol. Mat. day (dap)	79	79	0	101	100	1
Yield at harvest mat. (kg [dm]/ha	1705	1546	159	1783	1712	61
5kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiol. Mat. day (dap)	79	80	1	101	101	0
Yield at harvest mat. (kg [dm]/ha	1711	1577	134	1784	1753	31
15kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiol. Mat. day (dap)	79	79	0	101	101	0
Yield at harvest mat. (kg [dm]/ha	1704	1567	137	1774	1741	33
25kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiological maturity day (dap)	79	79	0	101	101	0
Yield at harvest maturity (kg [dm]/ha	1698	1583	115	1771	1766	5
35kg N/ha Application						
Anthesis day (dap)	33	34	1	44	44	0
First pod day (dap)	43	44	1	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiological maturity day (dap)	79	79	0	101	101	0
Yield at harvest mat. (kg [dm]/ha	1726	1594	132	1783	1778	5

dap – days after planting

Table 4.12: Comparison of selected field observation and their simulation in Gbonran, 2009

Variable	TGx1485-1D			TGx1448-2E		
	Simulated	Measured	Diff	Simulated	Measured	Diff
No N application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	66	1
Physiol. Mat. day (dap)	79	79	0	102	102	0
Yield at harvest mat. (kg [dm]/ha	1614	1500	114	1756	1610	146
5kg N/ha Application						
Anthesis day (dap)	33	33	0	44	43	1
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiol. Mat. day (dap)	79	79	0	102	102	0
Yield at harvest mat. (kg [dm]/ha	1612	1535	77	1758	1635	123
15kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiol. Mat. day (dap)	79	79	0	102	101	1
Yield at harvest mat. (kg [dm]/ha	1612	1522	90	1767	1630	137
25kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiological maturity day (dap)	79	79	0	102	102	0
Yield at harvest maturity (kg [dm]/ha	1606	1564	42	1774	1670	104
35kg N/ha Application						
Anthesis day (dap)	33	33	0	44	44	0
First pod day (dap)	43	43	0	56	56	0
First seed day (dap)	49	49	0	67	67	0
Physiological maturity day (dap)	79	79	0	102	103	1
Yield at harvest mat. (kg [dm]/ha	1597	1587	10	1779	1693	86

dap – days after planting

In 2010 cropping season, however, model prediction followed the trend of the previous cropping season with 0 – 1 day difference in soya bean growth and development parameters such as number of days to anthesis, first pod, first seed and physiological maturity at various nitrogen application rates in Ipapo field (Table 4.13). There were wide gaps in yield at harvest maturity which decreased as nitrogen application rates increased (Table 4.13). Conversely, in Gbonran field, model prediction followed the trend of the previous cropping season with 0 – 1 day difference in soya bean phenology; however, very wide yield gap existed particularly for variety TGx1448-2E (Table 4.14).

4.5.4 Root Mean Square Error and Percentage Error

The root mean square error (RMSE) and percentage error (PE) increased as the nitrogen application rate increased for number of days to anthesis and days to physiological maturity of variety TGx1485-1D. The RMSE values ranged from 0 – 0.9, while PE values ranged from 0 – 2.6 % for both soya bean varieties. However, these parameters increased as N rates increased with respect to variety TGx1485-1D. The RMSE and PE also decreased as N rates increased for the number of days to anthesis and days to first seed in variety TGx1448-2E and undulating in respect of number of days to first pod and physiological maturity (Table 4.15). The RMSE and PE values were low for soya bean phenology (< 10 %) but high for yields of variety TGx1448-2E with values greater than 60 %. (Table 4.15). The cumulative PE for phenology of both varieties in increasing order are 3.1% (15kg N/ha), 5.1% (5kg N/ha), 6.8% (control), 7.0% (25kg N/ha) and 8.3% for 35kg N/ha treatment.

4.5.5 Soil water balance

During 2009 cropping season in Ipapo field, runoff accounted for the highest share of total precipitation and drainage accounted for the lowest share (Table 4.16). Variety TGx1448-2E utilized more water for transpiration activities in Ipapo (Table 4.16). Similar observations were noticed in Gbonran field (Table 4.17). There were differential precipitation amount captured by the plants with variety TGx1448-2E capturing more precipitation than TGx1485-1D (Tables 4.16 and 4.17). Runoff and transpiration were higher with variety TGx1448-2E but with lesser amount of drainage (Table 4.16 and 4.17). During 2010 cropping season in Ipapo field, the trend of water balance followed that of previous year 2009; however, more precipitation was captured under variety TGx1448-2E (Table 4.18).
More runoffs were also observed than in the previous year, but with a lesser drainage. Similar trend of 2009 also occurred at Gbonran location (Table 4.19).

Table 4.13: Comparison of selected field observation and their simulation in Ipapo, 2010

Variable	TGx1485-1D			TGx1448-2E		
	Simulated	Measured	Diff.	Simulated	Measured	Diff.
No N application						
Anthesis day (dap)	32	32	0	44	44	0
First pod day (dap)	43	42	1	57	57	0
First seed day (dap)	48	48	0	68	67	1
Physiol. Mat. day (dap)	79	79	0	112	111	1
Yield at harvest mat. (kg [dm]/ha	1420	1241	179	3352	1795	1557
5kg N/ha Application						
Anthesis day (dap)	32	32	0	44	44	0
First pod day (dap)	43	43	0	57	57	0
First seed day (dap)	48	48	0	68	67	1
Physiol. Mat. day (dap)	79	79	0	112	111	1
Yield at harvest mat. (kg [dm]/ha	1407	1287	120	3361	1808	1553
15kg N/ha Application						
Anthesis day (dap)	32	32	0	44	44	0
First pod day (dap)	43	43	0	57	57	0
First seed day (dap)	48	48	0	68	68	0
Physiol. Mat. day (dap)	79	79	0	112	111	1
Yield at harvest mat. (kg [dm]/ha	1416	1376	40	3367	1856	1511
25kg N/ha Application						
Anthesis day (dap)	32	32	0	44	44	0
First pod day (dap)	43	43	0	57	58	1
First seed day (dap)	48	48	0	68	68	0
Physiological maturity day (dap)	79	80	1	112	111	1
Yield at harvest maturity (kg [dm]/ha	1431	1371	60	3372	1857	1515
35kg N/ha Application						
Anthesis day (dap)	32	31	1	44	44	0
First pod day (dap)	43	44	1	57	57	0
First seed day (dap)	48	49	1	68	68	0
Physiological maturity day (dap)	79	80	1	112	112	0
Yield at harvest mat. (kg [dm]/ha	1429	1342	87	3372	1887	1485

dap – days after planting

Table 4.14: Comparison of selected field observation and their simulation in Gbonran, 2010

Variable	TGx1485-1D			TGx1448-2E		
	Simulated	Measured	Diff	Simulated	Measured	Diff
No N application						
Anthesis day (dap)	32	32	0	44	43	1
First pod day (dap)	43	42	1	57	57	0
First seed day (dap)	48	48	0	68	67	1
Physiol. Mat. day (dap)	78	77	1	112	112	0
Yield at harvest mat. (kg [dm]/ha	1115	1095	20	3270	1504	1766
5kg N/ha Application						
Anthesis day (dap)	32	32	0	44	43	1
First pod day (dap)	43	43	0	57	57	0
First seed day (dap)	48	48	0	68	68	0
Physiol. Mat. day (dap)	78	78	0	112	112	0
Yield at harvest mat. (kg [dm]/ha	1088	1072	16	3279	1615	1664
15kg N/ha Application						
Anthesis day (dap)	32	32	0	44	43	1
First pod day (dap)	43	43	0	57	57	0
First seed day (dap)	48	48	0	68	68	0
Physiol. Mat. day (dap)	78	78	0	112	112	0
Yield at harvest mat. (kg [dm]/ha	1112	1080	32	3280	1650	1630
25kg N/ha Application						
Anthesis day (dap)	32	32	0	44	43	1
First pod day (dap)	43	43	0	57	57	0
First seed day (dap)	48	48	0	68	68	0
Physiological maturity day (dap)	78	78	0	112	112	0
Yield at harvest maturity (kg [dm]/ha	1115	1095	20	3305	1662	1643
35kg N/ha Application						
Anthesis day (dap)	32	33	1	44	44	0
First pod day (dap)	43	44	1	57	58	1
First seed day (dap)	48	48	0	68	68	0
Physiological maturity day (dap)	77	78	1	112	112	0
Yield at harvest mat. (kg [dm]/ha	1109	1070	39	3364	1697	1667

dap – days after planting

Table 4.15: Root Mean Square Error and Percentage Error for soya bean varieties

TRT	Anthesis		DFP		DFS		DPM		Yield (kg/ha)	
	RMSE	PE (%)	RMSE	PE (%)	RMSE	PE (%)	RMSE	PE (%)	RMSE	PE (%)
Variety TGx1485-1D										
0	0.0	0.0	0.7	1.7	0.0	0.0	0.5	0.6	133.0	9.9
5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.6	98.2	7.2
15	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.6	85.9	6.2
25	0.5	1.5	0.5	1.2	0.0	0.0	0.7	0.9	68.9	4.9
35	0.9	2.6	0.9	2.0	0.5	1.0	0.9	1.1	81.6	5.8
Variety TGx1448-2E										
0	0.7	1.6	0.5	0.9	0.9	1.3	0.7	0.7	1180.0	71.3
5	0.7	1.6	0.0	0.0	0.5	0.7	0.5	0.5	1139.8	66.9
15	0.5	1.1	0.0	0.0	0.5	0.7	0.7	0.7	1113.5	64.8
25	0.5	1.1	1.0	1.8	0.0	0.0	0.5	0.5	1119.0	64.4
35	0.0	0.0	0.5	0.9	0.0	0.0	0.7	0.7	1117.1	63.3

Legend:

RMSE – Root square mean error (kg / ha)

PE - Percentage error (%)

TRT – Treatments in kg/ha

DFP - Days to first pod

DFS - Days to fist seed

DPM - Days to physiological maturity

Table 4.16: Soil water balance of Ipapo 2009

	N application rate (kg/ha)									
	0		5		15		25		35	
Parameters	mm	%	Mm	%	mm	%	mm	%	mm	%
TGx1485-1D										
Precipitation	521.9	100.0	521.9	100.0	521.9	100.0	521.9	100.0	521.9	100.0
Drainage	59.6	11.4	59.6	11.4	59.7	11.4	59.7	11.4	59.7	11.4
Runoff	201.9	38.7	201.9	38.7	201.9	38.7	201.9	38.7	201.9	38.7
Transpiration	106.8	20.5	107.3	20.6	107.0	20.5	107.0	20.5	107.2	20.5
TGx1448-2E										
Precipitation	550.1	100.0	550.1	100.0	550.1	100.0	550.1	100.0	550.1	100.0
Drainage	59.8	10.9	59.8	10.9	60.7	11.0	60.7	11.0	60.7	11.0
Runoff	210.3	38.2	210.4	38.2	210.4	38.2	210.4	38.2	210.4	38.2
Transpiration	147.3	26.8	148.0	26.9	145.5	26.4	147.9	26.9	148.2	26.9

%- Percentage contribution to water balance

Table 4.17: Soil water balance of Gbonran 2009

	N application rate (kg/ha)									
	0		5		15		25		35	
Parameters	mm	%	Mm	%	mm	%	mm	%	mm	%
TGx1485-1D										
Precipitation	521.9	100.0	521.9	100.0	521.9	100.0	521.9	100.0	521.9	100.0
Drainage	52.2	10.0	52.3	10.0	52.3	10.0	52.3	10.0	52.3	10.0
Runoff	202.2	38.7	202.2	38.7	202.2	38.7	202.2	38.7	202.2	38.7
Transpiration	104.5	20.0	104.2	20.0	104.3	20.0	104.4	20.0	104.7	20.1
TGx1448-2E										
Precipitation	592.0	100.0	592.0	100.0	592.0	100.0	592.0	100.0	592.0	100.0
Drainage	52.5	8.9	52.5	8.9	52.5	8.9	52.5	8.9	52.5	8.9
Runoff	237.6	40.1	237.6	40.1	237.6	40.1	237.6	40.1	237.6	40.1
Transpiration	145.5	24.6	145.7	24.6	145.9	24.6	146.0	24.7	146.7	24.8

%- Percentage contribution to water balance

Table 4.18: Soil water balance Ipapo 2010

	N application rate (kg/ha)									
	0		5		15		25		35	
Parameters	Mm	%	Mm	%	Mm	%	mm	%	mm	%
<u>TGx1485-1D</u>										
Precipitation	510.7	100.0	510.7	100.0	510.7	100.0	510.7	100.0	510.7	100.0
Drainage	37.9	7.4	37.8	7.4	37.8	7.4	37.8	7.4	37.9	7.4
Runoff	220.1	43.1	220.1	43.1	220.1	43.1	220.1	43.1	220.1	43.1
Transpiration	110.6	21.6	111.0	21.7	111.2	21.8	111.4	21.8	110.7	21.7
<u>TGx1448-2E</u>										
Precipitation	808.1	100.0	808.1	100.0	808.1	100.0	808.1	100.0	808.1	100.0
Drainage	37.3	4.6	37.2	4.6	37.0	4.6	37.0	4.6	36.9	4.6
Runoff	361.4	44.7	361.4	44.7	361.5	44.7	361.5	44.7	361.5	44.7
Transpiration	220.7	27.3	220.8	27.3	221.6	27.4	221.9	27.5	222.6	27.5

%-Percentage contribution to water balance

Table 4.19: Soil water balance Gbonran 2010

	N application rate (kg/ha)									
	0		5		15		25		35	
Parameters	Mm	%	Mm	%	Mm	%	mm	%	mm	%
TGx1485-1D										
Precipitation	510.3	100.0	510.3	100.0	510.3	100.0	510.3	100.0	510.3	100.0
Drainage	29.5	5.8	29.2	5.7	29.3	5.7	29.5	5.8	29.5	5.8
Runoff	220.4	43.2	220.4	43.2	220.4	43.2	220.4	43.2	220.4	43.2
Transpiration	103.7	20.3	104.4	20.5	104.0	20.4	103.6	20.3	102.0	20.0
TGx1448-2E										
Precipitation	808.1	100.0	808.1	100.0	808.1	100.0	808.1	100.0	808.1	100.0
Drainage	28.0	3.5	28.1	3.5	28.1	3.5	28.1	3.5	28.0	3.5
Runoff	362.0	44.8	362.0	44.8	362.0	44.8	362.0	44.8	362.0	44.8
Transpiration	213.4	26.4	214.2	26.5	213.4	26.4	214.4	26.5	214.8	26.6

%- Percentage contribution to water balance

CHAPTER FIVE

DISCUSSION

The soils of the study area are low in nutrients. The total N, available P, exchangeable K and the organic matter are low. The topsoils are characteristically loamy sand, having over 800 g/kg sand component. This intrinsic property makes the soil porous and hence devoid of colloidal materials or surfaces on which plant nutrients can adhere to (i.e. low nutrient retention capacity). This is also affecting the water holding capacity of the soil and consequently affecting the growth and development of soya bean. The mopping of N further impoverished the soils so that the effects of the treatments could be easily monitored on soya bean planted.

The meteorological data of the area indicated that the area witnessed high intensity rainfall events early during the rainy seasons in 2009 and 2010 cropping seasons. The rainy season in 2009 commenced in April and ended in October; hence there were five months of dry season (November - March). The planting of soya bean in June ending in 2009 coincided with a period of heavy downpour. The rainfall amount peaked in July, during which time fertilizer application was made. At this period, a humid environment persisted when rainfall amount far exceeded the potential evapo-transpiration (environmental demand for water), leaving the soil saturated with moisture, thus making the fertilizer amenable to quick dissolution and leaching /runoff losses because of continuous rain water. During the 2010 cropping season, however, the rain started earlier and was with greater intensity and amount. There were nine months of rain and three dry months (December - February). The cropping season also witnessed a heavy downpour with a short spell towards August ending which was not long enough to give soya bean a moisture stress. As a result of the rainfall intensity and amount, fertilizer applied seven days after planting was not effectively utilized because the soils were saturated with moisture, thereby making the water-soluble fertilizer (urea) amenable to leaching and erosion losses.

Soya bean exhibited varietal difference with respect to plant height in the study locations. The plant height increases with age. This is in agreement with earlier works by Okpara and Ibiam (2000) as well as Yusuf and Idowu (2001), who observed significant differences among soya bean cultivars for plant height. Similarly, as the nitrogen application rate increased, plant height increased in Iseyin soil series (Ipapo location). Similar results were reported by Varon *et al* (1984), Startling *et al* (1998), as well as Manral and Saxena (2003). The trend in plant height was irregular in response to starter nitrogen in Sepeteri soil series (Gbonran location). The reason for this varied response in soils from both locations could not be explained, yet nitrogen application did not influence soya bean plant height in the study locations. Nitrogen application is known to favour leaf production. This did not influence leaf production in Iseyin soil series but 25 kg/ha application influenced vegetative growth in Sepeteri soil series.

Soya bean exhibited varietal difference with respect to the number of days to flowering and this corroborated the classification based on maturity grouping, where early maturing variety, TGx1485-1D, flowered earlier than medium/late maturing variety, TGx1448-2E. However, starter N application did not affect this attribute in soya bean.

The stem and leaf weights of soya bean were similar irrespective of N application rates in soils from both locations. This showed that N application had no effect on soya bean plant biomass. Varietal reactions were different in terms of biomass production, where variety TGx1448-2E plants had heavier stem and leaf weights than those of TGx1485-1D. This indicated that variety TGx1448-2E possessed a superior gene controlling biomass accumulation in soya bean. It is worthy of note that while soya bean varieties showed mixed responses during the screenhouse studies, the effects of starter nitrogen application on all measured parameters were not significantly different in soils from both locations. This is in conformity to works from various researchers that the application of N fertilizer did not have any effect on the performance of legumes, soya bean inclusive (Hoeft *et al.*, 2000; Heatherly *et al.*, 2003; Scharf and Wiebood, 2003; Mehmet, 2008).

The differences in varietal responses to some of the measured parameters in the screenhouse were however confirmed during field trials. The weight of 100 seeds is an important yield contributing component. It reflects the magnitude of seed development which ultimately reflects the final yield of the crop. In Gbonran field, soya bean responded differently to nitrogen doses in terms of weight of 100 seeds. The seed weight and nitrogen dose was inversely related. This revealed that nitrogen application favoured vegetative growth and by extension, could hinder seed yield. This result was in contrary to the works of

Taylor *et al* (2005) and Mehmet (2008), which showed that as nitrogen level increases, there was increase in weight of 100 seeds. There is also a report that 100 seeds weight is not affected by nitrogen application (Barker and Sawyer (2005). The two soya bean varieties also responded differently in terms of weight of 100 seeds in Ipapo field with TGx1448-2E producing 30% heavier seeds than TGx1485-1D. This might be ascribed to the genetic composition of the varieties.

Nitrogen application did not affect soya bean's shoot N-content but the varieties responded differently, with variety TGx1485-1D plants accumulating more nitrogen in shoot than those of TGx1448-2E. This might be due to the genetic composition of variety TGx1485-1D.

As regards shoot dry weight, various nitrogen application rates did not produce any statistically significant effects, although, shoot dry weight of soya bean increased as nitrogen rates increased. Similar report was given by Manral and Saxena (2003), who posited that soya bean dry matter accumulation increased with nitrogen rates. The two varieties responded differently with variety TGx1448-2E plants producing heavier shoot dry weight than those of TGx1485-1D. This could be ascribed to the genetic make-up of the varieties.

The grain yield response of soya bean to nitrogen application varied. While nitrogen rates did not influence grain yield in Sepeteri series soils of Gbonran field, positive effects were observed in Iseyin soil series of Ipapo field. Similar positive results were reported in some field investigations (Startling *et al.*, 1998; Taylor *et al.*, 2005; Osborne and Riedell, 2006) but not in others (Ying *et al.*, 1992). There was varietal response to soils from both locations. This is in agreement with earlier works by Okpara and Ibiam (2000) as well as Yusuf and Idowu (2001) who observed significant differences among soya bean cultivars.

Harvest index is a measure of conversion of plant total dry matter to yield. It is the partitioning of assimilated photosynthate to the seed. The application of nitrogen rates resulted in marked differences in soya bean response in terms of harvest index, where 5 kg N/ha gave the highest harvest index and 35 kg N/ha the lowest. This attribute as exhibited in Ipapo field could be ascribed to the genetic make-up of the soya bean varieties. No such response was observed in Gbonran field, but the two varieties responded differently with variety TGx1485-1D having a higher index than TGx1448-2E. This revealed that variety TGx1485-1D is more efficient in converting assimilated photosynthate to seeds. It is also a function of the genetic composition of the variety.

Although soya bean response to nitrogen fertilization has been studied extensively; while some researchers reported positive responses, others reported negative yield responses

(Salvagiotti *et al*., 2008). The finding of this work revealed that starter nitrogen dose has little or no effect on the performance of soya bean in the study area. This is in line with works by Hoeft *et al* (2000) and Heatherly *et al* (2003), whose reports have indicated that in most cases, soya bean grown on most soils does not respond to low rates of starter nitrogen. Randall and Schmitt (1998) in studies on the effects of fertilizer-N application to soya bean in Minnesota, concluded that soya bean yield could be increased by addition of soil applied fertilizer, however responses were inconsistent and varied with season, variety, rate, fertilizer source, application timing, and other yield- limiting factors. Similarly, Oplinger and Bundy (1998) in a review of soya bean N fertilization research over many years in Wisconsin summarized that in a few cases, yields were increased but in the majority of cases there was no response to applied N.

The variation in the effects of nitrogen starter-doses, to a large extent, depended on native soil fertility. The crucial concern is to reach the minimal soil fertility level required for good soya bean growth and performance. High yielding soya bean varieties such as TGx1485-1D and TGx1448-2E require enough P and also a starter dose of nitrogen for proper establishment because soils in the southern savanna zone of Nigeria have low fertility level. For instance, soils in both locations had very low P values (below the critical value of 15 mg P kg^{-1} soil). Even though soya bean can acquire P in the soil through other mechanisms, the roots of plants dependent on BNF had been reported to have a higher concentration of P than those supplied with nitrate (Breeze and Hopper, 1987). The N benefit of grain legumes to the soil depends on the N-fixing capability of the legumes and the native fertility of the soil (Sanginga *et al*., 1997). The quantification of the contribution of BNF to crop yield in this study is missing because the percentage of N fixed contained in the roots and nodules is outside the scope of this study and has not been accounted for. It has been reported that there is a strong interaction between genotype, soil type and inoculate on nitrogen fixation (Van Jaarsveld *et al*., 2002).

Consequent upon variability in rainfall pattern, especially rainfall distribution/amount and in order to further understand the underlying factors responsible for the performance of soya bean in the study region, CROPGRO-Soya bean of DSSAT model was employed to test the reliability of measured data and to unravel the dynamics of activities that occurred within the soil system as a result of nitrogen fertilizer application in the prevailing weather conditions. The results clearly demonstrated that the cropping system model (CROPGRO-soya bean) simulated soya bean phenology quite well for both varieties studied, but poorly for the yields of variety TGx1448-2E. The RMSE indicated the magnitude of the average error, but provides no information on the relative size of the average difference between the predicted and measured values; hence it was expressed as a percentage error of means of observations (PE). If the PE is less than ten percent (10%), the prediction is acceptable. The measured phenological data compared very well with its simulated counterparts generated by the model with differences not more than 1 day, which is far less than 10% in PE values for the number of days to anthesis, days to first pod, days to first seed and days to physiological maturity and yields of variety TGx1485-1D under different nitrogen application rates. This is an indication that the measured data were very reliable for these parameters with the reliability index ranking of 15kg N/ha > 5kg N/ha > 0kg N/ha> 25kg N/ha> 35kg N/ha. However, there were very high differences (with high PE values) between the simulated and measured yield values of variety TGX1448-2E. Thus, the model prediction of the phenological data was very good for both varieties, but the model prediction of the yield for variety TGx1448-2E was poor. The poor yield prediction by DSSAT model according to Banterng *et al*. (2004) was that the model design did not take into cognizance the effects of pests and diseases, hence contributing to the model's over-estimation of yield values.

The soil water balance output of the model revealed that runoff fell within 39 to 40 % in 2009, and in 2010, runoff accounted for between 43 to 45 % of the rainfall received during the cropping season. This implied that there was likelihood of dissolution and movement of mobile nutrients (especially from urea) during the cropping season and hence, is unavailable during the crucial time (Buman *et al.*, 2004; Babalola *et al.*, 2007). The deep drainage losses ranged from 3.5% in 2010 to 11% in 2009 of the total rainfall during the cropping seasons. This indicated that, although, some losses were from drainage, the bulk of the losses were through runoff. Hence, any conservation that would preserve water and prevent runoff will probably improve the N-use efficiency of soya bean in these fields. The adoption of an efficient soil tillage and water conservation practices geared towards the reduction of runoff and conservation of the soil and water such as minimum tillage and mulching would improve soil-water-nutrient retention for crop growth and development (Thierfelder *et al.*, 2005).

Variety TGx1448-2E also utilized more water for its transpiration processes, an activity closely related to plant growth and biomass production. This might be responsible for its higher dry matter or biomass production.

CHAPTER SIX

SUMMARY AND CONCLUSIONS

This study was undertaken to determine the influence of nitrogen starter dose on the performance of two soya bean varieties in the southern Guinea savanna of Nigeria. The study was conducted in three phases:

1. Screen-house studies using soils from Ipapo and Gbonran in Itesiwaju Local Government area of Oyo State, lying within the southern Guinea savanna of Nigeria was carried out in 2008 at the Department of Agronomy, University of Ibadan.
   The set-up was a 2 x 7 factorial experiment in a randomized complete block design with three replications.
2. Field trials were also conducted in the two locations in 2009 and 2010. There were 5 x 2 factorial experiments in a split-plot arrangement. The experiments were rain-fed. Climatic data of 30 years spanning 1981 - 2010 were obtained from National Meteorological Agency (NIMET) zonal station, Iseyin.
3. The DSSAT (CROPGRO - Soya bean) model was used to assess weather variability to simulate growth and yield of soya bean and compare with field observations. As pre-conditions to modeling, screen-house experiments were conducted to measure some phenological data which were fed into the model software in order to generate the genetic coefficients (GC) of soya bean required by the model to run successfully. The genetic coefficients were generated according to the procedures highlighted by Mavromatis *et al* (2001) and fed into the model application which culminated in various model outputs used to test reliability of data.

Based on the foregoings, the following conclusions and recommendations were arrived at:-

i) The application of starter nitrogen did not affect the yield of soya bean but 15 kg N/ha enhanced the yield of soya bean grown on ferric luvisol.

ii) There were varietal differences between the two soya bean varieties in response to the soil and climatic conditions of the southern guinea savanna agro-ecology of Oyo State, Nigeria.

iii) Variety TGx1485-1D exhibited varietal supremacy in terms of shoot N-content and seed production.

iv) Variety TGx1448-2E exhibited dominance in terms of foliage and biomass production.

v) The CROPGRO - Soya bean model accurately predicted days to anthesis, first pod, first seed and physiological maturity with very low PE values, hence the model's prediction was excellent and could be used to gauge the performance of soya bean varieties under different environmental conditions.

vi) Nitrogen application rates exhibited a reliability index ranking of 15kg N/ha > 5kg N/ha > 0kg N/ha> 25kg N/ha> 35kg N/ha with CROPGRO - soya bean model to predict soya bean phenology.

vii) Variety TGx1485-1D would be a better variety in environment of less water availability such as the dry regions of the northern guinea savanna.

viii) Although, some N losses were from deep drainage ($\leq$ 5% of total cropping season rainfall), the bulk of the losses were through runoff, accounting for $\leq$ 45% of the total cropping season rainfall in the two seasons studied. Hence, any conservation measure that would preserve water and prevent runoff would improve the N-use efficiency of soya bean in these fields.

The increased rate of N leaching/runoff from inorganic fertilizer into underground water is a major source of sub-surface and ground water pollution. Apart from this ground water pollution, the emerging trend of negative nutrient balances in cropping systems associated with continuous sole application of inorganic fertilizer (Vanlauwe, *et al.*, 2001; Babalola *et al.*, 2007) can be substantially reduced by practices that would conserve soil, water and nutrients in order to ameliorate such soil related constraint to crop production. Therefore, such practices could be adopted for future studies in the region so as to enhance N availability and soil organic matter improvement. This might also reduce leaching and erosion/runoff processes in the region by improving soil physical and hydrological properties, thus enhancing sustainable water and nitrogen utilization.

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APPENDIX IA

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*EXP.DETAILS: NGIP0901SB IPAPO, N STARTER DOSE ON SOYBEAN

*GENERAL
@PEOPLE
 OYATOKUN, O.S., OLUWASEMIRE, K.O. AND ADEOYE G.O.
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@SITE
 IPAPO, ITESIWAJU LOCAL GOVT. AREA, OYO STATE

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 09 NO N APPLIED            1  1  0  1  1  0  1  1  0  0  0  0  1
 2 1 1 0 09 5 KG N PER HA           1  1  0  1  1  0  2  1  0  0  0  0  1
 3 1 1 0 09 15 KG N PER HA          1  1  0  1  1  0  3  1  0  0  0  0  1
 4 1 1 0 09 25 KG N PER HA          1  1  0  1  1  0  4  1  0  0  0  0  1
 5 1 1 0 09 35 KG N PER HA          1  1  0  1  1  0  5  1  0  0  0  0  1
 6 1 1 0 09 NO N APPLIED            2  1  0  1  1  0  1  1  0  0  0  0  1
 7 1 1 0 09 5 KG N PER HA           2  1  0  1  1  0  2  1  0  0  0  0  1
 8 1 1 0 09 15 KG N PER HA          2  1  0  1  1  0  3  1  0  0  0  0  1
 9 1 1 0 09 25 KG N PER HA          2  1  0  1  1  0  4  1  0  0  0  0  1
10 1 1 0 09 35 KG N PER HA          2  1  0  1  1  0  5  1  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 SB IB0060 TGx 1485-1D
 2 SB IB0061 TGx 1448-2E

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGIP0901 NGIP       -99     0 IB000     0     0 00000 -99    150  NGIP090001 -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS
 1           29.63          -82.37        40                0     0     0     0

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    FA 09180   100   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1     5 0.111   -99   -99
 1    15 0.110   -99   -99
 1    30 0.112   -99   -99
 1    45 0.113   -99   -99
 1    60 0.117   -99   -99
 1    75 0.107   -99   -99
 1    90 0.117   -99   -99
 1   120 0.111   -99   -99
 1   135 0.118   -99   -99
 1   150 0.121   -99   -99

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL                        PLNAME
 1 09180 09184  26.7  26.7     S     R    75     0     4   -99   -99   -99   -99   -99                        -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 09188 FE005 AP004     5     0   -99   -99   -99   -99   -99 -99
 2 09188 FE005 AP004     5     5   -99   -99   -99   -99   -99 -99
 3 09188 FE005 AP004     5    15   -99   -99   -99   -99   -99 -99
 4 09188 FE005 AP004     5    25   -99   -99   -99   -99   -99 -99
 5 09188 FE005 AP004     5    35   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 09160 RE001     0   -99   -99   -99   -99   -99   -99 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 09275   -99   -99   -99   -99   -99
 2 09294   -99   -99   -99   -99   -99

*SIMULATION CONTROLS

@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE              1     1     S 09156  2150 SOY, N STARTER DOSE
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     Y     Y     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
 1 ME              M     M     E     R     S     L     R     1     G
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT  LONG CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     N     N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          09180 09180    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    70   100 IB001 IB001    10   .75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 IB001 IB001
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 09365   100     0
```

APPENDIX IB

```
*EXP.DETAILS: NGIP0901SB IPAPO, N STARTER DOSE ON SOYBEAN

*GENERAL
@PEOPLE
 OYATOKUN, O.S., OLUWASEMIRE, K.O. AND ADEOYE
@ADDRESS
 UNIVERSITY OF IBADAN,IBADAN, OYO STATE,NIGERIA
@SITE
 GBORAN,ITESIWAJU LOCAL GOVT. AREA, OYO STATE

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 09 NO N APPLIED            1  1  0  1  1  0  1  1  0  0  0  0  1
 2 1 1 0 09 5 KG N PER HA           1  1  0  1  1  0  2  1  0  0  0  0  1
 3 1 1 0 09 15 KG N PER HA          1  1  0  1  1  0  3  1  0  0  0  0  1
 4 1 1 0 09 25 KG N PER HA          1  1  0  1  1  0  4  1  0  0  0  0  1
 5 1 1 0 09 35 KG N PER HA          1  1  0  1  1  0  5  1  0  0  0  0  1
 6 1 1 0 09 NO N APPLIED            2  1  0  1  1  0  1  1  0  0  0  0  1
 7 1 1 0 09 5 KG N PER HA           2  1  0  1  1  0  2  1  0  0  0  0  1
 8 1 1 0 09 15 KG N PER HA          2  1  0  1  1  0  3  1  0  0  0  0  1
 9 1 1 0 09 25 KG N PER HA          2  1  0  1  1  0  4  1  0  0  0  0  1
10 1 1 0 09 35 KG N PER HA          2  1  0  1  1  0  5  1  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 SB IB0060 TGx 1485-1D
 2 SB IB0061 TGx 1448-2E

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGIP0902 NGIP       -99     0 DR000     0     0 00000 -99    150  NGIP090002 -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS
 1           29.63          -82.37        40                 0     0     0     0

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    FA 09166   100   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1     5 0.116   -99   -99
 1    15 0.105   -99   -99
 1    30 0.100   -99   -99
 1    45 0.107   -99   -99
 1    60 0.117   -99   -99
 1    75 0.107   -99   -99
 1    90 0.117   -99   -99
 1   120 0.101   -99   -99
 1   135 0.108   -99   -99
 1   150 0.125   -99   -99

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL                        PLNAME
 1 09180 09184  26.7  26.7     S     R    75     0     4   -99   -99   -99   -99   -99                        -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 09188 FE005 AP004     5     0   -99   -99   -99   -99   -99 -99
 2 09188 FE005 AP004     5     5   -99   -99   -99   -99   -99 -99
 3 09188 FE005 AP004     5    15   -99   -99   -99   -99   -99 -99
 4 09188 FE005 AP004     5    25   -99   -99   -99   -99   -99 -99
 5 09188 FE005 AP004     5    35   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 09160 IB001     0   -99   -99   -99   -99   -99   -99 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 09275   -99   -99   -99   -99   -99
 2 09294   -99   -99   -99   -99   -99

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE              1     1     S 09156  2150 SOY, N STARTER DOSE
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     Y     Y     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
 1 ME              M     M     E     R     S     L     R     1     G
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT  LONG CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     N     N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          09155 09200    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    70   100 IB001 IB001    10   .75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 IB001 IB001
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 09365   100     0
```

- APPENDIX IC

```
*EXP.DETAILS: NGIP1001SB IPAPO, N STARTER DOSE ON SOYBEAN

*GENERAL
@PEOPLE
 OYATOKUN, O.S., OLUWASEMIRE, K.O. AND ADEOYE G.O.
@ADDRESS
 UNIVERSITY OF IBADAN,IBADAN, OYO STATE,NIGERIA
@SITE
 IPAPO, ITESIWAJU LOCAL GOVT. AREA, OYO STATE

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 10 NO N APPLIED            1  1  0  1  1  0  1  1  0  0  0  0  1
 2 1 1 0 10 5 KG N PER HA           1  1  0  1  1  0  2  1  0  0  0  0  1
 3 1 1 0 10 15 KG N PER HA          1  1  0  1  1  0  3  1  0  0  0  0  1
 4 1 1 0 10 25 KG N PER HA          1  1  0  1  1  0  4  1  0  0  0  0  1
 5 1 1 0 10 35 KG N PER HA          1  1  0  1  1  0  5  1  0  0  0  0  1
 6 1 1 0 10 NO N APPLIED            2  1  0  1  1  0  1  1  0  0  0  0  1
 7 1 1 0 10 5 KG N PER HA           2  1  0  1  1  0  2  1  0  0  0  0  1
 8 1 1 0 10 15 KG N PER HA          2  1  0  1  1  0  3  1  0  0  0  0  1
 9 1 1 0 10 25 KG N PER HA          2  1  0  1  1  0  4  1  0  0  0  0  1
10 1 1 0 10 35 KG N PER HA          2  1  0  1  1  0  5  1  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 SB IB0060 TGx 1485-1D
 2 SB IB0061 TGx 1448-2E

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGIP1001 NGIP       -99     0 DR000     0     0 00000 -99    150  NGIP090001   -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS
 1           29.63          -82.37        40                 0     0     0     0

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    FA 10156   100   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1     5 0.111   -99   -99
 1    15 0.110   -99   -99
 1    30 0.112   -99   -99
 1    45 0.113   -99   -99
 1    60 0.117   -99   -99
 1    75 0.107   -99   -99
 1    90 0.117   -99   -99
 1   120 0.111   -99   -99
 1   150 0.118   -99   -99
 1   150 0.121   -99   -99

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL                        PLNAME
 1 10163 10167  26.7 18.69     S     R    75   -99     4   -99   -99   -99   -99   -99                        -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 10170 FE005 AP004     5     0   -99   -99   -99   -99   -99 -99
 2 10170 FE005 AP004     5     5   -99   -99   -99   -99   -99 -99
 3 10170 FE005 AP004     5    15   -99   -99   -99   -99   -99 -99
 4 10170 FE005 AP004     5    25   -99   -99   -99   -99   -99 -99
 5 10170 FE005 AP004     5    35   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 10156 IB001     0   -99   -99   -99   -99   -99   -99 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 10281   -99   -99   -99   -99   -99
 2 10281   -99   -99   -99   -99   -99

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE              1     1     S 10156  2150 SOY, N STARTER DOSE
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     Y     Y     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
 1 ME              M     M     E     R     S     L     R     1     G
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT  LONG CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     N     N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          10155 10200    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    70   100 IB001 IB001    10   .75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 IB001 IB001
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 10365   100     0
```

APPENDIX ID

```
*EXP.DETAILS: NGIP1002SB IPAPO, N STARTER DOSE ON SOYBEAN

*GENERAL
@PEOPLE
 OYATOKUN, O.S., OLUWASEMIRE, K.O. AND ADEOYE G.O.
@ADDRESS
 UNIVERSITY OF IBADAN,IBADAN, OYO STATE,NIGERIA
@SITE
 IPAPO, ITESIWAJU LOCAL GOVT. AREA, OYO STATE

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 1 0 10 NO N APPLIED            1  1  0  1  1  0  1  1  0  0  0  0  1
 2 1 1 0 10 5 KG N PER HA           1  1  0  1  1  0  2  1  0  0  0  0  1
 3 1 1 0 10 15 KG N PER HA          1  1  0  1  1  0  3  1  0  0  0  0  1
 4 1 1 0 10 25 KG N PER HA          1  1  0  1  1  0  4  1  0  0  0  0  1
 5 1 1 0 10 35 KG N PER HA          1  1  0  1  1  0  5  1  0  0  0  0  1
 6 1 1 0 10 NO N APPLIED            2  1  0  1  1  0  1  1  0  0  0  0  1
 7 1 1 0 10 5 KG N PER HA           2  1  0  1  1  0  2  1  0  0  0  0  1
 8 1 1 0 10 15 KG N PER HA          2  1  0  1  1  0  3  1  0  0  0  0  1
 9 1 1 0 10 25 KG N PER HA          2  1  0  1  1  0  4  1  0  0  0  0  1
10 1 1 0 10 35 KG N PER HA          2  1  0  1  1  0  5  1  0  0  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 SB IB0060 TGx 1485-1D
 2 SB IB0061 TGx 1448-2E

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGIP1002 NGIP       -99     0 DR000     0     0 00000 -99    150  NGIP090002 -99
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS
 1           29.63          -82.37        40                 0     0     0     0

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    FA 10156   100   -99     1     1   -99   -99   -99   -99   -99   -99 -99
@C  ICBL  SH2O  SNH4  SNO3
 1    15 0.116   -99   -99
 1    30 0.105   -99   -99
 1    45 0.100   -99   -99
 1    60 0.107   -99   -99
 1    75 0.117   -99   -99
 1    90 0.107   -99   -99
 1   105 0.117   -99   -99
 1   120 0.101   -99   -99
 1   135 0.108   -99   -99
 1   150 0.1250.098  -99   -99

*PLANTING DETAILS
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV  PLPH  SPRL                        PLNAME
 1 10170 10174  26.7 18.69     S     R    75   -99     4   -99   -99   -99   -99   -99                        -99

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 10177 FE005 AP004     5     0   -99   -99   -99   -99   -99 -99
 2 10177 FE005 AP004     5     5   -99   -99   -99   -99   -99 -99
 3 10177 FE005 AP004     5    15   -99   -99   -99   -99   -99 -99
 4 10177 FE005 AP004     5    25   -99   -99   -99   -99   -99 -99
 5 10177 FE005 AP004     5    35   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 10156 RE001     0   -99   -99   -99   -99   -99   -99 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 10280   -99   -99   -99   -99   -99
 2 10280   -99   -99   -99   -99   -99

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE              1     1     S 10156  2150 SOY, N STARTER DOSE
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     Y     Y     N     N     N     N     N
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
 1 ME              M     M     E     R     S     L     R     1     G
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     R     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT  LONG CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     Y     Y     Y     N     N     Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          10170 10170    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    70   100 IB001 IB001    10   .75
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 IB001 IB001
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 10365   100     0
```

APPENDIX IIA

*EXP.DATA (A): NGIP0901SB IPAPO, OYO STATE,NIGERIA NON-IRRIGATED

@TRNO	ETCM	PRCM	HDAT	HDAP	HWAM	NICM	ADAT	MDAT	PD1T	PDFT	HIAM	SDAT
1	345.7	401.3	275	95	1246	0.	210	263	223	231	.490	09156
2	345.7	401.3	275	95	1277	5.	210	262	223	231	.412	09156
3	345.7	401.3	275	95	1381	15.	211	263	224	231	.425	09156
4	345.7	401.3	275	95	1393	25.	211	264	224	232	.466	09156
5	345.7	401.3	275	95	1424	35.	211	263	224	232	.492	09156
6	424.4	471.4	294	114	1512	0.	218	276	232	237	.450	09156
7	424.4	471.4	294	114	1633	5.	218	276	233	238	.420	09156
8	424.4	471.4	294	114	1641	15.	219	277	233	238	.410	09156
9	424.4	471.4	294	114	1666	25.	219	278	234	238	.421	09156
10	424.4	471.4	294	114	1678	35.	219	278	234	238	.415	09156

APPENDIX IIB

*EXP.DATA (A): NGIP0902SB IPAPO, OYO STATE,NIGERIA NON-IRRIGATED

@TRNO	ETCM	PRCM	HDAT	HDAP	HWAH	NICM	ADAT	MDAT	PD1T	PDFT	HIAM	THAM	SDAT
1	345.7	401.3	275	95	1400	0.	210	263	223	231	.490	70.48	09156
2	345.7	401.3	275	95	1422	5.	211	264	223	231	.410	69.28	09156
3	345.7	401.3	275	95	1435	15.	211	264	224	231	.450	69.34	09156
4	345.7	401.3	275	95	1464	25.	212	264	224	230	.480	68.30	09156
5	345.7	401.3	275	95	1487	35.	210	263	224	231	.470	70.48	09156
6	424.4	471.4	294	115	1510	0.	218	276	232	237	.452	69.28	09156
7	424.4	471.4	294	115	1635	5.	218	277	232	237	.422	69.34	09156
8	424.4	471.4	294	115	1630	15.	219	277	233	238	.435	68.30	09156
9	424.4	471.4	294	115	1670	25.	219	278	233	238	.442	69.34	09156
10	424.4	471.4	294	115	1693	35.	218	278	234	238	.465	68.30	09156

APPENDIX IIC

*EXP.DATA (A): NGIP1001SB IPAPO, OYO STATE,NIGERIA NON-IRRIGATED

@TRNO	ETCM	PRCM	HDAT	HDAP	NICM	ADAT	MDAT	PD1T	PDFT	HWAH	HIAM	THAM	SDAT
1	447.3	768.8	281	118	0.	193	253	203	211	1241	.590	70.48	10156
2	447.3	768.8	281	118	5.	193	255	203	211	1287	.602	69.28	10156
3	447.3	768.8	281	118	15.	193	254	204	212	1376	.580	69.34	10156
4	447.3	768.8	281	118	25.	194	254	203	211	1391	.580	68.30	10156
5	447.3	768.8	281	118	35.	194	253	204	212	1442	.570	70.48	10156
6	447.3	768.8	281	118	0.	201	266	213	227	1495	.550	69.28	10156
7	447.3	768.8	281	118	5.	201	266	213	227	1508	.520	69.34	10156
8	447.3	768.8	281	118	15.	202	267	214	227	1556	.510	68.30	10156
9	447.3	768.8	281	118	25.	202	267	213	228	1557	.500	69.34	10156
10	447.3	768.8	281	118	35.	201	267	214	228	1587	.520	68.30	10156

APPENDIX IID

*EXP.DATA (A): NGIP1002SB GBORAN OYO STATE,NIGERIA NON-IRRIGATED

@TRNO	ETCM	PRCM	HDAT	HDAP	HWAH	NICM	ADAT	MDAT	PD1T	PDFT	HIAM	THAM	SDAT
1	416.5	727.2	280	110	1245	0.	198	260	210	218	.510	70.48	10156
2	416.5	727.2	280	110	1280	5	198	260	210	218	.500	69.28	10156
3	416.5	727.2	280	110	1372	15.	198	261	211	219	.470	69.34	10156
4	416.5	727.2	280	110	1395	25.	199	261	211	219	.450	68.30	10156
5	416.5	727.2	280	110	1440	35.	199	261	210	219	.470	70.48	10156
6	416.5	727.2	280	110	1494	0.	213	275	224	233	.540	69.28	10156
7	416.5	727.2	280	110	1515	5.	213	275	224	233	.550	69.34	10156
8	416.5	727.2	280	110	1550	15.	214	275	224	233	.510	68.30	10156
9	416.5	727.2	280	110	1562	25.	213	276	224	233	.550	69.34	10156
10	416.5	727.2	280	110	1577	35.	214	276	225	234	.510	68.30	10156

APPENDIX IIIA

*WEATHER DATA : IPAPO OYO STATE NIGERIA

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
IPAPO	8.130	3.500	249	26.7	9.8	2.0	-99.0

@DATE	SRAD	TMAX	TMIN	RAIN	DEWP	WIND	PAR
09001	20.8	35.0	20.0	0.0			
09002	20.2	33.0	19.0	0.0			
09003	21.2	33.8	19.1	0.0			
09004	21.0	33.7	19.0	0.0			
09005	21.1	33.8	21.6	0.0			
09006	21.2	34.4	21.5	0.0			
09007	20.6	34.7	22.3	0.0			
09008	20.2	34.8	22.4	0.0			
09009	19.0	34.0	22.5	1.7			
09010	20.2	33.5	21.6	0.0			
09011	20.1	34.5	22.2	0.0			
09012	15.4	33.6	23.7	0.0			
09013	18.7	34.6	22.1	0.0			
09014	21.5	36.1	20.3	0.0			
09015	22.2	37.0	21.6	0.0			
09016	21.6	33.4	22.6	0.0			
09017	21.7	34.4	22.1	0.0			
09018	21.5	35.4	22.5	0.4			
09019	19.4	35.4	20.8	0.0			
09020	21.9	33.5	20.9	0.0			
09021	21.1	33.5	20.5	0.0			
09022	22.2	33.4	20.2	0.0			
09023	20.6	33.1	19.5	0.0			
09024	22.4	34.0	19.5	0.0			
09025	22.5	34.0	19.8	0.0			
09026	22.5	34.0	20.1	0.0			
09027	22.2	36.0	21.6	0.0			
09028	19.2	33.4	22.6	0.0			
09029	21.6	34.3	23.4	0.0			
09030	19.1	33.6	23.0	0.0			
09031	18.2	33.6	23.6	0.0			
09032	21.7	35.0	22.4	0.0			
09033	20.2	34.6	22.4	0.0			
09034	17.6	32.9	22.5	0.0			
09035	20.6	34.5	22.2	0.0			
09036	21.6	37.0	22.5	0.0			
09037	21.8	36.0	23.2	0.0			
09038	21.9	36.4	23.4	0.0			
09039	21.2	36.5	23.5	0.0			
09040	17.2	34.1	23.2	0.0			
09041	21.5	36.4	24.0	0.0			
09042	22.1	35.3	21.8	0.0			
09043	23.0	35.9	23.7	0.0			
09044	21.3	35.8	23.4	0.0			
09045	20.6	35.4	24.0	0.0			

09046	16.9	34.1	21.9	0.0
09047	21.9	35.2	22.8	0.0
09048	20.7	35.5	22.8	0.0
09049	21.7	35.5	22.2	0.0
09050	22.1	35.5	23.0	0.0
09051	22.9	37.5	23.2	0.0
09052	21.2	30.0	23.7	0.0
09053	17.5	34.5	23.6	0.0
09054	23.3	38.0	24.1	0.0
09055	22.4	36.9	24.1	0.0
09056	19.8	36.2	24.4	10.6
09057	23.4	35.5	25.3	0.0
09058	22.4	34.7	21.2	0.0
09059	22.8	35.5	23.4	0.0
09060	17.2	34.9	24.2	0.0
09061	17.1	32.8	23.2	0.0
09062	20.5	35.4	22.8	0.0
09063	21.5	35.8	23.5	0.0
09064	22.3	36.6	23.2	0.0
09065	19.8	36.5	24.1	0.0
09066	21.6	35.6	24.2	0.0
09067	20.5	35.9	24.4	0.0
09068	23.4	37.4	23.0	0.0
09069	22.5	36.0	25.0	0.0
09070	21.5	36.1	23.9	0.0
09071	20.2	35.2	23.9	0.0
09072	14.5	33.6	23.6	0.0
09073	22.5	36.0	23.5	12.0
09074	24.5	36.2	22.5	0.0
09075	19.0	33.5	23.8	0.0
09076	21.3	34.5	23.8	0.0
09077	23.0	35.2	23.4	0.0
09078	19.3	33.7	21.5	0.0
09079	23.3	36.6	23.1	0.0
09080	22.9	35.8	23.4	0.0
09081	20.7	35.4	23.8	0.0
09082	21.9	35.6	24.6	0.0
09083	20.8	34.5	22.6	0.0
09084	22.5	36.0	23.3	0.0
09085	22.2	36.9	24.2	0.0
09086	22.9	36.0	24.2	0.0
09087	21.7	35.0	24.4	0.0
09088	21.0	34.1	23.0	0.0
09089	22.8	36.2	23.9	0.0
09090	20.2	35.0	25.0	17.0
09091	21.2	33.5	21.5	0.0
09092	22.4	35.4	23.5	0.0
09093	22.3	34.6	23.4	0.0
09094	21.2	34.8	22.9	23.4
09095	15.6	30.0	22.1	0.0

09096	22.3	32.5	23.0	3.2
09097	20.0	32.5	22.1	8.8
09098	16.7	30.2	20.6	0.0
09099	22.2	32.8	22.0	0.0
09109	22.5	33.3	22.6	0.0
09101	23.0	34.0	25.0	0.0
09102	17.0	31.9	23.7	10.1
09103	10.7	27.8	20.8	0.0
09104	23.8	32.4	21.6	0.0
09105	22.5	33.8	23.0	24.2
09106	14.8	29.9	20.6	0.0
09107	22.5	31.5	22.4	0.0
09108	17.6	31.6	22.5	31.2
09109	22.1	31.0	19.6	0.0
09110	24.6	33.3	23.3	0.0
09111	20.6	31.9	23.6	0.3
09112	16.5	32.9	21.6	0.0
09113	24.2	33.7	22.6	0.0
09114	5.5	28.6	23.2	1.2
09115	18.5	31.7	22.3	0.0
09116	15.9	31.2	23.6	0.0
09117	20.9	32.8	21.4	0.0
09118	20.7	31.2	23.4	0.0
09119	20.5	33.0	23.5	0.0
09120	19.2	33.2	24.4	0.0
09121	19.5	33.0	23.6	0.0
09122	21.0	33.5	24.4	3.9
09123	19.9	31.2	21.5	0.0
09124	20.9	32.6	23.6	25.2
09125	10.6	29.0	21.0	0.0
09126	13.0	27.0	23.4	19.8
09127	21.6	30.8	20.5	0.0
09128	19.9	31.0	22.6	0.0
09129	18.6	29.4	23.4	3.6
09130	19.3	28.9	21.0	0.0
09131	21.2	31.3	22.6	4.4
09132	23.9	32.2	23.4	0.0
09133	23.9	32.0	23.3	0.0
09134	20.1	32.0	23.0	12.1
09135	17.6	30.8	20.4	0.0
09136	21.6	32.2	22.2	9.1
09137	21.2	31.2	21.8	0.0
09138	22.1	32.5	22.8	0.0
09139	6.2	27.0	23.7	7.6
09140	19.1	30.9	21.0	0.0
09141	20.8	31.6	22.2	0.0
09142	19.9	31.7	22.5	0.0
09143	21.4	32.1	23.9	0.0
09144	22.7	32.5	23.1	0.0
09145	14.8	30.6	21.5	0.0

09146	20.0	31.4	21.4	0.0
09147	21.0	32.4	22.2	0.0
09148	21.6	33.4	22.2	0.0
09149	23.9	34.5	23.5	45.0
09150	14.6	29.5	21.5	0.0
09151	22.5	31.4	22.1	0.0
09152	19.6	32.0	23.4	0.0
09153	21.0	32.0	24.3	0.0
09154	21.2	32.3	23.6	0.2
09155	9.6	29.0	24.4	18.7
09156	20.3	31.7	19.1	3.1
09157	22.1	30.4	21.2	0.0
09158	22.5	32.0	23.0	0.0
09159	18.8	31.4	23.6	0.0
09160	21.2	31.5	20.0	13.4
09161	17.2	30.7	22.5	0.0
09162	9.8	27.5	19.8	1.2
09163	18.2	30.0	21.5	36.3
09164	17.6	29.3	21.0	0.0
09165	19.1	30.4	22.2	0.0
09166	15.8	28.5	22.5	8.2
09167	15.5	29.0	21.1	0.0
09168	19.5	31.4	21.6	0.0
09169	17.5	30.6	22.8	0.0
09170	18.5	30.4	23.1	0.0
09171	19.7	30.7	21.8	2.6
09172	16.1	29.4	22.6	39.5
09173	20.3	29.4	20.9	0.0
09174	20.3	30.4	21.6	0.0
09175	19.8	30.7	21.8	0.0
09176	20.5	31.4	22.3	0.0
09177	4.9	25.4	23.0	2.6
09178	19.5	30.2	21.2	5.6
09179	14.7	28.9	20.5	8.1
09180	19.2	30.0	20.6	0.0
09181	19.9	30.1	20.5	0.0
09182	19.1	29.4	20.2	0.0
09183	19.8	29.9	21.6	0.0
09184	18.4	30.9	22.0	41.2
09185	19.6	28.9	20.0	1.9
09186	20.8	30.3	22.4	0.0
09187	18.0	30.8	22.2	23.4
09188	18.4	29.5	20.6	18.0
09189	15.2	28.4	20.4	0.0
09190	12.1	26.3	21.3	0.0
09191	12.7	27.4	21.8	31.7
09192	6.5	24.1	21.0	4.7
09193	21.3	29.8	20.7	0.0
09194	16.3	28.7	21.5	5.8
09195	14.9	27.6	20.2	0.0

09196	20.4	29.0	22.0	0.1
09197	22.1	30.6	22.0	0.0
09198	13.0	27.9	21.4	17.8
09199	18.4	28.0	22.1	1.4
09200	15.2	26.5	22.0	0.2
09201	18.1	29.5	21.5	0.0
09202	17.6	29.8	20.1	31.4
09203	18.1	29.5	21.5	0.0
09204	16.8	30.1	21.3	2.0
09205	17.6	29.3	21.6	0.0
09206	13.2	29.3	21.2	4.9
09207	13.2	25.1	21.5	1.2
09208	11.7	25.6	21.4	2.5
09209	15.3	25.6	21.0	0.1
09210	15.8	27.0	21.0	0.0
09211	16.5	28.0	21.4	0.0
09212	9.5	26.0	21.2	29.4
09213	10.2	27.6	21.0	0.2
09214	11.7	26.9	20.9	0.0
09215	10.4	25.2	20.9	0.0
09216	13.6	25.8	21.4	0.0
09217	14.8	28.8	21.3	1.2
09218	11.1	25.6	21.0	0.2
09219	14.9	26.6	21.0	0.0
09220	14.3	29.4	21.2	0.0
09221	9.8	25.6	21.2	0.2
09222	10.3	26.9	21.3	0.0
09223	14.8	29.6	21.0	0.0
09224	11.3	27.2	21.2	0.0
09225	10.8	27.4	21.0	0.6
09226	10.7	27.1	21.0	0.1
09227	13.9	27.1	21.0	0.0
09228	13.8	27.9	21.4	0.0
09229	14.3	27.5	19.5	14.4
09230	14.4	27.2	20.0	14.0
09231	15.4	28.2	19.8	0.2
09232	11.0	27.3	20.8	0.0
09233	15.6	26.5	21.4	0.1
09234	12.0	27.6	20.8	0.0
09235	13.5	26.6	21.2	0.0
09236	11.5	28.5	20.1	5.3
09237	16.1	28.6	20.5	0.0
09238	15.2	28.1	22.0	0.0
09239	15.9	28.4	21.8	0.0
09240	6.0	23.0	21.4	25.3
09241	12.9	24.4	20.2	0.3
09242	13.4	26.5	21.4	0.0
09243	12.0	25.2	21.6	12.2
09244	12.3	27.9	20.5	0.4
09245	12.9	27.8	20.5	0.0

09246	12.1	26.3	21.7	0.0
09247	19.8	30.2	21.5	11.4
09248	17.9	28.4	20.3	4.2
09249	11.8	28.4	20.5	6.4
09250	16.8	29.4	22.0	0.0
09251	18.6	30.7	22.0	4.6
09252	19.4	29.3	20.1	0.0
09253	16.5	29.4	21.8	0.0
09254	15.9	29.6	21.9	0.0
09255	14.3	28.9	21.8	0.0
09256	8.6	27.1	22.3	23.8
09257	14.1	27.6	20.4	0.5
09258	11.2	26.6	21.5	0.1
09259	11.7	27.2	21.4	0.0
09260	20.1	29.8	21.5	2.7
09261	18.9	31.5	20.7	5.8
09262	16.6	27.5	19.6	0.4
09263	16.3	28.0	21.0	0.0
09264	13.2	26.0	21.4	0.0
09265	20.2	29.9	20.9	12.5
09266	21.2	29.3	20.1	0.0
09267	16.7	29.2	21.4	16.8
09268	20.5	28.5	20.0	0.1
09269	16.0	27.6	21.6	0.0
09270	12.5	27.6	21.7	0.0
09271	22.3	30.8	21.6	19.6
09272	18.6	30.0	20.9	0.0
09273	12.7	26.8	21.8	0.0
09274	18.3	29.0	21.4	0.0
09275	16.4	28.6	21.6	0.0
09276	17.6	30.2	20.8	1.0
09277	9.9	29.3	21.7	0.6
09278	18.3	30.5	21.7	0.0
09279	18.5	29.6	22.0	0.0
09280	16.0	29.6	22.5	0.3
09281	10.2	27.6	22.8	0.0
09282	18.5	29.8	21.4	0.0
09283	19.8	30.3	22.3	0.0
09284	18.5	30.1	20.5	2.6
09285	15.2	29.1	21.5	0.0
09286	16.8	30.0	21.7	0.2
09287	14.0	28.7	21.8	2.0
09288	19.3	30.2	21.5	0.0
09289	17.6	30.5	21.9	0.0
09290	16.2	30.4	21.8	0.0
09291	15.8	29.2	21.8	0.0
09292	19.2	29.7	21.6	0.0
09293	22.2	28.4	22.5	21.5
09294	13.9	30.0	22.3	41.9
09295	19.3	30.6	21.6	4.2

09296	17.9	30.4	21.6	30.7
09297	12.0	27.6	20.5	0.6
09298	18.8	32.1	20.0	0.0
09299	17.1	30.8	22.5	0.0
09300	18.9	30.4	22.3	2.4
09301	20.3	31.3	21.1	0.0
09302	9.6	27.5	22.0	9.8
09303	19.0	30.4	21.5	0.0
09304	22.1	32.8	22.3	0.0
09305	18.1	32.2	22.9	0.0
09306	18.0	31.4	23.0	0.0
09307	18.5	32.8	22.5	0.0
09308	19.8	32.0	23.6	0.0
09309	18.4	32.0	23.6	0.0
09310	18.7	32.0	23.0	0.0
09311	20.2	32.2	22.6	0.0
09312	16.7	31.4	22.9	0.0
09313	18.5	31.5	22.8	0.0
09314	19.3	31.9	20.8	2.1
09315	14.8	29.8	21.6	0.0
09316	17.7	31.4	22.4	0.0
09317	18.6	31.4	21.5	0.0
09318	18.6	31.5	21.7	0.0
09319	17.7	31.6	22.4	0.0
09320	21.3	32.6	21.2	0.0
09321	21.7	31.9	17.5	0.0
09322	22.1	32.0	18.4	0.0
09323	21.3	32.0	19.0	0.0
09324	21.7	32.2	14.8	0.0
09325	21.4	32.8	17.2	0.0
09326	21.6	33.5	18.0	0.0
09327	21.5	33.4	20.0	0.0
09328	12.9	30.5	19.5	0.0
09329	21.7	34.2	18.8	0.0
09330	21.7	34.2	19.5	0.0
09331	21.7	33.3	18.8	0.0
09332	19.6	32.2	19.5	0.0
09333	21.7	33.9	19.6	0.0
09334	21.7	35.0	15.4	0.0
09335	21.8	34.5	14.0	0.0
09336	21.3	35.0	16.0	0.0
09337	20.3	33.6	21.1	0.0
09338	21.1	35.0	20.5	0.0
09339	21.2	34.5	21.6	0.0
09340	21.1	34.0	20.7	0.0
09341	21.5	35.2	17.5	0.0
09342	21.0	34.7	19.6	0.0
09343	20.6	33.6	19.7	0.0
09344	19.2	34.2	20.5	0.0
09345	18.9	33.6	21.5	0.0

09346	18.6	34.2	22.3	0.0
09347	20.2	35.0	21.5	0.0
09348	19.3	34.8	22.5	0.0
09349	19.4	35.0	22.4	0.0
09350	19.9	34.2	22.5	0.0
09351	19.7	34.5	22.4	0.0
09352	19.0	32.5	22.5	0.0
09353	18.5	34.5	22.6	0.0
09354	20.7	35.2	23.0	0.0
09355	20.3	34.1	21.1	0.0
09356	20.3	33.5	20.8	0.0
09357	20.7	33.6	20.1	0.0
09358	20.7	33.6	20.2	0.0
09359	20.7	32.8	20.0	0.0
09360	20.7	33.8	19.2	0.0
09361	21.2	34.0	19.7	0.0
09362	21.1	33.9	20.3	0.0
09363	20.8	33.8	20.2	0.0
09364	21.2	34.0	20.1	0.0
09365	20.9	33.3	20.8	0.0

APPENDIX IIIB

*WEATHER DATA : IPAPO OYO STATE NIGERIA

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	NDHT
IPAPO	8.130	3.500	249	26.7	9.8	2.0	-99.0

@DATE	SRAD	TMAX	TMIN	RAIN	DEWP	WIND	PAR
10001	20.6	35.0	22.4	0.0			
10002	21.0	34.5	23.0	0.0			
10003	21.7	36.0	20.0	0.0			
10004	21.5	34.8	21.6	0.0			
10005	20.1	34.8	22.3	0.0			
10006	20.5	35.4	23.5	0.0			
10007	20.3	35.4	24.1	0.0			
10008	19.3	34.0	21.6	0.0			
10009	18.3	35.4	23.4	0.0			
10010	20.1	34.0	22.3	0.0			
10011	20.8	36.5	22.8	0.0			
10012	21.8	36.9	21.8	0.0			
10013	20.8	37.0	22.2	0.0			
10014	20.4	35.5	23.2	0.0			
10015	9.8	31.5	22.5	0.0			
10016	21.5	36.2	21.3	0.0			
10017	21.4	36.0	21.5	0.0			
10018	20.4	33.5	21.8	0.0			
10019	21.9	35.3	19.8	0.0			
10020	22.6	34.5	17.6	0.0			
10021	22.1	34.5	19.0	0.0			
10022	22.0	34.5	19.6	0.0			
10023	22.3	36.7	19.4	0.0			
10024	22.1	34.5	22.0	0.0			
10025	21.9	35.2	23.5	0.0			
10026	21.6	35.4	24.2	0.0			
10027	17.2	34.5	24.0	0.0			
10028	21.5	36.5	24.8	0.0			
10029	22.0	37.4	24.6	0.0			
10030	22.4	37.6	23.4	0.0			
10031	22.5	37.6	22.1	0.0			
10032	22.9	37.0	22.2	0.0			
10033	22.7	37.8	22.2	0.0			
10034	22.2	37.0	22.6	0.0			
10035	22.7	36.6	22.3	0.0			
10036	19.4	36.8	22.0	0.0			
10037	23.5	36.0	18.6	0.0			
10038	23.5	36.4	19.2	0.0			
10039	23.7	36.2	17.4	0.0			
10040	21.6	36.0	23.0	0.0			
10041	19.5	35.5	23.0	0.9			
10042	17.9	36.3	23.0	0.0			
10043	21.0	35.8	22.8	7.7			
10044	23.2	36.4	23.4	4.7			
10045	23.1	36.2	21.5	0.0			

10046	22.4	34.6	23.6	0.0
10047	22.9	35.4	23.6	0.0
10048	21.4	36.2	24.0	0.0
10049	21.4	36.5	23.4	0.0
10050	20.9	36.5	24.0	0.0
10051	22.7	37.0	25.0	0.0
10052	22.7	38.4	24.6	0.0
10053	22.5	37.0	23.0	3.6
10054	21.9	36.8	23.5	0.0
10055	23.5	38.3	23.8	0.0
10056	23.1	37.2	24.3	0.0
10057	22.6	37.8	24.5	0.0
10058	23.4	38.5	24.2	0.0
10059	21.7	37.6	24.6	2.6
10060	19.8	36.5	23.6	0.0
10061	22.5	36.8	23.2	0.0
10062	23.8	37.7	23.8	0.0
10063	21.5	37.2	24.8	0.0
10064	22.4	37.8	24.6	0.0
10065	22.4	38.0	23.4	26.0
10066	21.5	36.2	25.0	0.0
10067	22.5	36.3	24.9	0.0
10068	19.3	34.5	24.4	9.0
10069	24.2	35.8	22.1	0.0
10070	19.9	35.0	24.5	0.0
10071	19.2	34.8	25.2	0.0
10072	19.1	35.6	24.1	0.0
10073	19.0	35.3	25.4	0.0
10074	23.8	36.6	24.2	96.0
10075	11.5	28.5	20.4	0.0
10076	22.3	33.2	22.4	0.0
10077	21.3	33.5	23.5	0.0
10078	20.8	33.3	22.5	0.0
10079	17.8	31.5	23.0	0.0
10080	19.5	31.2	21.5	0.0
10081	17.7	32.7	16.0	0.0
10082	22.4	35.2	19.4	0.0
10083	22.4	35.1	19.7	0.0
10084	20.6	34.5	20.2	0.0
10085	23.4	35.7	23.0	0.0
10086	22.7	36.4	23.8	0.0
10087	24.0	36.2	24.7	0.0
10088	18.6	36.0	25.0	0.0
10089	13.2	34.8	25.1	0.0
10100	23.2	35.0	23.6	0.0
10101	22.0	36.0	25.0	0.0
10102	22.6	36.0	24.0	0.0
10103	21.4	35.5	24.2	0.0
10104	21.5	35.3	25.4	0.0
10105	20.4	35.9	24.4	0.0

10106	24.1	38.0	22.5	0.0
10107	22.1	36.2	24.2	0.0
10108	24.8	35.2	21.5	6.4
10109	22.0	35.8	24.4	0.0
10110	18.0	33.0	21.5	6.8
10101	22.2	33.2	23.4	0.0
10102	20.4	33.7	24.0	0.0
10103	19.8	35.0	25.0	0.0
10104	20.2	35.7	25.0	0.0
10105	20.6	35.3	25.0	0.0
10106	19.6	34.2	24.5	9.0
10107	18.2	32.5	22.8	0.0
10108	25.4	35.6	24.0	0.0
10110	20.5	35.6	24.0	0.0
10110	19.9	35.3	25.6	14.0
10111	17.2	33.0	20.5	0.0
10112	17.3	33.0	24.0	0.0
10113	21.5	34.4	23.7	0.0
10114	7.2	35.9	21.4	6.2
10115	23.9	33.2	22.0	0.0
10116	21.2	34.2	23.5	0.0
10117	21.8	31.2	22.2	0.0
10118	22.9	33.5	23.8	0.0
10119	17.1	32.6	23.0	0.0
10120	19.1	32.8	23.8	1.1
10121	21.2	33.3	23.8	0.0
10122	6.3	28.3	23.4	0.0
10123	22.8	34.0	23.0	27.0
10124	22.7	32.3	21.6	0.0
10125	14.4	27.2	22.0	41.0
10126	21.1	32.2	22.0	55.0
10127	15.8	29.4	21.5	0.0
10128	22.6	32.5	23.2	12.0
10129	19.5	32.2	21.8	0.0
10130	20.7	32.5	24.4	0.0
10131	21.2	32.5	24.1	0.0
10132	20.2	33.3	24.8	0.00
10133	21.5	33.2	24.2	5.6
10134	17.0	31.4	22.5	0.00
10135	21.4	32.7	24.0	0.0
10136	19.5	33.1	24.0	14.0
10137	17.6	29.6	20.3	0.0
10138	20.7	32.2	21.7	2.4
10139	19.3	32.4	22.0	0.0
10140	11.5	30.5	22.8	16.0
10141	14.4	30.5	21.6	0.0
10142	21.7	31.3	23.5	0.0
10143	20.0	32.4	23.8	0.6
10144	20.9	31.7	23.2	0.0
10145	20.9	32.3	24.0	19.0

10146	12.0	28.5	20.2	6.7
10147	14.3	30.5	22.5	0.0
10148	19.3	31.8	23.0	2.0
10149	19.4	31.7	22.0	0.8
10150	15.3	31.2	23.4	0.0
10151	16.1	28.8	23.4	0.0
10152	15.6	29.9	22.0	0.0
10153	15.0	32.1	23.4	0.0
10154	17.1	32.1	21.8	18.0
10155	11.7	29.0	21.8	1.4
10156	19.2	30.3	22.0	0.0
10157	18.4	31.1	23.4	0.0
10158	20.4	30.5	21.5	0.0
10159	20.3	32.4	22.2	0.0
10160	16.4	31.2	23.1	32.0
10161	18.8	29.4	21.3	0.0
10162	16.1	32.8	23.1	0.0
10163	19.4	31.4	24.4	0.0
10164	18.3	31.7	23.7	0.0
10165	17.8	31.5	23.4	34.0
10166	19.9	31.5	21.8	0.6
10167	15.8	29.4	22.0	0.8
10168	17.0	28.8	22.6	5.8
10169	20.8	31.3	22.8	0.0
10170	18.5	31.5	23.0	4.0
10171	12.8	31.3	24.0	26.0
10172	18.1	30.5	21.3	0.0
10173	19.2	32.2	23.4	0.0
10174	14.7	30.5	23.7	0.0
10175	18.5	30.0	21.8	0.0
10176	14.5	31.0	23.6	43.0
10177	12.9	28.9	22.0	0.0
10178	16.5	29.0	23.3	0.0
10179	20.9	31.0	22.0	0.0
10180	19.0	30.5	22.3	0.0
10181	19.7	30.7	22.4	0.0
10182	11.5	29.2	21.5	15.0
10183	18.3	28.6	20.9	0.0
10184	17.5	30.1	21.6	0.0
10185	16.8	29.5	21.2	0.0
10186	18.8	30.2	22.2	0.0
10187	17.9	30.4	22.2	0.0
10188	12.2	27.0	20.0	1.8
10189	19.3	30.3	21.0	0.0
10190	18.4	31.1	22.2	2.2
10191	12.1	26.5	22.0	10.0
10192	18.1	29.1	22.0	0.0
10193	16.1	31.0	22.7	6.5
10194	17.3	29.6	21.2	0.0
10195	14.9	27.6	22.1	0.0

10196	11.2	26.9	22.3	1.3
10197	16.3	27.9	20.6	18.0
10198	18.2	27.9	21.6	0.4
10199	18.8	29.0	21.7	0.2
10200	18.2	26.8	21.5	0.0
10201	17.7	27.6	20.5	0.5
10202	13.7	25.6	20.4	0.0
10203	18.6	28.9	20.8	1.2
10204	10.9	25.1	20.0	38.0
10205	20.6	28.4	20.5	0.0
10206	21.3	29.2	20.5	6.8
10207	13.4	28.3	21.5	1.9
10208	15.4	27.7	21.5	0.0
10209	16.2	29.3	22.0	0.0
10210	16.7	27.8	21.4	0.0
10211	11.1	25.8	21.0	0.0
10212	17.6	28.4	21.4	0.0
10213	20.5	27.8	20.2	0.0
10214	19.2	29.3	21.1	0.0
10215	12.2	28.0	21.6	0.0
10216	14.7	28.3	21.0	0.0
10217	17.2	30.3	21.3	0.0
10218	12.9	29.7	21.7	5.6
10219	12.2	29.0	21.8	0.8
10220	13.2	28.4	22.1	11.0
10221	10.5	26.0	21.6	1.2
10222	15.0	28.8	20.5	21.0
10223	12.3	27.8	20.8	10.0
10224	6.6	23.0	21.6	41.0
10225	11.9	26.4	20.6	13.0
10226	10.2	25.4	20.5	12.0
10227	15.8	28.2	21.7	0.0
10228	16.6	30.4	22.6	35.0
10229	12.9	26.2	20.0	0.0
10230	18.5	29.7	21.7	0.0
10231	19.9	29.2	21.2	42.0
10232	18.8	26.7	20.0	2.8
10233	17.7	29.0	21.0	3.0
10234	16.7	28.4	22.0	0.1
10235	14.7	28.7	22.0	0.0
10236	10.7	27.0	22.0	0.0
10237	16.8	30.5	22.3	0.0
10238	15.8	27.8	22.2	1.0
10239	17.7	30.0	22.0	0.0
10240	14.9	28.5	21.7	0.3
10241	15.0	27.6	22.0	1.0
10242	16.0	28.9	21.7	0.5
10243	15.5	27.3	21.5	0.8
10244	22.3	30.5	22.1	0.0
10245	18.6	28.3	21.5	5.3

10246	9.8	25.1	20.2	11.0
10247	14.9	28.6	21.5	1.0
10248	15.6	28.6	21.7	6.2
10249	17.0	28.5	22.0	2.4
10250	15.8	27.3	21.7	2.5
10251	17.9	28.4	20.2	21.0
10252	15.3	27.8	22.0	7.8
10253	16.9	29.3	22.0	1.0
10254	18.1	29.4	22.0	0.4
10255	19.1	30.0	22.0	0.0
10256	15.0	27.6	22.7	0.4
10257	15.9	29.0	21.4	19.0
10258	15.8	28.0	21.6	0.3
10259	20.7	29.6	21.9	0.0
10260	10.4	27.8	22.3	0.0
10261	10.6	29.1	22.7	2.1
10262	19.7	30.5	21.0	22.0
10263	19.7	30.3	20.4	0.0
10264	19.2	30.4	21.5	0.0
10265	18.6	30.3	21.8	17.0
10266	18.8	30.2	21.5	11.0
10267	19.2	29.5	21.5	18.0
10268	19.9	29.3	20.9	0.0
10269	19.5	29.6	21.6	7.2
10270	21.3	30.2	21.5	27.0
10271	14.9	27.6	20.0	1.7
10272	20.0	31.9	21.7	0.0
10273	19.5	32.0	21.6	69.0
10274	21.3	31.4	20.0	11.0
10275	18.5	30.2	20.2	45.0
10276	20.4	30.6	21.6	4.0
10277	18.3	30.2	22.5	19.0
10278	17.5	30.8	21.0	0.2
10279	16.2	28.6	21.8	2.8
10280	18.0	31.0	22.6	2.3
10281	19.3	30.4	22.1	0.0
10282	17.2	28.6	22.8	2.2
10283	7.1	28.5	21.6	1.7
10284	18.5	29.4	19.7	1.2
10285	18.9	29.4	22.0	0.0
10286	19.5	31.0	21.6	11.0
10287	19.2	30.8	21.7	2.3
10288	18.9	31.2	22.1	0.0
10289	18.4	31.5	21.5	0.0
10290	20.9	31.7	22.2	0.0
10291	19.5	31.0	22.5	0.0
10292	21.0	32.2	22.7	54.0
10293	22.5	31.0	20.5	18.0
10294	18.1	29.4	19.2	0.0
10295	19.8	30.5	22.0	26.0

10296	15.1	30.8	19.4	1.8
10297	12.3	26.0	20.0	0.7
10298	18.6	29.4	20.5	0.0
10299	19.8	31.5	21.0	0.0
10300	17.8	31.4	22.6	14.0
10301	18.6	29.7	20.2	8.9
10302	12.4	27.9	20.3	0.7
10303	20.2	32.0	22.3	0.8
10304	17.9	31.2	23.6	8.7
10305	19.5	31.2	20.8	53.0
10306	20.1	31.3	20.5	2.6
10307	22.3	32.4	21.2	0.2
10308	19.5	31.3	21.3	5.8
10309	19.7	31.3	21.2	19.0
10310	15.5	29.2	21.3	0.0
10311	17.0	29.7	21.6	0.0
10312	18.5	30.5	22.0	0.0
10313	20.8	32.0	21.3	0.0
10314	20.5	31.3	22.2	16.0
10315	16.2	31.0	21.0	0.0
10316	19.2	31.5	23.0	0.0
10317	20.1	32.0	23.0	0.0
10318	19.8	31.3	22.0	0.0
10319	20.3	31.6	22.1	0.0
10320	20.2	32.0	22.4	0.0
10321	21.3	32.6	22.9	0.0
10322	19.7	32.0	23.5	0.0
10323	18.6	31.6	23.5	0.0
10324	21.2	32.7	20.0	0.0
10325	20.5	33.0	20.5	0.0
10326	20.8	32.3	21.5	3.2
10327	20.8	31.8	21.4	0.0
10328	21.1	31.7	20.4	0.0
10329	21.3	32.1	21.7	0.0
10330	20.7	32.6	21.6	0.0
10331	20.4	32.6	22.4	0.0
10332	20.2	32.4	22.6	0.0
10333	20.3	32.2	22.5	0.0
10334	21.0	33.8	23.0	0.0
10335	19.7	33.3	23.0	0.0
10336	19.8	33.0	21.6	0.0
10337	19.5	33.2	22.0	0.0
10338	20.2	33.7	21.8	0.0
10339	20.0	33.6	22.0	0.0
10340	20.0	33.7	22.5	0.0
10341	18.1	31.8	23.0	0.0
10342	20.6	32.3	20.2	0.0
10343	21.0	33.3	16.6	0.0
10344	21.3	33.6	17.4	0.0
10345	21.7	34.0	15.7	0.0

10346	21.5	33.2	17.9	0.0
10347	20.6	33.2	18.6	0.0
10348	21.1	33.0	20.6	0.0
10349	20.7	35.2	20.2	0.0
10350	20.7	34.0	21.3	0.0
10351	21.0	35.6	19.5	0.0
10352	20.4	35.2	21.5	0.0
10353	20.0	35.0	21.7	0.0
10354	19.8	34.3	23.0	0.0
10355	20.0	35.0	21.0	0.0
10356	19.2	33.7	22.2	0.0
10357	17.1	31.4	22.0	0.0
10358	19.8	34.8	19.4	0.0
10359	21.0	33.3	21.5	0.0
10360	20.2	33.3	21.8	0.0
10361	19.5	34.0	23.0	0.0
10362	17.7	32.8	22.6	0.0
10363	18.3	30.7	19.4	0.0
10364	20.1	32.9	18.9	0.0
10365	21.3	32.8	17.7	0.0

APPENDIX IVA

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*NGIP090001  SCS         LS      150 (IPAPO  Experimental farm)
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 GBRAN  OYO  NIGERIA        8.042    3.300 FERRIC LUVISOLS  (EUTRIC ARENIC KANDUISTALF)
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN  0.13  10.1  0.60  94.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    15    AP 0.014 0.111 0.387  1.00 19.93  1.63  1.48  11.0   6.0  83.0 0.360  5.8   5.1  26.57  -99
    30    BW 0.017 0.110 0.295  1.00  6.31  1.74  1.05  13.0   5.0  82.0 0.250  5.7   5.0  31.29  -99
    45    BW 0.021 0.112 0.264  1.00 12.90  1.61  1.13  19.0   8.0  73.0 0.270  5.5   5.0  29.01  -99
    60    BW 0.016 0.113 0.407  0.60  2.01  1.64  0.97  39.0   8.0  53.0 0.240  5.7   5.1  31.22  -99
    75    BC 0.098 0.117 0.469  0.00  1.77  1.54  1.13  33.0   6.0  61.0 0.270  5.5   4.1  40.54  -99
    90    AP 0.014 0.107 0.357  0.00  0.69  1.59  0.39  31.0  10.0  59.0 0.090  5.6   5.8  30.01  -99
   105    BW 0.017 0.117 0.449  0.00  3.00  1.49  1.71  35.0  10.0  55.0 0.410  5.4   5.7  29.30  -99
   120    BW 0.021 0.111 0.714  0.00  2.14  1.51  0.86  33.0  13.0  54.0 0.210  5.8   5.1  36.49  -99
   135    BW 0.016 0.118 0.469  0.00  4.81  1.49  0.43  17.0   2.0  81.0 0.100  5.8   5.1  38.58  -99
   150    BC 0.098 0.121 0.376  0.00 54.40  1.24  0.04  23.0   6.0  71.0 0.010  5.8   5.1  28.57  -99
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APPENDIX IVB

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*NGIP090002  SCS         LS      150 (GBONRAN Experimental Plot)
@SITE        COUNTRY          LAT     LONG SCS FAMILY
 IPAPO  OYO  NIGERIA        08.08    3.240 Ferric Luvisol  (Plinthic kanduistalf)
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
    BN  0.13  10.1  0.60  94.0  1.00  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI  SLHW  SLHB  SCEC  SADC
    15    AP 0.011 0.116 0.387  1.00 19.93  1.63  4.44   7.0   6.0  87.0 1.080  6.2   5.5  36.57  -99
    30    BW 0.028 0.105 0.295  1.00  6.31  1.74  1.71  11.0   6.0  83.0 0.410  6.2   5.5  27.76  -99
    45    BW 0.010 0.100 0.264  0.80 12.90  1.61  0.08  14.0   7.0  79.0 0.020  6.2   5.5  42.76  -99
    60    BW 0.022 0.107 0.407  0.60  2.01  1.64  0.58  25.0  21.0  54.0 0.140  6.3   5.6  30.87  -99
    75    BC 0.098 0.117 0.469  0.20  1.77  1.54  1.17  28.0  10.0  62.0 0.280  6.4   5.6  26.09  -99
    90    AP 0.042 0.107 0.357  0.00  0.69  1.59  0.86   5.0  34.0  61.0 0.210  6.2   5.5  27.79  -99
   105    BW 0.078 0.117 0.449  0.00  3.00  1.49  1.87  25.0   6.0  69.0 0.450  6.2   5.5  37.03  -99
   120    BW 0.010 0.101 0.714  0.00  2.14  1.51  2.72  31.0   6.0  63.0 0.660  6.2   5.5  36.43  -99
   135    BW 0.062 0.108 0.469  0.00  4.81  1.49  2.34  35.0   4.0  61.0 0.570  6.0   5.3  29.42  -99
   150    BC 0.098 0.125 0.376  0.00 54.40  1.24  0.04  29.0  11.0  60.0 0.010  5.9   5.2  25.86  -99
```

APPENDIX Va: Detailed description of the soil at Ipapo

General Site Description

Profile ID	IP 1	
Profile location:	Ipapo	
	Coordinates:	N08°08.284'; E003°30.140'
	Elevation:	353m asl
Classification	Local	- Iseyin series
	USDA	- Arenic kanduistalf
	FAO/IUSS	- Ferric luvisol (Eutric)
Slope:	2 -6%	
Physiographic position:	Middle slope	
Rock outcrop:	None	
Parent material:	Quartz	
Profile thickness:	150cm	
Drainage:	Well drained	
Human influence	Digging / ploughing	
Extent of erosion	Water - sheet	
Lithology	Igneous	
Structure	Massive	
Hardness	Very hard	
Depth to water table	> 150 cm	
Evidence of biological activity	Burrowing (Ants)	
Land use:	Arable farming (Cassava)	
Season of the year	Dry	
Date of description:	29/07/2011	
Author:	Oyatokun and Okafor	

Soil Profile Description

Horizon	Soil depth (cm)	Description
AP	0 – 18	Brown (7.5YR4/3, dry) loamy sand, medium crumbs, non- sticky consistency and loose when dry, fine and common coarse roots, angular blocky structures, no stones
BW	18 – 66	(7.5YR5/6, dry) fairly stony with medium size, non-sticky consistency, friable when moist and loose when dry, fine and common coarse roots, angular and blocky structures.
BW	66 – 90	(7.5YR5/8, dry) stony, coarse crumbs with angular and blocky structures, non- sticky, friable when moist and hard when dry.
BW	90 – 128	(7.5YR4/6, dry) common mottles, medium with sub-angular and blocky structure, non-sticky consistency friable when moist and slightly hard when dry, medium and common roots, no stones
BC	128 – 150	(2.5YR5/6, dry) many mottles, medium with sub-angular and blocky structure, non-sticky consistency friable when moist and slightly hard when dry, medium and common roots

APPENDIX Vb: Detailed description of the soil at Gbonran

General Site Description

Profile ID	IP 2	
Profile location:	Gbonran	
	Coordinates:	N08°06.458'; E003°30.061'
	Elevation:	379m asl
Classification	Local	- Sepeteri series
	USDA	- Plinthic kanduistalf
	FAO/IUSS	- Ferric luvisol
Slope:	2 -6%	
Physiographic position:	Middle slope	
Rock outcrop:	None	
Parent material:	Biotite gneiss	
Profile thickness:	170cm	
Drainage:	Well drained	
Human influence	Farming	
Extent of erosion	Slight / sheet	
Lithology	Igneous	
Structure	Massive	
Hardness	Very hard	
Depth to water table	> 150 cm	
of biological activity	Burrowing / worm cast	
Land use:	farming / fallowing	
Season of the year	Dry	
Date of description:	29/07/2011	
Author:	Oyatokun and Okafor	

Soil Profile Description

Horizon	Soil depth (cm)	Description
AP	0 – 26	Brown (7.5YR4/3, dry) loamy sand, stony, coarse and angular blocky structure, non- sticky consistency and loose when dry, fine and many roots.
BW	26 – 64	(7.5YR5/8, dry) common mottles, very stony, coarse, sub-angular, blocky and massive structure, non-sticky consistency, friable when moist and loose when dry, medium and common roots, diffuse and irregular boundary form.
BW	64 – 118	(7.5YR5/8, 7.5yr4/6, dry) common mottles, very stony, very coarse crumbs with sub-angular, blocky and massive structure, non- sticky, friable when moist and hard when dry, many Fe – Mn concretions, boundary form is broken and diffuse.
BW	118 – 134	(7.5YR4/6, 7.5YR6/8, dry) common mottles, very stony, very coarse crumbs with sub-angular blocky and massive structure, non-sticky consistency very firm when moist and hard when dry, very many Fe – Mn concretions, diffuse and irregular boundary form.
BC	134 – 170	(2.5YR5/6, 2.5yr4/3, dry) many mottles, stony, coarse sub-angular, blocky and massive structure, non-sticky consistency, extremely firm when moist and extremely hard when dry, many Fe – Mn concretions.