EVALUATION OF CROPGRO-PEANUT MODEL FOR PREDICTING GROWTH AND YIELD OF GROUNDNUT (*Arachis hypogaea* L.) IN IBADAN AND OGBOMOSO, NIGERIA

BY

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CERTIFICATION

I certify that this work was carried out by Mrs. F. G. O. Oni in the Department of Agronomy, Faculty of Agriculture, University of Ibadan

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ABSTRACT

Groundnut is one of the most consumed oil crops in the tropics. Application of starter nitrogen and appropriate sowing dates are necessary for optimum growth and yield of groundnut. The use of crop growth models such as CROPGRO-Peanut can facilitate the evaluation of beneficial crop management practices with reduced undesirable impact on the environment. However, such models must be calibrated and evaluated for crop varieties in a given location before use. In this study, CROPGRO-Peanut model was calibrated and evaluated for groundnut performance in Ibadan and Ogbomoso, Nigeria.

In a field experiment, four groundnut varieties (SAMNUT10, SAMNUT22, SAMNUT23 and Kampala-local check) were grown at four Sowing Dates (SD1, SD2, SD3 and SD4), spaced at seven days interval from 19 April to 10 May, at Ogbomoso. Data collected were used to calibrate the CROPGRO-Peanut model. Thereafter, SAMNUT23 and Kampala sown at SD2 and SD3 were evaluated with application of three starter nitrogen rates (0, 10 and 20 kg N/ha). Data were collected and used to evaluate the model. In Ibadan and Ogbomoso, three sources each of starter nitrogen (NPK 15:15:15, organomineral fertilizer and poultry manure) applied at 20 kg N/ha were evaluated on SAMNUT23 and Kampala at SD2. Data were collected and used to validate the model. All experiments were laid-out as split-plot in randomised complete block design replicated thrice. Data were collected on Days to Emergence (DE), Days to Flowering (DF), Pod Yield (PY) and weather parameters. The reliability of the model was evaluated using Percentage Error-PE (excellent: 0-10%, good: 11-20%; fair, 21-30%, and poor: >30%). Groundnut pod yield was predicted from 2010 to 2050 using daily weather data generated from GCM-DSSAT file generator.

The simulated DE was excellent at SD1 (10%), but poor at SD2 (54%), SD3 (74%) and SD4 (358%). Simulated DF at SD1 was fair (30%) but excellent (2%)at SD2 while the simulated DF was good (20%) at SD3 and poor (39%) at SD4. Calibration of PY across the varieties was poor for all the sowing dates. The simulated DF with application of starter nitrogen at SD2 was fair for SAMNUT23 (25%) and poor for Kampala (35%), but fair for Kampala (28%) at SD3 and poor for SAMNUT23 (36%). The simulated PY was fair for both SAMNUT23 (26%) and Kampala (28%) at SD2, while it was fair for SAMNUT23 (22%) but poor for Kampala (36%) at SD3.For all sources of starter nitrogen, simulated DF was poor for both SAMNUT23 (43%), and Kampala (46%) while PY was excellent for SAMNUT23 (9%) and fair for Kampala (30%) (indicating the reliability of the model for the parameters). Model prediction for 2010 to 2050 showed decline in PY from 2,627 kg/ha to 700 kg/ha in Ibadan and from 4,568 kg/ha to 1,200 kg/ha at Ogbomoso.

The CROPGRO-Peanut model adequately simulated days to emergence and was good for predicting pod yield of groundnuts regardless of starter nitrogen source and sowing dates. Ibadan and Ogbomoso lacked potential for long term production of groundnut.

Keywords: Decision support system, Groundnut pod yield, Sowing dates, Crop simulation model, Yield forecast

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DEDICATION

To Our Lady Seat of Wisdom and blessed memory of Precious Bodunde Oni

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CHAPTER ONE

INTRODUCTION

1.1 Background Study

One of the factors that will affect future food production in the world is climate change (Challinor *et al*., 2004) which necessitated the need to detect theeffect of these changes on major crops, one of which is groundnut. Groundnut(*Arachis hypogaea* L.) also called peanut, earthnuts, goober peas, Monday nuts, pygmy nuts, and pig nuts originated in South America. Groundnuts are cultivated in the tropics, subtropics, and warm temperate regions between 40ºN and 40ºS latitudes. The world leader in groundnut production inChina. India is the second-largest producer followed by Nigeria and the United States of America (Juangjun, 2003). It is one of the most popular commercial crops in the tropics (Misari *et al*., 1988). According to FAO (1990), groundnut was cultivated on about 17.5 million hectares worldwide. Seventeen years later, groundnut was reported to be cultivated worldwide on 26.4 million hectares(FAO, 2007).

Groundnut is the third major oilseed of the world, next to soyabean and cotton (FAO, 1990). In West Africa, Nigeria is the largest producer of groundnut, with about 51% of production in the region (Echekwu and Emeka, 2005). Groundnut was one of Nigeria's most valued export crops. It is one of the most popular commercial crops in Nigeria between 1959 and 1967.This wasrepresentedthrough the legendary Kano groundnut pyramids. However, after 1967, the collective effects of incidence of diseases, drought, and fossil oil boom,led to adrop in groundnut production. For instance, the total amount of groundnut produced fell from 1.6 metric tonnes in 1970 to 0.47 metric tonnes in 1980 (Ajeigbe *et al*., 2015). But between 2000 and 2009, groundnut producing area grew annually by 2.6%.However, the pod yield declined by 3.3% annually resulting in a lack of progress of groundnut production. Despite that groundnut is one of the most common crops cultivated throughout the tropical and subtropical areas of the world, its production remains typicallyat the subsistence level in Nigeria (Alabi *et al*., 2013). The crop is grown mostly by smallholder farmers under rainfed conditions with limited input making it impossible to meet the demand of the increasing population of Nigerians.

Production of groundnut in Nigeria encounters many complex problems, the problems include the drought and rosette epidemic of 1975 which resulted in adecline in groundnut production. The decrease in production did not affect groundnut demand thus the production has shifted southward towards more suitable climatic conditions for its production (Vara Prasad*et al*., 2009).

Generally, soil and climate are important yieldsdetermining factors which together determine the amount of fertilizers to be applied; the form, and the mode of application. Also, tropical soils are synonymous with low soil fertility resulting fromnutrients mining, leaching losses, loss during cropping,soil erosion, and crop removal.Thus, the need for nutrients inputs from fertilizers to maintain a positive nutrient balance in the soil(Griffith, 2006).Although groundnut can form a symbiotic association with N-fixing bacteria, it takes about 25 to 30 days to develop groundnut nodules then, some available nitrogen is required in the early stages for plant growth. (Putnam *et al*., 1991; Singh and Oswalt, 1995; Juangjum, 2003; Buah and Mwinkaara, 2009). Also, the changing patterns of rainfall in the Nigerian semi-arid and humid regions call for a review of the management practices associated with groundnut cultivation in Nigeria (IPCC, 2001).

Agriculture and climate change takes place on a global and regional scale and they are both interrelated processes. Despite technological advances, such as improved varieties, and irrigation systems, theweather is still a key factor in agricultural productivity as well as soil properties and natural communities. The effect of climate on agriculture is related to variabilities in local climates rather than in global climate patterns.Despite the continuous research activities on climate change at regional scales, an assessment of the possible impacts of such climate change on agricultural resources under varying conditions is important for formulating response strategies, which should be practical, affordable, and acceptable to farmers.

Climatic change is projected to have significant impacts on conditions affecting agriculture, which include; temperature, solar radiation, precipitation, and the interaction of these factors. These conditions determine the carryingcapacity of the biosphere to produce enough food for the human population and animals. The overall effect of climate change on agriculture will depend on the balance of these effects (Fraser, 2008).

1.2 Statement of Problem

To assess the scope for increasing groundnut production, there is the need to know the pod yield potentials and understand factors limiting pod yield of groundnut in a given agroecological zone. Such understanding can be achieved by conducting experiments to sample a range of seasonal weather conditions and soil management practices which will be used to observe system responses to various management options. Understanding the nature of the response to various management options between and within seasons is essential as this provides possibilities for determining the frequencies of different types of responses. Simulation of crop growth and pod yield through appropriate procedures for the evaluation of crop management options for locations or regions on along-termbasis is a strategic way of achieving this goal.

Models have the potential to predict the performance of the crop under varying crop management practices and to help design agricultural research strategies for improved crop production (Thornton, 1991). Models have traditionally been used to extrapolate results from agricultural experiments to other situations such as different soils of differing fertility (Probert *et al*., 1995). Many crop models, including the Cropping System Model (CSM) CROPGRO-Peanut (Boote *et al*., 1998; Jones *et al*., 2003), use the concept of cultivar coefficients to characterize genotypes or cultivars (Hunt *et al*., 1993; Ritchie, 1993; Boote *et al*., 1998, 2003). The cultivar coefficients orcultivar–specific traits are crop characters that define the development, vegetative growth, and reproductive growth of individual genotypes (Hunt *et al*., 1993; Boote *et al*., 2003). They summarize quantitatively how a particular genotype responds to environmental factors. However, crop models must accurately predict several key characteristics of crops over several climatic conditions: Timing of key phenological events such as flowering and physiological maturity, through correct descriptions of phenological responses to temperature, day length,andvernalisation. Phenology is determined by phases that mark the appearance, transformation, or disappearance of vegetative and reproductive organs such as the emergence of theplant, appearance of nodules, flowers,and pods.

If the genotypes used are new breeding lines or local cultivars that have not been used previously with the crop simulation model, there is a need to determine first the cultivar coefficients and then evaluate them with independent data. By simulating probable outcomes of crop management strategies, models like CROPGRO-Peanut (Jones *et al*., 2003 and Hoogenboom *et al*., 2010) under Decision Support System for

Agrotechnology Transfer (DSSAT v4.5), will rapidly appraise new crops, products, and practices for adoption.

1.3 Aim and Objectives

This study aims at developing a cropping system model by adopting the CMS-CROPGRO-Peanut module within the 4.5 version of DSSAT, to simulate groundnut pod yield under different climatic conditions.To achieve the aim of this study, the objectives are to:

1. determine the Genetic Coefficients – CGs of four varieties of groundnut (3 improved and 1 popular local varieties);
2. determine the appropriate sowing windows for growing the selected groundnut varieties;
3. calibrate a model for the varieties using their determined CGs;
4. validate the outputs of the CROPGRO-Peanut model in the DSSATv4.5 for the selected groundnut varieties;
5. acquire data on the performance of groundnut under varying soil nutrient sources and starter dose of nitrogen fertilizer management, and
6. predict groundnut growth for different years and locations using CROPGRO-Peanut based on the projected climate

1.4 Justification of the study

Crop growth and development is a very difficultprogression and a product ofseries ofa complex interactionbetweenthe crop, weather,andsoil. Planners, economists, and researchers over the years have been interested in developing different methods of predicting crop yield. The prediction of crop yields aid in planning and makes production easier. Prediction also promotes maximum use of production inputs and better outputs with reduced wastage and better economic returns. Mitigation methods can also be suggested before production for optimum pod yield and crop performance. With these attributes of prediction, several regression models have been developed to predict agricultural systems and their components. However, these models especially when dealing with time series factors lumps every other factor except climate to a side as a regressor (Singh, 1995). Thus, no interactionwith other factors is considered leading to confusing and misleading results. These other factors include; edaphic, hydrologic, biotic, economic, agronomic, and social factors. Dynamic crop growth simulation models simplifythe quantifiable understanding of these factors and agronomic management practices on crop growth and productivity. Models can be used to evaluate crop production systems in terms of climatic variability, assessment of regional yield potential over a wide range of environmental conditions and to determine suitable planting dates and other management factors for increasing crop yield. Notable among these dynamic crop growth simulation models is the Decision Support System for Agrotechnology Transfer (DSSAT). DSSAT is a Microsoft Windows-based software package that integrated all the agronomic factors including soil, crop phenotype, weather, and management options. This feature is, however, lacking in most other models making simulated results from such models unreliable.

The study adopts the CROPGRO-Peanut v4.5 module in DSSAT to explore the use of starter nitrogen and determine the appropriate sowing dates necessary for optimum growth and yield of groundnutcrop in Ibadan and Ogbomoso, Nigeria, which is one of the most important oil and cash crop in sub–Saharan Africa (SSA) and an important staple food for people in SSA.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin, Spread,and Uses of Groundnut

Cultivated groundnut (*Arachis hypogaea* L.) is a tetraploid and an amphidiploid leguminous oilseed, derived from two diploid wild species. The botanical name of groundnut is derived from the Greek word *arachis*which means the formation of pods underground. *Arachis hypogaea*belong to the family, Fabaceae, andthe subfamily, papilioideae.It is a native of South America and probably originated around Peru or Brazil (De Waele and Swanevelder, 1983). Archaeological records suggestedgroundnut cultivation between 300 and 2500BC in Peruvian desert oases (Weiss 2000, Smith 2002). The recordfurthersuggested that the initiallycultivated groundnut was likely in the valleys of the Paraguay and Parana rivers in the Chaco region of South America.

Groundnut cultivation has since spread from its place of origin in South America to most areas of subtropical, tropical, as well as the warm temperate countiesas Spanish explorers discovered the groundnut's versatility.Groundnut is widely spread and has been adapted in many countries of the world. The most important countries for production are India, China, the USA, Brazil, West, and Southern Africa. Europe produces about 0.1%, Australia 0.2%, South America 5%,North America 10%,Africa 27%, and Asia the largest producer of about 58%.Groundnut is cultivated in 28 million hectares of land in over 100 countries with 65% produced in Asia and 26% in Africa (FAO, 2019). In West Africa, groundnut is one of the most commonly produce commercial crop with Nigeria as the largest producing country in West Africa. Nigeria accounts for 51% of groundnutin the region and about 10% globally (Ajeigbe *et al.,* 2015).It was first introduced into Nigeria in the early 16th century (Abalu and Etuk, 1986).

The commercial value of groundnut also made it veryvaluable in variousparts of the world. For instance, the development in West African production isa result of the oil market in France and Britain. Groundnut is also valued asa food crop, as an oil source and it is of important value in livestock feed (Cummins, 1986).

2.2 Description of Groundnut

The diagram of a typical groundnut plant, pod,and seed is shown in Fig. 2.1. Groundnut emergence is in-between the epigeal (hypocotyls elongates and cotyledons emerge above ground as in soyabean) and hypogeal (cotyledons remain below ground as in fieldpea) types. The hypocotyl elongates but usually stops before cotyledons emerge.Leaves are pinnate and alternate with four leaflets (with two pairs of leaflets per leaf), the pinnate leaves are between 3 to7cm long and 2 to 3cm wide. The groundnut plant can be erect or prostrate (measuring between 15 to 60cm tall or more) with well-developed taproot, many lateral roots, and nodules. Plant develops three major stems, i. e. two stems from the cotyledonary axillary buds equal in size to the central stem during early growth (Putnam *et al*., 1991).

The flower grows above the ground level and after it has beenpollinated,it withers,lengthening the stalks. The lengthened stalkthen bendsdownwards and pushes the ovary (peg) underneath the soil (Juangjum, 2003).Flowering in groundnut starts 20 to 30 days following emergence, differing on genotype and environment, in particular, temperature (Abdel, 1982).

It was observed that a higher number of flowers, pegs, and pods per plant may not always reflect higher seed pod yield, as the highest pod yielding cultivar in an experiment conducted, had the lowest total number of flowers, pegs, and pods, while it had the highest flower to peg ratio among the genotypes testedOsmaniye (2005). The report ishowever, contrary to that of Awal and Ikeda (2003), which reported that the number of flowers, pegs, and pods are the most significantpod yieldfactors that affect the pod yieldability of groundnut.

Different researchers have established periods for groundnut harvesting depending on days after seeding, for example, 85 to 100, 90 to 120 days after sowing for Spanish type cultivars, and between 110 and 130 days after sowing for Virginia type cultivars (Brink *et al*., 2006) although, Schilling and Gibbon (2002) argued that there are no commonlydependable indicators (markers) of groundnut maturity. It is, therefore,essential to check the crop consistently, commencing well before the recommended harvesting duration forthe variety. It is also not sufficient to use only foliage dry out to determine maturity. This is because moisture availability may prolong the vegetative stage even beyondthe pod filling stage. It is however, important to allow the groundnut to mature before harvesting because when harvested prematurely, the kernels shrink on drying reducing

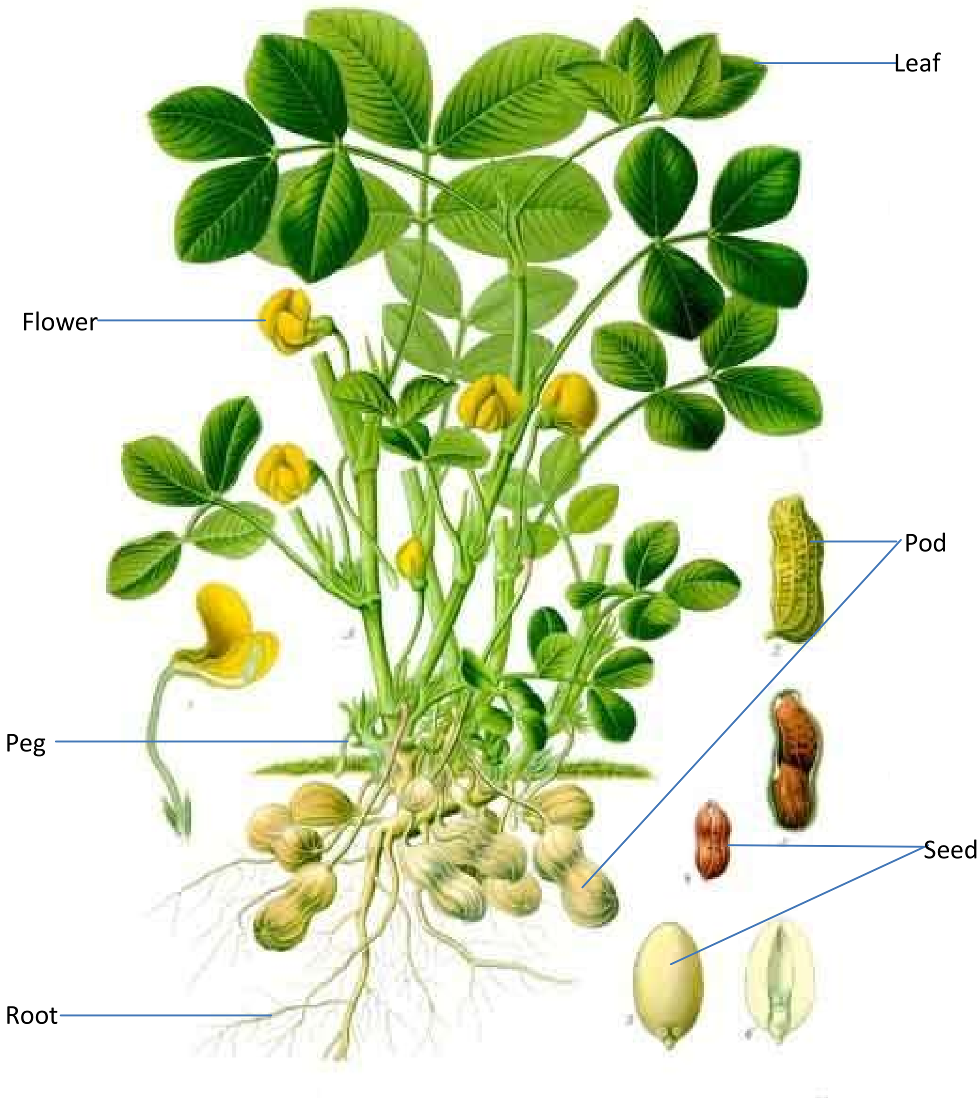


Fig. 2. 1: Groundnut plant, pod, and seed

Source: www.peanutvan.com.au

shelling percentage, seed quality, and oil content (De Waele and Swanevelder, 2001; Schilling and Gibbon, 2002; Brink *et al*., 2006).

2.3 Phenological Growth Stagesof Groundnut

Like other crops, groundnut has different growth stages descriptors. This study adopted the growth stage descriptors described by Boote (1982) because it is generally accepted. This growth descriptor was based on visual observations of reproductive growth (Table 2.1). This generallyaccepted system defines a sequence of vegetative (V) and reproductive (R) stages, and occurrences at all stages depends on certain populationthat are usuallydefined by observations from the field.

2.3.1 Vegetative Growth Stagesof Groundnut

It takes groundnuts about 3 to 5 days to germinate and emerge from the soil at 30° C. Though the main root system of groundnut is a taproot,majority of the lateral roots appear about 3 days after seed germination. Dependingon the cultivar and prevailingenvironmental conditions,the seedling grows autotrophically after 5 to 10 days and ithas the abilityto absorb minerals through the roots when the ‘epicotyl is exposed to light and capable of photosynthesis. The stems are angular and green or pigmented, the stems are initially solid, but become hollow as the plants grow. The initial vegetative growth stage is basicallyassociated with the mainstem elongation and leaf production, the formation of lateral branches comes in the later growth stages. In the first 35 days after sowing, >50% of the plant leaf area is accounted for by the main stem and by 90days, the main stem accounts for only 10%. Accumulation of dry matter after flowering, is generallywithin reproductive structures. The botanical and subspecies types determines the branching patterns and growth.

2.3.2 Reproductive Growth Stagesof Groundnut

The flowering pattern in groundnut varies with the botanical types, even within subspecies. Depending on the climatic conditions and cultivar, groundnut will typically flower (R1) withing 25 – 30 days after sowing. Flowers are borne in the leaf axils, often with three flowers on eachinflorescence.

Table 2.1: The vegetative and reproductive growth stages of groundnut

Stage	Stage Title	Description
VE	Emergence	Cotyledons near the soil surface with the seedling showing some part of the plant visible.
R1	Flowering	One open flower at any node
R2	Pegging	One elongated peg (gynophores)
R3	Podding	One peg in soil with a swollen ovary at least twice the weight of the peg
R4	Full pod stage	One pod fully expanded to dimensions characteristic of the cultivar
R5	Beginning seed	One fully expanded pod with which seed cotyledon growth is viable when the fruit is cut in cross-section
R6	Full seed	One pod with cavity filled with the seed when fresh
R7	Beginning maturity	One pod showing visible natural coloration or blotching of inner pericarp or testa
R8	Harvest maturity	66 – 75% of all developed pods have testa or pericarp coloration
R9	Over–mature pod	One undamaged pod showing orange–tan coloration of tests and/or natural peg deterioration

Source: Vara et al, (2009).

The flower colourdiffers from yellow, orange, dark orange andoccasionally, could be white. The style is contained within a calyx tube (hypanthium).The bud is about 6 to 10mm long 24 hours before flowering and, during daytime, the hypanthium slowly elongates, allowing the bud to attain 10–20 mmin length. Thehypanthium elongation becomes more rapid. The flower contains 10 anthers; five are small and globular, and the other five are oblong. One of the anthers is usually sterile and difficult to observe. The anther attains a maximum length of 5 to 7 mm at the time of flowering. Flowers open as soon as they receive light, early in the morning. The dehiscence of anther occurs just before or when the flower opens or sometimes much earlier. The stigma is receptive from 24 hours before to 12 hours after flower opening (Vara *et al.,* 2009).

Groundnuts are self–pollinated, the pollination usually occurs before the opening of flowers. Sporogenesis and gametogenesis occur 3 to 6 days before anthesis when buds are about 5mm long, and pollination occurs just before anthesis. After pollination, the pollen tube grows at varying rates depending on cultivars, application of fertilizer and/or other environmental factors. The pollen tube grows at a rate of 1 cm/hr. A stalk-like structure called a peg (Fig. 2.1), becomes visible within 4 to 6 days after fertilization under optimum environmental conditions. Peg elongationis initially slow, takes about 5 to 6 days to penetrate the bracts. Once pegs are 3 to 4 mm long, they become positively geotropic and start to grow towards the soil (R2, pegging stage).

The rate of peg elongation then increases rapidly between 5 to 10 days after fertilization and pegs can be as long as 15cm. The peg bears the ovary with the fertilized ovule at its tips. The tip of the ovary starts swelling immediately the peg penetrates the soil to a depth of 4–5cm leading to the next stage in groundnut growth (R3, podding stage). The peg then turns horizontally away from the base of the plant, and develops into a pod. The time from R1 to R3 is usually 15 to 20 days, after which the pod begins to expand rapidly until it reaches dimensions characteristic of the cultivar. Thefull pod stage (R4 stage) is defined as the time when 50% of the plants have achieved fully expanded pods. The number of flowers produced per day increases gradually; maximum numbers typically appear at 14 to 28 days after flower initiation, and numbers then decline to zero during the pod filling stage.

However, the flowering behaviour of cultivars may vary within botanical types. Pods become apparent at about 60 to 70 days after sowing and pod number per plant increases to a maximum at 80 to 120 days after sowing depending on the weather conditions, botanical type, andcultivar.

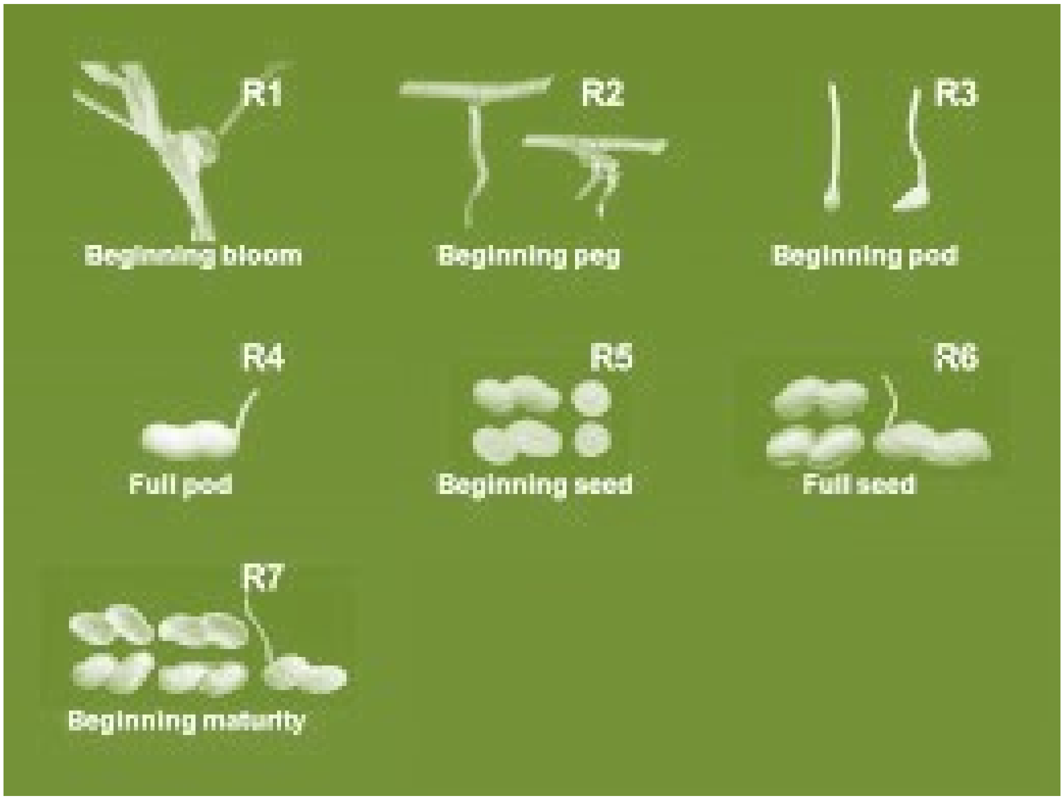


Fig. 2.2: Vegetative growth stages of groundnut

Source: Boote, J. W., 1982

The fresh weight of whole pod rapidly increases by the first 14 days of underground growth and reach their maximum size after 21 days. Duringthe R5 growth stage (seed growth phase), when seed cotyledon growth is visible in at least one pod on 50% of the plants, the endocarp recedes as the ovule grows and has disappeared completely by the time seeds are mature. During this period the inner phase of the pod is darkened by tannin deposition and turns dark brown on maturation. Pod growth rates vary among cultivars and are affected by thetemperature of the fruiting zone. Pod growth rates slow down as pods mature.

2.4 Phenology and thermal time

Phenology is determined by phases that mark the appearance, transformation or disappearance of vegetative and reproductive organs such as the emergence ofplant, appearance of nodules, flowers,and pods. The beginning and the end of these phases and stages are said to be good indicators of the plant's developmental rate (Torres, 1995 and Schwartz, 1997).

The stages of development are determined by theaccumulation of thermal time. Thermal time is a summation of cumulative differences between daily mean temperature and a specified base temperature and has units of degree–days (°Cd). Growing degree day (GDD) units are often used in agronomy to estimate or predict the lengths of different phases of development. Thermal time is the total heat accumulated by the plant that is required for its development and is an important tool in phenology. The effectiveness of GDD centered on the principle that the higher the temperature, until the optimum temperature is reached, the faster the plant develops (Yoldaş and Eşiyok, 2005). Often,GDD is used to describe timing of biological processes (Leong and Ong, 1983: McMaster and Wilhelm, 1997; Black and Ong, 2000; Butler *et al*., 2002; Calıskan *et al*., 2008). The GDD of a crop is accumulated throughout the growing season starting from sowing until harvest.The GDD have been used to predict the stages of crop development, theknowledge that can be important for timing the application of herbicides, insecticides,andfertilizer.

A crop enters the next stage of development when the thermal time reaches the required length for the respective stage.For instance, groundnut first flowering appearance was reported as 4 to 6 weeks after sowin (De Waele and Swanevelder, 1983, Putnam *et al*. 1991), and maximum flower production to occur 6–10 weeks after sowing while Juangjum (2003), reported that flowering begins 20–30 days after emergence, depending on the genotype and environment, especially temperature.

Reports on the effects of accumulation of GDD and photothermal units, PTU (the total amount of light plants needs to grow from one developmental stage to another) are conflicting. For instance, Phadnawis and Saini (1992) stated that GDD and PTU for each developmental stage are relatively constant independent of sowing date,but could be significantly modified by the crop variety. However, an early scientist like Ketring (1979) stated that sowingdate plays an important role in the accumulation of GDD and PTU from sowing to maturity of the crop particularly when the plant experience high temperature during it later stages of growth which may lead to forced maturity hence, low productivity. Further works have established that long days promote vegetative growth at the expense of reproductive growth, increase dry matter accumulation, decrease partitioning of photosynthate to pods and decrease theduration of the effective pod filling phase (Ketring, 1979; Schilling and Gibbons, 2002). Bagnal and King (1991) observed that flower, peg,and pod numbers were consistently enhanced by short-day treatment for several groundnut varieties. Flowers and peg numbers at 60–700 days from emergence were approximately doubled by 12hours/day exposure to light compared with plants receiving 16 hours of light per day.

2.5 Effects of Sowing Dates on Performance of Groundnut

Management practices such as thetime of sowing,duration of a cultivar life cycleandnutrient management mayinfluence yield parameters, pod yield, andquality of groundnut(Sogut*et al*., 2016). The pod yield, pod number per plant,and oil content of groundnut was affected sowing time, early sowings (15th April) resulted in higher pod yields, pod number per plant, and oil content compared to latesowing (25th June) for all cultivars in a field trial at University of Dicle, Diyarbakir, Turkey in 2010 and 2012(Sogut*et al*., 2016).In another study by Banik *etal*. (2009) at Instructional Farm, Nadia, West Bengal, the groundnut sown late (20th February) has a highernumber of pods per plant, leaf area index, and pod yieldthan the earlier sown dates (20th January and 5th February).Planting in early June was originally favoured in Minnesota due to the warm temperature required for optimal growth of peanut.

However, Putnam *et al*. (1991) observed thatplanting in early May gave higher yields, larger seeds, and higher shelling percentage. Groundnut planted in early May required 9 more days to emerge and had a slower development than a crop planted in June.

Planting in early May flowered earlier which allowed more pods to reach maturity before frost.Variationsin weather patterns affect the length of the growingseason as well as the flowering date and poddevelopment. Stern (1968) suggested thatdeclining minimum temperatures in laterplantings may have retarded or even preventedpod development.

2.6 Soil and Climatic Requirements of Groundnut

Essentially, groundnutthough a tropical plant andmay be produced on a variety of soils and climatic conditions, but warm, moist soil is more suitable for better performance. It is usually cultivated in well-drained, light sandy–loam, aerated soils. Furthermore, good soil preparation is essential for a good pod yield as this enables better pegging.

The most favorable climatic conditions for groundnut are a well-distributed rainfall of at least 500mm during the growing season (FAO, 1990). Though groundnuts is a drought-tolerant crop but persistent dry spells and low rainfall have been reported as the main cause ofbelow average pod yields particularly,during the growth periodsin Asia and Africa regions (Camberlin and Diop, 1999; Brink and Belay, 2006). Kochhar (1986), also supported that rainfall of 500 to 1000mm per year is enough to ensure high respiratory exchange during pod formation and vegetative period of growth. Challinor *et al*., 2004 analyzed 25 years of historical groundnut pod yield in India concerning rainfall and concluded that rainfall accounts for about half the variance in pod yield. Analysis of the relationship between simulated groundnut pod yield and climate in Ghana showed that the pod yield was influenced by rainfall from flowering to maturities (Christensen *et al*., 2004). During the sowing period up to flowering (0 to 30 days after sowing), the groundnut crop has good resistance to drought, but this is followed by a period of maximum sensitivity, during which there is considerable physiologically active flowering and pod formation. Relatively dry conditions are again favorable in the period to maturity. Rain at the pod formation stage can have a negative effect on pod yields especially in non–dormant types, which tend to germinate in wet soils or even while drying after harvest (Boote and Ketring, 1990; ICRISAT, 1992).Moisture from rainfall is essential for germinationand also a critical requirement for flowering, pegging, pod formation, and seed filling when pod yield and seed qualities are determined (De Waele and Swanevelder, 1983).

Temperature is another limiting factor for groundnut production (Robinson, 1984). For its groundnutproduction, a long and warm growing seasonis required. The cardinal temperatures for groundnut seed germination has long been establishedat 29°C to 36.5°C(Ketring, 1989). The required mean temperature of21°Cto26.5°Cwas reported by FAO (1990) for groundnut production. Schilling and Gibbon (2002), also gave a general optimum temperature for growth of groundnut as 25 °C to 33 °C. The temperaturerequirement for different growth stages of groundnut was reported as 24°C to 30°C but aminimum of 12°C to 15°C for germination and at least 24°C for flowering and seed setting (Tweneboah, 2000). By implication, thecultivatedgroundnut in the semi-arid tropics is frequently exposed to damaging hot temperatures usually above 40 °C (Vara Prasad *et al*., 2009). Although groundnut requires a long and warm growing season, lower temperatures are not suitable for groundnut's proper development, also ahigh temperature above 38°C from 21 to 90 days after sowing reduced total dry weight by 20 to 35%, seed harvest index by 10 to 65% and seed dry weight by 23 to78% (Ketring, 1984). Craufurd *et al*.(2003), also noted genotypic differences in response to temperature with areduction in thetotal dry matter, pod and seed dry weight, and harvest index at high temperature. During the ripening period groundnut requires about a month of warm and dry weather.

2.7 Economic Importance of Groundnut

All parts of the groundnut plant can be used. Groundnut is grown primarily for human consumption but has several uses as whole seeds or is processed to make peanut butter, oil, and other products. The seed contains 25 – 32% protein (average of 25% digestible protein) and 42 to 52% oil. A kilogram of groundnuts is high in food energy and provides about the same energy value as 2kg of beef, 1.5kg of Cheddar cheese, or 36 medium – eggs (Woodroof, 1983).Groundnut is a good source of minerals like P, Ca, Mg and k as well as vitamin E, K, and B (Schilling and Gibbon, 2002) and a primary source of digestible protein (25 – 45%), and cooking oil (44 – 56%) (Savage and Keenan, 1994). A large percentage of annual groundnut harvested is pressed forcooking oil. Groundnut oil is a pale yellow, neutral flavored oil with a very high smoking point that is ideal for frying, cooking, manufacturing of soap, lubricants, illuminants (Kochhar, 1986) as laxatives and emollient (Abbiw, 1990), and production of detergents. Groundnut oil has varieties of industrial uses. Paint, varnish, leather dressing, furniture polish, insecticide,and nitroglycerine are made from groundnut oil.

The protein portion of the oil is used in the manufacturing of some textile fibers while the shells are used in themanufacturing of plastic wallboards, abrasives,and fuel. The shells are also used in making cellulose and mucilage. The shafts from the oil pressing process are often pressed in cakes. The cake and haulms in many countries, are used as livestock feed and as asoil fertilizer.Groundnut cake is often deep fried or dried to make a snack locally called *kuli–kuli* (by Yorubas and Hausas of Nigeria).

Groundnut as a food is eaten fresh, boiled or roasted and used in soup preparation (De Waele and Swanevelder, 2001). Groundnut is often ground into abuttery paste, the peanut butter is a vital ingredient in Nigeria's 'Africa salad', also used in sandwiches, mixed into candies, cookies, pies and other bakery products. Also, in Nigeria, groundnut sauce prepared with onions, garlic, groundnut butter and vegetables such as carrots and cabbage ate with meat usually chicken is a delicacy. Groundnut is often a major component in mixed nut because it is cheap compared to other nuts like cashew and walnuts (Schilling, 2002).

As a legume, groundnut improves soil fertility by fixing nitrogen thereby increasing the productivity of the cropping system (Smartt, 1994).It is an annual, self–pollinated crop. Like other legumes, groundnut may be used to make alactose free milk–like beverage, peanut milk (Peanut CRSP, 1997). It is also used as a medium of preservation for preparation of pickles, chutney, etc. The groundnut oil is used in making different types of medicated ointments, plasters, syrups and medicated emulsion. Groundnut straw is used as animal feed and fuel and in preparation of compost. The green leaves and stems of plants are used as animal feed. The shells of pods obtained during threshing are also used as cattle feed (Taru *et al*., 2010).

2.8 Production Constraints of Groundnut in Nigeria

The majorgroundnut–producing areas in Nigeria are located in the Northern and SudanGuinea savanna ecological zones. The soil and agro–climatological conditions of the ecological zones arefavourable (Misari *et al*., 1980). There, the temperatures are averagely warm and relativelystable during the growing season at 20–25 ºC. Sudan Savanna zone receivesadequate rainfall for groundnut production. Groundnut is usually grownas acomponent in intercropping of a variety of crop mixtures (Misari *et al*., 1988). In Nigeria, the two main varieties grown are longseason varieties (late maturing, 130 to 145 days); and short season(early maturing, 90 to100 days).A rainfall of 500 to 1000 mm will allow commercial production (FAO, 1990)although crops can be produced on as little as 300 to 400 mm of rainfall.Drought and rainfall variability is one of the major causes of crop failure, however, once established, groundnut is drought tolerant, and to some extent it alsotolerates flooding. Groundnut is commonly sown when there isan adequate amount of moisture for the seed to germinate with the intent of reseeding if subsequent rain delays. At the inception of the growing season, drought stress affects establishment of plant, and at mid to end of the sowing season, drought may cause pod formation and filling, leading to yield reduction or crop failure (Ajeigbe, 2015).

Some noted limitations in groundnut production are land availability, labor, fund, availability of appropriate fertilizer dosage, disease control, post-harvest challenges, proper storage to marketing (Idoko and Sabo, 2014).Another groundnut production constraints factors are diseases especially rosette and leaf spots; drought; lack of quality planting materials; and inefficient market access to seed of improved varieties of groundnut and inconsistent government policies (Mohammed *et al*., 2021).

In the time past several technologies have been deployed by research to thefarmer and these have impacted positively on groundnut production and incomes. Timely sowing and harvesting were some of the several approaches deployed that made agreat impact on socio-economic characteristics of the respondents from the report of Idoko and Sabo, 2014. The survey pointed out that high adoption of insecticidal use in the study area (Taraba) by the respondents may be due to the devastating effect of pests on groundnut in the area. Constraints of groundnut production are said to be diversed due to contrasting agroecologies, inaccessibility of improved varieties, poor soil fertility, cultural practices, and seed management (Subrahmayam *et al*.,1999).

2.9 Field Preparation

The most effective system for land preparation is deep (10–15cm) soil turning, disked, harrowed to thoroughly break the soil until it is in the best condition (Coffelt, 1989). The suitable or favorablesowing field is a flat or slightly raised seedbed. To obtain good uniform groundnut plants, groundnut seeds to be used for sowing must be 70% viable or higher and the seed must be treated with a fungicide (Juangjun, 2003). General soil characteristics of well-drained sandy or sandy loam soils, as light soil, helps in easy penetration of pegs and their development and also harvesting (Putnam *et al*., 1991). Groundnut may be produced over many soils but warm, moist soil is more desirable. The well-drained, sandy loam, loamy sand, silty sand, and sandy clay loam are ideal soils for growing peanuts (Juangjun, 2003). Nautiyal (2002), also stated that groundnut is adapted to well-drained, loose, friable medium-textured soils. Heavy textures are said to cause problems in lifting the crop at harvest. According to Schilling and Gibbon (2002), groundnut needs well-drained and aerated soils, owing to high respiratory exchange during pod formation that sandy or fine-textured friable soil with good infiltration is most suitable.

Clay or heavy soils are not appropriate for groundnut, becausethey obstructthe penetration of pegs and make harvesting very difficult (De Waele and Swanevelder, 2001). Groundnut is highly sensitive to salinity; however, it tolerates a wide range of pH and prefers neutral to slightly acidic soil (Schilling and Gibbon, 2002). Putnam *et al*., (1991), further stated that groundnut gives good pod yields in the soil with pH between 6.0–6.5. A report from Chong *et al*., (1978)highlighted that maximum root growth occurred at pH 7.3 while shoot growth, nodulation,and N_2 fixation were best at pH 5.9 –6.3.

2.10 Manure and Fertilizer Requirements of Groundnut

Singh and Oswalt (1995), in their compilation on groundnut production practices, noted that since it takes about 25 to 30 days to develop nodules then, some available nitrogen is required in the early stages for plant growth. Buah and Mwinkaara (2009) also stated that because nutrients are exported and lost during cropping, there is a need for nutrients inputs from fertilizers to maintain a positive nutrient balance in the soil. An application of between 20 to 40 kg nitrogen per hectare as a starter dose is recommended to meet the nitrogen requirement of the crop in the initial stage in poor fertility soils (Juangjum, 2003). If farmyard manure or compost is available, 10 to15 tonnes may be added per hectare about 15 to 20 days before sowing. The starter dose of nitrogen is being side-dressed along with phosphorus and potassium application just before sowing (Putnam *et al*., 1991). Lambin *et al.,* (2003) reported that the results of the various studies on existing fertilizer recommendations for groundnuts in the savanna zone of tropics are becoming inadequate under a system of continuous intensive cultivation. Soil erosion and crop removal were also reported as significant ways by which soil nutrient is lost (Griffith, 2006).

Federal Ministry of Agriculture, Water Resources and Rural Development (FMAWRRD) Nigeria, in 1990 reported that under traditional agriculture, groundnuts normally receive no manure, but earlier research findings of Goldsworthy and Heathcote (1963) reported the use of single superphosphate as the only fertilizer for groundnut production in northern Guinea and Sudan Savanna Zones of Nigeria. Singh (1984) also suggested an application of a starter dose of 5 to 10 kg N/ha for groundnut production in this region.

In other countries like Thailand, nitrogen, phosphorus,and potassium fertilizer grades 12:24:12 or 15:15:15 at the rate of 315 kg per ha during land preparation or at sowing time is used (Juangjun, 2003). It was observed in a long-termfertility study that P application results in better nodulation and seed pod yield. The N pod yield per plant increased significantly with P, K, and B application, but the promoting effect of K and B on N content per plant was not reflected in the final pod yield (Balasubramanian *et al*.,1980).

2.11 Starter Nitrogen Fertilizer

Plants are surrounded by nitrogen (N) in our atmosphere, but atmospheric gaseous nitrogen is present as inert dinitrogen (N_2) molecules, which is not directly available to the plants that need it to grow, develop and reproduce. Despite nitrogen is one of the most abundant elements on earth, Nitrogen deficiency is probably the most common nutritional problem affecting plants worldwide(Singh, 1994). N is said to be the most required mineral nutrient in all cropping systems, this is due to its key functions in various biochemical and physiological processes in the plant (Leghari *et al*., 2016; Pourranjbari-Saghaiesh *et al*., 2019).

Foliar or soil application of N fertilizers has been shown to significantly influence the growth, yield, and quality of many crops (Dehnavard*et al*., 2017). Though leguminous crops like groundnut fix nitrogen in association with nitrogen-fixing bacteria on their nodules, it however takes between 25 to 30days for the nodule to form.Therefore, starter nitrogen should be introduced to initiate the presence of nitrogen in the root zone (Singh, 1994) for the full establishment of the root and for proper fixation of nitrogen to take place. Subsequently, like the other legumes, groundnut meets a major part of its nitrogen requirement through nitrogen fixation (Putnam *et al*.,1991).

An application of 20to40 kg nitrogen per hectare as a starter dose is suggested to be given to meet the nitrogen requirement of the crop in the initial stage in poor fertility soils. If farmyard manure or compost is available, 10to15 tonnes may be added per hectare about 15to20 days before sowing(Putnam *et al*.,1991).

The soil should be tested for the availability status of phosphorus and potassium and fertilizer recommendations for groundnut should be obtained before soil fertilizer application for groundnut,however, in the absence of soil test,general fertilizer application of NPK kg ha^{-1} is 25 kg of N- 50 kg of P_2O_5 - 100 kg of K_2O is recommended (Ajeigbe *et al*., 2015).

2.12 Climate Change

Climate change is defined as adeviation from the long-term weather patterns that characterize aregion over a long period. The main cause of climate change is the anthropogenic increase in greenhouse gas,GHGs(carbon dioxide (CO_2), water vapour (H_2O), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6)) concentrations in the earth's atmosphere. Increased anthropogenic activities such as industrialization, urbanization, deforestation, agriculture, change in land use patterns leads to emission of greenhouse gases (Mahato, 2014).

Carbon dioxide (CO_2) is the principal greenhouse gas. Its concentration in the atmosphere is the result of a cycle between different carbon pools, $CO_2$is the product of the oxidation of carbon from these pools.The concentration of CO_2 in the atmosphere has increased by 31% since the beginning of the industrial era, from 280 to 360 ppm (IPCC, 2016).The average global surface temperature has increased by 0.74°C since the late 19th century and is expected to increase by 1.4°C -5.8°C by 2100 AD with significant regional variations (IPCC,2007). Also, the atmospheric CO_2concentration has increased from 280 ppm to 395 ppm, CH_4concentration increased from 715 ppb to 1882 ppb, and N_2O concentration from 227 ppb to 323 ppb from the year 1750 and 2012 (Mahato, 2014). Anthropogenic emissions of CO_2originate primarily from the burning of fossil fuels and deforestation in tropical regions.The greenhouse effect may be important for agriculture. The concentration of atmospheric CO_2 may have a direct impact on the growth rate of crop plants (Pederson, 2000).

Agriculture is closely tied to climatic conditions (Rosenzweig and Hillel, 2008) and has largely determined the historical agricultural activities of a region. Climate change could affect the quality, quantity, and growth rates of crops through processes like photosynthesis and transpiration rates. The CO_2-induced changes of climate may alter temperature levels, rainfall, and sunshine thereby affecting the productivity of plants and animal. In areas where temperatures are already close to the physiological maximum for crops, warming will impact crop yields more immediately (IPCC, 2019). The significances of agriculture's impact on climate change, and climate change's negative impact on agriculture, are severe which is projected to have a great impact on food production and may threaten food security, hence, require special agricultural measures to combat with (Beck, 2013). Also, rises in sea level may lead to loss of farmland by inundation and increasing salinity of groundwater in the coastal areas.

2.13 Climate Change Impacts on Agroecologies for Groundnut Production in Nigeria

The major groundnut-producing areas in Nigeria are located in the Sudan and Northern Guinea Savanna ecological zones where the soil and agro–climatological conditions are favorable (Misari *et al*., 1980). Traditional commercial groundnut production areas in Nigeria encompass the Sahel (12º–13ºN), Sudan (10º–13ºN), the Northern half of the Northern Guinea Savannah (8º–11ºN), and most part of the Southern Guinea Savanna (6º–8ºN) vegetation zones.The major groundnut producing states in Nigeria are Borno, Bauchi, Adamawa, and Yobe in the Northeast; Zamfara, Kano, Kebbi, Katsina, Kaduna, Sokoto, and Jigawa in the Northwest;and Kwara, Benue, Plateau, Taraba, Niger, FCT Abuja, Nasarawa and Kogi in the North Central zone.

Climate change will require major transformations in agricultural systems, including increased irrigation and moving production from one region to another (Leclère *et al*., 2014). Inadequate and erratic rainfall patterns and extreme temperature variations induced by climate change are being experienced which have compromised the cropping systems in their traditional producing areas (Muktar, 2011).

Hence, adrift in the producing areas towards a more conduciveenvironment will be experienced with varying impacts based on the morphology crop. For instance, in mid-latitude andhigh–latitudes, the suitability, and productivity of crops are projected to increase and extend northwards, especially for cereals and cool-season seed crops (Maracchi *et al*., 2005 and Tuck *et al*., 2006). Crops prevalent in southern Europe such as maize, sunflower,and soya beans could also become viable further north and at higher altitudes (Hildén *et al*., 2005 and Audsley *et al*., 2006).

However,Leclère *et al*. (2014)observed that without careful planning for uncertain climate impacts, the chances of getting crop adaptation wrong are high. These drifts and possible outcomeson crop production are better studied using different scenarios for countries to better plan for the impacts of climate change with the suitable crop–climate models.

2.14 Crop Models

System simulation was described as the mimicking of the operation of a real system, such as the day–to–day operation of a bank, or the value of a stock portfolio over some time, or the running of an assembly line in a factory, or the staff assignment of a hospital or a security company, in a computer. Instead of embarking on expensive experiments, theexistence of mathematical models by experts has made readily available simulation software possible to simulate and analyze the operation of a real system.

Crop models are generally designed to operate at the field level, and they rely on detailedfield–scale inputs, such as the soil, plant genotype, and weather, to predict pod yield and other crop variables (Challinor *et al*., 2004). Crop models are valuable in measuring theresponse of specific production factors separately or in combinations on crop growth and development (Huda *et al*., 1984).Semenov and Porter (1995) stated that crop simulation models are being used increasingly to predict crop responses to various environmental conditions and management.

A common application is the assessment of the likely impact of climate change on grain yield, pod yield variability, and geographic distribution of the crop. Others include the use of crop models in decision support systems as a tool to target crop genetic improvement. For such uses, crop models must accurately predict several key characteristics of the crop over a wide range of climatic conditions: Timing of key phenological events such as flowering and physiological maturity, through correct descriptions of phenological responses to temperature, daylength,andvernalization. Models have been classified into various categories depending on different approaches (Ritchie, 1985 and Mandel, 1992). However, Mandel (1992) observed that the complexity of meteorological and biological phenomena and processes may lead to the necessity for a greater diversity of models.

2.15 Overview of CSM Models

The Internal Benchmark Sites Network for Agrotechnology Transfer (IBSNAT)–CERES–Maize model is one of the early CSM Models. IBSNAT–CERES–Maize was used to simulate a sole crop of maize between 1990 and 1991 growing seasons at Ibadan in southwestern Nigeria (Jagtap *et al*., 1993). The model was used to simulate plant physiological processes, predict the growth and cob yield of maize like the real processes. The model gave results that were within 10% which implies that thebuilt-in partitioning rules in the CSM model were adequate.

The CERES–Maize model, which is distributed in the DSSAT v 4.5 package (Tsuji *et al*.,1994) simulates nitrogen (N) response for growth, leaf area, leaf weight, stem weight, grain pod yield, andpod yield components. The model uses two sets of N stress indices as afunction of the N deficiency factor (NFAC) to simulate the effect of N stress on leaf expansion andphotosynthesis. The NFAC is estimated as the ratio of N supply (from soil and fertilizers) to plant Ndemand. Godwin and Singh (1998) have presented a complete description of the N model. The model,however, does not simulate the effect of N stress on phenology.

A study to determine the feasibility of estimating the cultivarcoefficients for new peanut lines using typical data from pod yieldperformance trials of 17 peanut lines with the optimization procedures of GENCALC was carried out in Thailand (Anothai*et al*., 2008). GENCALC is asoftware package that facilitates the calculation of cultivar coefficients for use in existing crop models (Hunt *et al*., 1993b), including the CSM–CROPGRO-Peanut model. The cultivar coefficients of the 17 peanut lines from routineperformance trials resulted in simulated values of developmentand growth characteristics that were close to their correspondingobserved values from which they were derived. Invariably, simulations usingthese cultivar coefficients with independent data resulted inaccurate predictions of growth, development,andpod yield for all the peanut lines. Thus, it appears feasible to estimate the cultivarcoefficients for new peanut lines from typical data of routineperformance trials by using GENCALC.

The CSM–CROPGRO–Soyabean in Kenya was evaluated to generate genetic coefficients of the new varieties ofsoyabean and also the reliability of the CSM–CROPGRO–Soyabeanby simulating the phenology and pod yield of soyabean under various management conditions (Nyambane *et al*., 2012). From the evaluation, it was concluded that the model can be reliably used to gauge the performance of introduced soyabean varieties and for breeding purposes but suggested that more characteristic from the site be included for more reliable results.

The processes involved in the response of maize to N fertilizer application in a Subhumid Region of Ghana was studied with CSM–CERES–Maize model of the DSSAT version 4.0 (MacCarthy *et al.*, 2012). Simulations for the processes were generally better with nitrogen fertilizer application than under no fertilizer applicationtreatment.The model was also used to determine the stage at which to target inorganic fertilizer and water for irrigation to obtain maximum grain pod yield. However, the CSM–CERES–Maize model is not responsive to phosphorus fertilizer when applied.

However, DSSAT–CSM was restructured from previous DSSAT crop models into a modular format, which isdescribed by Jones *et al*. (2001) and Wheeler*et al*. (2000). The most important features of this approachare:

1. Modules separate along disciplinary lines.
2. Clear and simple interfaces are defined for each module.
3. Individual modular components can be plugged in or unplugged with little impact on the mainprogram or other modules, i.e., for comparison of different models or model components.
4. The modular format facilitates documentation and maintenance of code.
5. Modules can be written in different programming languages and linked together.
6. Modules can be easily integrated into different types of application packages due to thewell–definedand documented interfaces.
7. The modular format allows for thepossibility of integrating other components, such as livestockand intercropping, through well–defined module interfaces.
8. Cooperation among different model development groups is facilitated. Each group can focus onspecific modules as building blocks for expanding the scope and utility of the cropping systemmodel.

The new modular format is shown in Fig 2.3. DSSAT v 4.5 also contains some crop-specific input.

2.16 The DSSAT Model

DSSAT, Decision Support for Agrotechnology Transfer was designed by The International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) to accelerate theflow of agrotechnology and increase thesuccess rate of technology transfer from agricultural research centers to farmer's field (IBSNAT, 1998). Decision

Support for Agrotechnology Transfer version 4.5 (DSSATv4.5was developed from collaborative works between scientists at the University of Florida, University of Guelph,University of Hawaii,the University of Georgia,Iowa State University, the International Center for Soil Fertility and Agricultural Development,and other scientists associated with the International Consortium for Agricultural Systems Applications (ICASA).

DSSAT is a Microsoft Windows-based software package integrating the effects of soil, crop phenotype, weather, and management options. By simulating probable outcomes of crop management strategies, DSSAT offers users information with which to rapidly appraise new crops, products, and practices for adoption. DSSAT also allows users to compare simulated outcomes with observed results. The DSSAT software allows linking the crop models and linkage with Geographic Information Systems (GIS) (http://www.icasa.net/dssat/index.html). DSSAT comprises the following components:

1. A DataBase Management System (DBMS) to enter, store, and retrieve the “minimum data set” needed to validate, list, and use the crop models to provide an outcome to alternative management input
2. A set of validated crop models
3. An application program for analyzing and displaying outcomes of long-termsimulated agronomic experiments

DSSATv4’s application programs and data entry and analysis tools were designed to be compatible with the latest Windows standards. To corroborate the application, all crop models of DSSATv4 were combined into the Cropping System Model (CSM), which is based on a modular modeling approach (Hoogenboom *et al.,* 2003).DSSAT is being used as:

1. As a teaching and training tool by providing interactive responses to "what if" questions related to improved understanding of the influence of season(weather), location (site and soil), and management on growth processes of plants.
2. As a research tool, to derive recommendations concerning crop management and to investigate environmental and sustainability issues.
3. As a business tool, to enhance profitability and improve input marketing.
4. As a policy tool, for pod yield and area forecasting and land use planning.
   (Jones *et al*., 1998)

DSSAT requires the following minimum data set:

1. Weather: latitude and longitude, daily solar radiation, maximum and minimum air temperature, and rainfall
2. Soil: upper and lower horizon depths, texture, bulk density, organic carbon, pH and aluminium saturation, and

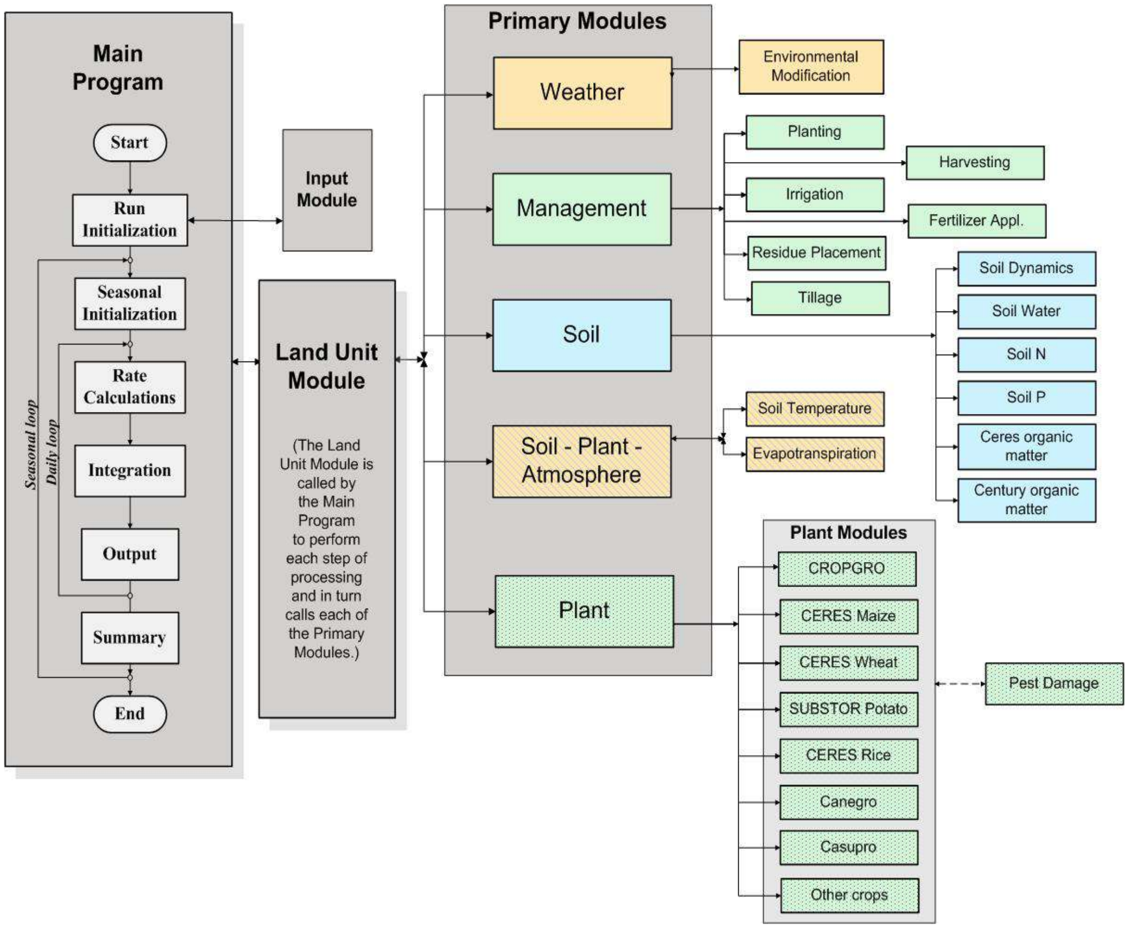


Fig. 2.3: Overview of the components and modular structure of DSSAT-CSM (Hoogenboom*et al.*, 2010)

3. Management: sowing date, dates when soil conditions were measured before sowing, sowing density, row spacing, sowing depth, crop variety, irrigation, and fertilizer practices. (Jones *et al*., 2003).

2.16.1 The components and modular structure of DSSAT–CSM (Cropping System Model)

The DSSAT Cropping System Model (CSM) simulates crop growth and development over a period. It also simulates the carbon and nitrogen processes, soil water, and management practices. Fig.2.1 shows the main components of CSM. These include:

1. The main driver program, which controls timing for each simulation
2. A Land unit module, which manages all simulation processes which affect a unit of land
3. Primary modules that individually simulate the various processes that affect the land unit including weather, plant growth, soil processes, soil-plant–atmosphere interface and
4. Management practices.

Collectively, these components simulate the changes over time in the soil and plants that occur on a single land unit in response to weather and management practices. Unlike previous versions of DSSAT and its crop models, the DSSAT-CSM incorporates models of all crops within a single set of codes.

The DSSAT cropping system model (CSM) design is a modular structure in which components separate along scientific discipline lines and are structured to allow easy replacement or addition of modules. It has one soil module, a Crop Template module, a Weather module, and a module for dealing with competition for light and water among the soil, plants, and atmosphere (Jones *et al.,* 2001).

CSM uses one set of code for simulating soil water, nitrogen, and carbon dynamics, while crop growth and development are simulated with the CERES, CROPGRO, CROPSIM, and SUBSTOR modules. The CENTURY-based soil carbon and nitrogen model for improved performance in low input agricultural systems and simulation carbon sequestration were added as a separate soil module to CSM (Hoogenboom *et al.,* 2003).

2.16.2 CROPGRO template module

CROPGRO model is one of the CSM in DSSAT used in different applications in many countries of the world (Tsuji *et al*., 1994; Boote *et al*., 1998b). The CROPGRO crop template module in DSSAT–CSM provides a generic means for modeling crops (Boote *et al*., 1998a). A single source code can be used to simulate the growth of several different crops by the use of species characteristics defined in an external species file. Currently, the CROPGRO plant growth and development model simulates seven grain legumes (soyabean (*Glycine max* L. Merr.); peanut (*Arachis hypogaea* L.); drybean (*Phaseolus vulgaris* L.*);* chickpea; cowpea; velvet bean, and faba bean (*Viciafaba* L.), and non–legumes such as tomato (*Lycopersicon esculentum* M.) (Scholberg *et al*., 1997; Boote *et al*., 1998a,b), cabbage, bell pepper, and two grasses: bahia and brachiaria.

2.17 The statistics for accessing and comparing model performance

Over the past decades, the development of models has increasingly become a major focus of the physical science community. An important aspect of the modeldevelopment process is the evaluation of model performance (Willmott *et al*., 1985).There are several statistical tools available to evaluate the relationship between predicted (*P*) and observed (*O*) values.Evaluation involves comparison of model outputswith real data and a determination ofsuitability for an intended purpose. The tools also measure the extent to which the model'sbehavior is consistent with prevailing scientific theory (Jones et al., 2003).There are difference measures derived from the fundamental quantity ($P — O$), although each measure is scaled in a different way in order to describe particular features of the scales of the differences(Willmott, 1982). Some of the measures are:

Root Mean Square Error, RMSE is described (Willmott, 1982) as, among the best overall measures of model performance, it quantifies the difference between a set of values. RMSE is more sensitive to extreme values due to its exponentiation and therefore can be considered as a high estimate of actual average error and the smaller RMSE, the better the model is RMSE aggregates the magnitudes of the errors in predictions for various times into a single measure of predictive power. RMSE is a good measure of accuracy, but only to compare forecasting errors of different models for a particular variable and not between a set of variables, as it is scale–dependent.

The Percentage Error, PE otherwise called the normalised Root Mean Square Error (nRMSE) facilitates the comparison between a set of variables or models with different scales and lower values indicate less variation in the model and thus, better prediction.

Mean Absolute Error, MAE is less sensitive to extreme values than RMSE, but it is intuitively more appealing, since it avoids the physically artificial expo-nentiation that is an artifact of the statistical-mathematical reasoning from which RMSE comes.

The mean absolute bias, MAB is determined by taking the absolute difference between all simulated and observed values and determining an average.

Index of agreement, d-index is meant tobe a descriptive measure, and it is both a relative and bounded measure which can be widely applied in order to make cross-comparisons between models.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Experimental Sites

The experiment was carried out at two locations within the southern/derived savanna agroecological zones of southwestern Nigeria (Fig 3.1). These sites are at Ogbomoso and Ibadan.

3.1.1 Ogbomoso Experimental Site

The site was located within the Ladoke Akintola University of Technology, (LAUTECH), Ogbomoso (8º07′N; 4º14′E; altitude 341m asl) in the Southern Guinea Savanna agroecological zone of Nigeria. The Southern Guinea Savanna is a subset of the Guinea Savannaagro-ecological zone of Nigeria and is the most extensive ecological zone in Nigeria, covering nearly half of Nigeria's land area which was reported at 910770 km^2 (The Word Bank, 2017). It is a belt of mixture of trees and tall grasses in the South, with shorter grasses and fewer trees in the north. The Guinea Savanna, with its typically short trees and tall grasses, is the most luxuriant of the Savanna vegetation belts in Nigeria. The zone is characterized by low rainfall and long dry periodwith an average annual temperature of 27.3ºC and rainfall of 1051.7mm respectively. The wet season lasts for 6–8 months (Eroarome, 2016). Most of the tall grasses found in the derived Savanna are also found in the Guinea Savanna, however, they are less luxuriant. The appearance of this zone differs from season to season. During the rainy season, the whole zone is green and covered with tall grasses that grow and reach maturity rapidly and thus become fibrous and tough. In the dry season, they tend to die and disappear, and one can see for kilometers without obstruction. This clearing is due to several periodical bush–burning that occurs during the dry season between November and April, carried out to either assist in farm clearance or hunting.

In the last ten (10) years, the average annual rainfall of Ogbomoso is 1200 mm with minimum and maximum temperature of 28ºC and 38ºC respectively. Mean annual humidity of 74%, solar radiation of 20 MJ/m^2/d, thealtitude of 341m above sea level and wind speed of 2.92 m/s were reported for the location.

The soil the experimental site is well drained and belongs to the Gambari series (USDA – Udic Paleustalfs; FAO/UNESCO – Eutric Planosol: U.S.S.R - Podbels). The slope of the land is 0–5% straight, depth of water table >190 cm, soil surface form is flat with an effective soil depth of >190cm (Olatunji, 2011).

3.1.2 Ibadan Experimental Site

Ibadan site was within the University of Ibadan Organomineral Fertilizer Demonstration Plant premises along Barth road (7º22′N; 3º55′E; altitude; 241m above sea level). This site is at the fringe of rainforest belt of Nigeria (Derived Savanna zone), with alfisol derived from basement complex (Iwo series) as the soil type. The mean rainfall in Ibadan is 1289 ± 206.1 mm (Alabi and Ibiyemi, 2000) with mean minimum and maximum daytime temperatures of 22ºC and 33ºC respectively. There are two growing seasons in Ibadan; early (March–July) and late (August–November). Mean annual humidity is 73%, solar radiation – 6.28 MJ/m^2/d and wind speed of 1.1 m/s.

Derived Guinea Savannais found after the tropical rainforest zone and it is the transition between the tropical rainforest and guinea savanna zones. The high forest trees were destroyed due to cultivation, bush burning, overgrazing, and hunting activities over a long period. The initial forest of the zone is now replaced with a mixture of grasses and scattered trees. The zone is covered with scattered trees and tall grasses (Eroarome, 2016).

3.1 Soil Sampling, preparation and laboratory analysis

Soil samples were collected from both sites at two soil depths (0–15 cm and 15–30 cm depths). The soil samples were composited and stored separately. Samples for bulk density were taken using 5 x 5 cm core sampler. The samples were air–dried and passed through 2 mm sieve. The fine soil from the sieve was used for the physical (percentage clay, silt, sand) and chemical analyses. The soil pH was measured in water and in $CaCl_2$ with a glass electrode (Mclean, 1982). Subsequently, total nitrogen was determined using micro–Kjeldahl technique (Bremner and Mulvaney, 1982) while the available phosphorus was determined using Bray–1 (Bray and Kurtz, 1945) method. The particle size was determined using the sieve analysis procedure.

p

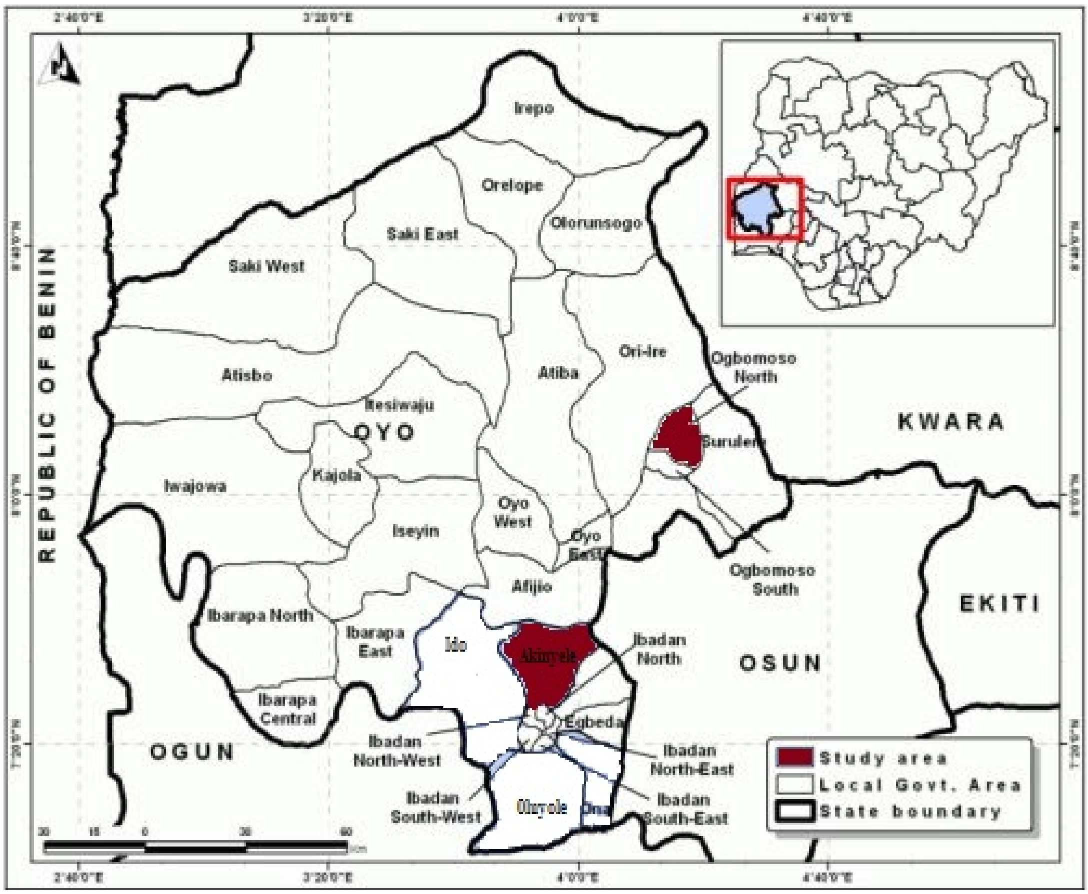


Fig. 3. 1: Map showing the locations of the experimental sites within the moist savanna of Oyo state, Nigeria.

The other parameters were generated through the Soil Module in the CROPGRO-Peanut model v4.5. The soil dynamic module integrates information from four sub modules: soil water, soil temperature, soil carbon and nitrogen, and soil dynamics. The variables produced by the soil module is for use in other modules. The soil dynamics module is designed to read-in soil parameters for the land unit and to modify them based on tillage, long-term changes in soil carbon, or other field operations (Jones, 2003). The characteristics determined by the soil module are: Stone %, DUL drained upper limit, LL lower limit of plant extractable soil water, SAT saturated soil water contact, RGF root growth factor, SSKS saturated hydraulic conductivity and BD bulk density were calculated by the model.

Phase I: Modeling of groundnut growth and pod yield using CSM–CROPGRO-Peanut model in the DSSATv4.5.

3.2 EXPERIMENT 1: Calibration of the CSM–CROPGRO-Peanut Model forgroundnut production in Oyo state, Nigeria.

3.2.1 Justification for calibrating CSM–CROPGRO-Peanutmodel for Oyo state, Nigeria.

The modular structure of the DSSAT cropping system model which includes the Crop Template module was used to access the crop's performance and several characteristics of groundnut. Crop Template module – CROPGRO-Peanut was used to simulate groundnut growth and development. To ensure accurate prediction, thetiming of key phenological stages of groundnut in relation to variation in weather conditions was determined. A field experiment was carried out and in accordance with the model calibration requirements the following were recorded:

i. Weather: latitude and longitude, daily solar radiation, maximum and minimum air temperature and rainfall
ii. Soil: upper and lower horizon depths, texture, bulk density, organic carbon, pH and aluminum saturation, and
iii. Management: sowing date, dates when soil conditions were measured prior to sowing, sowing density, row spacing, sowing depth, crop variety, irrigation, and fertilizer practices. (Jones *et al.*, 1998).

The informationwas required for CROPGRO crop template module which relies on detailed field input such as the soil details, thegenetic coefficient of each variety and weather condition of the locations.

The Objectives are to:

i. generate data for weather, soil, phenotypic stages and thermal time required for model calibration by the CROPGRO crop template module in DSSAT–CSM program;
ii. determineanappropriate onset date(s) for growing of selected groundnut varieties in the derived guinea savanna agro-ecological zone in Nigeria;
iii. calibratetheDSSAT Model for groundnut production in moist Guinea Savanna of Nigeria.

3.2.2 Experimental detailsfor the calibration of CSM-CROPGRO-Peanut ModelforOgbomoso, Nigeria.

Groundnut varieties used were SAMNUT 10, SAMNUT 22, SAMNUT 23 and *Kampala* (local var.). Details of the varieties used is shown in Table 3.1. The SAMNUT varieties were sourced from the Institute of Agricultural Research, Ahmadu Bello University, Zaria, Nigeria while *Kampala* was bought from Waso (a local market in Ogbomoso). Four sowing dates (SD) between April and May at 7days interval were used (SD1= 19/04/2010, SD2 = 26/04/2010, SD3 = 03/05/2010, SD4 = 10/04/2010).

The data from the experiment conducted during 2010 were used to calibrate the CROPGRO-Peanut (DSSAT V4.5) model. The first sowing date was determined by the onset of rain and subsequent one spaced at 7 days interval to evaluate the impact of weather variation on the obtained crop parameters. The variation in the sowing date usher the variation in the climatic situation within the crop canopy and the microclimatic variation that was then introduced has aremarkable effect on the growth and yield of the crop. The genetic coefficients used in the model were adjusted and fitted manually to match data on phenology. The model was calibrated following the sequence of steps described by Hunt and Boote (1998).

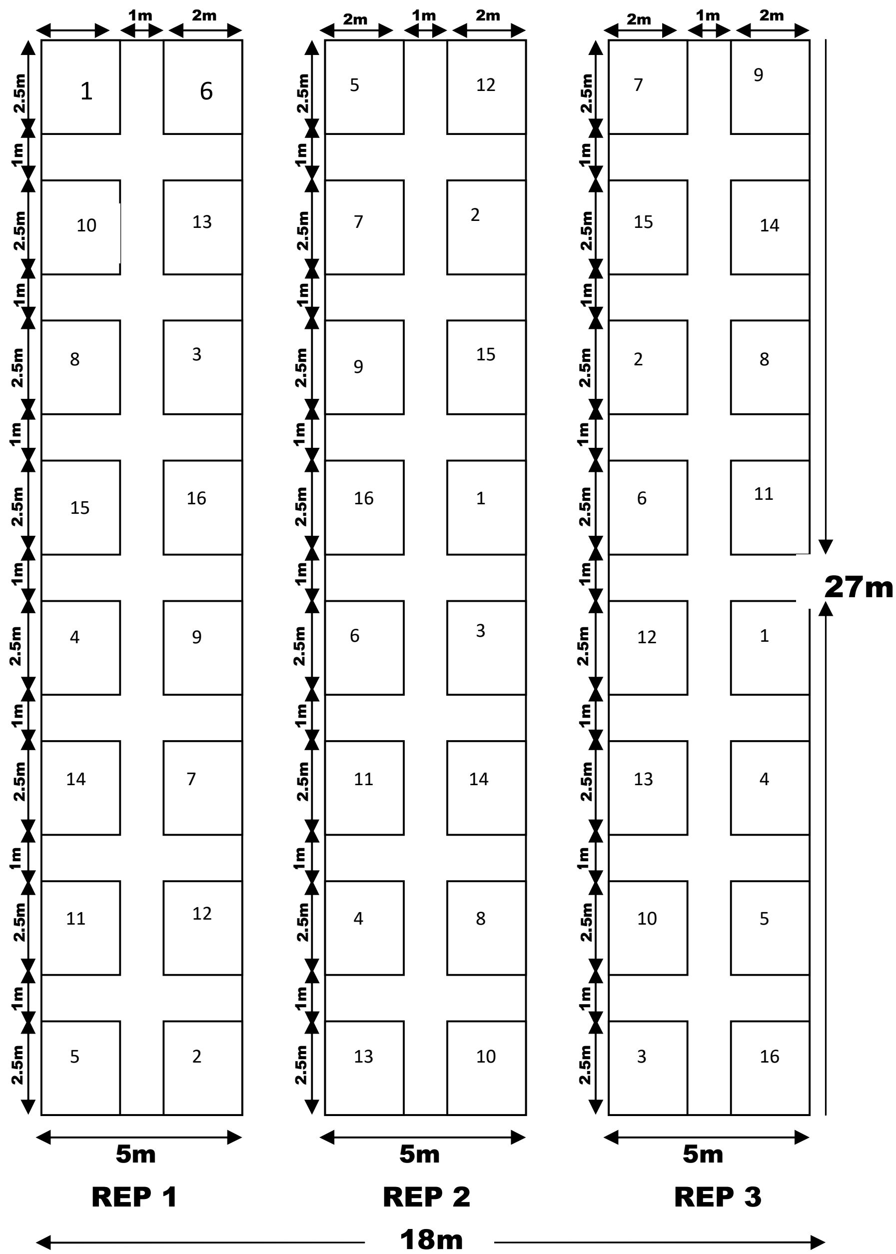
Crop vegetative and reproductive growth stages were evaluatedby observing phenological events and recording thelength of time in terms of number of days for a particularphenological event to occur.Each stage was defined to have occurred if at least 50% of the plants in a plotreached that stage.Ten central plants fromeach plot in each replication were tagged (Fig 3.3) as final harvest plot. Four other plant stands (not on border rows) were tagged for observation of phenological stages (GA1, GA2, GA3 and GA4). Podding stage, beginning of seed, and full seed was determined through destructivesampling at 14 days interval starting from the 14th day after emergence. Days to physiological maturity was recorded when 70% of all developed pods pericarp colouration (Vara *et al*., 2009).

For plant growth analysis, the four tagged plants for GAs were used for the pant growth analysis. The plants were uprooted, and root rinsed under running tap. The leaves and flowers were separated from the stem and root (from above soil level) were also separated.Leaf area index was calculated by multiplying the leaf length (L) (measured from leaf tip to the point of attachment to the main stem), leaf width (W) (at the widest point) and by a factor of 0.75. The separated parts were weighted separately and dried at 70°C for 48 hours and weighed for biomass.

The yield and yield components that were determined include the number of seedper plot (seed no/m^{-2}), seed weight per plot (weight/gm^{-2}), pod weight per plot (pod weight/gm^{-2}) and all the weight converted to kg ha^{-1}.

3.2.3 Experimental design and treatments for the calibration of CSM–CROPGRO-Peanut modelforOgbomoso, Nigeria.

The experiment was laid in a Split–plot arrangement in a Randomised Complete Block Design, RCBD with sowing date as the main plot and groundnut as the subplot and replicated three times (Fig. 3.2). Shown in Table 3.1 are the codes and definitions of cultivar coefficients of groundnut as stipulated by the DSSAT CRGRO045 model. The codes were used in entering data into various shells of the model. The spacing arrangement is as shown in Fig 3.2. The treatments were combination of 4 varieties of groundnut and 4 sowing dates (SD1, SD2, SD3, and SD4). Beds of 2.5 m x 2 m were made for each treatment plot with an inter–row spacing of 50 cm and intra–row spacing of 25 cm (Fig. 3.3). Each treatment plot was replicated thrice. Each replicate has 16 plots (5 m^2) x 3 to include 1 m spacing between treatments, giving 135 m^2. 1.5 m space was between replicates giving a total land area of 486 m^2.



Treatment Combination

1= P_1V_1
2= P_1V_2
3 = P_1V_3
4= P_1V_4
5 = P_2V_1
6 = P_2V_2
7 = P_2V_3
8 = P_2V_4
9 = P_3V_1
10 = P_3V_2
11 = P_3V_3
12 = P_3V_4
13 = P_4V_1
14 = P_4V_2
15 = P_4V_3
16 =P_4V_4

P = Planting date
P1 = 19/04/2010
P2 = 23/04/2010
P3 = 03/05/2010
P4 = 10/05/2010

V = Varieties
V1 = SAMNUT 10
V2 = SAMNUT 22
V3 = SAMNUT 23
V4 = Kampala

Fig. 3. 2: Field layout for thecalibration of CSM-CROPGRO-peanut model in Ogbomoso, Nigeria

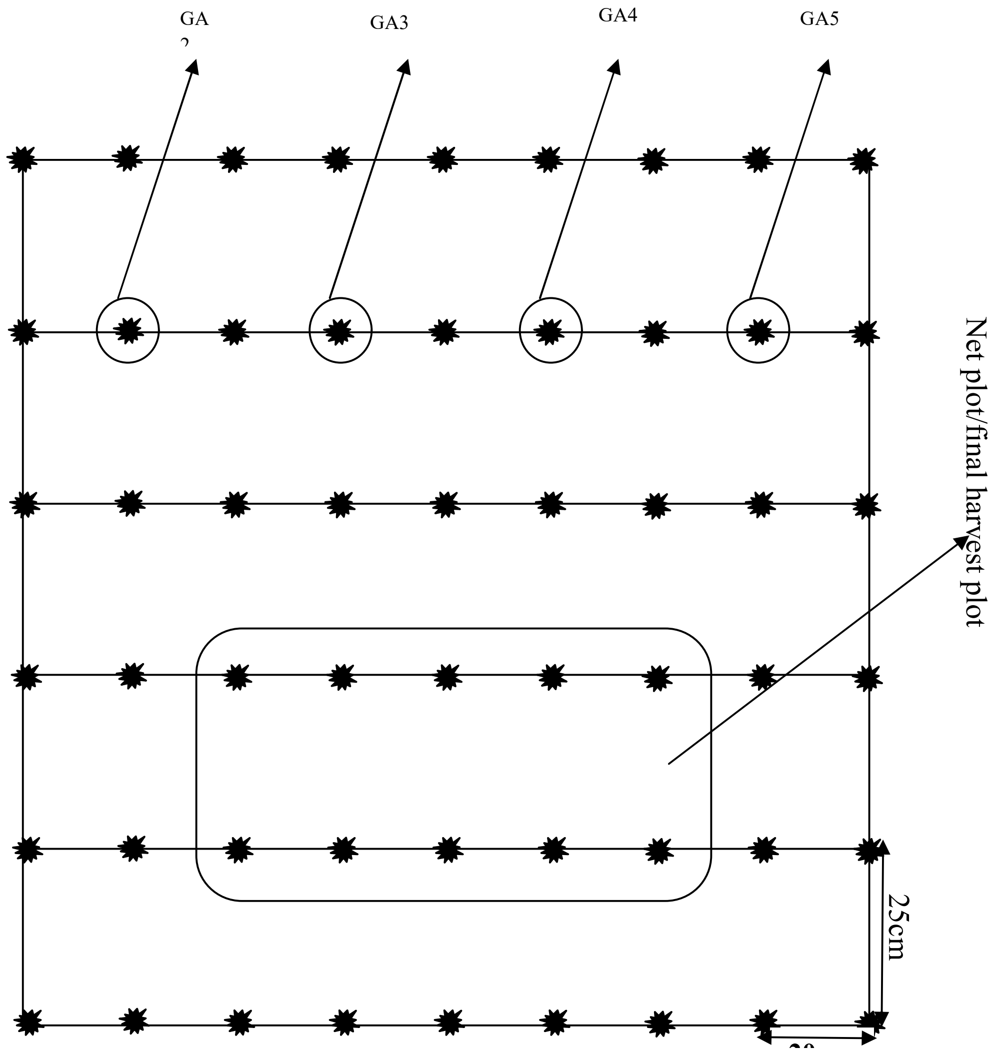


Fig. 3. 3: Treatment plot layout showing area of sample collection points for growth analysis for 2010, 2011 and 2012 at Ogbomoso and Ibadan.

GA = plant stand uprootedfor destructive analysis

Table 3.1: Variety codes and features of the evaluated groundnut varietiesstudied

Variety name	Original name	National code	Developing Institute	Outstanding Characteristics	Maturity (Days)	ADAStation	Seed colour
SAMNUT 10	RMP–12	NGAH 91–13	I. A. R. Samaru, Zaria	Large Seed size, very high oil content 55–60% (Dry matter basis), rosette resistant	Late 135–150	Guinea Savanna and Forest	Variegated (tan and white)
SAMNUT 22	M–572.801	NGAH 01–22	I. A. R. Samaru, Zaria and ILRI–ICRISAT	High seed and forage, pod yields and quality (dual purpose)	Medium 110–120	Sudan and guinea savanna	Variegated (tan and white)
SAMNUT 23	ICCGV–1596894	NGAH 01–23	ICRISAT Kano and I. A. R. Samaru, Zaria	Extra early maturity and rosette resistant	Early 90–100	Sudan and Sahel savanna	Red
Kampala	–	–	–	It is a common variety used	Medium 110 –120	Guinea Savanna	Variegated (brown and white)

Source: National Centre for Genetic Resources and Biotechnology. 2014: Catalogue of Crop Varieties Released and Registered in Nigeria. Volume No. 6 USDated at September 2014

Note that *Kampala* refers to a locally used variety commonly used in South Western Nigeria, its characteristics are stated as observed

3.2.4 Land preparation and cultural practicesfor the calibration of CSM–CROPGRO-Peanut modelfor Ogbomoso, Nigeria.

The land was cleared, harrowed and ridged manually using cutlass and hoe. The field layout is as shown in Fig. 3.2. Seeds were sown on the prepared seed beds at depth of 5 cm and three seeds per hole. Thinning was done at two weeks after sowing to two plants per stand to give a population of 108 plant stands per plot.

Plots were hoed to remove weed as required. Experimental plot was fenced with wired–mesh and rodenticide were used to prevent rodent attack. Fertilizer was not applied.

3.2.5 Plant sample collection

Plant samples were collected from designated areas of the plots (Fig 3.3). This commenced after thinning and subsequently at two weeks interval. The thinned plants were used as samples for the first growth analysis. All plant stands within the marked final harvest area (1 m x 1.5 m) were however used for the determination of pod yield parameters and pod yield at harvest. Harvesting was done at pod maturity for all the varieties (Table 3.1).

3.2.6 Data requirements for model calibration and evaluation of the CSM–CROPGRO-Peanut model

1. Daily records of weather parameters: maximum air temperature, minimum air temperature (°C), radiation ($MJ/m^2/d$), precipitation (mm), humidity (%), wind speed (m/s) and rainfall (mm). Weather record for Ogbomoso site was with an Automatic Weather Station (HOBO model no U–DT–2, USA). The weather station is positioned at 8º10´N, 4º16´E, and altitude of 341m above sea level. For Ibadan, the rainfall data was taken with a manual rain gauge located directly on the experimental site while other data were collected from International Institute for Tropical Agriculture IITA, Ibadan.
2. Soil data: soil classification using the local system and (to family level) the USDA-NRCS taxonomic system Basic profile characteristics by soil layer: in situ water release curve characteristics (saturated drained upper limit, lower limit); bulk density, organic carbon; pH; root growth factor; drainage coefficient.
3. Phenology data:

i. Sowing and establishment: Records of the date of sowing, date of emergence (>50%), date of thinning, plant population after thinning was recorded. Other records on dates of reproductive stages–date of first flower, days to 50% flowering, days to 50% pod filling, days to pod physiological maturity and date of harvest, total number of leaves on main stem and weights were also made at harvest.

Crop growth data: Destructive plant sampling commenced from two weeks after emergence and was subsequently carried out at two–week intervals for growth analyses. Two plant stands were uprooted from plot areas outside the designated final harvest area, oven–dried and weighed to obtain their dry matter. Whole plant leaves were also detached and measured for leaf area values which were used for calculating leaf area index (LAI). The square method was regressed against the length x breath method to obtain the factors that were used for converting the obtained length x breath values to plant leaf area.

ii. Groundnut pod yield and pod yield parameters data: Pod yield and pod yield parameters recorded include days to first flower appearance, number of nodules, days to physiological maturity. Others included thedate of harvest, plant stand per plot, number of pods per plot, number of leaves on stem and seed weight per plot, number of grains per pod (average of 20 randomly selected pods from pods harvested within the net plot) were recorded.

4. Thermal Time: Thermal time for different phenotypic stages of the selected groundnut varieties was calculated using Peterson (1965) equation from the summation of cumulative differences between mean daily temperature and base temperature (10°C). Thermal time was expressed as growing degree–days, GDD (unit is °Cd) as shown in equation 3.1.

$$GDD = \frac{T_M - T_m}{2} - T_b \quad \text{..........................Equation 3.1}$$

where, TM : Daily maximum temperature

Tm : Daily minimum temperature

Tb : Base temperature and

$$PTU = GDD \times L \quad \text{........................ Equation 3.2}$$

where, GDD : Growing Degree Days

L : Maximum possible sunshine hours

5. Photothermal time, PTU: PTU was calculated as the products of the growing Degree Days and the day length (Maximum possible sunshine hours) using Wilsie (1962) equation, presented in equation 3.2.
6. Site description: Latitude and longitude, elevation; average annual temperature; average annual amplitude in temperature Slope and aspect; major obstruction to the sun (e.g. nearby mountain); drainage (type, spacing and depth); surface stones (coverage and size).

3.2.7 Calibration of CSM–CROPGRO-Peanut model forOgbomoso, Nigeria

The mean estimated measured parameters were used as initial coefficients. Adjustments were then made for the EM–FL, FL–SH, FL–SD and the SD–PM (Table 3.2) in the sensitivity analysis shell in the model in order to get the best fit values which provided the least RMSE.

These coefficients were measured in photothermal days (Eqn. 3.1 and Eqn. 3.2). The adjustments were done in an optimization shell which allowed different combinations either singly or in a combination of genetic coefficients to give results that best compared with the observed.

The data collected from the 2010 experiment in Ogbomoso were used to create crop management file NGGB1001.PNX (FileX), time series file NGGB1001.PNT (FileT) and the observed data NGGB1001.PNA (FileA). Model requirements of daily weather inputs, soil parameters and details of management practices obtained were input into the CROPGRO-Peanut template.

3.2.8 Evaluation of CSM–CROPGRO-Peanut Model forOgbomoso, Nigeria

The evaluation of model was assessed by comparing the predicted and observed values of groundnut phenological characteristics such as days to emergence, number of days to flowering, days to first pod, days to first seed, and pod weight at harvest.The values were evaluated to test the reliability of data using the Root Mean Square Error, RMSE (Equation 3.3) and the normalized root mean square error otherwise called Percentage Error, PE (Equation 3.4). The equations are as written below:

$$\text{RMSE} = \sqrt{[\sum(\text{Pi} - \text{Oi})^2/\text{n}]} \text{..........Equation 3.3}$$

$$\text{PE} = \frac{\text{RMSE}}{\bar{\text{O}}} x\ 100\% \text{..................Equation 3.4}$$

where:

RMSE : Root Mean Square Error

Pi : Predicted value

Oi : Observed value

Ō : Mean of observed value

n : Number of replicates/locations

∑ : Summation sign

√ : Square root

Loague and Green (1991)

3.3 EXPERIMENT 2: Calibrating groundnut response to starter nitrogen application with the CSM CROPGRO-Peanut model

3.3.1 Justification for simulating groundnut response to starter nitrogen application forOgbomoso, Nigeria

Groundnut like other legumes, meet the major part of its nitrogen requirement and even enrich the soil with nitrogen through root associated nitrogen fixation. The soils of the humid southwestern zone of Nigeria have been associated with low soil nitrogen nutrient (Agboola and Obigbesan, 1974, Uyovbisere and Lombim, 1991, Okotete, 2008). Hence, the inherent low soil nitrogen cannot sustain groundnut growth till nodulation. Therefore, a small amount of the required nitrogen as starter nutrient is required as a supplement (Singh 1984; Putnam, 1991; and Juangjun, 2003), before the development of effective groundnut roots and the commencement of nodule formation.

Objectives of this experiment were to:

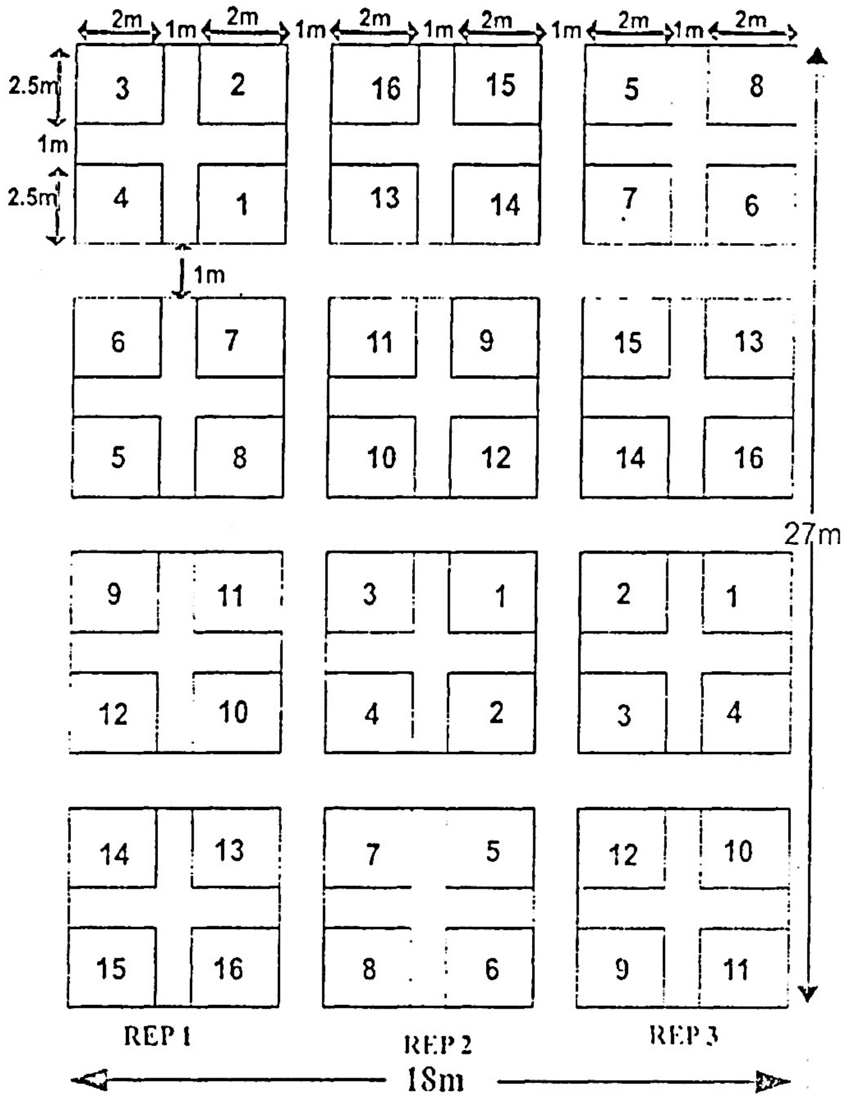
i. determine the adequate rate(s) of starter NPK fertilizer necessary to initiate groundnut development for better growth and pod yield in Ogbomoso and Ibadan, Nigeria.
ii. obtain data on the N-fertilizer application for groundnut pod yield model calibration using the CROPGRO crop template module in DSSAT-CSM program.
iii. evaluate the response of the CSM-DSSAT-peanut model to starter N fertilizer application

The prediction is considered excellent if PE is 0-10%; good, 11-20%; fair, 21-30%, and poor if PE is >30%. The PE value of 0 indicated that there was better simulation of the parameters by the model (Soler *et al.,* 2007).

Table 3.2: Groundnut (Peanut) Cultivar Coefficients: CROPGRO045 model

Coeff	Definitions
EXPNO	Number of experiments used to estimate cultivar parameters
ECO#	Code for the ecotype to which this cultivar belongs
CSDL	Critical Short Day Length below which reproductive development progresses with no daylength effect (for shortday plants) (hour)
PPSEN	Slope of the relative response of development to photoperiod with time (positive for shortday plants) (1/hour)
EM–FL	Time between plant emergence and flower appearance (R1) (photothermal days)
FL–SH	Time between first flower and first pod (R3) (photothermal days)
FL–SD	Time between first flower and first seed (R5) (photothermal days)
SD–PM	Time between first seed (R5) and physiological maturity (R7) (photothermal days)
FL–LF	Time between first flower (R1) and end of leaf expansion (photothermal days)
LFMAX	Maximum leaf photosynthesis rate at 30°C, 350 vpm CO_2, and high light (mg CO_2/m^{2-s})
SLAVR	Specific leaf area of cultivar under standard growth conditions (cm^2/g)
SIZLF	Maximum size of full leaf (three leaflets) (cm^2)
XFRT	Maximum fraction of daily growth that is partitioned to seed + shell
WTPSD	Maximum weight per seed (g)
SFDUR	Seed filling duration for pod cohort at standard growth conditions (photothermal days)
SDSDV	Average seed per pod under standard growing conditions (#/pod)
PODUR	Time required for cultivar to reach final pod load under optimal conditions (photothermal days)
THRSH	The maximum ratio of (seed/(seed+shell)) at maturity. Causes seed to stop growing as their dry weights increase until shells are filled in a cohort. (Threshing percentage).
SDPRO	Fraction protein in seeds (g(protein)/g(seed))
SDLIP	Fraction oil in seeds (g(oil)/g(seed))

Source: Hoogenboom *et al,*(2010).



Treatment Combination

1 = $N_1P_1V_1$
2 = $N_1P_1V_2$
3 = $N_1P_2V_1$
4 = $N_1P_2V_2$
5 = $N_2P_1V_1$
6 = $N_2P_1V_2$
7 = $N_2P_2V_1$
8 = $N_2P_2V_2$
9 = $N_3P_1V_1$
10 = $N_3P_1V_2$
11 = $N_3P_2V_1$
12 = $N_3P_2V_2$
13 = $N_4P_1V_1$
14 = $N_4P_1V_2$
15 = $N_4P_2V_1$
16 = $N_4P_2V_2$

N = Fertiliser rate
N1 = 0 kg N/ha
N2 = 5 kg N/ha
N3 = 10 kg N/ha
N4 = 20 kg N/ha

P = Planting date
P1 = 13/06/2011
P2 = 20/06/2011

V = Varieties
V1 = SAMNUT 23
V2 = Kampala

Fig. 3. 4:Field layout for simulating groundnut response to starter nitrogen application in Oyo State

3.3.2 Experimental details for simulating groundnut response to starter nitrogen applicationforOgbomoso, Nigeria

Two groundnut varieties, SAMNUT 23 and *Kampala*(Tables 3.1) and two sowing dates were selected based on a result obtained from experiment 1. The experimental details for experiment 2 are as shown in Fig 3.4. The fertilizer used was N: P: K 15: 15:15 atthe following rates (i) 0 kg N ha^{-1} (ii) 5 kg N ha^{-1}, (iii) 10 kg N ha^{-1} and (iv) 20 kg N ha^{-1}.

3.3.3 Experimental design and treatments for simulating groundnut response to starter nitrogen application inOgbomoso, Nigeria

The experimental design was a split-split plot arrangement in an RCBD, with N–fertilizer rate as the main plot, sowing date as subplot and groundnut variety as the sub–subplot and replicated 3 times (Fig. 3.4). The treatments were combinations of four fertilizer rates (0 kg N ha^{-1}, 5 kg N ha^{-1}, 10 kg N ha^{-1}and 20 kg N ha^{-1}), two sowing dates (SD1 = 13/06/2011 and SD2 = 20/06/2011) and two varieties of groundnut (SAMMUT 23 and *Kampala*) which gave a total of 16 treatment combinations. Each treatment plot measured 2 m x 2.5 min size. There were three replications with a total land area of 486 m^2.

3.3.4 Model Calibration Requirements for simulating groundnut response to starter nitrogen application inOgbomoso, Nigeria

Data obtained for experiment 1 were collected and the following required information was recorded:

i. fertilizer type (organic or inorganic),
ii. date of fertilizer application,
iii. applications (material, depth of incorporation, amount and nutrient concentrations)
iv. the method of application

3.3.5 Model Calibration for simulating groundnut response to starter nitrogen application inOgbomoso, Nigeria

The fertilizer used, N: P: K 15: 15: 15 was not included in the list of fertilizer amendments in the DSSAT v 45 CSM thus ammonium nitrate was selected in the module. The fertilizer concentration partition of the DSSAT v 4.5 model was adjusted to fit NPK 15:15:15 concentration. Data collected from the 2011 experiment in

Ogbomoso were used to create crop management file NGGB1101.PNX (FileX), time series file NGGB1101.PNT (FileT) and the observed data NGGB1101.PNA (FileA). Model requirements of daily weather inputs, soil parameters and details of management practices obtained were input into the CROPGRO-Peanut template.

3.3.6 Model validation for simulated groundnut response to starter nitrogen applicationinOgbomoso, Nigeria

The evaluation of model was assessed by comparing the predicted and observed values of groundnut phenological characteristics such as days to emergence, number of days to 50% flowering, first pod, and pod weight. They were analyzed to test the reliability of data using the Root Mean Square Error (Equation 3.3) and the normalized root mean square error (percentage error (PE)) –Equation 3.4.

3.4 EXPERIMENT3: Calibration of the CSM-CROPGRO-Peanut Model for groundnut usingdifferent starter Nitrogen sources

3.4.1 Justificationfor calibration of the CSM-CROPGRO-Peanut Model for groundnut usingdifferent starter Nitrogen sources

Farmers use different sources of nutrient amendments on their crop across the globe. Since the broad objective of this study is to adapt the CSM-DSSAT-peanut for use in the humid southwestern of Nigeria, this experiment was aimed at assessing the model's adaptation for different fertilizer sources. Ibadan was considered in anticipation of decrease trend of rainfall for further adaptation to groundnut production in thesouth of Nigeria.

Objectives of the study were to:

i. determine the most appropriate source of starter fertilizer for groundnut production
ii. obtain data for model calibration using the CROPGRO modular program of DSSAT.
iii. validate the DSSAT GROPGRO-Peanut Model validation using obtained data

3.4.2 Experimental details for calibration of the CSM–CROPGRO-Peanutmodel for groundnut using different starter fertilizer sources

Two groundnut varieties (SAMNUT 23 and *Kampala)* and the bestfertilizer rate obtained from Experiment 2 (that is 20 kg N ha^{-1}) and control were (0 kg N ha^{-1}). Three different sources of fertilizer, N: P: K: 15: 15: 15, poultry waste manure (N:

1.2%, P: 9.4%, K: 5.8%) and Aleshinloye organomineral fertilizer (N: 3.0%, P: 2.5%, K: 1.5%) were used.

The experiment was carried out simultaneously at two locations namely:

i. the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso and
ii. the organomineralfertilizer plant, Barth road,University of Ibadan, Ibadan.

3.4.3 Experimental design and treatments for calibration of the CSM-CROPGRO-Peanutmodel forgroundnut using different starter fertilizer sources

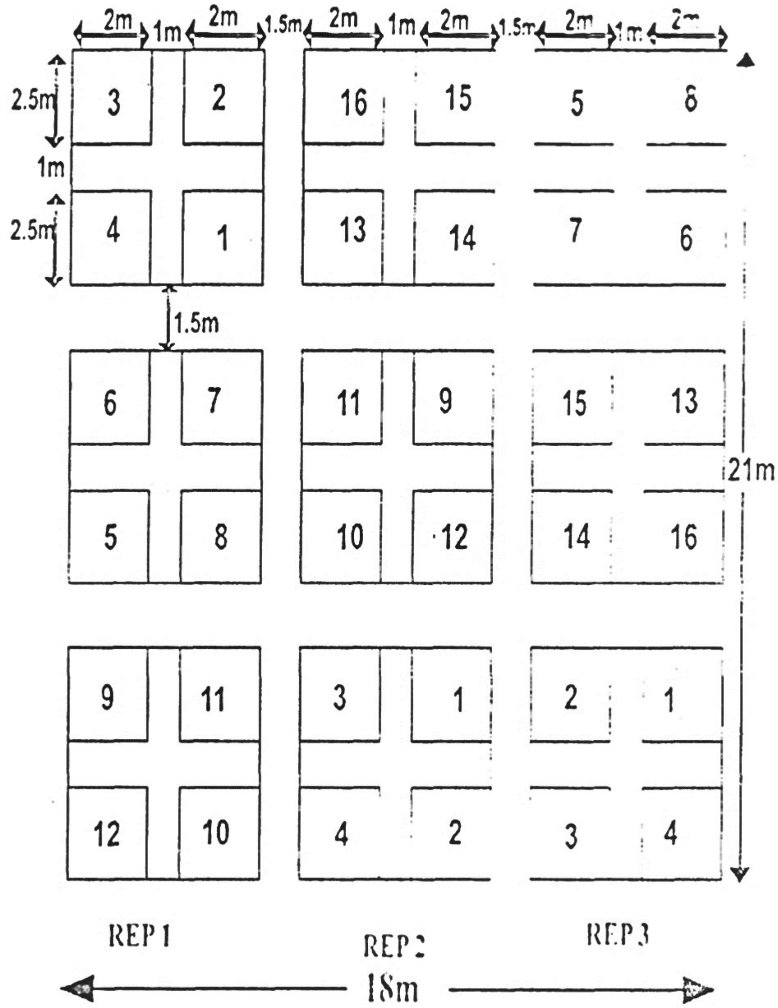
The experimental layout is as shown in Fig 3.5. The experiment was laid in a 3x3x2 (i.e. 3 sources of starter fertilizer x 2 fertilizer rates x 2 groundnut varieties) split–split plot arrangement in an RCBD, with a source of starter fertilizer as the main plot, fertilizer rates as subplot and groundnut variety as the sub–subplot and replicated 3 times. Each treatment was on 2 m x 2.5m plot and a total land area of 378m^2.

3.4.4 Model requirements for calibration of the CSM–CROPGRO-Peanutmodel for groundnut using different starter fertilizer sources

The model calibration requirement is the same as in experiments 1 and 2

3.4.5 CSM–CROPGRO-Peanut Model calibration for groundnut using different starter fertilizer sources

The fertilizerpartition of the DSSAT v 4.5 model was adjusted to fit the concentration of NPK 15:15:15, poultry manure and Aleshinloye organomineral fertilizers used. Data collected from the 2012 experiment were used to create crop management file NGGB1201.PNX (FileX), time series file NGGB1201.PNT (FileT) and the observed data NGGB1201.PNA (FileA); and NGIB1201.PNX (FileX), time series file NGIB1201.PNT (FileT) and the observed data NGIB1201.PNA (FileA) for Ogbomoso and Ibadan respectively. Model requirements of daily weather inputs, soil parameters and details of management practices obtained were input into the CROPGRO-Peanut template.



Treatment Combination

1 = $S_1R_1V_1$
2 = $S_1R_1V_2$
3 = $S_1R_2V_1$
4 = $S_1R_2V_2$
5 = $S_2R_1V_1$
6 = $S_2R_1V_2$
7 = $S_2R_2V_1$
8 = $S_2R_2V_2$
9 = $S_3R_1V_1$
10 = $S_3R_1V_2$
11 = $S_3R_2V_1$
12 = $S_3R_2V_2$

S = Nitrogen source
S1 = NPK 15: 15: 15
S2 = Poultry manure
S3 = Organomineral

V = Varieties
V1 = SAMNUT 23
V2 = Kampala

Fig. 3. 5: Field layout for CSM–CROPGRO-Peanut Model calibration of groundnut using different starter fertilizer sources

3.4.6 CSM-CROPGRO-Peanut Model validation for groundnut using different starter fertilizer sources

The model was evaluated by comparing the predicted and observed values of groundnut phenological characteristics such as days to emergence, number of days to 50% flowering, first pod, first seed, and pod weight. They were analyzed to test the reliability of data using the Root Mean Square Error (Equation 3.3) and the normalized root mean square error (percentage error (PE)) – Equation 3. 4. The CROPGRO-Peanut model in DSSAT v 4.5 was evaluated using the data collected at Ogbomoso in 2012. Model calibration was done based on the genetic coefficients obtained from Ogbomoso in 2010 experiment.

3.5 Phase II: Pod yield Prediction for groundnut in Ibadan and Ogbomoso, Oyo State, Nigeria

3.6 Justificationfor pod yield prediction for groundnut in Ibadan and Ogbomoso, Oyo State, Nigeria

There are different factors affecting the growth, pod yield and sustainable production of groundnut. Indicators to quantify changes in crop production systems over time at different levels are needed for evaluating and maintaining sustainability. This involves development and evaluation of sustainability concepts such as the modeling and pod yield forecasting in and out of season.

Experiments 1, 2 and 3 were used to simulate groundnut crop models under varying starter N–sources management for Ibadan and Ogbomoso, Oyo state in Nigeria. The models providedcritical tools for finding combinations of nitrogen management strategies for a sustainable crop production. With some adjustments, the modelswere used to predict groundnut growth for different years and locations using CROPGRO-Peanut model in the DSSATv4.5.

For a successful attempt at predicting groundnut growth, development,andpod yield, weather parameters for the duration to be predicted will be required. Weather prediction was done using the *MarkSim GCM* web application, designed to be used with DSSAT. MarkSim uses CLI files (Climate files), existing, or constructed by the user, to create new CLI files and WTG (Weather) files for the simulated weather data under a range of scenarios (Jones *et al*. 2011a, b). The Intergovernmental Panel on Climate Change, IPCC identified about six scenarios (Fig. 3.6) organized into families, which contain scenarios that are similar to each other in some respects (IPCC, 2001).

The similarity includes assumptions about future technological development as well as the future economic development, assumptions for future greenhouse gas pollution, land–use and other driving forces. The six families of scenarios are as discussed in the IPCC's Third Assessment Report (TAR) and Fourth Assessment Report (AR4). These are A1FI, A1B, A1T, A2, B1, and B2. The Coupled Model Intercomparison Project Phase 5 (CMIP5) of IPCC presents an unprecedented level of information on which to base projections including new Earth System Models with a more complete representation of forcing, new Representative Concentration Pathways (RCP) scenarios and more output available for analysis. The four RCP scenarios used in CMIP5 lead to a total radiative forcing (RF) at 2100 that spans a wider range than that estimated for the three Special Report on Emission Scenarios (SRES) scenarios (B1, A1B, A2) used in the Fourth Assessment Report (AR4), RCP2.6 being almost 2 W m–2 lower than SRES B1 by 2100. The ensemble means total effective RFs at 2100 for CMIP5 concentration-driven projections are 2.2, 3.8, 4.8 and 7.6 W m–2 for RCP2.6, RCP4.5, RCP6.0 and RCP8.5 respectively. Global mean temperatures will continue to rise over the 21st century if greenhouse gas (GHG) emissions continue unabated. Under the assumptions of the concentration-driven RCPs, global mean surface temperatures for 2081–2100, relative to 1986–2005 will likely1 be in the 5 to 95% range of the CMIP5 models; 0.3°C to 1.7°C (RCP2.6), 1.1°C to 2.6°C (RCP4.5), 1.4°C to 3.1°C (RCP6.0), 2.6°C to 4.8°C (RCP8.5). (Collins et al., 2013).

While none of the scenarios was judged better than the other but rather, a scenario that represents a "best guess" of future emissions of the location, RCP 4.5was chosen.

The objective of the study was to:

i. Predict groundnutpod yield under varying N sources, climatic and management conditions.

3.6.1 Description of model prediction tools

Measured plant characteristics from 2010 experiment were used as initial coefficients. The phenology of the crop (days to first flower, R1), and days to maturity were adjusted to match the observed values by adjusting the duration from emergence to start of flower (EM–FL) and from beginning of seed to physiological maturity (SD–PM) in the model in order to get the best fit values which provided the least PE (%). Data collected from Experiments 2 and 3 were inputs into CROPGRO modular program of DSSAT for validation. The calibrated model was used to predict groundnut pod yield over the next 30years.The model was calibrated using collected data from experiment 1 by determination of genetic coefficients of SAMNUT 10, SAMNUT 22, SMNUT23 and *Kampala* in the CSM–DSSAT–peanut model. The calibrated model was validated with the simulated and observed data for Experiment 2. For pod yield simulation processes, the soil data were kept the same; that is, all differences in pod yield were attributed to the climatic data. The model was used for prediction of groundnut growth and pod yield under different fertilizer management and weather conditions. The climate models in this experiment were run against theB2 scenario (Fig. 3.6) as it has similar human activities with the environment worked on. The B2 scenario has the following characteristics:

i. Continuously increasing population, but at a slower rate.
ii. Emphasis on local rather than global solutions to economic, social and environmental stability.
iii. Intermediate levels of economic development.
iv. Less rapid and more fragmented technological change than the increasing population.

Fig. 3.6a shows aconsistent increase in CO_2 emission over the next decade (between 2000 and 2100).

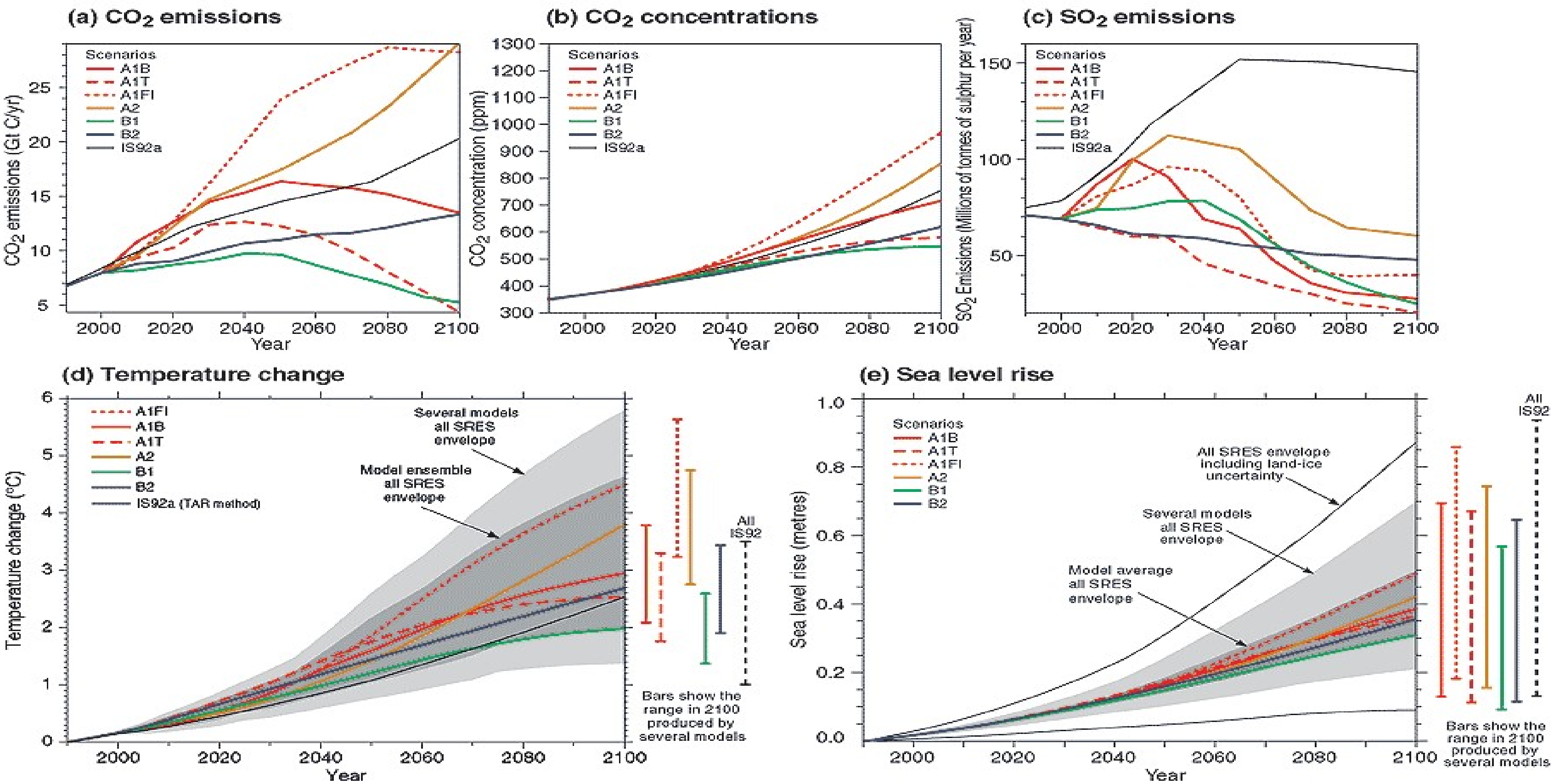


Fig. 3.6: The global climate change of the 21st century: The global climate of the 21st century will depend on natural changes and the response of the climate system to human activities.

Source: IPCC Climate Change 2001 Working Group I: The Scientific Basis

The increment of CO_2 emission was projected to be lower for B2 scenariothan other scenarios predicted to have moreadvanced technology (A1B, A1T, A2, and b2)over the decade and higher than the IS92a scenario that was projected with the lower level of technological changes. There was anincrease in projected CO_2 concentration in the environment (Fig. 3.6b) regardless of the level of the CO_2 emission. Generally, there was an initial increment in the projected SO_2 emission between 2010 and 2030 which reduced between 2040 and 2100 (Fig. 3.6c), but with the B2 scenario, there were lower CO_2 emissions from 2020 without the initial surge experienced by others. The IPCC (2001) shows increased temperature (°C) and sea level (meters) for all the scenarios and is expected to follow the trend shown in Fig. 3.6c and Fig. 3.6d between 2000 and 2100.

3.6.2 Model Statistical Evaluation

The *MarkSim* weather predictions for 2010 – 2012 were compared with the observed values to determine the accuracy of the predicted weather variables.

Plotted graphs were used to evaluate the predicted pod yield values for thirty years (2020 –2050). For pod yield evaluation without fertilizer amendment, known simulated and observed pod yield values (2010) were plotted against the predicted pod yield values (2020 –2050) of the four varieties of groundnut.

To evaluate groundnut pod yield with fertilizer amendments, known simulated and observed pod yield values for 2011 and 2012 were plotted against the pod yield values of the four varieties of groundnut used for pod yield evaluation for theyear 2020–2050.

CHAPTER FOUR

RESULTS

4.1 Weatherdata at the experimental sites between 2010 and 2012

The daily records of solar radiation ($MJ/m^2/d$), maximum air temperature (°C), minimum air temperature (°C), and total rainfall (mm) of the experimental sites for 2010, 2011 and 2012 are shown in Appendices 2 and 3.

4.1.1 Weather data at the experimental site in Ogbomoso

The long-term(1995–2015) average value of annual rainfall was 1470.2 ± 247.8 mm with September as the wettest month. There was a clear August break in the long-termaverage (Fig 4.1).

In 2010, the average monthly maximum temperatures at Ogbomoso ranged from 26.2 °C to 29.6 °C and, from 21.4 °C to 24.3 °C asthe minimum temperature. The total annual rainfall of 1416.8 mm with apeak in September and the mean monthly solar radiation ranged from 14.4 to 21.6 $MJ/m^2/d$. The wettest month was September with total rainfall of 266.6 mm and thedriest monthisJanuary with rainfall value of 1.7 mm. February was the hottest month with a maximum temperature 29.6 °C while August, with atemperature of 21.4 °C was the coolest. The mean annual relative humidity was 85.6%.

April to October was the growing season in 2010. The average monthly maximum temperature range for the season was 26.2 °C to 29.3 °C and 22.0 °C to 24.3 °C for minimum temperature. A total rainfall of 1276.3 mm and mean monthly solar radiation of 17.5 $MJ/m^2/d$ was recorded for the growing season. Total annual rainfall in 2010 was lower than the long-termaverage.

The average monthly maximum temperature in Ogbomoso for 2011 ranged from 26.2 °C to 29.8 °C while 19.7 °C to 23.5 °C was the range for the minimum temperature. The total annual rainfall was 1204.1 mm with peak in September while the mean monthly solar radiation ranged from 15.3 to 21.9 $MJ/m^2/d$. The driest month was December (0.2 mm rainfall) and wettest was September (219.7 mm rainfall).

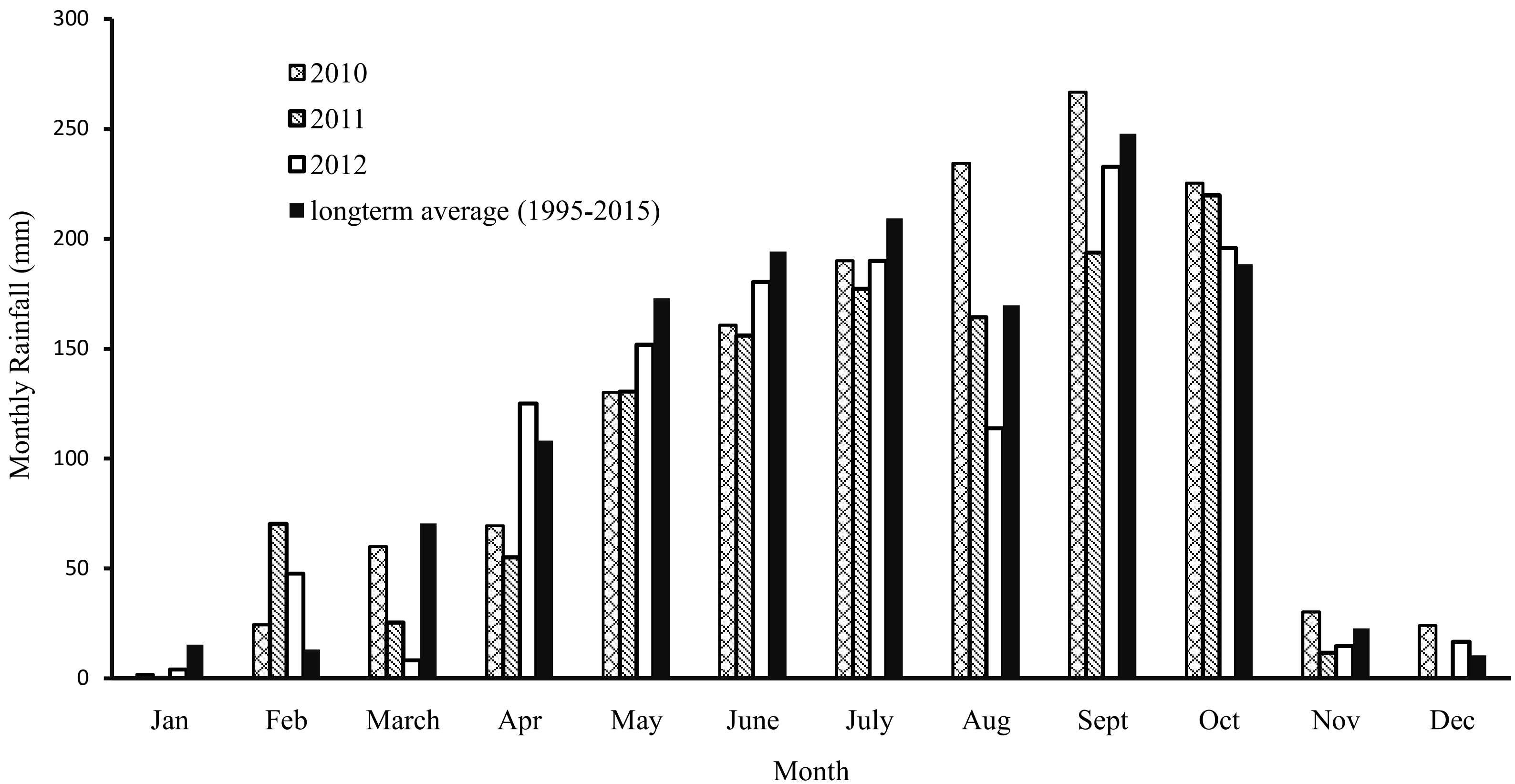


Fig. 4. 1: Monthly total rainfall from 2010 to 2012 and long-termaverage(1995–2015) for Ogbomoso, Nigeria

January was the hottest month with a maximum temperature 29.8°C while August with atemperature of 15.0°C was the coolest. The mean annual relative humidity was 84.7%. The total rainfall was lower than thelong-termaverage and the driest month was in December rather than January in the long-termaverage.

For 2011 growing season (June to October), the average monthly maximum and minimum temperature ranged from 26.2 °C to 27.8 °C and 21.7 °C to 22.9 °C respectively. A total rainfall of 910.8 mm with apeak in October and mean monthly solar radiation ranging from 15.0 to 17.5 MJ/m^2 per month was recorded.Growing period was, however, shorter in 2011 than in 2010 with about 60 days.

The average monthly maximum temperature at Ogbomoso for 2012 ranged from 26.0 °C to 30.0 °C and 19.7 °C – 23.4 °C for minimum temperature. Year 2012 had a total annual rainfall of 1280.6 mm with a peak in September while the mean monthly solar radiation ranged from 14.6 to 23.8 MJ/m^2/d. The driest month was January (4.1 mm rainfall) while the wettest month was September (232.7 mm rainfall). January was the hottest month with a maximum temperature 30.0°C while August with atemperature of 14.6 °C was the coolest. The mean annual relative humidity was 85.2%.

For the growing season (June to October), the average monthly maximum temperature ranged from 26.0 °C to 27.4 °C while 21.2 °C to 22.6 °C was for the minimum temperature. A total rainfall of 912.6 mm and mean monthly solar radiation ranging from 14.6 to 19.3 MJ/m^2 per month were recorded.

The rainfall pattern between 2010 and 2012 in Ogbomoso (Fig. 4.1) shows that volume of rainfall (mm) in 2010 was more than in 2011 and 2012. It was also shown that rainy season in Ogbomoso is between April and October while thedry season is between November and March. Generally, September is the peak of rainfall in Ogbomoso with adry season from November to March. The month of January was the driest of the months. There was a clear August break in the long-termaverage, 2011 and 2012 monthly rainfall pattern, however, 2010 rainfall pattern was different with a rise in rainfall till October which was not so in 2011 and 2012.

Generally, the rainfall pattern followed the long-term average (1995–2015) in Ogbomoso. The seasonal pattern in Ogbomoso in 2011 was similar to that of 2010 with rainfall between May and October with November to April is the dry season (five months).Sowing in 2011 started in June based on the onset of rain. Thetotal rainfall volume at sowing was more in 2010 than in 2011. A total rainfall of 910.8 mm was recorded for the growing period which though lower than the volume recorded in 2010 season is still adequate for groundnut production hence there was no water stress.There was also a good rainfall spread from emergence to physiological maturity, which was between May and August. The rainfall was at its peak in October during the process of pod maturation. The average monthly maximum temperature range for the growing season was optimum for groundnut establishment and maturity.

The onset of rain was earlier in 2012, started in April and ended in October making the rainy season longer in 2012 by one month than in 2010 and 2011. Sowing was done in May and was enough rainfall volume (1064.3 mm) for field establishment and vegetative growth till pod maturity for the growing period.

4.1.2 Weather data at the experimental site in Ibadan

The value of the long-term(1995–2015) average annual rainfall was 1355.2 ± 205.5 mm with September as the wettest while January the driest month (Fig. 4.2). There was a drop in rainfall volume in August in the long-termaverage.

In 2010, the average monthly maximum temperature at Ibadan ranged from 27.1 °C to 30.1 °C while 22.6 °C to 25.4 °C was the range for minimum temperature. The total annual rainfall was 1608.2mm with apeak in September. The mean monthly solar radiation ranged from 15.2 to 22.0 MJ/m^2/d. The wettest month was September with total rainfall of 222.9 mm. The month of January was the driest with rainfall value of 11.6 mm. The mean annual relative humidity was 87.7%. The rainfall was more than the long-termvalue but followed the same pattern with September being the wettest and January being the driest.

The average monthly minimum and maximum temperature for 2011 ranged from 22.1 °C to 24.7 °C and 27.0 °C to 30.0 °C respectively. The mean monthly solar radiation ranged from 14.9 to 21.2 MJ/m^2/d with total annual rainfall of 1283.6 mm with apeak between May and October. The mean annual relative humidity was 87.0%. During the 2011 growing season (June to October), the average monthly minimum and maximum temperature range from 22.2 °C to 23.7 °C and 27.0 °C to 28.0 °C respectively. A total rainfall of 928.5 mm and mean monthly solar radiation ranged from 14.9 and 17.6 MJ/m^2 per month were respectively recorded. The driest month was observed to be January (0.1 mm rainfall) and wettest was October (260.8 mm rainfall). Total annual rainfall in 2011 was lower than the long-termtotal rainfall with apeak in October while January also is the driest month of the year.

The average monthly maximum temperature in Ibadan for 2012 ranged from 27.1 °C to 30.2 °C while the minimum temperature was from 21.7°C to 24.4 °C. The total annual rainfall of 1268.6 mm with apeak in September was observed in 2012. January was the driest month while the mean monthly solar radiation ranged from 14.0 to 21.6 MJ/m^2/d. The mean annual relativehumidity was 86.9%. The driest month was January (0.8 mm rainfall) and wettest was September (212.0 mm rainfall).

The 2012 growing season was between May and October, with an average monthly minimum and maximum temperature respectively ranging from 21.7 °C to 24.0 °C and 27.1 °C to 28.0 °C. A total rainfall of 9242.6 mm and mean monthly solar radiation ranging from 13.9 to 17.6 MJ/m^2 per month were recorded.

The month of January was the hottest with a maximum temperature of 30.2 °C. When compared with the long-term average, the rainfall in 2012 was lower but followed the same pattern. The rainfall pattern between 2010 and 2012 (Fig. 4.2) shows that the dry season was between November and March and inception of rainfall in April. Rainy season in Ibadan was between April and October and drop in rain volume in the month of August across the years. January was the driest month for 2010, 2011 and 2012. The peak of the rainy season was September in 2010, 2012 and the long-termaverage but October in 2011. In 2012, there was a clear break in the raining season during the month of August.

In Ibadan, the long-term average (1995 – 2015) rainfall pattern indicated a raining season of between May and October. However, the rainfall pattern within the experimental years showed trend variation from the long-term average (1995 – 2015). For instance, in 2010 and 2011 the raining season was between April and October with a clear break in August break 2012. The peak of raining season in 2011 was October as against September in the long-term average while the volume of rainfall in June and September 2012 were close to the long-termaverage. Generally, there is no specific rainfall pattern for the experimental years (2010 and 2012) and the forecast (2020 and 2050). A total rainfall of 942.6 mm was recorded for the growing season. Though the rainfall volume was lower than the volume recorded in the same period at Ogbomoso, the volume was enough to sustain the groundnut production (FAO, 1990).

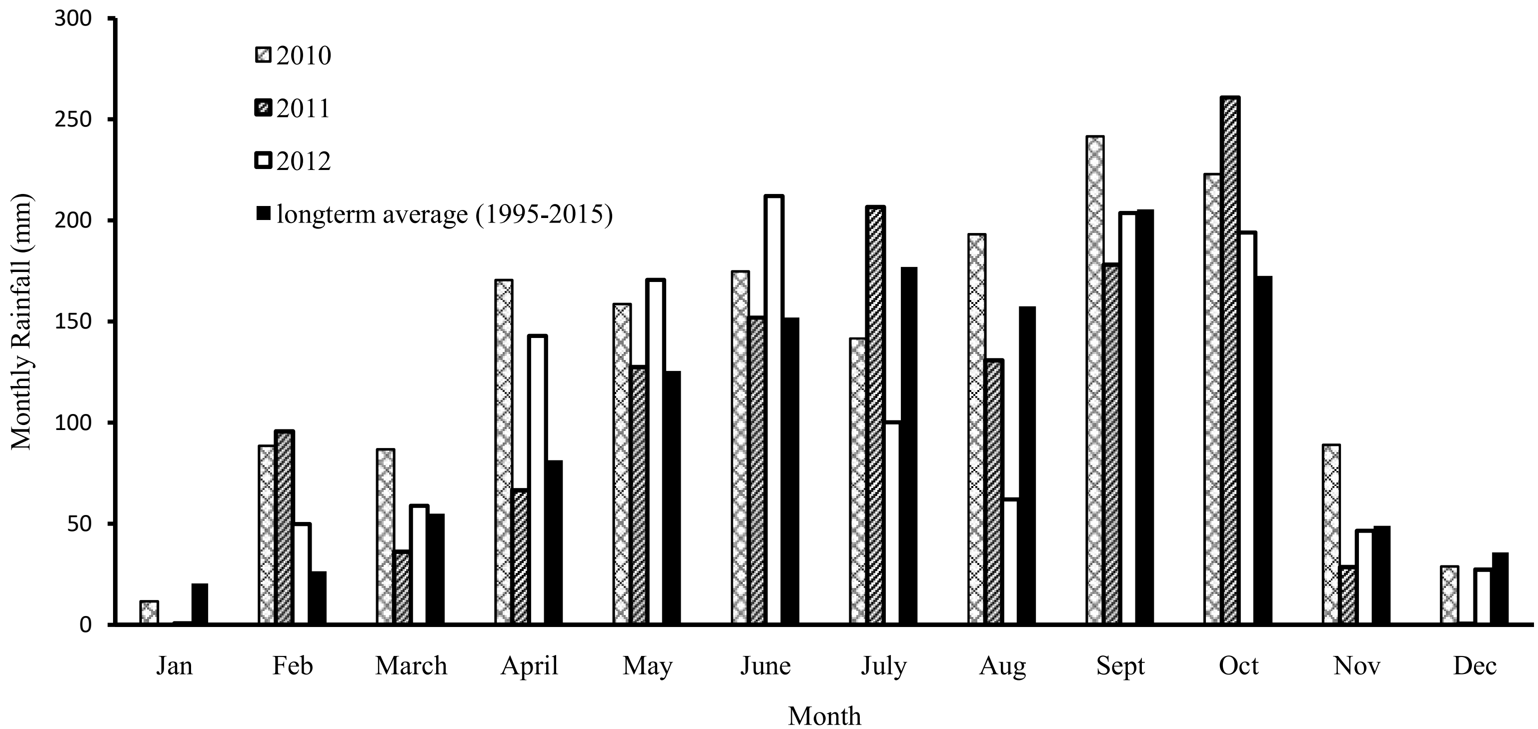


Fig. 4. 2: Monthly total rainfall from 2010 to 2012 and long-term average (1995-2015) at Ibadan, Nigeria

4.2 Soil Characteristics of the experimental sites

Soils from the two experimental sites were sampled and analyzed for nitrogen, organic carbon, texture and bulk density. The other parameters were generated by the Pedotransfer functions in the soil module of the DSSAT v 45. To reflect the inherent soil fertility of the tropical soils, the fertility factor was set at 0.7.

4.2.1 Soil characteristics at the experimental site in Ogbomoso Site

The physical, hydrological and chemical properties of the soil from Ogbomoso are presented in Table 4.1. Ogbomoso soil is well drained and belongs to the Gambari series (USDA – Udic Paleustalfs; FAO/UNESCO –Eutric Planosol: USSR – Podbels: WRB – Planosol). The parent material is basement complex. The slope of the land is 0-5%, depth of water table >190 cm (Olatunji, 2011). The values of the Drained Upper Limit (DUL), Lower Limit of Plant Extractable soil water (LL), Saturated Water content (SAT), Bulk Density (BD), Saturated Hydraulic conduct (SSKS) were determined using the SBuild program having prepared a soil file (NGGB100001.SOL) compatible with the DSSAT input requirements parameters were as shown in Table 4.1. Also presented in Table 4.1 were values obtained from the SBuild program (IBSNAT, 1989) for the Root Growth Factor (RGF) and function of the clay, silt, sand plus carbon content of different layers of the soil.

4.2.2 Soil characteristics at the experimental site in Ibadan

Table 4.1 also shows the physical, hydrological and chemical properties of the experimental soil at Ibadan. Ibadan soil is also well drained and belongs to the Iwo series (FAO/UNESCO – Alfisol). The parent material is basement complex. The slope of the land is 0–5% straight, depth of water table > 190 cm, soil surface form is flat with an effective soil depth of > 190 cm (Alabi *et al*., 2000). A soil file (NGIB120001.SOL) compatible with the DSSAT input requirements prepared using SBuild program that estimates Drained Upper Limit (DUL), Lower Limit of Plant Extractable soil water (LL), Saturated Water content (SAT), Bulk Density (BD), Saturated Hydraulic conduct (SSKS), Root Growth Factor (RGF) and function of the clay, silt, sand along with the carbon content of different layers of the soil are in Table 4.1 (IBSNAT 1989).

Table 4.1: Characteristics of different layers of the soil profile at the study sites

Depth (cm)	CL (%)	SI (%)	Sand (%)	Stone (%)	Organic C %	LL ($cm^3\ cm^{-3}$)	DUL ($cm^3\ cm^{-3}$)	SAT ($cm^3\ cm^{-3}$)	BD ($g\ cm^{-3}$)	SSKS ($cm\ h^{-1}$)	RGF (0.0– 1.0)	pH (1:1 H_2O)
Ogbomoso			(N 8° 07', E 4° 14', 341 m asl)									
0–15	45	35	15	5	0.65	0.242	0.385	0.447	1.33	0.06	1.000	6.40
15–75	35	45	15	5	5.06	0.165	0.301	0.415	1.28	0.23	0.407	6.40
75–140	34	36	30	0	3.31	0.135	0.232	0.317	1.38	0.23	0.116	6.20
140–190	40	10	45	5	4.13	0.120	0.175	0.215	1.55	0.12	0.037	6.00
Ibadan			(N 7° 22', E 3° 55', 241 m asl)									
Depth (cm)	CL (%)	SI (%)	Sand (%)	Stone (%)	Organic C %	LL ($cm^3\ cm^{-3}$)	DUL ($cm^3\ cm^{-3}$)	SAT ($cm^3\ cm^{-3}$)	BD ($g\ cm^{-3}$)	SSKS ($cm\ h^{-1}$)	RGF (0.0– 1.0)	pH (1:1 H_2O)
0–15	10.8	28	57.2	4	0.25	0.016	0.028	0.070	1.60	6.11	1.000	6.40
15–75	10.2	36	47.8	6	0.69	0.016	0.026	0.064	1.53	6.11	0.407	6.50
75–140	11.4	26	57.6	5	0.71	0.018	0.030	0.069	1.53	6.11	0.116	6.40

The following characteristics were measured: *CL* % clay, *SI* % silt, Organic C %, Stone %, *DUL* drained upper limit, *LL* lower limit of plant extractable soil water, *SAT* saturated soil water contact, *RGF* root growth factor, *SSKS* saturated hydraulic conductivity and *BD* bulk density.

SOIL ALBEDO: 0.13 EVAPORATION LIMIT: 6.00 MIN. FACTOR: 1.00

RUNOFF CURVE #: 64.00 DRAINAGE RATE: 0.60 FERT. FACTOR: 1.00

4.3 Genetic coefficients of groundnut varieties

The values of the recommended genetic coefficients of the CSM-CROPGRO-Peanut model were used to define the development and growth characteristics of the peanut cultivars studied. This is in accordance with the format of theDSSAT45 version(Table 4.2).

4.3.1 Phenological data of the selected groundnut varieties

The first emergence for sowing date 1, SD1 (19thApril 2010) and SD2 (26thApril 2010) occurred in *Kampala*the local variety 6 Days After Sowing (DAS) while other varieties emerged 7 DAS (Table 4.2). However, for SD3 (3rd of May, 2010), SAMNUT 10, SAMNUT 22 and SAMNUT 23 emerged 7 DASwhile*Kampala* was the last to emerge at 10DAS.

Days to flowering fromdays to emergence were an average of 28 days after emergence for SAMNUT 10, SAMNUT 22 and SAMNUT 23 and *Kampala,* for SD1, SD2, SD3,andSD4. The number of days between the appearance of first flower and first pod set had an average of 14 days after the first flower appeared in SAMNUT 10, SAMNUT 22, SAMNUT 23 and *Kampala* for SD1, SD2, SD3,andSD4.

SAMNUT 10 showed areduction in number of days to first seed appearance after flowering from SD1 to SD4. First seed in SAMNUT 10 for SD1 was 28 days after flowering, 21 days after flowering for SD2, 17 days after flowering for SD3 and 16 days after flowering for SD4. The earliest pod filling for this experiment was observed in SAMNUT 22 for SD1 with 15 days after flowering. First seed in SAMNUT 22 for SD2 was 23 days after flowering while 28 and 29 days after flowering was recorded in SAMNUT 22 for SD3 and SD4 respectively. First seed in SAMNUT 23 and *Kampala* for the four sowing dates were between 27 and 29 days after flowering which were statistically the same.

Days to physiological maturity from first seed was 37 days for SAMNUT 23 for all the four sowing dates which make SAMNUT 23 the first to reach physiological maturity after first seed. *Kampala* matured between 54 and 59 days after first seed which shows no significant difference in days to maturity across the four sowing dates. SAMNUT 22 matured between 57 and 71 days after first seed. This showed that there was a significant difference in maturity of SAMNUT 22 with sowing date. SD1 for SAMNUT 22 was the latest maturing (71 days after first seed), 57 days (SD3 and SD4) after the first seed was

Table 4.2: Phenological stages of the selected groundnut varieties at different sowing dates at Ogbomoso during 2010 planting season

Varieties	SDAT	PL–EM	EM–FL	FL–SH	FL–SD	SD–PM
SAMNUT10	SD1	7	28	14	28	72
	SD2	7	27	15	21	80
	SD3	7	28	14	17	83
	SD4	7	28	14	16	84
	Mean	7	27.8	14.3	20.5	79.8
SAMNUT22	SD1	7	27	15	15	71
	SD2	7	29	13	23	61
	SD3	7	28	14	28	57
	SD4	7	27	15	29	57
	Mean	7	27.8	14.3	23.8	61.5
SAMNUT 23	SD1	7	27	15	29	37
	SD2	7	29	13	27	37
	SD3	7	28	14	28	37
	SD4	7	28	14	28	37
	Mean	7	28	14	28	37
Kampala	SD1	6	27	15	29	58
	SD2	5	28	14	28	59
	SD3	10	28	14	28	54
	SD4	7	28	14	28	57
	Mean	7	27.8	14.3	28.3	57.0

SDAT = Sowing date, SD1= 19/04/2010, SD2 = 26/04/2010, SD3 = 03/05/2010, SD4 = 10/04/2010 PL–EM = Time between sowing and emergence (DAS), EM–FL = Time between plant emergence and flower appearance (R1) (photothermal days), FL–SH = Time between first flower and first pod (R3) (photothermal days), FL–SD = Time between first flower and first seed (R5) (photothermal days), SD–PM = Time between first seed (R5) and physiological maturity (R7) (photothermal days) the earliest for SAMNUT 22. SAMNUT 10 was the latest maturing of them all with days to maturity from first seed set ranging from 72 (SD1) to 84 (SD4).

The days to emergence, flowering and pod formation were not significantly different among the four varieties used. However, days from sowing to pod first seed and maturity vary significantly. Pod weight at harvest varies from the variety and sowing dates. Apart from *Kampala*, other varieties emerged by 7 DAS across the sowing dates. The flowering of the selected varieties from the days to emergence across the used varieties was an average of 28 days while pod formation was about 14 days after flowering (35 DAS). Pod filling varies and was affected by sowing date especially in SAMNUT 10 and SAMNUT 22. Days to pod filling for SAMNUT 10 in SD1 was the highest number of days (28 days) from flowering but the days to maturing of same variety was the least (72 days) also for SD1 but days to pod filling for SAMNUT 10 in SD14 was the least number of days (16 days) from flowering. The days to maturing of SAMNUT 10 for same sowing date (SD4) was the highest (84 days). The reverse was the case with SAMNUT 22 where its highest days to maturing (71 days after flowering for SD1) was associated with the least no of days to pod filling of 15 days after flowering.

However, pod filling was not affected by sowing date in *Kampala* and SAMNUT 23. There was a varietal influence on the maturity; SAMNUT 23 can be classified as early maturing (37 days after initiation of pod filling), SAMNUT 22 and *Kampala* medium (60 days and 56 days respectively) while SAMNUT 10 is late maturing (80 days). Early podding does not affect number of days to physiological pod maturity and the stages followed the samepattern for the foursowing date. The difference in performance observed was, therefore, due to varietal difference and not sowing date.

4.3.2 Thermal time for different phenotypic stages of the selected groundnut varieties

Thermal time accumulation of the selected groundnut varieties for SD1, SD2, SD3 and SD4 in Ogbomoso experimental site is shown in Table 4.4. From sowing to emergence SAMNUT 10 used between 49.2 °Cd and 52.9 °Cd and between 143.8 °Cd and 173.7 °Cd from emergence till flowering. For SAMNUT 22 and SAMNUT 23, between 49.2 and 52.9 °Cd was used from sowing till emergence and from emergence to sowing 143.8 and 169.5°Cd was used by SAMNUT 22 while 148.0 and 169.5 °Cd will be needed by SAMNUT 23.

Table 4.3: Days (°Cd) and Photothermal Unit (°Cd) of different Groundnut varieties from sowing to flowering at Ogbomoso, 2010

Varieties	SDAT	PL–EM		EM–FL	
		GDD	PTU	GDD	PTU
SAMNUT 10	SD1	49.3	467.9	173.7	1650.2
	SD2	52.9	502.1	162.0	1538.5
	SD3	52.3	496.4	151.6	1439.7
	SD4	49.2	467.4	143.8	1365.6
	Mean	50.9	483.5	157.8	1498.5
SAMNUT 22	SD1	49.3	467.9	169.5	1610.3
	SD2	52.9	502.1	167.5	1590.8
	SD 3	52.3	496.4	151.6	1439.7
	SD 4	49.2	467.4	143.8	1365.6
	Mean	50.9	483.5	158.1	1501.6
SAMNUT 23	SD1	49.3	467.9	169.5	1610.3
	SD2	52.9	502.1	167.5	1590.8
	SD 3	52.3	496.4	151.6	1439.7
	SD 4	49.2	467.4	148.0	1578.4
	Mean	50.9	483.5	159.2	1554.8
Kampala	SD1	37.3	354.4	169.5	1610.3
	SD2	32.4	307.3	188.5	1383.0
	SD 3	62.3	591.9	151.6	1439.7
	SD 4	49.2	467.4	148.0	1578.4
	Mean	45.3	430.3	164.4	1502.9

SDAT = Planting date, SD1= 19/04/2010, SD2 = 26/04/2010, SD3 = 03/05/2010, SD4 = 10/04/2010, PL–EM = Time between sowing and plant emergence, EM–FL = Time between plant emergence and flower appearance (R1) (photothermal days)

Kampala emerged at a lower growing degree day, GDD of 32.4 °Cd and much higher GDD of 62.3 °Cd. Thus, the highest (obtained from SD1 sowing) and the lowest (obtained from SD2) GDD are for *Kampala*. About 467.9, 502.1, 496.4 and 467.4 °Cd was accumulated for SAMNUT 10, SAMNUT 22 and SAMNUT 23 but the thermal time accumulation of *Kampala*, the local variety (Table 5) was 354.4, 307.3, 591.9 and 467.4 respectively for SD1, SD2, SD3 and SD4 respectively. Also, from emergence to flowering thermal time accumulation of about 1650.2, 1538.5, 1439.7 and 1365.6°Cd would accumulate for SAMNUT 10; 1610.3, 1590.8, 1439.7 and 1365.6 for SAMNUT 22; 1610.3, 1590.8, 1439.7 and 1578.4 for SAMNUT 23 and 1610.3, 1383.0, 1439.7 and 1578.4 for SD1, SD2, SD3 and SD4 respectively.

A similar heat accumulation pattern for the three SAMNUT varieties from sowing to emergence but a different pattern for *Kampala* was observed.

4.4 Calibration outcomeof CSM–CROPGRO-Peanut modelforOgbomoso, Oyo state, Nigeria

From the obtained weather data and the estimated mean data from the 2010 experiment, the following files were calibrated (Tables 4.5, 4.6, 4.7 and 4.8):

i. NGGB100001.SOL (Soil data)
ii. NGGB1001.PNA (Pod yield and pod yield parameters)
iii. NGGB1001.PNX (Experimental details)
iv. NGGB1001.PNT (Time series file for time and time parameters)
v. NGGB1001.WTH (Weather data)

A CROPGRO-Peanutmodel was simulated for groundnut production in Ogbomoso, oyo state, Nigeria using the created files. The CROPGRO model was used to simulate days to flowering day, days to first pod day, days to first seed day, pod weight at maturity (kg ha^{-1}, number at maturity (no/m^2),unit weight at maturity (g/unit), and foliar days to emergence for all the four groundnut cultivars and for the four (4) sowing dates (Tables 4.4, 4.5, 4.6 and 4.7).

4.5 Model validation of mean values for the groundnut phenology and pod yield

The reliability of simulated groundnut phenological characteristics was analyzed with PE. Tables 4.4, 4.5, 4.6 and 4.7show the comparison of mean values for the groundnut phenology and pod yield for the four sowing dates used.

Table 4.4: Predicted and measured groundnut phenology and pod yield data for first sowing date, SD1 in 2010

	Days to emergence (DAS)		Days to flowering (DAS)		Days to First pod (DAS)		Days to First seed (DAS)		Pod wt at Harvest(kg ha^{-1})		Seed number at maturity (no/m^2)		Seed number at maturity (no/pod)		Harvest maturity day (DAS)	
	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs
SAMNUT 10	6	7	35	27	53	44	58	50	5210	2133	930	1073	1.61	1.75	140	140
SAMNUT 22	6	7	35	27	55	43	61	50	5432	2974	1003	1150	1.65	2.00	125	120
SAMNUT 23	6	7	35	28	57	45	66	43	5459	1453	934	1186	1.65	1.75	105	100
Kampala	6	6	35	28	57	44	67	51	5755	4035	1052	945	1.63	1.75	126	140
RMSE	0.9		7.5		11.6		15.6		2937.5		171.0		0.2		7.8	
PE	10		30		30		30		110		20		10		10	

Prd = Predicted, Obs = Observed, RMSE = Root Mean Square Error, DAS= Days After Sowing, wt = weight
PE = Percentage Error (PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction)
SD1= 19/04/2010

4.5.1.1Phenology and pod yield values for first sowing date (19thApril 2010)

The simulated and measured mean values for the groundnut phenology and pod yields for first sowing date in Ogbomoso in 2010 are in Table 4.4.

Days to flowering was overpredicted by about 8 days to the observed days to flowering (RMSE = 7.5 days). The PE of 30% shows that the number of days to flowering prediction was fair. Days to first pod set was also fairly well predicted with RMSE of 11.6 days. Prediction for pod weight at harvest was poor, the model overestimated the pod weight at harvest by 110%. Predicted pod weight for Kampala was the closest to observed while for SAMNUT 23, it was poor (PE > 30%) compared with the observed for the four varieties (Table 4.4). However, groundnut seed days to emergence, number of seed per pod and days to harvest was well predicted with PE of 10%. The difference in predicted days to emergence and the observed day was less than 1 day (0.9 days) and 7.8 days for days to harvest (Table 5). Leaf area index and number of seeds per pod at maturity were also not far from observed with PE of 20%.

4.5.2 Phenology and pod yield values for Second sowing date (26thApril 2010)

The mean values for the groundnut phenology and pod yields for sowing date 2 are in Table 4.6. Generally, simulated values are close to the observed phenological values in sowing date two. Like it was for sowing date one, the level of accuracy of phenological data varies for each phenological data and at a different degree of accuracy.

Observed seed days to emergence for all the varieties was 6 DAS but was overpredicted for all the varieties with RMSE of 7.1 days and the PE > 50%. However, days to flowering was well predicted (RMSE =.8 days) with PE < 2%. Days to first pod was also well predicted with RMSE of 6.02 days and PE of 12%. The model overestimated the pod weight at harvest by 74% with predicted pod weight for*Kampala* as the closest to observed for the four varieties (Table 4.6).

The predicted number of days to harvest maturity was well predicted with PE < 8% and RMSE of 11.16 days different from the observed. Number of groundnut per pod was well predicted (PE = 9%) and Leaf area index fairly predicted (PE = 27%).

Table 4.5: Predicted and measured groundnut phenology and pod yield data for second sowing date, SD2 in 2010

	Days to emergence (DAS)		Days to flowering (DAS)		Days to First pod day(DAS)		Days to First seed day (DAS)		Harvest maturity day (DAS)		Pod wt at Harvest(kg ha^{-1})		Unit wt at maturity (g/unit)		Seed number at maturity (no/pod)		Leaf area index, maximum	
	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs
SAMNUT 10	14	6	35	34	53	49	58	56	140	147	4631	2276	0.39	0.54	1.62	1.75	11.2	9.0
SAMNUT 22	14	6	35	36	55	51	61	49	125	127	4555	2700	0.36	0.41	1.59	1.75	11.5	9.6
SAMNUT 23	12	6	35	35	57	50	66	57	105	107	4281	1752	0.29	0.85	1.63	1.75	11.9	8.0
Kampala	12	6	35	34	57	49	67	57	126	147	4279	3878	0.29	0.51	1.50	1.75	12.2	10.7
RMSE	7.1		0.9		6.0		9.1		11.2		1971.3		0.3		0.2		2.6	
PE	54		2		12		17		8		74		54		9		27	

Prd = Predicted, Obs = Observed, RMSE = Root Mean Square Error, DAS= Days After Sowing, wt = weight
PE = Percentage Error (PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction) SD2= 26/04/2010

4.5.3 Phenology and pod yield values for third sowing date (3rd May 2010)

The simulated and measured mean values for the groundnut phenology and pod yields for third sowing date in Ogbomoso in 2010 are in Table 4.7.

Prediction for days to flowering was a good one with PE of 20% and RMSE of 6.8 days. Number of days to first pod was underpredicted by 2.5 days but was an excellent prediction with PE of 2%. Days to first seed was also excellently predicted with PE > 7% and RMSE of 6.5 days. Pod weight at harvest was poorly predicted in SD3 but with a lower RMSE of 1341.8 kg ha^{-1}compared with RMSE of SD1 and SD2. Number of pod at harvest maturity and number of seed per pod at harvest were predicted with PE > 30% which indicated a fair prediction. Days to emergence of seed was poorly predicted (RMSE = 16.3 days), it was overpredicted by 74%.

4.5.4 Phenology and pod yield values for fourth sowing date (10th May 2010)

The simulated and measured mean values for the groundnut phenology and pod yields for fourth sowing date in Ogbomoso in 2010 (Table 4.8).

Days to flowering was underpredicted by about 9 days to the observed days to flowering (RMSE = 8.8 days). The PE of 15% shows that the number of days to flowering prediction was good. Days to first pod was also well predicted with RMSE of 4.3 days. Prediction for pod weight at harvest was poor; the model unlike in SD1, SD2 and SD3 underestimated the pod weight at harvest by 48%. Predicted pod weight for*Kampala* was again the closest to observed. Days to seed days to emergence was overestimated with RMSE of 21.5 days, the number of seed per pod and days to harvest was well predicted with PE ≤ 19%. The difference in predicted and the observed days to emergence was less than 21 days and 23 days for days to harvest.

Table 4.6: Predicted and measured groundnut phenology and pod yield data for thirdsowing date, SD3 in 2010

	Days to emergence (DAS)		Days to flowering (DAS)		Days to First pod day(DAS)		Days to First seed day (DAS)		Pod wt at Harvest(kg ha^{-1})		Seed number at maturity (no/m^2)		Unit wt at maturity (g/unit)		Seed number at maturity (no/pod)		Leaf area index, maximum	
	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs
SAMNUT 10	22	6	35	43	53	57	58	65	3050	1981	729	980	0.25	0.21	1.52	1.75	11.22	9.56
SAMNUT 22	22	6	35	42	55	57	61	65	2798	3048	703	827	0.22	0.68	1.44	1.50	11.57	8.11
SAMNUT 23	21	6	35	41	57	59	66	66	2501	2206	636	989	0.19	0.42	1.33	1.75	11.90	7.75
Kampala	24	6	35	41	57	58	67	64	2470	4901	628	747	0.19	0.7	1.33	2.00	12.25	7.01
RMSE	16.3		6.8		2.5		4.3		1341.8		233		0.3		0.4		3.9	
PE	74		20		4		7		44		26		72		23		48	

Prd = Predicted, Obs = Observed, RMSE = Root Mean Square Error, DAS= Days After Sowing, wt = weight
PE = Percentage Error (PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction)
SD3= 03/05/2010

Table 4.7: Predicted and measured groundnut phenology and pod yield data for fourths sowing date, SD4 in 2010

	Days to emergence (DAS)		Days to flowering (DAS)		Days to First pod day(DAS)		Days to First seed day (DAS)		Harvest maturity day (DAS)		Pod wt at Harvest(kg ha^{-1})		Pod number at maturity (no/m^2)		Unit wt at maturity (g/unit)		Seed number at maturity (no/pod)		Leaf area index, maximum	
	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs	Prd	Obs
SAMNUT 10	28	6	49	35	63	53	69	58	161	140	2629	5207	1489	931	0.96	0.40	2.0	1.6	6.9	11.4
SAMNUT 22	28	6	49	35	66	55	68	61	141	125	1774	5398	1540	1003	0.35	0.38	2.0	1.7	8.4	11.5
SAMNUT 23	27	6	49	35	64	57	63	66	121	105	2975	5464	960	935	0.66	0.42	1.8	1.7	7.4	11.8
Kampala	27	6	48	35	63	57	71	67	161	126	4568	5794	1113	1059	0.39	0.38	1.8	1.6	7.5	12.1
RMSE	21.51		13.76		8.75		6.98		23.33		2620.96		388.35		0.31		0.27		4.19	
PE (%)	358		39		15		11		19		48		39		77		17		36	

Prd = Predicted, Obs = Observed, RMSE = Root Mean Square Error, DAS= Days After Sowing, wt = weight
PE = Percentage Error (PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction)
SD4= 10/05/2010

4.6 Determination of the onset date(s) of growing seasons for the selected groundnut varieties

Onset date was determined for each of the used varieties based on days to pod maturity, thermal time and average pod yield at pod maturity for each of the sowing dates as observed in 2010. It was observed that performance of each variety was affected differently by the sowing date. SAMNUT 10 reached pod maturity at an average of 143 DAS, SAMNUT 22 at 134 DAS, SAMNUT 23 at 100 DAS and *Kampala* at 120 DAS (Table 4). The earliest matured SAMNUT 10 (135 DAS) was planted on SD1 about a week after the onset of rain while it was SD4 and SD3 for SAMNUT 22 (130 DAS) and *Kampala* (117 DAS) respectively. For SAMNUT 23, pod maturity was 100 DAS for the SD1, SD2, SD3, and SD4.

Highest pod weight at maturity was at SD4; when rainfall was much steady (Fig. 4. 3) for the four varieties of groundnut used. Groundnut matured earlier with better pod yield when adequate water was supplied. Despite that SAMNUT 23 reached pod maturity at the same number of days after sowing regardless of the sowing date, pod weight (5901 kg ha^{-1}) at sowing date 4 was about 4000 kg ha^{-1} more than the pod weight (1981 kg ha^{-1}) at SD1.

4.7 CSM CROPGRO-Peanut model calibration in response to different rates of starter nitrogen for Ogbomosoexperimental site

From the mean estimate of parameters obtained in experiment 2 (Tables 4.9 and 4.10), the following files were generated in accordance with the requirement of DSSAT CROPGRO program (Appendix 4):

i. NGGB1101.PNX (FileX) – details of crop management file
ii. NGGB1101.PNT (FileT) – time series file
iii. NGGB1101.PNA (FileA) – the observed data
iv. NGGB1101.WTH – daily weather inputs and
v. NGGB110001.SOL – soil parameters

The CROPGRO model was calibrated from the generated files. The model simulated flowering day, first pod day, first seed day, pod weight at maturity (kg [dm]/ha, Number at maturity (no/m^2), unit weight at maturity (g [dm]/unit), and days to emergence for all the tested cultivars and for the four (4) rates of fertilizer and two varieties of groundnut used (Tables 4.9 and 4.10).

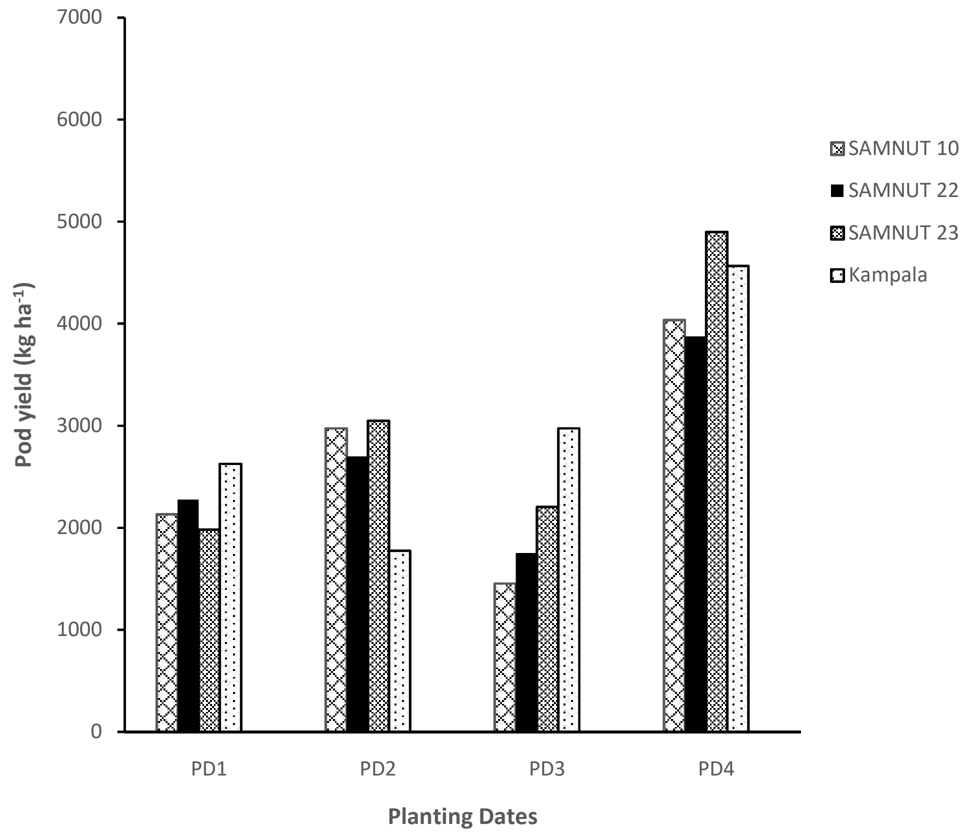


Fig. 4. 3: Pod yield of groundnut at different sowing dates

4.7.1 Response ofthe two varieties of groundnut to different rates of starter nitrogen application at Ogbomoso experimental site

The effect of different nitrogen application rates (0 kg N ha^{-1}, 5 kg N ha^{-1}, 10 kg N ha^{-1}and 20 kg N ha^{-1}) and two sowing dates (SD1 = 13/06/2011, SD2 = 20/06/2011) on fresh pod weight (FPW), fresh top weight (FTW), no of pod (NP) and seed weight (HWUM) of *Kampala* and SAMNUT 23 for 2011 growing season (Table 4.8.).

All the growth parameters were influenced by the combination of the sowing dates and nitrogen fertilizer application level for both varieties of groundnut. During the 2011 experiment, the highest and least FPW at harvest were 12,298.8 kg ha-^{1} and 5872.5kg ha^{-1} respectively. At SD1, *Kampala* produced the least FPW (5872.5 kg ha^{-1}) at control (0 kg N ha^{-1}) and the highest FPW (12, 298.8 kg ha^{-1}) at application of 20 kg N ha^{-1} while SAMNUT 23 produced the least FPW with the application of 5 kg N ha-^{1}and the highest FPW of 13,296.3 kg ha^{-1} also at application of 20 kg N ha^{-1}. For SD2, *Kampala* produced the least FPW of 10,192.5 kg ha^{-1} at application of 10 kg N ha^{-1} and the highest FPW of 17,301.3 kg ha^{-1} at application of 5kg N ha^{-1} while SAMNUT 23 produced the least FPW of 6,115.0 at application of 10kg N ha^{-1}and the highest FPW of 11,382.1 kg ha^{-1} also at application of 20 kg N ha^{-1}. Application of 20 kg N ha^{-1} produced the highest FPW for both sowing dates except for *Kampala* at SD2 for which application of 5 kg N ha^{-1} produced the highest. All rates of N fertilizer application significantly affected FPW of both varieties of groundnut.

Lowest FTW at harvest was 3094.7 kg ha^{-1} (at the application of 5 kg N ha^{-1}) and highest, 4910.7kg ha^{-1} (at the application of 10 kg N ha^{-1}) both at SD1.There was no significant difference between FTW values at all rates of N fertilizer applied in SD2 for both *Kampala* and SAMNUT 23. Application of 5 kg N ha^{-1} for the first sowing date gave the least FTW (3094.7 kg ha^{-1}) for SAMNUT 23 and 10 kg N ha^{-1} the highest value of FTW (4036.7 kg ha^{-1}) in SAMNUT 23 which is statistically the same as the 3898.0 kg ha^{-1} obtained at control (0 kg N ha^{-1}). There was a statistical difference in the number of pods harvested from both varieties and across the rates of starter N fertilizer used.

The highest NP (ha) for this experiment was 12,600 and least was 4467. At SD1, least NP for SAMNUT 23 was 4467 at control (0 kg N ha^{-1}) and the highest NP (9267) at the application of 20 kg N ha^{-1} also for SAMNUT 23. For SD2, *Kampala* produced the highest NP of 12,600 (*Kampala*) at the application of 5kg N ha^{-1} and the least of 4,600 (SAMNUT 23) at the application of 10 kg N ha^{-1}.

Table 4.8: Effect of N fertilizer rates and sowing dates on pod yield and growth parameters of the cultivated varieties at Ogbomoso

N fertilizer rates (kg ha^{-1})	FPW (kg ha^{-1})	FTW (kg ha^{-1})	NP (ha)	HWUM (g)
Kampala				
SD1				
0	5872.5^{e}	4114.7^{a}	4800^{e}	0.77
5	8168.3^{d}	3647.3^{b}	6533^{d}	0.76
10	8361.3^{d}	4910.7^{a}	7133^{c}	0.69
20	12298.8^{b}	3450.0^{b}	8267^{b}	1.02
SD2				
0	12666.3^{b}	3747.3^{b}	9467^{b}	0.78
5	17301.3^{a}	3648.7^{b}	12600^{a}	0.83
10	10192.5^{c}	3887.3^{b}	7400^{c}	0.85
20	13920.4^{b}	3474.7^{b}	8667^{b}	0.98
Mean	11097.7	3860.1	8108	0.84
SAMNUT 23				
SD1				
0	9533.3^{b}	3898.0^{a}	7333^{b}	0.76
5	6377.5^{e}	3094.7^{c}	4467^{e}	0.80
10	8455.0^{c}	3374.0^{b}	6467^{c}	0.82
20	13296.3^{a}	4036.7^{a}	9267^{a}	0.86
SD2				
0	8775.4^{c}	3674.7^{b}	6000^{c}	0.91
5	7296.3^{d}	3509.3^{b}	5533^{d}	0.73
10	6115.0^{e}	3452.7^{b}	4600^{e}	0.79
20	11382.1^{b}	3594.7^{b}	7267^{b}	0.98
Mean	8903.9	3579.4	6367	0.83

SD1 = 13/06/2011, SD2 = 20/06/2011, FPW = Fresh Pod Weight, FTW = Fresh top weight, NP = Average no of pod, HWUM = Average seed weight (g)

Application of 20 kg N ha^{-1} produced the highest NP for both sowing dates except for *Kampala* at SD2 for which application of 5 kg N ha^{-1}has the highest produce. Starter N fertilizer rates significantly affected NP of both varieties of groundnut.

4.7.2 CROPGRO-Peanut model outcome for starter nitrogen application

The CROPGRO-Peanut model was evaluated for simulations of crop phenology; pod weight at maturity (kg ha^{-1}), number of pod at maturity (no/m^2) and unit weight at maturity (g/unit). Data obtained from thefield trial in 2010 was used for calibrating the model.A similar experiment in 2011 with different starter rates of N fertilizer carried out in Ogbomoso led to data obtained from the 2011 trial. The datasets were used for the model validation. Table 4.9 shows the effect of different levels of starter nitrogen fertilizer application and sowing dates on some pod yield parameters. Also shown in Table 4.10 is the comparison of both simulated and the measured parameters for the 2011 experiment.

For sowing date 1, the model underpredicted days to emergence for SAMNUT 23 at the application of 5 kg N ha-^{1}, 10 kg N ha^{-1} and at control. There was a difference of 2, 1 and 3 days respectively. However, the model accurately predicted days to emergence (6DAS) for SAMNUT 23 when 20 kg N ha-^{1} was applied. There was underprediction of days to the emergence of *Kampala* at the application of 5 kg N ha-^{1} and 20 kg N ha^{-1} with a difference of 4 and 1 days. Days to emergence for *Kampala* were accurately predicted (6DAS) at control and overpredicted at the application of 10 kg N ha-1 with a difference of +2 days.

For sowing date 2, the model underpredicted days to emergence for every rate of N fertilizer that was applied to SAMNUT 23 with a difference of 1 day for control, 5 days for application of 5 kg N ha^{-1}, 2 days for application of 10 kg N ha^{-1} and under predicted by 3 daysfor application of 20 kg N ha^{-1}. The model underpredicted days to emergence for *Kampala* with a difference of 1 day. Days to emergence at the application of 5 and 20 kg N ha^{-1} was also under predicted with a difference of 4 and 1 day respectively.

Table 4.9: Predicted and measured groundnut phenology and pod yield data for 2011

	Emergence (DAS)		NP (no/m^2)		Unit wt at maturity(g/unit)		HPW (kg ha^{-1})		Pod yield RMSE
kg N ha^{-1}	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	(kg ha^{-1})
SD1 SAMNUT 23									
0	6	9	924	918	0.272	0.256	2404	2383	12.1
5	6	8	929	558	0.271	0.233	2404	1595	467.1
10	6	7	924	808	0.272	0.255	2404	2114	167.4
20	6	6	907	1158	0.277	0.232	2406	3324	530.0
PE	25		27		13		26		
SD1 *Kampala*									
0	5	5	924	600	0.266	0.272	2362	1468	516.2
5	6	10	928	818	0.265	0.266	2362	2042	184.8
10	6	4	922	893	0.266	0.284	2363	2090	157.6
20	6	7	928	1033	0.265	0.224	2362	3075	411.7
PE	35		21		9		28		
SD2 SAMNUT 23									
0	6	7	940	750	0.271	0.228	2393	2194	114.9
5	6	11	940	700	0.271	0.253	2393	1824	328.5
10	6	8	940	600	0.271	0.251	2393	1824	328.5
20	6	9	940	925	0.271	0.213	2393	2846	261.5
PE	36		31		16		22		
SD2 *Kampala*									
0	6	7	930	1175	0.264	0.249	2346	3167	474.0
5	6	10	930	1575	0.264	0.243	2346	4325	1142.6
10	6	6	930	925	0.264	0.242	2346	2548	116.6
20	6	7	930	1100	0.264	0.207	2346	3480	654.7
PE	28		30		14		36		

SD1= 13/06/2011,SD2 = 20/06/2011, DAS = Days after sowing, NP = PAverage number of pod PE = Percentage Error. PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction, RMSE measures the difference between values predicted by a model and the values observed,   HPW = Pod yield at harvest maturity

The number of days to emergence at the application of 10 kg N ha^{-1} was however accurate (6DAS).

In general, the pod yield predicted as affected by the level of N-fertilizer rate was fair (Table 4.10). The predicted pod yield at harvest across all rates of fertilizer applied for SAMNUT 23 SD1 gave almost the same value for *Kampala* at sowing date 1. The trend is the same for sowing date 2 for both varieties used. This could be because another fertilizer (ammonium nitrate) other than the one used (N: P: K 15: 15:15) on the field was selected in the module to run the model. However, the pod yield prediction for SAMNUT 23 without fertilizer application was the closest to observed pod yield value for this experiment with RMSE of 74.5 kg ha^{-1}. Same was observed for all the phenological parameters simulated whereas there was clear difference in the measured parameters as affected by the rate of fertilizer applied. Highest pod weight was recorded for both SAMNUT 23 and *Kampala* when planted at both date 1 and 2 at the application of 20 kg N ha^{-1}.

4.8 CSM CROPGRO-Peanut model calibration in response to different rates of starter nitrogen for Ogbomosoagro-ecological zone Nigeria

The adjustments made with field data from 2012 for both Ogbomoso and Ibadan experimental sitesare indicated in Appendices 5 and 6. The adjustments were for the EM–FL, FL–SH, FL–SD and the SD–PM as obtained from the field trial (shown in Table 4.2) in the sensitivity analysis shell in the model in order to get the best fit values which provided the least RMSE.

4.8.1 CSM CROPGRO-Peanut model calibration in response to different rates of starter nitrogen application at Ogbomososite

Model requirements of daily weather inputs (NGGB1201.WTH), soil parameters (NGGB120001.SOL) and details of crop management file NGGB1201.PNX (FileX), time series file NGGB1201.PNT (FileT) and the observed data NGGB1201.PNA (FileA) were obtained from the 2012 field experiment in Ogbomoso as shown in Appendix 5 and the weather data in Appendix 1. The model was used to predict theflowering day, fresh pod weight at maturity (kg ha^{-1}, Leaf area index (LAI) and days to emergence (Table 4.10) for the three sources of fertilizer and two varieties of groundnut.

Table 4.10: Evaluation of CROPGRO-Peanut model predicted with data from different sources of nitrogen used in Ogbomoso, Nigeria

	Emergence (DAS)		LAI		Flowering (DAS)		Pod yield(kg ha^{-1})		RMSEpod yield (kg ha^{-1})
kg N ha^{-1}	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	
SAMNUT 23									
0	6	6	11.38	11.16	39	27	2559	2667	62.4
NPK 20	6	6	11.63	12.90	38	27	2627	2720	53.7
PWM 20	6	6	11.63	11.34	38	27	2559	3040	277.7
AOM 20	6	6	11.63	12.07	38	26	2627	2629	1.2
$RMSE_{var}$	0.0		0.7		11.5		250.8		
PE	0.0		6		43		9		
Kampala									
0	6	6	11.63	15.08	38	26	2559	2667	62.4
NPK 20	6	5	11.38	12.08	39	26	2185	2214	16.7
PWM 20	6	6	11.38	10.53	39	27	2185	3767	913.4
AOM 20	6	5	11.38	13.02	39	27	2185	2984	461.3
$RMSE_{var}$	0.7		2.0		12.3		887.9		
PE	13		16		46		30		

NPK = N: P: K 15: 15: 15, PWM = Poultry waste manure manure, AOM = Aleshinloye organomineral fertilizer, DAS = Days after sowing, PE = Percentage Error. PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction, RMSE measures the difference between values predicted by a model and the values actually observed, PE gives the accuracy of model prediction

Days to emergence for both SAMNUT 23 and *Kampala* were predicted very well with a difference of 1 day (Table 4.11). The LAI also was well predicted for both varieties. However, there was a difference of 12–13 days between the predicted and observed days to flowering for both varieties. The difference is outside an acceptable range of the three sources and rates of fertilizers used.

RMSE of between 1407 kg ha^{-1} and 2165.1 kg ha^{-1} was recorded for SAMNUT 23 and 818.1 kg ha^{-1} and 1895.4 kg ha^{-1} for *Kampala* across the three fertilizer sources used. The accuracy of the predicted pod yield was evaluated using PE. PE of between 19.2 and 27.1 % was observed across all sources and rates of fertilizer used for SAMNUT 23 indicating a fair prediction of the pod yield. PE of less than 20% (12.2 – 14%) was observed with N: P: K 15: 15: 15 as a source of nitrogen and PE of less than 30% (10.5–24.9%) with poultry waste manure manure as a source of nitrogen. The PE of less than 30% (14.8–25.2%) was calculated for Aleshinloye organo–mineral fertilizer as a source of nitrogen. The same value of LAI, flowering days and pod yield value was predicted for both Samnut 23 and *Kampala* at the application of NPK 0 kg N ha^{-1} and also at the application of NPK 20 kg N ha^{-1}.

4.8.2 CSM CROPGRO-Peanut model calibration in response to different rates of starter nitrogen application at Ibadan Site

Model requirements of daily weather inputs (NGIB1201.WTH), soil parameters (NGIB120001.SOL) and details of crop management file NGIB1201.PNX (FileX), time series file NGIB1201.PNT (FileT) and the observed data NGIB1201.PNA (FileA) were obtained from the 2012 field experiment in Ibadan and shown in Appendix 6 and the weather data in appendix 2. The model was used to predict the Flowering day, Pod weight at maturity (kg [dm]/ha, Leaf area index (LAI) and Days to emergence (Table 14) for all the tested cultivars, the three sources of fertilizer and two varieties of groundnut used.

For SAMNUT 23, days to emergence across the three types of fertilizers used was perfectly predicted while for *Kampala* there was under predicted by 1 daydifference in the number of days to emergence when 20 kg ha^{-1} of poultry waste manure and Aleshinloye organomineral fertilizer were applied.

Table 4.11: Evaluation of CROPGRO-Peanut model predicted with data from different sources of nitrogen used in Ibadan, Nigeria

	Emergence (DAS)		LAI		Flowering (DAS)		Pod yield(kg ha^{-1})		RMSE pod yield
kg N ha^{-1}	Predicted	Observed	Predicted	Observed	Predicted	Observed	Predicted	Observed	(kg ha^{-1})
SAMNUT 23									
0	6	6	9.05	9.16	39	27	1247	2500	723.4
NPK 20	6	6	9.30	10.30	38	27	1251	2252	577.9
PWM 20	6	6	9.30	9.43	38	27	1259	2783	879.9
AOM 20	6	6	9.30	9.70	38	26	1267	2116	490.2
$RMSE_{var}$	0.0		0.55		11.5		1184.8		
PE	0.00		6		43		50		
Kampala									
0	6	6	9.05	12.98	38	26	1247	2500	723.4
NPK 20	6	6	9.30	10.11	39	26	1275	1531	147.8
PWM 20	6	5	9.30	7.53	39	27	1283	1772	282.3
AOM 20	6	5	9.30	10.25	39	27	1291	1969	391.4
$RMSE_{var}$	0.71		2.24		12.26		763.9		
PE	13		22		46		39		

NPK = N: P: K 15: 15: 15, PWM = Poultry waste manure manure, AOM = Aleshinloye organomineral fertilizer, DAS = Days after sowing, PE = Percentage Error. PE < 10% = excellent prediction, 10 – 20% = good prediction, 20 – 30% = fair prediction and 30% > poor prediction, RMSE measures the difference between values predicted by a model and the values actually observed, PE gives the accuracy of model prediction

Days to flowering was predicted as 39 DAS for both varieties at the application of all the sources used. However, differences in a number of days to flowering were observed on the field. Flowering was observed at 27 DAS when NPK and poultry manure were added to SAMNUT 23, same for application of poultry waste manure manure and Aleshinloye organomineral fertilizer. Flowering was earlier (26 DAS) at the application of Aleshinloye organomineral fertilizer in SAMNUT 23 and application of NPK in *Kampala*.

Same LAI of 9.30 was measured for the three sources of fertilizer used. Also, thesame pod yield of 3754 kg $ha^{-1}$was measured for both varieties with all sources of fertilizer used. However, there were differences in the measured value for both varieties. LAI for SAMNUT 23 at the application of NPK was 10.30, 9.43 for poultry waste manure manure and 9.70 for Aleshinloye organomineral fertilizer. The measured LAI for *Kampala* at the application of NPK fertilizer was 10.11, at application poultry waste manure was 7.53 and for Aleshinloye organomineral fertilizer it was 10.25. PE of pod yield was below 20% which signifies good pod yield prediction for both SAMNUT 23 and *Kampala*.

4.9 Prediction of groundnut pod yieldwith projected climatic conditions using CROPGRO-Peanut model in the DSSATv4.5formoist savanna agro–ecology of Nigeria

The predicted pod yield of SAMNUT 10, SAMNUT 22, SMNUT23 and *Kampala*for 2020, 2030, 2040 and 2050 are shown in Tables 4.12 and 4.13. Predicted weather data were generated using the *MarkSim* web application using the B2 scenario. The B2 scenario considered continuously increasing population but at a slower rate with anemphasis on local rather than global solutions to economic, social and environmental stability.The B2 scenariois an intermediate level of economic development, less rapid and more fragmented technological change.

Generally, increase in maximum temperature to an average of 32.0 °Cwas projected for both sites. Predicted total rainfall varies largely with projected years and site specific. The solar radiation of Ogbomoso is expected to increase with about 4.8% as against the reduction of about 6.3% of Ibadan.

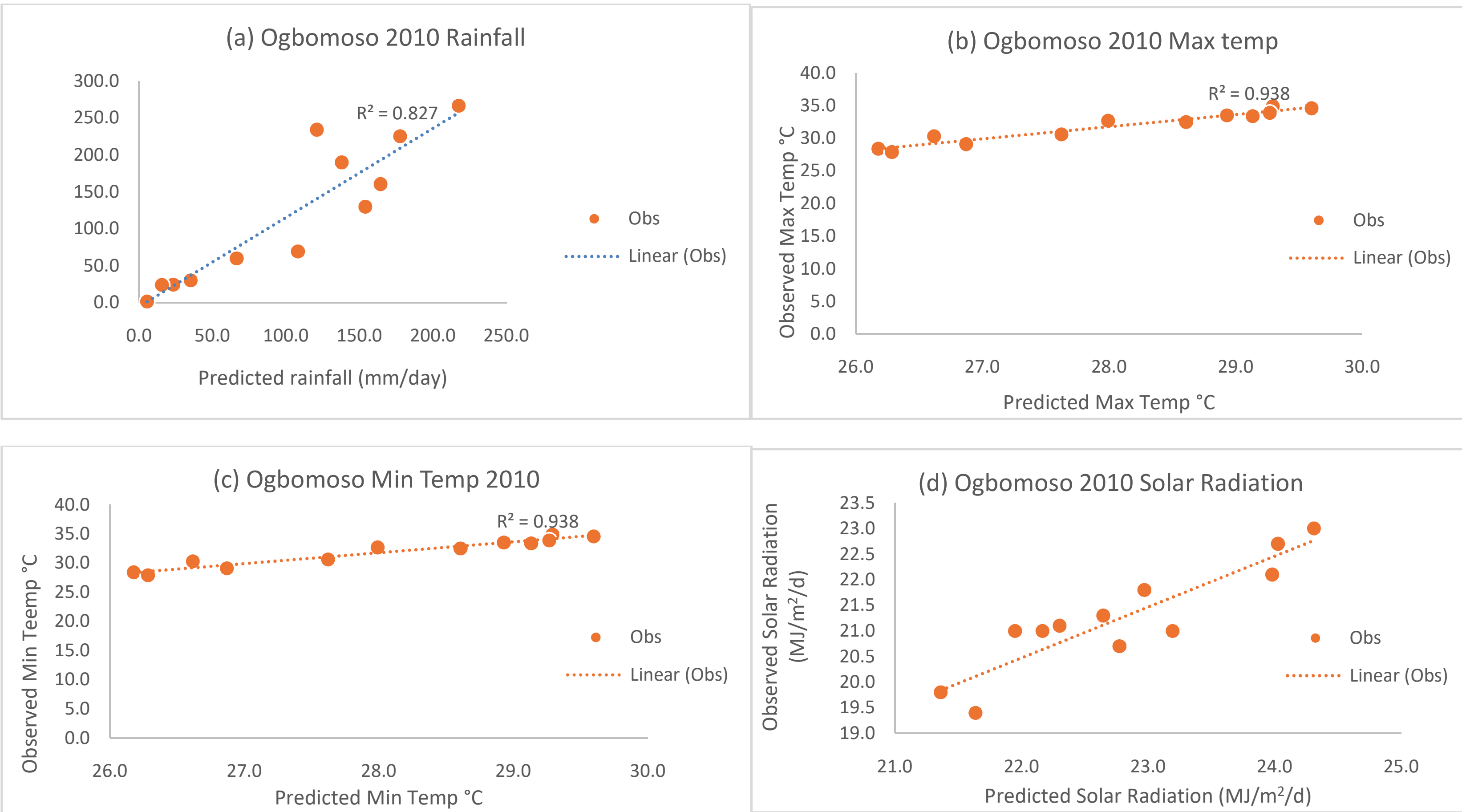


Fig. 4.4: The comparison of the observed and *MarkSim* predicted climatic data for Ogbomoso

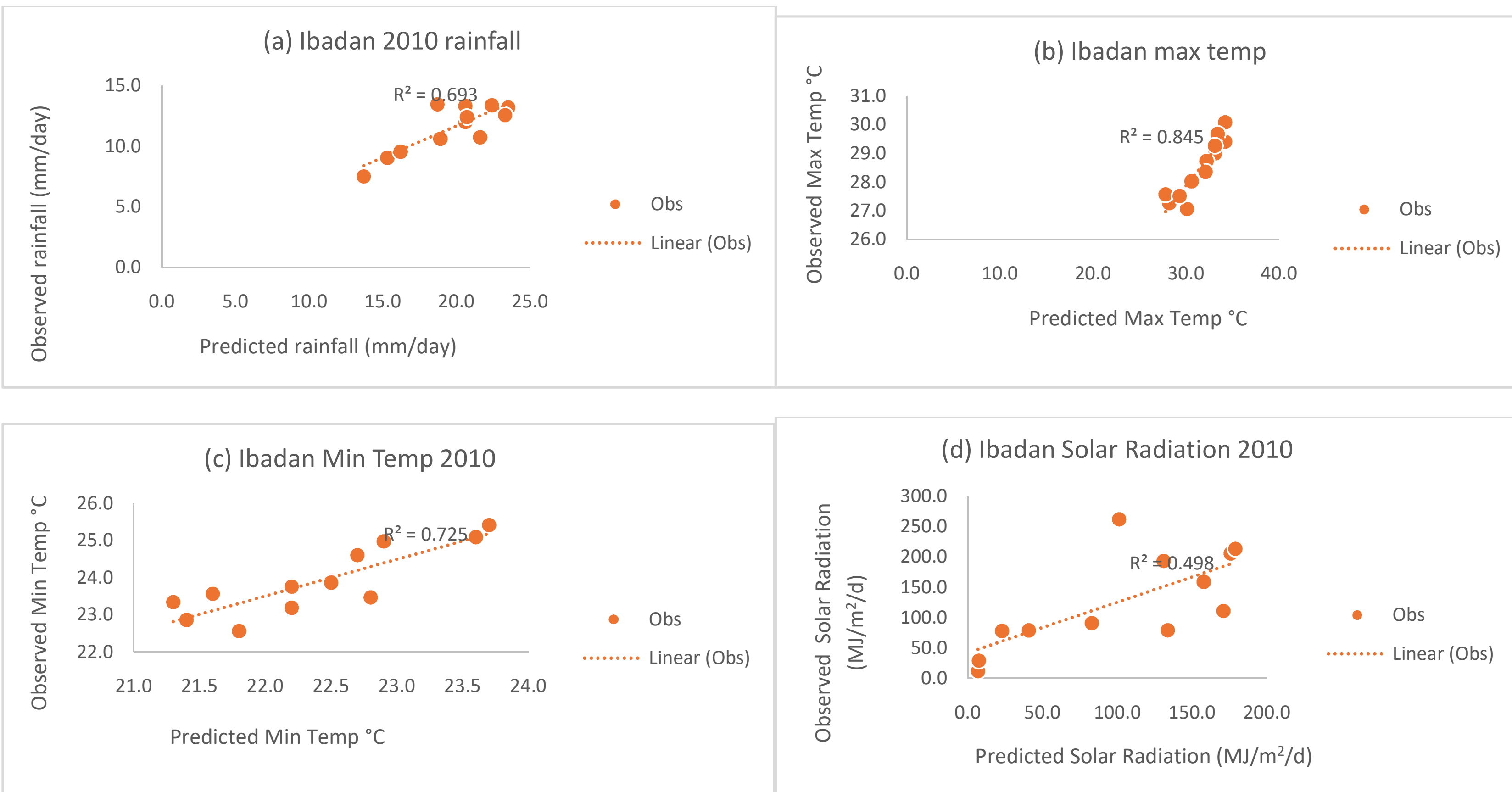


Fig. 4.5: The comparison of the observed and *MarkSim* predicted climatic data for Ibadan

4.9.1 Evaluation of the MarkSim weather prediction app

The comparison between the observed and predicted weather data for Ibadan and Ogbomoso sites (Fig. 4.3 and 4.4) using MarSim shows that the predicted and observed values have high correlation (> 1), thus the prediction for the two location is reliable.

4.9.2 Predicted climate changes in Ogbomoso Site

Predicted weather data for minimum temperature, maximum temperature, daily solar radiation and total rainfall for 2020, 2030, 2040 and 2050 (Table 4.12)indicated that solar radiation will increase by about 9.6% in 2040 and by 2050 revert back to 18.6MJ/m^2/dayas it was in 2010 and 2011.

The maximum temperature will increase with about 15% from 2012(27.8 °C) till 2020 (32.2°C) and remain constant at an average of 32.2 °C till 2050 (32.4 °C). Minimum temperature will be fairly constant at an average of 22.0 °C through the predicted period which was same average value for the observed years.

Flunctuation in total rainfall was predicted for the Ogbomoso site. Total rainfall will increase with about 10% by 2030, between 2030 and 2040 total rainfall will drop by 14% and increase again by 13% in 2050.

4.9.3 Predicted climate changes in Ibadan Site

Predicted weather data for minimum temperature, maximum temperature, daily solar radiation and total rainfall for 2020, 2030, 2040 and 2050 (Table 4.12) for the experimental site at Ibadan shows progress reduction in solar radiation from 19.0 MJ/m^2/day measured in 2010 to 17.1 MJ/m^2/day in 2050.

When compared with measured maximum temperature in 2012,the maximum temperature will increase with about 12% in 2020,and will remain higher than the measured maximum temperature at an average of 31.9 °Cthrough the predicted period. However, the minimum temperature will be fairly constant at an average of 23.0 °C through the predicted period which was same average value for the observed years.

Total rainfall will fluctuate within the predicted years at the Ibadan study site. There will be 25% increase in total rainfall by 2020, drop by 31% between 2020 and 2030, increase by 42% in 2040 and reduced by 25% between 2040 and 2050.

4.10 Predicted groundnut pod yield (with no fertilizer) for 2020 –2050

Simulation results of groundnut pod yields for SAMNUT 10, SAMNUT 22, SAMNUT 23 and *Kampala* varieties under B2 climate change scenario vary across the simulated years in DSSAT showsyield reuction for the simulated years compared with the present (Figs 4.4 and 4.5).

4.10.1 Groundnut pod yield prediction (with no fertilizer) for Ogbomoso Site

The pod yield varies for each of the variety used (Fig 4.4), however; SAMNUT 22 and *Kampala* had the highest pod yield for the predicted years. Of the varieties, the predicted pod yield for SAMNUT 23 (1053 kg ha^{-1}) over the next 30 years is the least though, was the highest observed in 2010 (3034 kg ha^{-1}).

Generally, the lowest pod yield predicted was for SAMNUT 23 in 2040 (1053 kg ha^{-1}) with about 61% pod yield reduction and the highest pod yield of 2707 kg ha^{-1} was for *Kampala* also in 2040 with about 42% pod yield reduction. The highest pod yield predicted is not significantly different from the predicted 2705 kg ha^{-1} for SAMNUT 10 in 2040.

The predicted pod yields were compared with those observed in 2010. By 2020, the pod yield of SAMNUT 10 will be reduced by 19%, SAMNUT 22 by 50%, SAMNUT 23 by 53% and *Kampala* by 49%. Between 2020 and 2030, the pod yield of SAMNUT 10 will be increased by 7%, SAMNUT 22 by 18%, *Kampala* by 7% but SAMNUT 23 pod yield will reduce by 7%.

For both SAMNUT 10 and *Kampala*, the prediction indicated there will be an increase in pod yield by 6% by 2040 and pod yield reduction by 9% for both SAMNUT 22 and SAMNUT 23. Between and 2050, there was a prediction of a 1% decrease in pod yield of SAMNUT 22 while SAMNUT 22 (12%) and *Kampala* (13%) pod yield will also be reduced and SAMNUT 22's pod yield will increase by 12%.

Table. 4.12: Observed (2010 – 2012) and Predicted(2020 – 2050) weather datafor the experimental sites at Ogbomoso and Ibadan

	Observed			Predicted				
Ogbomoso	2010	2011	2012	2020	2030	2040	2050	Range
Solar radiation (MJ/m2/day)	18.6	18.6	19.4	19.5	19.0	20.4	18.6	1.8
Maximum temperature (°C)	28.0	28.1	27.8	32.2	32.1	32.2	32.4	4.6
Minimum temperature (°C)	22.8	22.3	22.1	22.1	22.0	21.9	22.1	0.9
Total rainfall (mm)	1416.8	1204.1	1280.6	1270.9	1400.1	1197.9	1348.8	218.9
Ibadan								
Solar radiation (MJ/m2/day)	19.0	18.6	18.4	17.8	17.6	17.0	17.1	2.0
Maximum temperature (°C)	28.5	28.3	28.3	31.7	31.9	31.8	32.0	3.7
Minimum temperature (°C)	23.9	23.4	23.2	23.3	23.2	23.1	23.2	0.8
Total rainfall (mm)	1608.2	1623.5	1268.6	1587.5	1088.1	1552.9	1252.0	535.4

4.10.2 Groundnut pod yield prediction (with no fertilizer) for Ibadan site

The pod yield prediction of groundnut for 2020 – 2050 is shown in Fig. 4.5. SAMNUT 22 and SAMNUT 23 showed apod yield of less than 20 kg ha^{-1} for the next 30 years, while the pod yield of SAMNUT 10 and *Kampala* was 3881 – 3886 kg ha^{-1}and 1757 – 1760 kg ha^{-1} for the predicted years (Fig.4.5).

Generally, the lowestpod yield was predicted for 2040, a pod yield of 4 kg ha^{-1} and was predicted for SAMNUT 23 indicating about 99.8% pod yield reduction of the variety. The highest pod yield predicted was 3886 kg ha^{-1}for SAMNUT 10 in 2050, indicating a pod yield of about 46% when compared to the observed pod yield in 2010. The highest pod yield predicted is, however, not significantly different from the predicted 3,881 kg ha^{-1}for SAMNUT 10 in 2020. It was only in 2040 that there will be a reduction in pod yield of SAMNUT 10 by 46%.

4.11 Predicted groundnut pod yield (with fertilizer) under changing climate

Groundnut pod yield for Samnut 23 and *Kampala* varieties at the application of 20 kg ha^{-1} were simulated under future climate conditions in DSSAT (Figs 4.6 and 4.7). The climatic conditions were simulated under the B2 climate change scenario (Tables 4.12).

4.11.1 Groundnut pod yield prediction (with fertilizer) Ogbomoso Site

The predicted pod yield is highly influenced by the variety used (Fig. 4.6). Generally, the pod yield prediction of *Kampala* over the next 30 years is higher than that of SAMNUT 23. According to the prediction, the overall least pod yield of 1050 kg ha^{-1} in 2040 (SAMNUT 23) and the highest predicted pod yield of 2707 kg ha^{-1} for *Kampala* also in 2040.

The pod yield predicted for the Ogbomoso site shows a decline in groundnut pod yield over the years from 2030 to 2040 and a slight increase in 2050 for SAMNUT 23. An average pod yield reduction of around 1200 kg ha^{-1} (48%)lower than the average pod yield observed in 2011 was predicted for SAMNUT 23 in 2020 and about 1400 kg ha^{-1} (53%) lower in 2030. The pod yield will also be about 1500 kg ha^{-1} (51%) lower than the average pod yield observed in 2011 in 2040 and lower by 1300 kg ha^{-1} (51%) in 2050. There was also a predicted decline in thepod yield of *Kampala* with a slight increase in 2040. When compared with the average pod yield observed in 2011, pod yield reduction of around 1000 kg ha^{-1} (23%) was predicted for 2020, reduction of 900

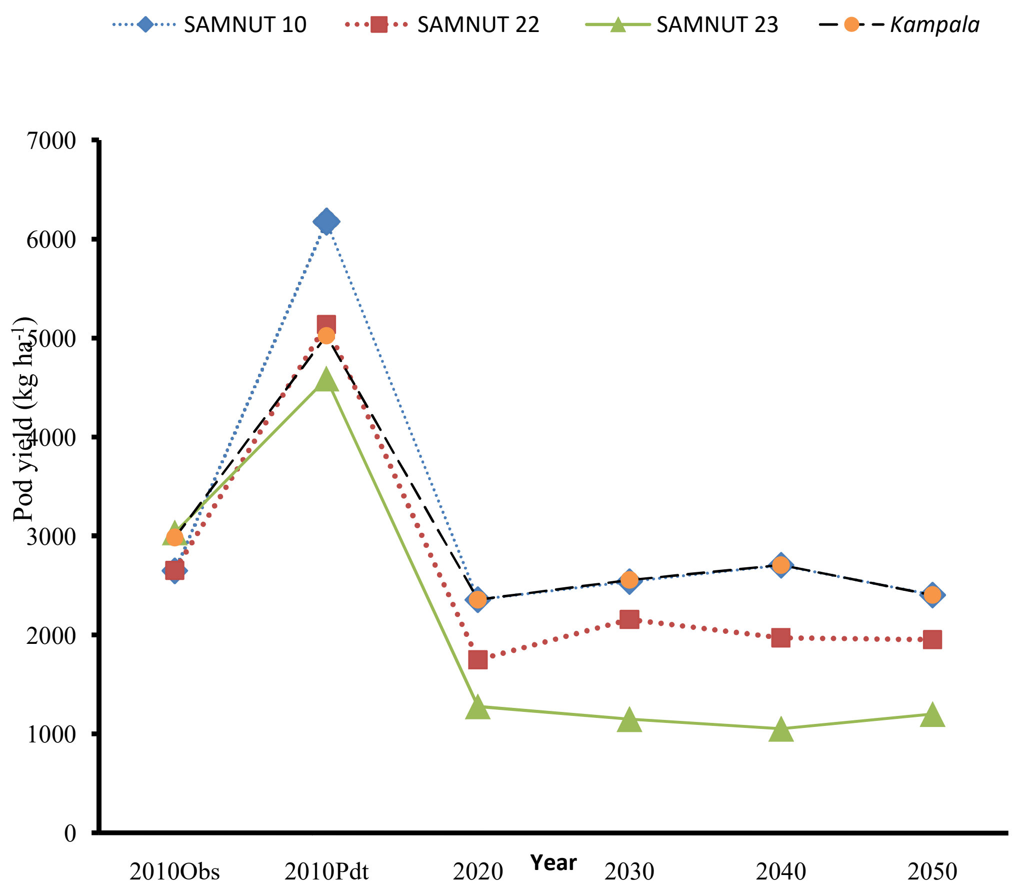


Fig. 4. 6: Predicted groundnut pod yield (without fertilizer) for Ogbomoso

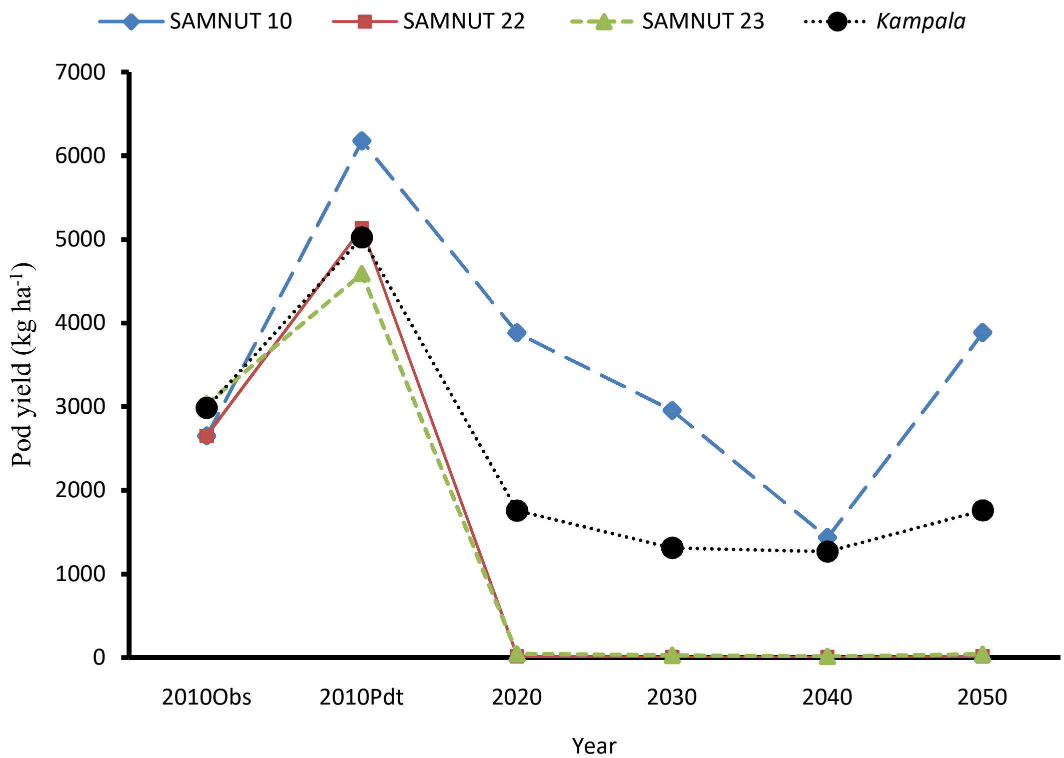


Fig. 4. 7: Predicted groundnut pod yield (without fertilizer) for Ibadan

kg ha^{-1} (17%) in 2030, reduction of 600 kg ha^{-1} (12%) in 2040 and 900 kg ha^{-1} (22%) in 2050.

4.11.2 Groundnut pod yield prediction (with fertilizer) Ibadan Site

The predicted pod yield was highly influenced by the variety used (Fig.4.7). The same pod yield value of (2559 kg ha^{-1}) for SAMNUT 23 between 2020 and 2050 was predicted. This steady pod yield is about 100 kg ha-1 more than the observed pod yield in 2011. *Kampala* pod yield was predicted to reduce in 2020 (2627 kg ha^{-1}) from what it was in 2011(3075 kg ha^{-1}). *Kampala* pod yield too was the same (2627 kg ha^{-1}) from 2020 to 2050.

Generally, the predicted pod yield for *Kampala* between 2020 and 2050 was lower than the obtained pod yield for *Kampala* in 2011 with about 700 kg ha^{-1} while the predicted pod yield for SAMNUT 23 between 2020 and 2050 was 42 kg ha^{-1} lower than the predicted pod yield for *Kampala* in 2011.

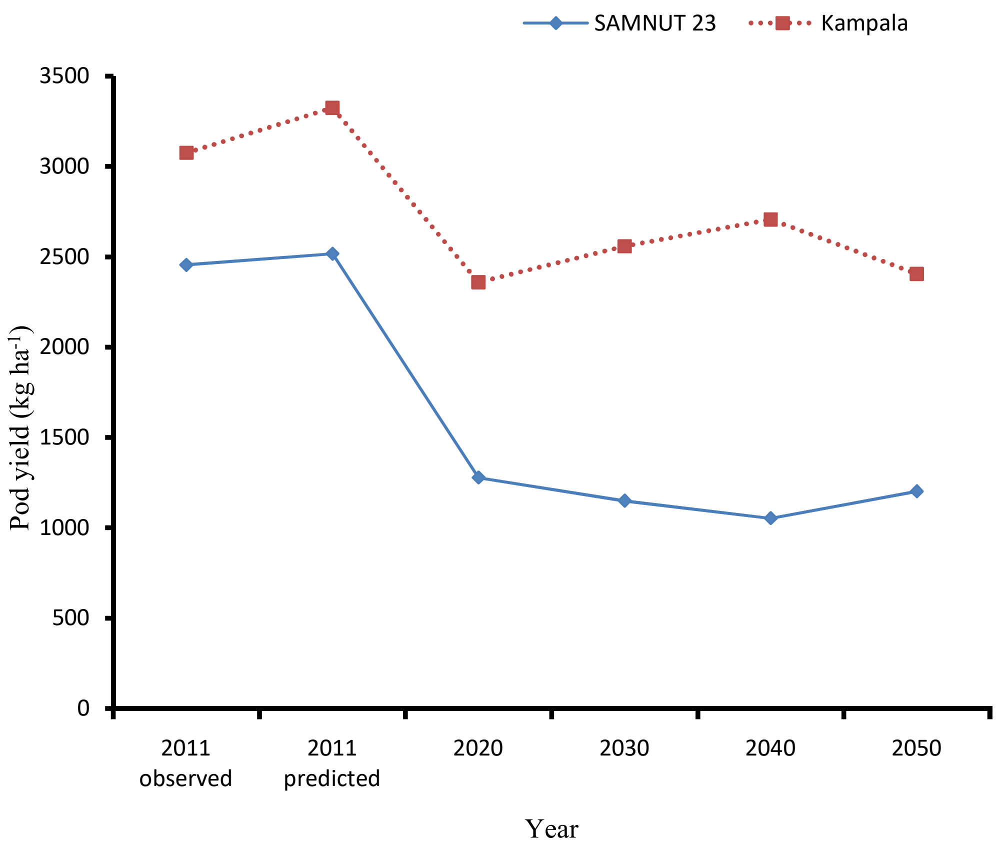


Fig. 4. 8: Predicted groundnut pod yield (with fertilizer) for Ogbomoso

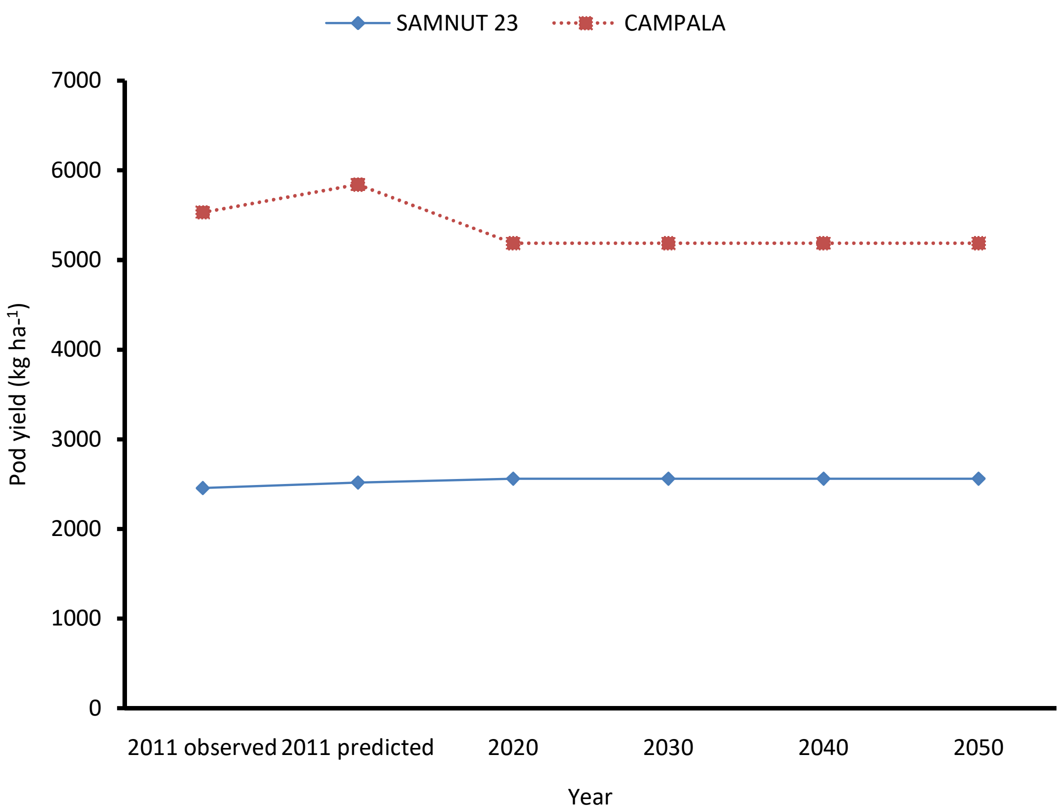


Fig. 4. 9: Predicted groundnut pod yield (with fertilizer) in Ibadan

CHAPTERFIVE

DISCUSSION

Given the current trends in climate change and its uncertain specific effects on the general crop yields formulating practical, affordable and acceptable response strategies for crop production is required especially on well consumed and popular crops like groundnut, with a study that evaluates the impacts of climate change on the crop under varying climatic conditions.

Groundnut production was evaluated for predicted climate change in Ibadan and Ogbomoso, Oyo state Nigeria. Production of some improved cultivars of groundnut new to Ibadan and Ogbomoso were evaluated with the CROPGRO-Peanut model in DSSAT v4.5. The model was also used to evaluate the use of different starter nitrogen rates and different sources of stater N for groundnut production in the two sites under varying sowing dates. The study also explores the reliability of the CROPGRO-Peanut model in simulating phenology, and the potential yield of the varieties under varying climatic conditions in the moist savanna of Nigeria. The CROPGRO-Peanut model in DSSAT v4.5 was calibrated, evaluated and validated for groundnut production with three field experiments conducted under the rainfed condition in Ibadan and Ogbomoso, a moist savanna of Nigeria. The planting dates used were based on the inception of rainfall in all the experiments.A set of weather data were generated for Ibadan and Ogbomoso for the 2010 sowing season to evaluate the reliability of the data simulated using the Marksim software by comparing the data with the observed. Weather projection for Ibadan and Ogbomoso (2020 – 2050) were then simulated and used to predict groundnut growth and pod yield over the next 30 years.

The rainfall pattern in Ogbomoso during the study shows a decline in the total rainfall from 2010 to 2012 showing the trend of a projected decline in total rainfall (IPCC, 2007). The rainy season span over seven months between April and October and should,therefore, be targeted for rainfed groundnut production which requires about 6 months from the establishment to harvest. Groundnut production should be avoided in extreme dry months (December to February) as this will affect the plant establishment with consequent effects on the pod yield and risk of exposing the crop to diseases like rosette (Idoko and Sabo, 2014). The rainfall pattern in Ibadan between 2010 -2012 was not specific, it fluctuated between the sowing seasons (IPCC, 2019) and the pattern was quite different from the long-term average recorded. The rainy season also varies from 2010 -2012. The variation indicated that proper planning putting into consideration the clear break in August is needed for groundnut production. Early maturing varieties (>100 days to maturity) like SAMNUT 23 is recommended for Ibadan.The total rainfall for Ogbomoso (1470.2 mm/year) and Ibadan (1355.2 mm/year) was higher than the long-term average (1995-2015). The amount and distribution of rainfall during the sowing seasons indicated that there was no moisture stress at the experimental site. The total rainfall of 1276.3 mm recorded for the growing period was adequate for groundnut production hence there was no water stress. The rainy season at Ogbomoso in 2010 started in May and ended in October with November to April was the dry season (six months). There was also a good rainfall spread from emergence to physiological maturity, which was between May and October. The rainfall amount peaked in September which was during the process of pod maturation. Moisture requirement of groundnut during the flowering, pegging, pod formation and seed filling stages as described by Boote and Ketring (1990) and ICRISAT (1992) are therefore met. The average monthly maximum temperature range for the growing season was optimum for groundnut production.The temperature during germination (ranged from 26.6 °C - 28.6 °C for maximum temperature and 23.0 °C - 24.0 °C for minimum temperature) was also adequate hence, a high rate of field establishment was achieved (Ketring, 1989 and Schilling and Gibbon, 2002).

The total rainfall in 2011 was lower than the 2010 and long-term average (1995-2015). The total rainfall (910.8 mm) distribution during the sowing season (between June and October) was more than the minimum recommended (500mm) by FAO (1990) and was well distributed hence there was a constant water supply for groundnut production during the sowing season. The distribution of water also ensured the was enough moisture to nutrient uptake and other crop physiological processes as suggested by Christensen *et al*, (2004). The average monthly maximum temperature range for the growing season was optimum for groundnut production. The temperature ranged from 26.2 °C - 27.8 °C for maximum temperature and 21.7 °C - 22.9 °C for minimum temperature. This was lower than the minimum and maximum temperature observed in 2010 but adequate for groundnut production (Ketring, 1989 and Schilling and Gibbon, 2002).

The total annual rainfall for the year 2012 in Ogbomoso was higher than the long-term and again well spreadduring the growing season spanning from May to October with rainfall volume of within the recommended range (FAO, 1990). The average monthly maximum temperature ranged from 26.0 °C to 27.4 °C while 21.2 °C to 22.6 °C was for the minimum temperature. The value of the long-term (1995-2015) total rainfall in Ibadan was lower than the total rainfall in 2012 with sowing season between May and October. The distribution was adequate for groundnut production hence there was a constant water supply. The average monthly maximum temperature range for the growing season was adequate for groundnut production. The temperature ranged from 27.1 °C - 30.2 °C for maximum temperature and 21.7 °C - 24.4 °C for minimum temperature. The temperature was within the recommended range(Kochhar, 1986 and FAO, 1990). The soil of Ibadan was also low in total N, available P and exchangeable K.

The soil of Ibadan and Ogbomoso sites were low in total N, available P and exchangeable K. The organic matter too was low especially on the topsoils, thus, the need to apply nutrient amendments to the soils (Singh, 1984, Singh 1994; Singh and Oswalt, 1995; Juangjum, 2003) for proper crop establishment and subsequently, the total crop yield quality and quantity.

The first experiment conducted in Ogbomoso during the 2010 growing season with three improved groundnut varieties; SAMNUT 10, SAMNUT 22, SAMNUT 23 and a local variety *Kampala* (as a check) planted at four sowing dates (SD) between April and May at 7days interval were used (SD1= 19/04/2010, SD2 = 26/04/2010, SD3 = 03/05/2010, SD4 = 10/04/2010). Data collected on days to emergence, days to flowering, and pod yield at harvest. management, soil characteristics and weather parameters as required by the CSM-CROPGRO-Peanut model were used as initial Genetic coefficients for the model calibration (Challinor. *et al*., 2003). Based on observations from experiment 1, SAMNUT 23 and *Kampala* were selected to test the effects of sowing date and starter nitrogen rates on the pod yield of groundnut for the second experiment at Ogbomoso which was conducted in 2011 with four levels of N: P: K 15:15:15 fertilizer; (i) 0 kg N ha^{-1} (ii) 5 kg N ha^{-1}, (iii) 10 kg N ha^{-1} and (iv) 20 kg N ha^{-1},as a starter nitrogen source. Data were collected on the number of days to emergence, the number of days to flowering, and pod yield at harvest, nitrogen management, soil characteristics and weather parameters as required by the CSM-CROPGRO-Peanut model. The first sowing date in 2011was in June and it was 4 weeks after the inception of rainfall and the second sowing date was 7 days later. The third experiment was in Ibadan and Ogbomoso in 2012 with different nitrogen sources (N: P: K: 15: 15: 15, Aleshinloye organomineral fertilizer and poultry manure) applied at the same rate (20 kg N ha^{-1}) and control. Data collected were used to validate the model and Ibadan data also used to evaluate the performance of the model in the zone. Sowing was done at once in May which was deep in the raining season for both Ogbomoso and Ibadan in 2012.

Variation in the sowing dates has a significant effect on the pod yield, the phenotypic stages and the interactions among the varieties and sowing date (Banik *et al*., 2009). The response of these varieties to different sowing date could be attributed to the interaction between environmental and genetic variations of each of the used varieties as each variety has its growth requirements. Simulated data for the earlier sowing dates were closer to the observed values than for the later sowing dates. This suggeststhat there is some adjustment be made on the files to fit in better (Mahato, 2014).However, the late sowing dates for all the varieties produced higher pod yield at harvest compared to the early planting and the lowest pod yield was obtained at the first sowing date. The soil moisture at sowing date one was low and could affect the crop established leading to lower yield. The average plant emergence for all the used varieties was 7 DAS with *Kampala* showing a significant difference at SD2 and SD3. Flowering in the varieties was on the average of 28 days after emergence which conforms with the reported 20 to 30 days after emergence by Abdel (1982). This also conforms to the 4 to 6 weeks after sowing (i. e. 28 to 42 DAS) reported by De Waele and Swanevelder (1983) and Putnam *et al*. (1991) (i.e. 21 to 35 days after emergence) considering the 7 days after emergence. The difference in performance observed was attributed to the sowing date and not the varietal difference. Statistical appraisal of the model shows that the phenological stages prediction of all varieties of groundnut used was better in the first two sowing dates (SD1 and SD2) than the later dates (SD3 and SD4). Meanwhile, the pod yield prediction was closer to observed at a later sowing date (SD3 and SD4). The cool temperature for the late sowing when the rainfall was better distributed (FAO, 1990) was an added advantage for root and vegetative growth, hence better pod yield. The Growing Degree Days (°Cd) and Photothermal Unit (°Cd) for Kampala were the least when compared with other varieties indicating the maturity group. SAMNUT 23 had a better pod yield during the later sowing dates (SD3 and SD4) than SAMNUT 10 and SAMNUT 22. Until the optimum temperature is reached for a particular phenological stage, it will not progress into the next stage (Yoldaş and Eşiyok, 2005).

The CROPGRO-Peanut model was then evaluated for starter N in 2011 since the soil had low total N and it will be necessary to add N before groundnut could form nodules to fix its Nitrogen (Putnam *et al*., 1991). At SD1, the average foliar emergence for SAMNUT 23 and Kampala varied. SAMNUT 23 with 20 kg N ha^{-1} emerged earlier at 6 days compared to 0 kg N ha^{-1} and 5 kg N ha^{-1} and 10 kg N ha^{-1} showing a significant difference in nitrogen application rates; foliar emergence for Kampala also varied and unlike for SAMNUT 23, the pattern was not specific, thus, the variation could not be attributed to the application of starter nitrogen but the starter Osmaniye (2005). The result also shows that the starter N requirement of SAMNUT 23 and Kampala are not the same.The application of 20kg N ha^{-1} produced the highest pod weight for SAMNUT 23 at SD1 and SD2 the but *Kampala* has the overall highest pod yield with an application of 5 kg N ha^{-1}. The simulated number of days to flowering with an application of starter nitrogen at SD1 was fair for SAMNUT 23 and the simulation poor for *Kampala*. At SD2, the simulation was poor for SAMNUT 23 and the simulation fair for *Kampala*. The simulated pod yield was fair for both SAMNUT 23 and *Kampala* except for *Kampala* at SD2. The difference in performance observed was, therefore, attributed to nitrogen rates and varietal requirements of the two varieties (Juangjun, 2003, and Lambin *et al*., 2003). Both SAMNUT 23 and *Kampala* produced a higher pod yield at the application of 20 kg N ha^{-1} at both SD1 and SD2. However, the pod yield at SD1 was lower than in SD2 with *Kampala* having the highest overall pod yield, indicating the varietal interaction with the soil fertility, the environmental factors and interactive effects of moisture and soil fertility on the pod yield at harvest. Despite the application of fertilizer, the pod yield at harvest was generally lower in 2011 than in 2010 when fertilizer was not added. This confirms that the pod yield at harvest is a function of many factors other than soil fertility and environmental factors (Idoko and Sabo, 2014). The reduced yield could also have resulted from nutrient lost through previous harvest or erosion (Griffith, 2006).

Since farmers use different types of N sources (Lambin *et al*., 2003), CROPGRO-Peanut model v4.5 was further evaluated with data generated by using different sources of N at 20 kg N ha^{-1}which was the optimum rate observed. The observed number of days to emergence across the three sources of nitrogen including control was the same for SAMNUT 23, it was the same for poultry waste manure (PWM) and

Aleshinloye organomineral (AOM) but a day more in control and NPK application to Kampala. The observed number of days to flowering was also the same for the three sources of nitrogen including control and was the same for SAMNUT 23 but less than a day for AOM, while control and NPK were the same numbers of days for Kampala but a day more PWM and AOM. The difference in the number of days was less than a day, thus nitrogen source could not be attributed to the difference (Osmaniye, 2005). The highest pod yield for this experiment at Ibadan was recorded in PWM application to SAMNUT 23 and the least in NPK application to Kampala. The CROPGRO-Peanut model simulated the number of days to emergence excellently for SAMNUT 23 regardless of the sources of nitrogen while the simulation was good for Kampala also regardless of the sources of nitrogen. For both SAMNUT 23 and Kampala, the simulated number of days to flowering was between 10 and 12 days more (over-predicted) than the number of days observed on the field. Simulated pod yield was lower (under-predicted) for both SAMNUT 23 and *Kampala*. Pod yield was generally low especially for Kampala and was underpredicted for Ibadan. SAMNUT 23 showed better pod yield than Kampala but the application of fertilizer did not improve the pod yields of both varieties. The pod yield at Ibadan was lower than what was obtained in Ogbomoso though were planted simultaneously. Pod yield difference may be due to lower solar radiation at Ibadan and higher thermal time makes the groundnut in Ogbomoso to develop faster than that in Ibadan (Yoldaş and Eşiyok, 2005).

The MarkSim web app was able to predict weather data that are close to the observed data (R^2<1) in both Ibadan and Ogbomoso in 2010, hence they were used to project weather variables for 2020 – 2050. The CROPGRO-Peanut model was used to predict groundnut pod yield over the next thirty years (2020 – 2050) using the RCP 4.5 climate change scenario (Collins*et al*., 2013). Simulated groundnut pod yield (without fertilizer application), when compared with the 2010 observed pod yield, implies a reduction in pod yield of the four varieties between 2020 and 2050 for the two locations. It is expected that of the four varieties, the pod yield SAMNUT 10 and *Kampala* will be more in future (2020 – 2050) than SAMNUT 22 and SAMNUT 23. The highest pod yield (SAMNUT 10 and *Kampala*) and lowest pod yield (SAMNUT23) were predicted for 2040. Also, the highest solar radiation (20.4 MJ/m^2/day) and the least total rainfall volume was predicted for 2040. The differences in the predicted pod yield of the four varieties indicated that SAMNUT 10 and *Kampala* could tolerate low available water. Generally, simulated groundnut pod yield with fertilizer application, has a higher pod yield for 2020 to 2050 when compared with predicted future pod yield for the same period without fertilizer application. Pod yield prediction was higher for *Kampala* than SAMNUT 23. Between 2020 to 2050, the predicted pod yield (with fertilizer application), however, was lower compared with the observed 2011 pod yield. The reduction in the predicted pod yield is an indication the of the predicted effect of climate change on agriculture (IPCC, 2007; Rosenzweig and Hillel, 2008; Beck, 2013; IPCC 2019). It was projected that in areas prone to RCP 4.5 climate change scenarios like Ibadan and Ogbomoso where temperatures are already close to the physiological maximum for crops, warming will impact crop yields more immediately (IPCC, 2019). The impact is a threat to food security, and special measures to combat this on agriculture is suggested (Beck, 2013).

Conclusively, with the predicted fluctuation in weather, to give a standard date for sowing will be difficult. Thus, planting should be once there is consistent and adequate moisture available for good germination and better pod yield at harvest. Proper timing is very essential because the water and heat requirement of groundnut varies for each phenological stage. To meet up with the future groundnut demand, it is recommended that varieties that could withstand high temperature and are drought tolerant like SAMNUT 10 and *Kampala*be used in future groundnut production in the agro-ecological zone.

DSSAT CROPGRO-Peanut crop simulation model could reliably predict the phenology, starter nitrogen requirements and potential pod yield of SAMNUT 10, SAMNUT 22, SAMNUT 23 and *Kampala* groundnut varieties in the moist savanna of Oyo state.

CHAPTER SIX

SUMMARY AND CONCLUSION

To develop a model for groundnut that can be used in thehumid tropic of Nigeria for makinga reasonably precise pod yield estimate, the CSM-CROPGRO-Peanut v4.5 module in DSSAT was used. The model was calibrated and evaluatedduring 2010, 2011 and 2012 growing seasons under rainfed conditionsfor starter nitrogen management practices and climatic conditions to predict growth, andpod yield of groundnut in Ibadan and Ogbomoso, Nigeria.

A field trial was setup to obtain data for phenotypic coefficients of the used groundnut varieties (SAMNUT 10, SAMNUT 22, SAMNUT 23 and *Kampala*); daily weather data and soil profiles to calibrate the CSM-CROPGRO-Peanut model for the locations in the 2010 experiment. The calibrated model was evaluated and validated with data obtained in 2011 and 2012. Daily weather data were also collected in 2011 and 2012 and were used as specified in the CSM-CROPGRO-Peanutv4.5 module in DSSAT. No modifications were made to the soil files in 2011 and 2012.

The study was split into three experiments and conducted in two phases:

1. Modeling of groundnut growth and pod yieldusing CROPGRO-Peanut model in the DSSATv4.5.
2. Pod yield Prediction for groundnut in Ibadan and Ogbomooso derived guniea savanna of Nigeria

Data obtained from the 2011 and 2012 experiments were used to evaluate the model. The genotypic coefficients used in the model were adjusted and fitted manually to match data on phenology. The model was calibrated following the sequence of steps described by Hunt and Boote (1998). For pod yield prediction, weather data were generated using the MarkSim web application using the B2 scenario

From the study, the following conclusions and recommendations were arrived at:

1. Increase in temperature was projected and rainfall varies largely with projected years while solar radiation increases over the predicted years. In the next thirty (30) years, themaximum temperature will increase with about 4.6°C in Ogbomoso and 3.7°C in Ibadan while minimum temperature will increase with

about 0.9°C in Ogbomoso and 0.8°C in Ibadan. Rainfall volume will fluctuate over the years with about 218.9 mm in Ogbomoso and 535.4 mm in Ibadan

2. Proper timing is essential because the water and heat requirement of groundnut varies for each phenological stage. However, with the fluctuation inweather, it is difficult to give a standard date for sowing, but farmers shouldplant as soon there is consistent and adequate moisture available for good germination as this will later affect the final pod yield.
3. A simulation model that could be used in policy and mitigation methods planning groundnut pod yield with DSSAT in Ibadan and Ogbomoso was developed.
4. Modeling groundnut production towards site-specific fertilizer recommendation in Nigeria is appropriate.
5. Locally available fertilizers need to be incorporated into the model and the performance in simulation for a long-termbasis evaluated.
6. This study recommends 20 kg N ha^{-1} as the most economically and strategically efficient N rate that gives maximum pod yield in the Guinea savanna agro-ecological zone of Nigeria.
7. The pod yield prediction shows that the pod yield performance of the varieties improved with the application of starter Nwith enabling environmental factors.
8. The performance of some high pod yielding groundnut varieties would drop while those that are not giving good pod yields now willperform better in the future.
9. Groundnut production in the moist guinea savanna of Nigeria requires good Nmanagement to be sustained.
10. From this experiment, *Kampala* and SAMNUT 10 are promising varieties over the next 30 years.
11. It is therefore recommended that varieties that could withstand high temperature and are drought tolerant be used in future groundnut production in the agro-ecological zone to meet up with the future groundnut demand.

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APPENDICES

Appendix 1: Fertilizer Calculations

1) 0 kg ha-1 = No fertilizer application

2) 5 kg ha-1 =5 kg N, 5 kg P_2O_5, 5 kg K_2O

from N: P: K 15: 15:15, 100kg of NPK fertilizer will give 15 kg N, 15 kg P_2O_5 and 15 kg K_2O

$$\text{That is}\,;5\text{ x }\frac{100\text{ kg NPK }15:15:15}{15}\approx 5\text{ kg ha}^{-1}$$
$$=33.33\text{ kg NPK }15:15:15\equiv 5\text{ kg N}, 5\text{ kg P}_2\text{O}_5, 5\text{ kg K}_2\text{O/ha}$$
$$\text{i.e.}\,1\text{ ha}=10{,}000\text{ m}^2\text{ will require }33.33\text{ kg NPK }15:15:15$$
$$\text{since plot size will be }2\text{ x }2.5\text{ m}^2=5\text{ m}^2$$
$$\text{then }5\text{ m}^2=\frac{33.33}{10{,}000}\text{ x }5$$
$$=0.0167\text{ kg NPK }15:15:15\,/\,\text{plot}\cong 17\text{g NPK }15:15:15\,/\text{plot}$$

3) 10 kg ha-1 =10 kg N, 10 kg P_2O_5, 10 kg K_2O

from N: P: K 15: 15:15, 100kg of NPK fertilizer will give 15 kg N, 15 kg P_2O_5 and 15 kg K_2O

$$\text{That is}\,;10\text{ x }\frac{100\text{ kg NPK }15:15:15}{15}\approx 10\text{ kg ha}^{-1}$$
$$=66.67\text{ kg NPK }15:15:15\equiv 5\text{ kg N}, 5\text{ kg P}_2\text{O}_5, 5\text{ kg K}_2\text{O/ha}$$
$$\text{i.e.}\,1\text{ ha}=10{,}000\text{ m}^2\text{ will require }66.67\text{ kg NPK }15:15:15$$
$$\text{since plot size will be }2\text{ x }2.5\text{ m}^2=5\text{ m}^2$$
$$\text{then }5\text{ m}^2=\frac{66.67}{10{,}000}\text{ x }5$$
$$=0.033\text{ kg NPK }15:15:15\,/\,\text{plot}\cong 33\text{g NPK }15:15:15\,/\text{plot}$$

4) 20 kg ha-1 =20 kg N, 20 kg P_2O_5, 20 kg K_2O

from N: P: K 15: 15:15, 100kg of NPK fertilizer will give 15 kg N, 15 kg P_2O_5 and 15 kg K_2O.

$$\text{That is} ;\ 20 \text{ x } \frac{100 \text{ kg NPK } 15:15:15}{15} \approx 20 \text{ kg ha}^{-1}$$

$$= 133.33 \text{ kg NPK } 15:15:15 \equiv 5 \text{ kg N}, 5 \text{ kg } P_2O_5, 5 \text{ kg } K_2O/\text{ha}$$

$$\text{i. e. } 1 \text{ ha} = 10{,}000 \text{ m}^2 \text{ will require } 133.33 \text{ kg NPK } 15:15:15$$

$$\text{since plot size will be } 2 \text{ x } 2.5 \text{ m}^2 = 5 \text{ m}^2$$

$$\text{then } 5 \text{ m}^2 = \frac{133.33}{10{,}000} \text{ x } 5$$

$$= 0.067 \text{ kg NPK } 15:15:15 \text{ / plot} \cong 67\text{g NPK } 15:15:15 \text{ /plot}$$

Appendix 2: Weather data for Ogbomoso between 2010 and 2012

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
NGGB	8.070	4.140	274	-99	-99	-99	10

JDAY	Solar Radiation, MJ/day	Max Temp °C	Min Temp °C	RAIN mm
10001	21.2	29.6	20.8	0.0
10002	21.3	30.8	21.3	0.0
10003	22.1	29.5	18.0	0.0
10004	21.9	30.6	19.6	0.0
10005	21.5	30.0	21.2	0.0
10006	21.3	27.6	21.1	0.0
10007	21.2	27.4	22.7	0.0
10008	21.3	28.9	22.7	0.1
10009	21.5	23.6	22.2	0.0
10010	21.2	27.4	23.7	0.0
10011	21.6	28.5	22.6	0.0
10012	22.4	31.0	20.0	0.0
10013	21.3	29.5	21.1	0.0
10014	21.3	28.6	23.2	0.0
10015	18.4	27.1	22.9	0.0
10016	21.4	28.3	22.6	0.0
10017	21.2	28.6	23.4	0.0
10018	21.6	29.4	22.4	0.0
10019	22.4	28.8	20.1	0.0
10020	22.9	29.9	17.9	0.0
10021	22.6	30.2	18.9	0.0
10022	22.5	30.5	19.3	0.0
10023	22.8	31.5	18.5	0.0
10024	22.5	31.7	20.6	0.0
10025	22.3	29.2	22.4	0.0
10026	22.1	27.8	22.5	1.6
10027	22.2	28.3	23.3	0.0
10028	22.0	28.0	23.4	0.0
10029	22.4	27.9	23.1	0.0
10030	22.7	31.1	20.8	0.0
10031	23.3	31.8	19.9	0.0
10032	22.9	30.2	21.9	0.0
10033	21.2	30.7	21.6	0.0
10034	23.0	28.4	23.3	0.0
10035	23.0	28.2	23.9	0.0
10036	19.1	29.8	24.0	0.0
10037	24.2	29.3	18.6	0.0
10038	24.8	29.4	15.7	0.0
10039	23.9	30.9	18.6	0.0
10040	22.6	28.4	22.6	0.0

10041	21.7	29.9	23.2	0.0
10042	23.1	29.6	24.1	0.0
10043	23.0	29.2	23.8	3.3
10044	22.5	29.3	24.0	10.1
10045	23.4	32.1	22.9	8.7
10046	23.2	28.1	23.4	0.0
10047	23.7	29.5	23.8	0.0
10048	23.4	29.0	23.6	0.0
10049	21.2	28.5	24.7	0.0
10050	22.9	29.8	24.5	0.0
10051	23.5	30.3	24.8	0.0
10052	24.1	30.1	24.4	2.3
10053	24.0	30.1	24.2	0.1
10054	22.9	30.4	24.3	0.0
10055	24.3	29.5	25.0	0.0
10056	23.9	29.5	24.8	0.0
10057	24.3	29.9	24.8	0.0
10058	24.2	29.6	24.5	0.0
10059	24.3	29.0	24.4	0.0
10060	24.3	30.1	24.6	0.0
10061	24.7	29.3	23.8	0.0
10062	24.9	29.5	24.4	0.0
10063	24.2	29.9	24.9	0.3
10064	24.3	29.6	24.9	0.0
10065	21.2	30.2	24.7	0.0
10066	23.9	29.6	24.5	0.0
10067	23.3	29.1	24.4	6.8
10068	18.2	28.6	24.8	10.0
10069	24.3	28.3	24.3	6.1
10070	21.6	28.0	24.3	0.0
10071	19.8	29.9	24.2	0.7
10072	23.7	28.6	25.0	2.0
10073	21.7	28.5	24.5	0.0
10074	24.6	27.6	24.5	33.4
10075	19.5	27.8	23.7	0.5
10076	16.8	28.5	23.5	0.0
10077	22.8	28.0	23.1	0.2
10078	23.1	28.4	23.3	0.0
10079	17.6	27.6	23.5	0.0
10080	19.2	28.9	23.5	0.0
10081	21.2	29.9	23.2	0.0
10082	25.2	32.1	23.4	0.0
10083	23.2	28.5	23.6	0.0
10084	22.9	29.4	22.6	0.0
10085	24.3	31.7	22.7	0.0
10086	25.2	31.1	24.2	0.0

10087	25.3	30.1	24.4	0.0
10088	23.7	29.9	23.7	0.0
10089	25.1	29.8	24.4	0.0
10090	23.8	29.5	24.2	0.0
10091	25.2	29.7	24.4	0.4
10092	23.3	29.1	24.7	5.1
10093	23.1	29.4	24.3	0.0
10094	23.2	28.3	24.8	1.7
10095	22.6	29.1	24.8	0.0
10096	25.0	29.2	24.2	1.8
10097	21.2	28.6	24.3	1.6
10098	25.5	29.5	24.2	0.0
10099	24.5	29.7	24.3	0.0
10100	18.2	30.0	24.5	0.1
10101	24.9	29.2	24.4	0.0
10102	23.4	29.8	24.1	0.0
10103	22.8	29.4	24.5	3.2
10104	18.5	29.2	24.7	0.0
10105	21.9	29.5	24.7	3.7
10106	21.7	28.8	24.6	17.3
10107	21.1	31.8	23.9	6.7
10108	25.9	31.0	23.7	0.0
10109	24.1	30.8	23.5	0.0
10110	22.7	28.7	24.9	2.4
10111	21.9	29.5	24.7	2.5
10112	21.6	28.0	24.4	0.0
10113	21.2	24.1	23.6	0.0
10114	12.9	28.2	24.1	6.6
10115	25.2	29.8	23.6	0.0
10116	24.6	30.3	24.3	19.4
10117	19.9	28.8	24.3	0.2
10118	22.2	30.3	24.6	0.2
10119	16.1	30.0	23.9	1.4
10120	19.5	28.2	24.3	0.7
10121	22.0	28.4	24.1	0.2
10122	12.5	27.2	24.3	4.0
10123	22.0	29.1	23.3	16.6
10124	24.3	27.9	23.9	7.1
10125	18.8	27.7	24.2	16.2
10126	22.5	27.7	24.3	20.3
10127	15.7	27.9	24.3	6.3
10128	22.8	29.8	23.8	8.5
10129	21.2	28.9	24.4	1.2
10130	23.2	29.2	24.4	0.0
10131	23.5	30.8	23.6	0.0
10132	22.2	28.9	24.4	0.2

10133	21.5	28.5	24.8	0.7
10134	16.5	28.9	24.2	0.0
10135	22.4	29.8	24.1	0.9
10136	21.2	28.7	24.6	2.5
10137	22.4	29.1	24.6	12.3
10138	21.9	28.5	23.5	0.0
10139	19.5	28.7	23.8	0.5
10140	11.6	28.3	23.5	0.7
10141	14.9	26.2	22.9	0.0
10142	21.7	28.4	22.6	0.0
10143	21.3	29.6	24.1	10.4
10144	22.7	28.9	24.4	12.0
10145	21.2	28.5	24.9	1.3
10146	15.4	28.4	24.8	20.5
10147	15.2	29.4	23.5	0.3
10148	21.1	29.4	23.2	0.0
10149	17.7	28.9	24.1	5.0
10150	21.2	28.4	23.3	1.8
10151	14.5	26.7	23.5	1.4
10152	21.4	26.1	22.8	0.1
10153	19.6	25.3	23.1	18.5
10154	22.2	25.6	23.0	4.5
10155	21.2	26.0	22.9	0.0
10156	18.7	26.3	22.6	0.5
10157	14.7	26.2	22.9	12.8
10158	23.4	27.2	23.0	0.0
10159	22.6	28.6	23.4	0.0
10160	19.5	27.6	23.6	29.1
10161	21.2	27.8	23.2	18.0
10162	21.8	23.9	23.3	9.7
10163	22.0	27.9	24.0	0.9
10164	21.4	27.5	23.9	0.3
10165	21.2	26.9	23.8	14.5
10166	21.6	28.1	23.5	0.0
10167	21.4	27.1	23.4	0.0
10168	17.3	26.1	22.4	0.0
10169	21.2	27.6	22.3	2.6
10170	22.5	26.3	23.1	24.5
10171	9.2	26.6	22.9	2.6
10172	22.6	26.4	22.6	14.8
10173	21.2	26.8	23.0	3.0
10174	16.2	27.1	23.4	2.5
10175	19.5	25.9	23.0	0.0
10176	21.2	25.2	22.6	3.9
10177	21.2	24.8	22.1	0.0
10178	12.2	25.9	21.7	0.0

10179	21.2	27.1	22.1	0.0
10180	19.6	27.0	22.5	0.0
10181	21.2	27.6	23.0	16.4
10182	9.4	25.6	23.0	24.8
10183	16.2	26.2	22.0	3.2
10184	17.2	26.7	22.6	0.0
10185	19.0	26.8	22.7	7.8
10186	19.1	26.3	23.0	2.4
10187	18.5	27.1	22.8	4.8
10188	18.2	25.6	22.6	22.1
10189	18.6	27.1	22.8	3.4
10190	18.3	26.2	22.4	16.5
10191	12.5	25.1	22.8	27.6
10192	16.6	26.0	22.1	0.3
10193	21.2	27.4	21.8	11.3
10194	18.0	25.3	22.3	7.3
10195	12.0	25.9	21.8	5.9
10196	121.2	24.2	21.8	1.1
10197	18.5	25.7	21.2	6.5
10198	17.8	25.1	21.0	9.5
10199	19.2	27.6	21.9	2.1
10200	14.2	25.8	21.3	6.3
10201	18.2	26.0	21.9	25.6
10202	8.0	26.8	21.1	0.0
10203	19.9	27.6	20.9	0.4
10204	11.8	25.2	21.6	20.6
10205	12.1	26.4	21.0	1.0
10206	18.5	27.7	21.1	0.1
10207	9.2	27.0	22.0	3.9
10208	121.2	24.9	21.9	1.8
10209	21.2	25.9	21.7	1.7
10210	18.3	26.5	22.0	0.0
10211	11.0	25.3	21.9	0.0
10212	16.5	26.5	21.4	0.0
10213	21.2	27.0	21.1	0.9
10214	18.4	25.7	21.0	2.4
10215	13.4	27.1	21.6	0.0
10216	15.8	26.3	21.6	0.2
10217	17.8	27.6	22.0	1.2
10218	12.1	24.6	22.5	14.8
10219	15.4	24.4	22.3	4.1
10220	16.4	25.9	22.4	2.4
10221	9.2	26.3	22.0	16.0
10222	18.4	26.8	22.6	8.8
10223	15.0	27.2	22.2	10.5
10224	4.5	25.0	22.1	29.5

10225	21.2	24.7	21.8	1.6
10226	15.4	26.5	21.6	2.6
10227	17.9	27.4	22.2	0.0
10228	18.5	27.4	22.3	27.7
10229	19.6	25.2	23.0	15.0
10230	17.6	24.4	22.1	0.0
10231	17.5	26.7	22.3	6.5
10232	11.5	26.5	22.3	35.3
10233	17.0	26.1	22.6	10.1
10234	11.0	26.9	22.2	0.0
10235	12.2	27.0	22.2	8.5
10236	16.3	26.1	22.9	4.8
10237	19.4	26.3	22.9	0.0
10238	21.2	27.0	22.6	0.1
10239	19.2	26.4	22.5	6.3
10240	14.7	26.4	22.0	15.2
10241	21.2	26.9	22.4	0.9
10242	15.4	26.5	21.9	5.7
10243	14.5	26.5	21.9	6.4
10244	21.9	27.6	21.6	0.5
10245	15.3	26.5	21.7	3.4
10246	15.0	26.4	22.1	9.0
10247	16.8	26.5	22.6	18.9
10248	18.2	26.1	22.7	25.9
10249	16.5	26.0	21.8	0.0
10250	9.9	25.4	22.0	7.5
10251	18.9	27.6	22.2	0.0
10252	17.0	27.1	22.3	6.6
10253	15.5	25.2	22.2	3.1
10254	11.4	26.2	22.1	13.2
10255	21.4	27.4	22.4	1.0
10256	11.9	26.0	22.7	3.9
10257	21.2	24.9	22.3	0.5
10258	17.3	26.5	21.6	1.7
10259	15.2	27.4	22.0	4.1
10260	6.3	26.4	22.8	18.3
10261	19.7	27.0	22.8	2.5
10262	21.2	27.6	22.7	4.9
10263	21.2	28.3	22.6	9.4
10264	18.6	26.8	22.4	9.2
10265	19.6	27.9	21.9	11.6
10266	19.0	27.4	22.8	24.6
10267	21.2	27.4	21.4	16.4
10268	21.9	26.8	21.9	4.8
10269	19.0	27.6	22.7	8.5
10270	23.1	27.1	23.4	21.5

10271	17.1	26.3	22.6	13.0
10272	22.9	28.4	22.5	5.1
10273	21.2	28.3	22.2	21.4
10274	21.9	27.6	23.5	30.8
10275	22.0	27.0	23.0	10.6
10276	21.4	28.7	22.9	3.5
10277	9.0	26.6	23.0	9.3
10278	21.4	25.1	22.7	8.2
10279	18.0	26.6	22.2	0.0
10280	21.9	26.2	22.7	3.0
10281	21.2	27.9	22.7	13.3
10282	12.3	28.1	22.9	11.2
10283	8.0	27.6	23.2	1.1
10284	19.2	28.1	22.1	7.8
10285	18.6	27.6	22.6	5.1
10286	19.7	28.2	22.3	8.4
10287	19.1	26.7	23.0	3.7
10288	21.8	28.7	22.9	4.5
10289	21.2	28.6	23.2	0.0
10290	21.2	28.4	23.2	2.2
10291	21.1	27.6	22.9	9.0
10292	19.8	26.8	22.7	13.6
10293	22.9	27.8	22.6	18.1
10294	21.2	27.2	22.2	42.4
10295	18.5	28.1	21.4	0.8
10296	21.2	28.5	22.3	10.7
10297	11.5	25.9	22.2	14.1
10298	17.3	27.2	21.9	1.0
10299	17.1	28.2	21.8	0.9
10300	21.2	29.1	22.8	1.2
10301	19.4	27.8	22.9	9.8
10302	18.2	28.4	22.7	2.3
10303	21.1	28.5	22.7	2.7
10304	17.8	27.5	22.8	20.9
10305	21.2	29.1	22.7	7.6
10306	19.3	28.7	22.6	4.5
10307	22.5	31.0	21.1	0.5
10308	21.7	28.1	22.1	0.2
10309	21.2	27.9	23.1	1.6
10310	18.0	28.0	22.6	1.9
10311	17.8	26.4	22.7	0.0
10312	19.3	28.1	22.5	0.0
10313	22.4	28.9	21.7	0.2
10314	21.3	28.4	23.7	0.8
10315	21.4	28.4	23.2	9.5
10316	21.2	28.4	22.7	0.0

10317	21.8	27.6	24.0	0.0
10318	21.5	28.3	23.3	0.1
10319	21.7	28.2	22.7	0.0
10320	21.7	27.4	22.9	0.0
10321	21.2	27.0	23.0	0.0
10322	21.5	26.2	22.9	0.0
10323	21.1	27.3	22.6	0.1
10324	21.6	27.9	22.8	3.0
10325	21.2	27.4	22.7	12.0
10326	21.6	26.8	23.1	0.3
10327	21.5	28.0	22.6	0.0
10328	21.5	28.2	22.6	0.0
10329	21.5	28.3	22.6	0.0
10330	21.0	28.3	22.6	0.0
10331	21.9	27.4	23.4	0.0
10332	21.2	27.6	23.0	0.0
10333	21.3	28.0	22.5	0.0
10334	21.4	28.4	23.2	0.0
10335	21.2	28.6	23.8	0.0
10336	21.2	28.8	22.5	0.0
10337	21.2	27.7	23.2	0.0
10338	21.1	28.8	22.8	0.0
10339	21.8	29.1	23.0	0.0
10340	21.2	28.1	23.1	17.5
10341	19.4	27.8	23.2	0.0
10342	21.2	28.0	22.3	0.0
10343	21.0	29.4	21.9	0.0
10344	21.7	29.4	20.1	0.0
10345	21.7	29.5	19.6	0.0
10346	21.9	28.4	17.0	0.0
10347	21.4	29.8	19.0	0.0
10348	21.2	30.6	21.3	0.0
10349	21.2	31.3	21.1	0.0
10350	21.9	28.9	21.9	0.0
10351	21.2	30.6	22.4	0.0
10352	21.1	29.1	22.2	0.0
10353	21.2	29.0	23.4	0.0
10354	21.2	29.8	21.3	0.0
10355	21.2	30.5	20.0	0.0
10356	21.2	27.9	22.2	0.0
10357	19.1	28.9	23.1	0.9
10358	21.2	28.5	21.8	0.0
10359	21.3	28.9	22.1	0.0
10360	21.2	28.8	22.2	0.2
10361	21.2	27.2	21.8	0.0
10362	21.2	27.8	22.2	0.2

10363	19.9	28.2	22.2	4.8
10364	21.2	28.4	19.5	0.5
10365	21.0	29.0	18.5	0.0
11001	21.3	29.7	17.9	0.0
11002	17.6	29.2	20.2	0.3
11003	21.0	29.9	20.9	0.0
11004	21.2	30.4	20.9	0.0
11005	21.7	29.1	21.3	0.0
11006	19.0	27.9	21.0	0.0
11007	21.2	28.1	20.1	0.0
11008	21.6	29.1	17.0	0.0
11009	21.7	29.2	17.9	0.0
11010	21.7	29.4	18.5	0.0
11011	22.0	30.6	18.7	0.0
11012	22.1	31.1	17.3	0.0
11013	21.7	30.8	19.9	0.0
11014	21.9	29.9	18.4	0.0
11015	22.0	28.0	17.5	0.0
11016	22.5	28.3	14.6	0.0
11017	22.6	29.6	14.9	0.0
11018	22.6	29.9	16.9	0.0
11019	22.4	30.8	19.0	0.0
11020	21.2	30.9	20.5	0.0
11021	22.1	31.4	21.4	0.0
11022	21.9	32.2	19.8	0.0
11023	22.3	31.6	20.2	0.0
11024	21.6	28.9	20.7	0.0
11025	22.0	28.6	22.2	0.0
11026	22.2	29.0	22.0	0.0
11027	22.7	31.0	20.5	0.0
11028	21.9	32.3	21.7	0.0
11029	22.3	29.5	22.4	0.0
11030	22.6	29.2	23.5	0.0
11031	21.4	28.4	22.8	0.0
11032	22.0	29.6	23.6	3.9
11033	22.2	28.9	23.5	4.0
11034	19.2	29.0	23.3	3.4
11035	19.3	25.5	22.5	4.8
11036	21.2	30.5	18.9	0.0
11037	23.3	31.4	19.8	0.0
11038	22.4	28.3	22.5	0.0
11039	23.1	30.1	22.0	0.0
11040	23.0	28.4	22.8	0.0
11041	22.0	27.1	23.2	9.7
11042	22.2	30.3	22.0	1.6
11043	22.9	29.7	23.2	2.5

11044	22.2	28.5	23.1	4.2
11045	23.2	27.6	23.1	4.3
11046	22.9	29.4	22.9	0.0
11047	24.0	31.1	21.5	0.0
11048	24.0	29.9	24.0	0.0
11049	23.4	28.6	23.5	13.2
11050	22.1	29.6	23.1	1.9
11051	24.2	29.8	22.9	0.0
11052	21.2	29.6	23.1	7.1
11053	22.8	28.6	23.4	0.0
11054	19.2	27.8	23.1	0.1
11055	22.8	28.9	22.9	0.3
11056	22.9	29.2	22.4	0.4
11057	21.5	28.9	22.7	5.2
11058	22.9	29.1	23.0	3.4
11059	23.9	29.5	22.6	0.0
11060	23.7	28.2	23.3	0.0
11061	23.3	30.5	23.4	0.0
11062	21.0	29.2	23.0	3.8
11063	24.6	28.9	23.0	0.8
11064	23.7	29.1	22.9	0.0
11065	22.9	29.8	23.7	0.0
11066	23.1	28.6	23.8	0.0
11067	23.3	29.3	24.0	3.3
11068	21.2	29.6	23.9	0.0
11069	23.3	29.4	23.9	0.0
11070	23.8	28.2	23.5	2.5
11071	21.5	29.8	23.4	0.0
11072	24.8	29.5	23.6	0.2
11073	21.7	28.8	24.0	0.0
11074	23.0	30.5	23.5	0.0
11075	22.2	29.6	23.8	0.4
11076	24.1	28.5	24.0	0.0
11077	21.0	29.4	23.9	0.0
11078	25.1	28.4	23.6	0.1
11079	25.2	29.1	23.1	0.5
11080	24.2	27.6	23.4	1.2
11081	22.6	28.8	23.7	7.4
11082	21.2	27.5	23.7	4.3
11083	22.8	28.4	22.9	0.0
11084	21.2	27.5	23.5	0.0
11085	25.1	30.2	22.7	4.3
11086	25.2	28.4	23.4	0.4
11087	25.0	29.1	23.9	0.0
11088	25.4	28.2	23.5	0.0
11089	24.5	27.8	23.9	0.0

11090	25.1	27.9	23.9	0.0
11091	24.9	29.0	23.6	0.0
11092	23.4	28.2	23.9	4.2
11093	24.3	28.9	24.0	6.6
11094	11.3	27.9	23.4	0.0
11095	23.0	28.9	22.8	0.0
11096	24.8	28.7	23.0	0.0
11097	25.3	28.9	22.9	0.0
11098	23.7	29.0	23.5	0.0
11099	19.9	29.9	24.2	15.4
11100	21.2	30.8	23.1	0.0
11101	22.9	28.5	23.0	0.0
11102	23.5	27.6	23.6	0.0
11103	21.7	27.6	23.8	22.6
11104	22.0	29.5	23.3	0.0
11105	22.9	29.2	23.7	0.0
11106	22.7	29.3	23.5	0.0
11107	21.0	30.0	23.6	0.0
11108	22.9	28.9	23.6	0.0
11109	24.1	30.7	23.4	0.0
11110	24.0	28.4	24.0	0.0
11111	21.9	28.1	23.9	0.0
11112	22.2	28.7	24.2	1.5
11113	21.2	28.8	24.0	1.1
11114	19.7	26.8	23.6	3.0
11115	7.6	27.4	23.4	0.2
11116	21.2	28.9	22.1	4.7
11117	23.9	28.6	23.6	0.0
11118	16.1	27.7	23.8	0.0
11119	22.3	27.8	23.1	0.0
11120	14.1	28.7	22.9	0.0
11121	24.4	27.9	23.3	0.0
11122	21.2	27.7	24.0	2.9
11123	19.3	28.3	23.9	9.2
11124	24.1	29.8	23.4	9.3
11125	23.4	29.1	23.0	0.0
11126	22.5	29.9	23.9	0.9
11127	22.8	28.6	24.4	0.0
11128	21.8	28.5	23.9	12.7
11129	19.3	28.3	23.4	6.5
11130	22.3	29.9	23.2	0.0
11131	14.7	30.6	23.4	0.0
11132	21.2	27.9	23.6	0.2
11133	21.8	28.3	23.8	8.7
11134	14.8	28.5	24.1	14.7
11135	22.2	29.1	23.7	0.0

11136	23.1	29.1	23.7	0.0
11137	21.2	29.0	24.3	20.8
11138	19.3	28.3	23.9	7.9
11139	21.0	29.6	24.1	0.0
11140	21.3	28.5	23.8	1.2
11141	22.6	28.1	23.7	0.7
11142	21.2	28.5	23.5	9.8
11143	24.3	27.5	22.6	2.9
11144	22.1	28.2	23.2	0.0
11145	19.4	27.9	23.1	2.8
11146	21.8	26.9	23.5	0.0
11147	15.0	26.7	22.9	0.1
11148	21.2	26.4	23.3	5.1
11149	21.3	27.8	22.7	8.4
11150	21.2	28.2	23.2	16.3
11151	21.5	28.1	22.8	1.4
11152	16.5	28.5	23.9	0.0
11153	21.5	29.4	23.3	0.0
11154	21.2	27.7	23.9	6.3
11155	17.6	26.7	24.0	31.5
11156	22.0	27.9	23.4	0.0
11157	23.9	28.3	22.9	0.0
11158	19.9	27.7	23.6	20.4
11159	11.6	27.9	23.3	17.4
11160	15.7	26.1	22.8	9.7
11161	21.1	27.8	21.9	6.5
11162	21.6	26.1	22.9	0.0
11163	21.2	26.9	22.5	0.0
11164	21.2	27.7	22.5	0.0
11165	18.5	28.8	22.2	5.8
11166	21.1	27.3	23.4	18.9
11167	19.8	28.0	23.0	0.0
11168	18.7	27.0	22.8	16.7
11169	13.8	29.2	22.9	13.1
11170	21.5	26.3	23.1	0.0
11171	13.3	28.0	23.1	0.2
11172	19.0	26.6	23.2	1.6
11173	16.5	27.6	22.8	0.0
11174	21.2	26.1	22.6	1.0
11175	21.7	26.9	22.1	2.2
11176	15.8	26.6	22.7	0.0
11177	16.8	26.2	22.6	4.5
11178	19.3	27.4	22.3	0.0
11179	19.1	27.4	21.4	0.0
11180	21.2	26.2	22.4	0.1
11181	17.1	26.7	22.8	0.0

11182	22.0	26.8	22.2	0.7
11183	14.8	27.4	22.4	27.9
11184	23.7	26.0	22.6	20.1
11185	21.6	26.4	22.4	0.1
11186	9.4	27.9	22.7	12.6
11187	17.9	26.8	23.1	0.1
11188	16.1	25.6	22.9	0.1
11189	15.0	25.7	22.5	0.0
11190	16.8	26.0	22.6	11.5
11191	7.2	25.9	22.3	22.2
11192	11.9	25.2	21.5	0.0
11193	18.9	26.5	21.7	0.0
11194	17.5	25.5	22.1	1.9
11195	19.5	26.8	22.2	0.7
11196	21.2	25.4	22.2	15.7
11197	19.1	26.5	21.9	0.7
11198	13.6	27.1	22.6	20.8
11199	23.0	26.9	22.1	2.4
11200	21.1	26.8	22.4	9.3
11201	5.8	25.9	22.6	19.2
11202	18.9	25.2	22.0	9.7
11203	15.8	25.6	21.7	0.0
11204	18.5	26.1	22.0	0.7
11205	16.9	25.8	21.9	0.5
11206	14.2	25.5	21.6	0.1
11207	14.7	26.1	21.2	0.0
11208	13.5	26.6	21.5	0.0
11209	16.6	27.6	21.7	0.0
11210	13.8	25.2	21.8	0.3
11211	15.6	26.6	21.0	0.0
11212	21.2	26.3	21.2	0.6
11213	17.4	27.9	21.6	13.4
11214	15.0	25.9	22.8	17.1
11215	16.8	25.6	22.2	12.9
11216	12.9	26.8	21.9	0.0
11217	14.6	26.5	21.9	0.0
11218	18.5	25.8	21.5	28.3
11219	17.4	26.7	22.2	2.5
11220	13.3	25.6	21.3	0.0
11221	13.5	25.9	21.4	0.0
11222	15.0	27.1	21.4	3.2
11223	13.7	26.2	21.7	2.8
11224	12.6	27.0	21.6	4.1
11225	13.9	25.8	21.4	2.2
11226	11.9	26.9	21.3	0.0
11227	14.5	25.5	21.5	0.0

11228	21.2	27.1	21.4	0.0
11229	16.7	26.7	20.5	0.0
11230	17.3	25.5	20.9	0.0
11231	16.3	25.8	21.1	0.2
11232	22.8	28.5	20.8	0.9
11233	19.4	27.5	22.0	15.1
11234	15.8	25.0	22.0	13.3
11235	12.9	25.3	21.7	0.0
11236	21.8	25.7	22.3	0.0
11237	14.0	25.8	22.4	0.1
11238	14.3	24.8	22.0	22.7
11239	15.6	26.6	21.6	4.7
11240	14.0	25.9	21.8	0.4
11241	21.3	26.8	22.4	5.2
11242	11.2	25.6	22.4	21.4
11243	15.2	25.9	22.1	7.2
11244	21.2	26.1	22.1	6.3
11245	19.4	26.9	22.4	2.3
11246	18.4	25.8	22.7	0.9
11247	14.7	25.6	22.0	15.0
11248	18.6	26.1	22.2	3.6
11249	21.2	26.8	22.4	1.1
11250	19.4	26.9	22.7	5.0
11251	13.1	25.3	22.8	17.9
11252	12.7	25.0	21.9	4.6
11253	21.2	26.4	21.9	0.2
11254	17.7	27.2	22.3	11.3
11255	16.5	25.7	22.8	2.1
11256	15.3	26.8	22.5	5.7
11257	17.2	26.5	22.5	8.9
11258	8.9	25.6	22.0	5.9
11259	17.1	25.4	21.8	1.2
11260	21.2	25.6	22.1	10.7
11261	14.8	24.9	22.2	5.8
11262	16.6	26.5	22.1	3.9
11263	19.9	25.8	22.6	1.4
11264	12.0	26.1	22.2	9.7
11265	19.5	26.4	22.6	2.6
11266	17.9	28.3	22.4	12.7
11267	19.4	26.8	22.7	7.1
11268	21.0	28.2	22.6	0.0
11269	21.3	27.8	22.6	13.4
11270	17.8	25.9	22.7	7.5
11271	18.4	27.7	22.0	10.6
11272	18.0	29.1	21.8	6.1
11273	19.6	26.6	22.3	10.2

11274	19.7	26.8	22.6	2.9
11275	19.6	28.5	21.9	3.9
11276	21.2	28.4	22.4	3.1
11277	22.8	29.5	22.0	6.3
11278	18.3	28.4	22.9	0.7
11279	11.0	27.0	23.1	9.4
11280	8.2	26.9	22.8	15.3
11281	21.6	28.6	22.7	2.4
11282	19.8	26.8	23.0	14.8
11283	16.8	26.2	23.0	8.6
11284	21.2	29.0	22.4	8.7
11285	21.7	27.4	22.5	24.9
11286	18.1	27.9	22.4	10.8
11287	17.9	28.8	22.3	0.0
11288	9.0	27.3	22.2	0.1
11289	22.8	27.9	21.9	10.2
11290	21.1	28.8	22.6	3.2
11291	12.5	26.8	23.4	5.5
11292	21.2	29.1	22.3	3.2
11293	18.0	28.3	23.4	6.5
11294	17.8	27.9	22.9	26.8
11295	13.3	26.1	23.0	33.3
11296	22.5	28.1	21.8	1.3
11297	21.2	26.5	22.6	6.8
11298	19.4	26.8	22.4	3.1
11299	22.2	27.3	22.0	0.0
11300	22.8	27.5	22.0	0.0
11301	22.4	28.9	22.5	0.0
11302	21.9	29.3	21.8	0.1
11303	22.3	27.3	22.4	5.2
11304	21.7	26.7	23.1	5.5
11305	21.2	28.8	22.6	5.3
11306	21.4	27.9	22.6	4.9
11307	22.0	26.9	22.3	0.2
11308	21.2	27.5	23.2	0.0
11309	21.9	27.3	22.8	0.0
11310	21.7	28.3	22.4	0.8
11311	21.7	27.9	23.0	0.0
11312	22.1	27.7	22.9	0.0
11313	21.8	28.2	22.9	0.0
11314	21.6	28.3	23.1	0.1
11315	22.2	28.4	22.9	0.0
11316	22.2	27.9	23.5	0.0
11317	18.7	27.4	23.2	0.1
11318	22.0	28.3	23.0	0.0
11319	21.7	28.6	22.8	0.0

11320	19.8	27.8	22.9	0.0
11321	21.8	30.0	22.5	0.0
11322	21.6	28.6	21.6	0.0
11323	21.7	27.7	23.1	0.0
11324	21.2	28.0	22.9	0.0
11325	21.5	27.9	22.6	0.0
11326	18.5	27.5	23.3	0.2
11327	21.3	27.0	23.1	0.0
11328	21.4	28.6	22.4	0.0
11329	21.6	28.8	22.7	0.0
11330	21.6	30.5	22.5	0.0
11331	21.6	30.5	22.3	0.0
11332	21.7	29.7	22.0	0.0
11333	21.7	29.4	22.6	0.0
11334	22.2	29.8	20.9	0.0
11335	22.3	29.9	19.5	0.0
11336	22.3	29.9	18.6	0.0
11337	22.2	30.3	18.2	0.0
11338	22.0	30.0	17.9	0.0
11339	21.2	29.7	21.4	0.0
11340	21.2	29.4	21.9	0.0
11341	21.4	30.2	21.1	0.0
11342	21.4	29.8	21.1	0.0
11343	22.1	29.4	17.6	0.0
11344	22.1	29.6	16.2	0.0
11345	21.9	28.9	17.0	0.0
11346	21.7	29.4	16.3	0.0
11347	21.8	28.9	16.1	0.0
11348	21.5	30.1	17.3	0.0
11349	21.6	30.0	19.2	0.0
11350	21.8	30.2	17.8	0.0
11351	21.3	30.9	17.8	0.0
11352	21.1	31.1	18.7	0.0
11353	21.2	29.1	19.9	0.0
11354	21.4	28.8	21.4	0.0
11355	21.2	29.1	21.9	0.0
11356	21.2	28.5	22.8	0.0
11357	21.0	28.9	21.3	0.0
11358	21.8	29.4	21.8	0.0
11359	22.2	29.5	22.3	0.0
11360	22.6	29.2	22.0	0.0
11361	21.2	29.7	22.0	0.0
11362	21.0	28.9	22.3	0.0
11363	19.6	28.7	23.4	0.1
11364	21.2	30.4	20.4	0.1
11365	21.5	30.7	19.8	0.0

12001	21.5	30.6	19.3	0.0
12002	21.5	30.8	20.6	0.0
12003	21.7	30.3	19.2	0.0
12004	22.1	30.2	17.5	0.0
12005	21.3	30.3	17.4	0.0
12006	21.0	30.9	18.3	0.0
12007	21.2	29.7	16.8	0.0
12008	21.9	30.6	16.5	0.0
12009	21.9	31.0	18.9	0.0
12010	22.1	30.9	18.6	0.0
12011	22.1	31.1	18.7	0.0
12012	22.0	30.4	18.9	0.0
12013	22.4	29.8	16.9	0.0
12014	21.0	29.5	15.2	0.0
12015	21.2	30.7	16.3	0.0
12016	20.8	30.9	17.6	0.0
12017	21.8	31.7	19.8	0.0
12018	20.7	30.3	19.9	0.0
12019	20.8	29.4	20.4	0.0
12020	21.4	30.6	21.6	1.4
12021	19.5	27.9	22.4	0.1
12022	21.9	29.4	22.2	0.0
12023	21.2	30.3	21.6	0.0
12024	22.4	31.8	20.4	0.0
12025	22.5	31.6	20.2	0.0
12026	22.1	29.2	22.2	0.0
12027	20.4	29.1	22.7	2.6
12028	21.9	28.5	22.3	0.0
12029	20.8	28.5	22.6	0.0
12030	22.1	26.6	22.9	0.0
12031	22.7	28.1	22.4	0.0
12032	22.8	28.1	21.8	0.0
12033	22.1	28.4	22.8	0.6
12034	22.6	28.5	23.0	0.1
12035	22.9	30.5	22.5	0.0
12036	23.0	30.6	22.5	0.0
12037	22.4	28.6	22.9	0.0
12038	23.0	28.7	17.4	0.0
12039	21.2	32.5	19.2	0.0
12040	22.7	29.9	22.1	0.0
12041	22.3	30.0	21.1	0.0
12042	22.4	30.1	22.0	0.0
12043	22.5	28.6	22.4	0.0
12044	21.3	28.9	23.1	0.0
12045	22.6	28.7	23.0	0.0
12046	20.6	28.2	23.0	0.0

12047	18.9	27.6	22.3	0.0
12048	21.6	29.2	22.8	0.0
12049	22.4	28.6	23.1	9.2
12050	22.8	30.3	22.6	0.0
12051	21.0	28.5	22.2	29.8
12052	17.1	31.0	22.6	0.1
12053	15.8	27.5	22.3	0.0
12054	24.2	28.0	22.5	0.0
12055	21.2	28.3	22.6	0.0
12056	24.3	28.7	22.2	0.0
12057	22.1	28.2	23.1	0.0
12058	23.9	28.7	21.9	0.6
12059	23.9	30.0	22.4	3.8
12060	22.9	29.9	22.6	3.5
12061	22.7	29.0	22.7	5.7
12062	24.3	29.0	22.4	0.8
12063	24.6	30.0	22.5	5.2
12064	24.5	31.1	23.1	0.3
12065	21.8	29.5	22.9	1.8
12066	24.0	29.2	21.9	0.0
12067	24.5	28.8	22.7	0.0
12068	22.6	27.9	23.4	0.0
12069	24.7	27.8	23.2	4.5
12070	24.7	28.9	22.9	0.5
12071	21.2	29.7	21.9	0.0
12072	25.5	30.5	22.4	0.0
12073	25.4	28.6	22.8	0.0
12074	25.6	29.2	23.0	0.0
12075	24.8	30.1	22.8	0.0
12076	24.4	29.7	23.0	0.0
12077	24.3	29.6	23.4	0.0
12078	17.2	29.4	23.1	0.0
12079	23.1	29.9	23.2	0.0
12080	21.6	30.3	22.4	0.0
12081	25.6	28.7	23.1	0.0
12082	25.6	29.4	23.5	0.0
12083	24.4	29.3	24.1	0.0
12084	22.9	29.1	24.5	0.0
12085	22.8	28.7	23.6	1.1
12086	25.1	28.7	23.2	0.0
12087	21.2	32.3	22.7	0.0
12088	24.4	29.7	23.2	0.0
12089	24.6	27.9	24.7	0.0
12090	18.4	29.8	23.5	0.0
12091	23.1	29.4	23.6	0.0
12092	23.7	29.6	23.6	0.2

12093	22.7	28.9	23.8	0.5
12094	25.3	29.1	23.4	0.0
12095	22.9	28.2	22.6	13.6
12096	21.2	28.5	22.6	16.1
12097	20.6	28.1	23.0	0.1
12098	24.3	28.4	23.8	0.0
12099	22.8	29.0	24.1	9.4
12100	19.7	28.9	24.1	5.5
12101	21.5	28.5	23.7	0.0
12102	24.2	28.9	23.2	19.9
12103	21.2	28.1	24.1	4.0
12104	17.6	28.8	23.8	3.7
12105	19.3	27.6	23.4	0.1
12106	18.9	27.5	23.5	5.7
12107	20.4	27.7	23.7	18.6
12108	14.8	28.6	22.9	4.8
12109	25.1	29.1	22.9	4.0
12110	9.4	27.3	23.7	0.3
12111	21.9	28.1	23.0	0.0
12112	23.0	29.7	23.1	0.0
12113	22.0	27.3	23.4	0.0
12114	23.4	28.9	23.5	0.0
12115	24.0	28.5	22.6	10.9
12116	13.8	29.6	23.3	7.5
12117	25.1	29.7	22.0	0.0
12118	25.3	28.6	23.0	0.1
12119	21.2	29.0	23.3	0.0
12120	21.3	28.8	24.1	0.0
12121	25.3	28.9	24.1	0.0
12122	22.0	27.3	24.1	3.3
12123	20.8	29.1	22.8	16.2
12124	19.7	28.3	23.7	0.0
12125	15.1	28.7	23.9	6.2
12126	9.5	28.3	23.5	9.4
12127	25.3	30.2	23.0	0.0
12128	22.0	28.1	23.8	0.2
12129	17.2	27.9	23.6	0.7
12130	21.9	27.8	23.3	0.0
12131	22.0	27.7	23.0	0.0
12132	20.7	28.8	22.9	1.8
12133	21.7	29.5	23.0	2.8
12134	16.3	27.5	22.6	11.8
12135	21.2	26.7	22.4	12.3
12136	19.7	29.0	22.6	14.2
12137	20.6	27.6	23.1	19.2
12138	20.9	28.4	23.0	3.7

12139	22.4	29.0	23.5	0.0
12140	11.6	26.8	23.2	6.3
12141	23.4	27.8	22.7	0.0
12142	8.1	27.6	22.9	8.9
12143	21.3	27.3	22.9	1.4
12144	20.6	26.7	22.8	7.5
12145	20.7	27.6	23.3	1.2
12146	12.9	26.4	23.4	3.4
12147	19.9	28.6	22.4	0.0
12148	23.2	27.7	22.6	0.0
12149	13.2	26.5	22.9	8.8
12150	17.9	26.8	22.8	10.1
12151	21.2	26.7	22.5	1.6
12152	12.7	26.8	22.5	0.7
12153	22.1	28.6	23.0	1.2
12154	15.6	28.1	22.5	6.3
12155	23.0	27.0	22.6	0.0
12156	23.2	29.1	22.3	6.4
12157	14.0	26.5	23.1	23.8
12158	20.6	28.4	22.7	0.4
12159	16.8	26.7	22.8	0.0
12160	21.6	27.7	22.6	2.0
12161	13.4	27.8	22.9	11.0
12162	21.7	27.7	23.2	0.0
12163	22.2	27.9	23.3	12.1
12164	8.5	26.4	23.2	28.7
12165	18.9	28.7	22.4	0.0
12166	16.8	27.6	22.8	4.7
12167	21.2	26.8	22.9	5.9
12168	15.0	28.2	22.7	9.0
12169	22.4	26.0	22.7	0.0
12170	21.3	27.8	21.5	2.6
12171	21.5	27.3	22.5	7.2
12172	20.2	25.5	22.6	9.5
12173	21.3	26.6	22.5	0.0
12174	16.6	25.6	22.6	2.6
12175	21.0	26.2	22.5	0.0
12176	18.6	25.2	22.6	14.2
12177	18.8	25.5	22.3	0.0
12178	20.4	26.6	22.2	10.5
12179	16.1	25.4	22.5	19.7
12180	16.1	24.4	22.1	2.6
12181	20.6	26.0	21.3	0.0
12182	18.4	26.0	21.9	0.0
12183	21.2	25.7	22.4	23.2
12184	10.9	26.9	21.6	18.9

12185	17.7	26.3	21.9	5.2
12186	20.4	24.3	21.9	0.0
12187	14.0	27.2	21.6	0.0
12188	15.6	27.6	21.6	0.3
12189	9.7	25.1	22.3	15.2
12190	10.7	25.8	21.7	2.0
12191	18.6	27.3	21.2	0.0
12192	19.2	26.9	21.6	8.1
12193	10.9	25.8	22.1	7.9
12194	14.1	25.3	22.5	0.0
12195	16.4	27.3	22.5	8.2
12196	13.2	25.8	22.6	28.6
12197	15.8	25.3	21.9	3.7
12198	21.6	27.0	21.2	0.0
12199	21.2	25.9	21.6	0.0
12200	14.5	24.7	21.6	18.1
12201	16.8	25.9	21.6	0.5
12202	19.5	27.0	21.3	0.0
12203	18.4	25.7	21.7	3.0
12204	16.0	25.9	22.2	11.5
12205	14.4	25.8	21.4	0.0
12206	14.6	26.4	21.4	0.0
12207	16.1	25.9	21.6	0.0
12208	12.8	23.9	22.4	12.8
12209	10.4	24.8	21.9	1.6
12210	17.4	25.5	22.0	0.8
12211	18.8	25.8	22.2	0.0
12212	17.0	27.1	21.7	0.4
12213	8.7	25.3	21.9	19.9
12214	15.0	24.6	22.2	1.0
12215	21.2	24.6	20.7	1.6
12216	17.0	27.0	21.1	16.8
12217	15.4	23.9	21.3	0.0
12218	11.7	25.9	20.6	0.0
12219	11.2	25.1	20.5	0.0
12220	13.4	26.6	20.4	0.0
12221	17.7	26.9	21.3	0.0
12222	17.7	26.7	22.2	8.5
12223	13.5	26.5	22.4	5.7
12224	8.6	24.2	21.7	0.0
12225	14.4	26.7	20.5	0.0
12226	13.5	27.0	19.9	0.0
12227	7.9	25.0	20.6	4.5
12228	20.3	27.0	19.6	0.0
12229	23.4	27.4	20.1	0.0
12230	15.8	26.7	20.7	0.0

12231	21.2	27.2	21.7	36.0
12232	15.8	27.4	21.0	0.0
12233	17.7	25.6	21.3	3.6
12234	8.9	25.9	21.6	3.2
12235	10.1	25.7	21.4	8.0
12236	16.4	26.8	21.1	0.1
12237	9.9	24.5	21.4	8.6
12238	15.8	26.0	21.0	0.0
12239	15.5	27.1	21.5	4.2
12240	11.6	26.4	22.2	8.5
12241	15.8	25.3	22.2	0.2
12242	16.4	27.4	21.8	0.0
12243	15.4	25.1	21.7	0.0
12244	14.8	24.6	21.1	3.3
12245	16.1	26.9	21.4	2.6
12246	15.3	25.9	21.8	3.2
12247	21.2	26.7	21.3	0.3
12248	11.1	24.3	22.0	0.0
12249	19.0	26.1	21.7	3.2
12250	19.1	26.2	21.8	0.6
12251	19.3	27.6	21.9	0.0
12252	15.8	25.6	22.3	6.2
12253	17.4	26.8	21.8	1.7
12254	9.7	25.8	22.0	0.1
12255	12.3	25.0	21.7	7.4
12256	18.5	25.4	22.1	0.6
12257	16.3	25.3	21.9	3.9
12258	19.8	27.5	22.0	0.0
12259	15.3	27.0	22.5	0.0
12260	9.6	25.3	21.6	13.9
12261	13.3	25.9	21.5	0.0
12262	18.5	25.9	21.5	27.4
12263	21.2	26.0	21.6	9.3
12264	15.3	24.9	22.1	2.7
12265	21.6	27.1	21.9	0.9
12266	15.9	26.3	22.4	10.0
12267	21.2	26.6	22.2	17.5
12268	21.1	27.6	22.0	0.1
12269	21.0	27.4	22.1	13.8
12270	19.3	26.3	22.8	58.4
12271	15.3	24.7	22.3	2.9
12272	23.4	28.1	22.2	0.5
12273	9.0	28.6	22.4	39.6
12274	13.2	26.3	22.3	5.9
12275	19.1	25.4	22.2	3.5
12276	13.8	27.1	22.1	2.2

12277	14.7	28.6	21.0	0.0
12278	16.2	26.5	22.8	0.0
12279	21.2	28.1	22.4	0.1
12280	19.5	26.7	22.4	0.1
12281	20.7	28.0	21.9	4.4
12282	16.9	25.2	22.6	13.3
12283	19.6	27.6	22.2	0.0
12284	22.0	26.7	22.2	26.1
12285	22.5	27.9	22.6	8.6
12286	20.0	28.1	22.9	11.1
12287	21.8	28.7	22.8	1.9
12288	20.4	28.3	22.7	5.5
12289	20.4	27.6	23.1	12.5
12290	17.5	26.8	22.5	0.5
12291	14.3	26.6	22.5	1.5
12292	18.4	27.9	22.5	5.3
12293	20.1	28.1	22.1	8.6
12294	21.9	27.5	21.9	4.2
12295	21.2	27.7	22.4	13.3
12296	18.0	27.2	22.2	13.2
12297	21.6	27.8	22.3	17.3
12298	18.5	26.8	22.3	3.8
12299	22.1	28.4	21.9	0.0
12300	19.4	26.5	22.8	15.8
12301	18.5	26.7	22.9	0.0
12302	19.7	27.7	22.2	21.6
12303	20.9	26.9	22.5	1.3
12304	19.0	27.5	22.7	0.1
12305	21.1	27.8	22.8	0.0
12306	23.1	28.0	22.7	0.0
12307	20.9	27.4	23.0	10.2
12308	20.5	27.7	23.1	0.5
12309	21.2	28.4	23.1	0.4
12310	21.7	29.2	22.1	0.5
12311	21.2	28.6	23.4	0.0
12312	19.9	27.9	22.8	0.2
12313	21.6	27.6	22.9	0.6
12314	19.1	27.5	22.6	0.0
12315	21.9	28.0	22.5	0.0
12316	16.8	26.9	23.0	0.0
12317	12.2	27.8	23.1	0.0
12318	18.9	27.1	23.2	0.0
12319	21.6	29.0	23.0	0.5
12320	21.3	29.6	22.9	0.0
12321	22.2	29.1	22.5	0.0
12322	21.9	28.6	24.2	0.0

12323	21.1	28.0	23.3	1.8
12324	20.8	27.3	23.2	0.0
12325	21.1	26.6	23.2	0.0
12326	21.5	28.1	23.2	0.0
12327	21.2	28.2	23.2	0.0
12328	19.9	27.7	22.7	0.0
12329	20.3	28.1	22.4	0.0
12330	20.2	27.0	23.2	0.0
12331	13.8	26.1	22.9	0.0
12332	20.9	27.4	22.7	0.0
12333	20.9	28.4	22.4	0.0
12334	19.3	28.5	22.4	0.0
12335	21.3	28.5	23.2	0.0
12336	21.0	26.8	23.8	0.5
12337	18.4	27.6	22.8	1.4
12338	19.1	26.1	23.3	1.4
12339	20.1	26.7	23.1	0.1
12340	19.4	26.3	23.1	0.0
12341	17.6	27.2	23.1	0.4
12342	19.5	27.5	22.4	0.6
12343	21.2	25.8	22.8	0.2
12344	20.8	27.7	22.1	0.0
12345	20.5	27.6	22.7	0.0
12346	18.4	27.7	23.2	12.0
12347	20.2	27.8	23.1	0.0
12348	20.4	27.5	22.7	0.0
12349	21.1	28.6	22.1	0.0
12350	20.8	28.1	23.1	0.0
12351	20.8	28.3	21.9	0.0
12352	20.6	27.2	21.9	0.0
12353	20.5	29.4	18.7	0.0
12354	19.6	28.0	19.6	0.0
12355	20.8	27.0	21.2	0.0
12356	21.1	28.4	21.9	0.0
12357	20.6	28.8	21.5	0.0
12358	21.3	29.5	20.8	0.0
12359	21.2	29.3	19.9	0.0
12360	21.8	29.5	17.9	0.0
12361	21.5	28.7	16.6	0.0
12362	21.4	29.9	17.8	0.0
12363	21.6	30.3	19.8	0.0
12364	21.4	30.7	18.3	0.0
12365	21.0	29.4	20.9	0.0
12366	21.0	28.5	21.2	0.0

Appendix 3: Weather data for Ibadan between 2010 and 2012

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
NGIB	7.22	3.55	274	-99	-99	-99	10

JDAY	Solar Radiation, MJ/day	Max Temp °C	Min Temp °C	RAIN mm
10001	20.6	29.5	22.6	0.0
10002	21.0	29.2	23.1	0.0
10003	21.7	30.5	22.9	0.0
10004	21.5	30.2	22.6	0.0
10005	20.1	29.0	24.2	0.0
10006	20.5	27.7	24.2	0.0
10007	20.3	28.1	23.6	0.0
10008	21.2	28.8	23.8	0.0
10009	18.3	24.6	24.1	0.0
10010	20.1	28.4	24.5	0.0
10011	20.8	28.6	23.7	0.0
10012	21.8	29.6	23.5	0.0
10013	20.8	27.9	24.6	0.0
10014	20.4	27.8	24.0	2.2
10015	9.8	28.5	24.2	6.5
10016	21.5	28.9	23.7	0.0
10017	21.4	28.8	24.0	0.0
10018	20.4	28.3	24.6	0.0
10019	21.9	28.3	23.4	0.0
10020	22.6	30.2	19.7	0.0
10021	22.1	29.6	21.7	0.0
10022	22.0	29.0	23.5	0.0
10023	22.3	30.6	22.0	0.0
10024	21.2	30.0	23.1	0.0
10025	21.9	29.2	24.1	0.0
10026	21.6	28.5	23.2	0.0
10027	17.2	28.2	23.9	2.9
10028	21.5	28.7	24.5	0.0
10029	22.0	28.8	24.1	0.0
10030	22.4	30.8	23.8	0.0
10031	22.5	31.5	24.2	0.0
10032	22.9	30.1	24.9	0.0
10033	22.7	29.6	23.9	0.0
10034	22.2	29.3	24.9	0.0
10035	22.7	29.4	24.6	0.0
10036	19.4	30.7	25.1	0.0
10037	23.5	30.3	21.7	0.0
10038	23.5	30.6	18.5	0.0
10039	23.7	31.3	20.8	0.0
10040	21.2	29.7	24.2	0.0
10041	19.5	30.3	24.5	0.0

10042	17.9	29.9	25.1	9.8
10043	21.0	30.1	25.0	0.0
10044	23.2	30.3	25.0	11.8
10045	23.1	31.8	24.2	15.6
10046	22.4	28.5	24.8	0.0
10047	22.9	29.9	24.6	0.0
10048	21.4	29.3	24.7	0.0
10049	21.4	29.4	25.8	1.0
10050	20.9	29.9	25.4	0.0
10051	22.7	30.4	25.3	0.0
10052	22.7	30.1	25.5	7.2
10053	22.5	31.3	25.2	18.6
10054	21.9	30.2	25.4	6.4
10055	23.5	30.8	26.2	0.0
10056	21.2	29.8	25.8	1.5
10057	22.6	29.8	25.9	0.0
10058	23.4	30.2	25.3	0.0
10059	21.7	29.4	25.5	5.0
10060	19.8	29.9	26.0	0.8
10061	22.5	29.9	25.5	0.0
10062	23.8	30.1	25.5	0.0
10063	21.5	30.2	25.7	0.0
10064	22.4	29.8	26.2	2.0
10065	22.4	30.4	25.6	0.0
10066	21.5	29.8	25.2	0.0
10067	22.5	29.6	25.2	2.8
10068	19.3	29.4	25.9	23.7
10069	24.2	28.9	25.3	5.3
10070	19.9	28.6	25.7	0.0
10071	19.2	29.6	25.3	1.9
10072	21.2	29.3	25.7	0.0
10073	19.0	28.9	25.6	0.0
10074	23.8	28.4	25.5	11.8
10075	11.5	28.5	25.1	13.9
10076	22.3	28.6	24.0	0.0
10077	21.3	28.1	24.4	0.0
10078	20.8	28.3	24.5	13.1
10079	17.8	28.1	24.6	0.0
10080	19.5	29.2	23.9	0.0
10081	17.7	28.8	24.1	0.0
10082	22.4	29.2	24.1	0.0
10083	22.4	29.4	24.2	0.0
10084	20.6	30.2	23.6	0.5
10085	23.4	29.9	24.7	0.0
10086	22.7	30.1	25.2	0.0
10087	24.0	30.4	25.1	0.0

10088	21.2	29.9	25.9	0.1
10089	13.2	29.9	25.7	10.8
10090	23.2	29.9	25.1	0.0
10091	22.0	30.2	25.6	4.8
10092	22.6	29.6	26.3	4.3
10093	21.4	30.2	24.8	0.1
10094	21.5	29.3	25.9	0.0
10095	20.4	30.0	25.6	0.0
10096	24.1	29.5	25.3	1.6
10097	22.1	29.2	25.5	0.0
10098	24.8	30.3	25.4	0.2
10099	22.0	30.7	25.6	0.2
10100	18.0	29.9	25.6	7.2
10101	22.2	30.0	25.2	0.1
10102	20.4	29.9	25.4	0.0
10103	19.8	29.6	25.9	1.0
10104	21.2	29.8	25.6	0.4
10105	20.6	29.7	26.0	1.4
10106	19.6	29.2	26.2	8.1
10107	18.2	31.0	25.7	2.5
10108	25.4	32.9	24.2	0.0
10109	20.5	31.1	24.7	0.0
10110	19.9	29.8	26.5	0.3
10111	17.2	29.5	25.7	16.7
10112	17.3	28.5	25.8	10.4
10113	21.5	25.1	24.6	0.2
10114	7.2	28.5	25.2	0.6
10115	23.9	30.0	24.3	0.0
10116	21.2	30.4	25.2	12.8
10117	21.8	29.3	25.2	2.3
10118	22.9	30.4	25.6	0.0
10119	17.1	29.9	24.5	0.0
10120	21.2	28.3	25.3	8.6
10121	21.2	28.7	25.5	0.0
10122	6.3	27.8	25.6	11.9
10123	22.8	28.1	24.8	2.6
10124	22.7	28.1	24.8	1.6
10125	14.4	27.9	25.3	8.0
10126	21.1	28.2	25.1	7.9
10127	15.8	27.3	25.0	5.5
10128	22.6	29.0	24.8	2.2
10129	19.5	28.7	25.3	2.5
10130	20.7	28.7	25.5	0.0
10131	21.2	30.6	24.6	0.0
10132	20.2	29.8	25.4	2.2
10133	21.5	28.7	25.9	16.3

10134	17.0	29.0	25.5	3.5
10135	21.4	29.9	24.9	4.0
10136	21.2	29.4	25.5	0.3
10137	17.6	28.7	25.5	11.2
10138	20.7	29.1	24.6	0.0
10139	19.3	28.9	24.5	18.4
10140	11.5	28.4	24.6	12.4
10141	14.4	27.4	23.9	0.0
10142	21.7	28.6	23.8	0.0
10143	20.0	29.3	25.2	11.7
10144	20.9	29.4	24.9	0.5
10145	20.9	29.3	25.7	0.7
10146	12.0	29.3	25.9	17.2
10147	14.3	29.5	25.0	7.1
10148	19.3	29.1	24.5	0.2
10149	19.4	29.4	25.0	5.8
10150	15.3	29.2	24.2	0.0
10151	16.1	27.4	24.8	5.0
10152	21.2	26.4	24.0	0.0
10153	15.0	26.7	24.4	11.2
10154	17.1	26.1	24.2	5.3
10155	11.7	26.6	23.9	2.4
10156	19.2	27.5	23.2	0.0
10157	18.4	27.2	23.6	14.4
10158	20.4	27.8	24.5	0.0
10159	20.3	28.5	24.7	0.6
10160	16.4	27.6	24.7	34.0
10161	18.8	28.4	23.9	0.0
10162	16.1	24.9	24.2	7.3
10163	19.4	28.4	25.0	1.7
10164	18.3	27.8	25.2	0.1
10165	17.8	27.3	24.6	25.7
10166	19.9	27.8	24.1	17.8
10167	15.8	27.1	24.2	6.2
10168	21.2	27.4	23.1	0.0
10169	20.8	27.6	23.3	4.9
10170	18.5	27.4	24.2	0.2
10171	12.8	26.4	23.7	11.5
10172	18.1	26.5	23.7	0.6
10173	19.2	26.8	23.9	0.6
10174	14.7	27.4	24.2	16.5
10175	18.5	26.7	24.1	0.0
10176	14.5	26.0	23.4	6.4
10177	12.9	25.3	22.9	0.0
10178	16.5	25.7	22.7	7.1
10179	20.9	27.1	22.5	0.3

10180	19.0	27.4	22.8	0.0
10181	19.7	27.8	23.5	0.0
10182	11.5	26.8	23.5	30.9
10183	18.3	26.6	22.7	0.0
10184	21.2	27.3	23.4	0.8
10185	16.8	28.2	23.6	5.5
10186	18.8	27.5	23.4	0.7
10187	17.9	27.2	23.5	2.8
10188	12.2	26.9	23.4	10.9
10189	19.3	26.8	23.5	0.3
10190	18.4	27.3	23.1	7.2
10191	12.1	25.8	23.7	15.0
10192	18.1	27.1	22.9	1.6
10193	16.1	27.9	23.1	21.2
10194	17.3	25.7	23.1	10.1
10195	14.9	26.1	22.6	0.1
10196	11.2	25.3	22.5	5.2
10197	16.3	25.8	22.2	0.4
10198	18.2	27.2	21.6	1.6
10199	18.8	29.2	22.3	0.0
10200	21.2	27.8	21.2	0.0
10201	17.7	27.3	22.9	12.7
10202	13.7	27.7	22.0	0.1
10203	18.6	28.6	21.8	0.0
10204	10.9	26.2	22.4	7.7
10205	20.6	28.4	21.4	0.0
10206	21.3	29.1	21.3	0.0
10207	13.4	27.9	22.6	5.0
10208	15.4	26.5	23.0	1.2
10209	16.2	26.4	22.4	0.5
10210	16.7	28.7	22.2	0.0
10211	11.1	26.7	22.3	0.2
10212	17.6	28.0	22.1	0.0
10213	20.5	28.2	21.2	0.0
10214	19.2	27.6	21.5	0.0
10215	12.2	27.9	22.3	0.0
10216	21.2	28.2	22.3	0.0
10217	17.2	30.0	22.3	0.0
10218	12.9	25.1	23.2	0.7
10219	12.2	25.6	23.0	6.8
10220	13.2	26.9	23.3	2.6
10221	10.5	26.6	22.8	8.4
10222	15.0	28.0	23.3	1.9
10223	12.3	28.1	23.0	1.7
10224	6.6	26.1	23.1	40.7
10225	11.9	25.4	22.7	0.8

10226	10.2	27.2	22.6	3.1
10227	15.8	29.8	22.7	0.0
10228	16.6	28.5	23.5	12.3
10229	12.9	26.5	23.7	23.0
10230	18.5	26.9	22.9	0.3
10231	19.9	28.1	22.6	21.9
10232	21.2	28.1	22.5	30.5
10233	17.7	26.9	23.2	0.0
10234	16.7	27.5	23.0	0.0
10235	14.7	28.5	22.5	12.1
10236	10.7	27.2	23.1	22.1
10237	16.8	27.4	23.1	0.0
10238	15.8	27.8	23.2	0.0
10239	17.7	27.9	23.1	0.0
10240	14.9	26.8	22.8	1.0
10241	15.0	28.0	23.1	0.0
10242	16.0	28.9	22.6	1.9
10243	15.5	28.0	22.9	1.4
10244	22.3	29.3	22.8	0.0
10245	18.6	28.2	21.8	0.0
10246	9.8	28.1	22.6	0.9
10247	14.9	27.6	23.1	0.1
10248	21.2	27.4	23.4	1.9
10249	17.0	27.6	22.8	0.4
10250	15.8	26.5	22.6	5.6
10251	17.9	27.8	23.3	2.4
10252	15.3	27.4	23.2	11.4
10253	16.9	26.0	22.9	7.1
10254	18.1	26.3	23.0	6.0
10255	19.1	28.0	23.2	1.6
10256	15.0	26.7	23.4	4.2
10257	15.9	25.6	23.3	4.0
10258	15.8	26.0	23.3	9.4
10259	20.7	29.0	22.6	0.0
10260	10.4	26.6	23.5	7.7
10261	10.6	27.1	23.7	6.6
10262	19.7	28.6	22.9	11.1
10263	19.7	28.2	23.3	7.8
10264	21.2	27.7	23.5	0.0
10265	18.6	27.6	23.3	16.3
10266	18.8	26.9	23.5	39.0
10267	19.2	27.1	22.9	19.7
10268	19.9	27.5	22.9	0.0
10269	19.5	28.2	23.5	3.8
10270	21.3	29.1	23.6	29.4
10271	14.9	28.1	23.4	16.4

10272	20.0	29.2	22.9	17.3
10273	19.5	28.2	23.7	11.6
10274	21.3	27.2	24.5	20.1
10275	18.5	27.4	23.8	12.8
10276	20.4	29.2	24.1	2.8
10277	18.3	27.5	23.8	10.5
10278	17.5	25.7	24.0	8.8
10279	16.2	27.1	23.4	7.2
10280	21.2	26.2	23.8	7.3
10281	19.3	27.7	23.6	0.0
10282	17.2	28.8	24.0	3.4
10283	7.1	27.7	24.1	15.5
10284	18.5	29.0	23.1	0.0
10285	18.9	28.2	23.4	0.2
10286	19.5	28.8	23.1	0.1
10287	19.2	27.6	23.9	0.1
10288	18.9	28.8	24.0	3.0
10289	18.4	28.9	23.7	0.7
10290	20.9	28.8	24.2	13.6
10291	19.5	27.8	23.9	0.5
10292	21.0	27.0	23.5	2.9
10293	22.5	27.8	23.4	35.8
10294	18.1	26.8	23.5	28.5
10295	19.8	28.9	22.4	0.4
10296	21.2	28.8	22.8	7.9
10297	12.3	26.5	22.9	8.3
10298	18.6	28.5	22.2	0.1
10299	19.8	28.5	22.0	0.9
10300	17.8	28.7	23.5	2.8
10301	18.6	28.2	23.9	2.5
10302	12.4	29.1	23.4	1.6
10303	20.2	27.8	23.2	0.1
10304	17.9	28.2	23.5	24.5
10305	19.5	28.9	23.4	10.4
10306	20.1	29.0	23.5	7.8
10307	22.3	32.2	21.4	0.1
10308	19.5	28.2	23.6	0.1
10309	19.7	28.0	23.9	8.7
10310	15.5	27.4	23.7	0.0
10311	17.0	27.3	23.5	2.9
10312	21.2	28.2	23.1	0.0
10313	20.8	29.2	23.3	2.4
10314	20.5	28.9	24.6	8.6
10315	16.2	28.6	24.2	12.7
10316	19.2	27.8	24.6	0.0
10317	20.1	27.7	24.9	1.4

10318	19.8	28.2	24.3	2.7
10319	20.3	29.0	23.5	0.0
10320	20.2	27.7	23.7	2.4
10321	21.3	27.2	24.1	0.8
10322	19.7	26.8	24.3	0.0
10323	18.6	27.7	23.7	2.2
10324	21.2	29.1	23.6	7.0
10325	20.5	28.4	23.8	11.5
10326	20.8	27.2	24.3	7.3
10327	20.8	28.4	23.5	0.0
10328	21.2	29.0	23.3	0.0
10329	21.3	29.1	23.2	0.0
10330	20.7	28.2	24.0	0.0
10331	20.4	27.2	24.4	0.0
10332	20.2	28.0	23.9	0.0
10333	20.3	29.2	22.4	0.0
10334	21.0	28.2	24.2	0.0
10335	19.7	29.6	24.1	0.0
10336	19.8	29.1	24.2	0.0
10337	19.5	28.6	24.4	0.0
10338	20.2	28.7	24.1	0.0
10339	20.0	28.3	24.2	0.5
10340	20.0	27.5	24.1	5.0
10341	18.1	28.4	23.6	5.5
10342	20.6	29.0	23.4	0.0
10343	21.0	29.5	23.4	0.0
10344	21.2	30.4	23.9	0.0
10345	21.7	31.4	21.6	0.0
10346	21.5	31.0	21.2	0.0
10347	20.6	30.6	22.0	0.0
10348	21.1	30.8	22.2	0.0
10349	20.7	30.2	23.6	0.0
10350	20.7	28.9	23.7	0.0
10351	21.0	30.1	23.7	0.0
10352	20.4	28.6	24.6	0.0
10353	20.0	29.4	24.3	0.0
10354	19.8	29.4	23.4	0.0
10355	20.4	28.6	24.2	0.0
10356	19.2	28.1	24.6	0.2
10357	17.1	29.1	24.1	13.6
10358	19.8	28.8	23.3	0.2
10359	21.0	29.1	23.7	0.0
10360	21.2	29.6	23.2	0.0
10361	19.5	28.4	23.3	0.9
10362	17.7	27.9	23.8	0.0
10363	18.3	28.5	23.6	2.0

10364	20.1	28.8	23.3	1.0
10365	21.3	30.3	21.5	0.0
11001	21.4	30.1	19.4	0.0
11002	18.0	28.9	21.6	0.1
11003	21.3	29.8	21.7	0.0
11004	21.3	30.3	23.5	0.0
11005	18.5	27.7	24.3	0.0
11006	17.4	26.9	23.9	0.0
11007	19.9	27.5	23.8	0.0
11008	21.6	29.3	20.8	0.0
11009	20.9	29.8	21.3	0.0
11010	21.6	30.1	20.7	0.0
11011	21.2	31.3	21.2	0.0
11012	22.2	31.8	20.4	0.0
11013	22.0	30.1	22.3	0.0
11014	21.0	28.8	23.6	0.0
11015	21.8	28.9	22.9	0.0
11016	22.6	30.0	17.4	0.0
11017	22.6	30.3	17.4	0.0
11018	22.6	30.6	19.4	0.0
11019	22.6	31.0	20.4	0.0
11020	21.3	29.8	21.4	0.0
11021	22.0	29.7	22.0	0.0
11022	21.7	29.9	23.2	0.0
11023	22.0	29.5	23.2	0.0
11024	21.8	28.9	23.8	0.0
11025	21.2	29.0	23.7	0.0
11026	20.6	29.5	23.8	0.0
11027	21.2	30.0	24.0	0.0
11028	20.7	30.2	24.7	0.0
11029	22.2	29.7	24.6	0.0
11030	20.0	30.3	24.0	0.0
11031	19.6	29.5	24.3	0.0
11032	21.1	29.2	24.9	0.4
11033	20.9	28.5	24.5	1.0
11034	16.8	28.5	24.5	0.0
11035	17.5	27.6	24.0	0.0
11036	19.7	30.8	21.3	0.0
11037	22.9	30.0	22.1	0.0
11038	23.1	29.4	23.2	0.0
11039	22.6	29.3	23.4	0.0
11040	21.9	28.3	24.3	0.0
11041	19.7	27.2	24.1	22.0
11042	23.3	28.0	22.7	0.0
11043	21.2	28.1	23.8	0.0
11044	20.3	28.3	24.1	7.7

11045	22.9	27.9	24.2	0.6
11046	18.1	30.0	24.1	0.0
11047	23.4	29.9	24.1	0.0
11048	22.8	29.6	24.8	2.5
11049	21.1	28.6	24.5	6.2
11050	21.3	29.6	23.9	12.6
11051	23.9	29.7	23.7	0.0
11052	20.4	28.6	24.3	11.0
11053	20.6	28.0	24.6	5.3
11054	13.3	27.2	24.7	7.8
11055	21.1	29.2	23.8	0.0
11056	20.8	29.5	23.3	0.2
11057	21.0	28.1	23.8	10.8
11058	22.5	29.6	23.9	7.6
11059	21.2	30.1	23.8	0.0
11060	21.9	27.6	24.5	0.0
11061	21.8	30.3	24.8	0.1
11062	18.9	28.5	23.9	0.9
11063	22.8	28.9	24.2	0.2
11064	20.4	28.9	24.6	0.0
11065	19.8	30.0	25.1	0.0
11066	21.5	28.9	25.1	0.9
11067	20.3	29.8	24.7	0.6
11068	21.0	29.6	25.1	2.2
11069	20.1	29.2	25.1	0.0
11070	22.2	29.6	24.7	0.9
11071	21.0	29.1	24.8	0.7
11072	22.9	29.6	24.9	0.0
11073	20.1	28.8	25.2	5.3
11074	20.8	29.9	24.8	0.0
11075	21.8	30.3	24.9	4.4
11076	21.8	29.1	25.2	4.0
11077	22.4	29.1	25.0	0.0
11078	23.4	28.6	24.7	1.5
11079	22.4	28.1	24.8	0.0
11080	21.7	28.2	24.7	0.3
11081	20.3	27.9	24.7	6.6
11082	17.3	28.3	24.6	2.5
11083	19.0	29.1	23.9	0.0
11084	15.3	28.0	24.9	0.0
11085	23.7	29.7	23.8	4.1
11086	23.5	29.0	24.0	0.0
11087	21.6	28.8	24.9	0.1
11088	23.2	29.1	24.9	0.0
11089	21.5	28.1	25.1	0.8
11090	23.4	28.6	25.1	0.1

11091	21.2	28.9	24.7	1.2
11092	21.3	28.8	24.7	0.0
11093	22.7	28.5	25.1	10.7
11094	9.8	27.9	24.4	0.0
11095	22.8	28.8	23.3	0.0
11096	22.9	29.8	23.7	0.0
11097	24.7	29.2	24.1	0.0
11098	21.2	30.0	24.5	0.0
11099	20.7	30.1	25.2	7.7
11100	17.2	30.9	23.9	1.1
11101	20.7	29.7	23.8	0.0
11102	21.3	28.8	24.8	0.0
11103	20.3	28.7	25.0	4.8
11104	20.0	29.1	24.3	0.0
11105	19.7	29.6	25.2	0.0
11106	21.7	29.4	24.8	0.1
11107	21.2	29.7	24.8	11.4
11108	16.7	28.7	24.3	0.1
11109	23.9	31.0	24.1	0.0
11110	20.6	29.0	24.9	0.0
11111	19.4	28.4	24.9	0.0
11112	20.1	29.2	25.3	2.9
11113	18.2	29.2	25.1	0.0
11114	14.9	27.4	24.6	0.0
11115	9.8	27.8	24.3	1.5
11116	24.0	29.2	23.6	0.0
11117	21.6	28.7	24.9	0.0
11118	14.7	28.0	24.8	25.0
11119	21.0	28.4	24.2	0.0
11120	11.9	28.5	24.2	0.0
11121	23.6	28.7	24.4	0.0
11122	18.6	28.1	25.5	8.4
11123	21.2	28.3	25.1	26.3
11124	22.9	29.2	24.6	6.1
11125	23.0	29.6	24.0	0.0
11126	20.7	30.1	25.2	0.1
11127	20.9	28.9	25.7	0.0
11128	18.5	28.9	25.0	6.1
11129	19.4	29.3	24.5	1.0
11130	20.2	30.0	23.9	0.0
11131	19.3	30.0	23.9	0.0
11132	20.7	28.2	24.7	0.9
11133	21.9	29.2	25.1	3.7
11134	13.0	28.5	25.1	14.7
11135	20.3	29.8	24.2	0.0
11136	23.0	29.4	24.8	0.0

11137	18.7	29.4	25.1	21.4
11138	16.8	28.5	25.2	10.2
11139	21.2	29.7	25.1	0.0
11140	18.8	29.5	24.6	0.8
11141	22.2	28.9	24.9	0.0
11142	18.8	29.4	24.2	1.2
11143	20.7	27.8	24.0	1.2
11144	21.2	28.8	24.4	0.5
11145	17.9	28.0	24.4	7.4
11146	18.5	27.1	24.7	0.4
11147	15.0	28.0	23.9	2.8
11148	19.4	27.1	24.2	0.2
11149	20.5	28.5	23.9	0.8
11150	15.2	27.4	24.2	13.3
11151	16.2	28.6	22.7	0.0
11152	13.6	28.6	24.4	0.1
11153	21.8	29.6	24.2	0.0
11154	21.1	28.3	24.8	3.7
11155	21.2	27.9	24.7	20.8
11156	19.8	29.1	24.2	0.0
11157	22.5	29.4	24.1	0.0
11158	16.5	28.0	24.8	11.9
11159	15.2	27.1	24.3	8.6
11160	13.1	27.0	23.6	0.0
11161	20.5	28.1	22.9	8.4
11162	18.8	26.7	23.9	0.0
11163	19.0	26.9	23.5	2.8
11164	19.3	28.3	23.2	0.5
11165	18.2	28.9	23.2	0.9
11166	18.9	28.6	23.6	17.4
11167	19.2	28.5	23.6	2.1
11168	15.0	27.9	23.4	20.3
11169	15.3	27.3	23.5	17.5
11170	19.8	27.2	24.0	0.0
11171	21.2	28.7	23.7	0.0
11172	15.4	26.8	24.2	12.9
11173	6.5	27.8	23.6	1.5
11174	18.9	27.2	23.2	0.7
11175	9.8	27.5	22.9	1.7
11176	16.9	26.9	23.2	0.2
11177	17.9	26.8	23.6	16.5
11178	17.7	27.2	23.1	0.0
11179	14.2	28.6	22.3	0.1
11180	11.7	27.2	23.2	0.2
11181	17.6	27.5	23.2	3.2
11182	17.1	27.7	22.9	0.0

11183	14.3	27.5	22.8	13.6
11184	18.4	26.7	23.3	31.9
11185	19.9	25.9	23.1	5.3
11186	18.7	28.6	22.9	16.6
11187	21.2	27.2	23.6	0.8
11188	12.2	26.8	23.3	20.9
11189	19.6	27.0	23.1	0.0
11190	14.8	27.2	23.1	12.3
11191	4.5	25.8	23.1	17.9
11192	11.4	25.3	22.4	0.0
11193	15.3	27.3	22.0	0.0
11194	14.9	26.6	22.4	5.6
11195	10.2	27.1	22.9	16.9
11196	11.8	25.9	22.7	1.4
11197	19.9	26.2	22.8	5.2
11198	15.3	27.0	23.1	23.6
11199	20.8	27.7	22.5	9.9
11200	17.8	28.0	22.8	0.1
11201	9.8	27.8	22.8	16.9
11202	11.1	26.7	22.8	7.8
11203	21.2	26.1	22.6	0.0
11204	17.9	26.7	22.7	0.0
11205	14.7	27.5	22.0	0.0
11206	14.5	26.1	22.4	0.0
11207	9.2	26.7	22.2	0.0
11208	11.7	27.6	22.2	0.0
11209	15.8	27.8	21.8	0.0
11210	11.2	27.2	21.9	0.0
11211	15.3	27.2	21.6	0.0
11212	15.7	28.3	21.6	0.0
11213	10.8	28.7	22.4	0.0
11214	11.9	27.9	22.8	0.7
11215	15.2	26.5	23.2	1.4
11216	16.5	28.0	22.6	0.0
11217	12.9	27.0	22.5	0.1
11218	11.4	26.9	21.9	37.8
11219	21.2	26.8	22.5	1.9
11220	12.5	28.1	21.9	0.0
11221	15.9	28.0	21.6	0.0
11222	17.3	28.7	21.7	0.0
11223	14.6	27.7	22.3	0.0
11224	10.3	27.3	22.3	0.0
11225	10.4	24.1	22.2	6.5
11226	13.6	27.8	22.1	0.0
11227	12.8	28.2	21.9	0.0
11228	18.3	28.1	21.8	0.0

11229	14.3	28.8	21.5	0.7
11230	18.8	27.8	21.4	0.4
11231	16.0	28.2	21.3	0.1
11232	21.2	28.7	21.5	0.7
11233	21.1	28.5	21.9	13.8
11234	8.2	24.9	22.4	10.7
11235	21.2	27.6	22.4	0.0
11236	18.0	27.9	22.4	0.0
11237	17.8	27.9	22.6	0.0
11238	12.0	26.4	22.7	25.0
11239	17.2	26.8	22.4	20.9
11240	14.8	25.7	22.5	1.7
11241	16.1	27.6	22.8	0.0
11242	10.3	27.5	22.4	4.4
11243	9.3	25.9	23.0	4.0
11244	16.0	26.3	23.0	7.3
11245	15.1	27.9	22.7	0.0
11246	18.4	27.9	22.7	0.0
11247	13.8	27.0	22.7	0.0
11248	19.0	27.2	22.8	1.6
11249	16.7	27.3	22.8	0.0
11250	19.5	28.2	23.1	0.0
11251	21.2	27.0	23.4	11.7
11252	11.8	26.9	22.8	7.8
11253	21.2	27.9	22.8	0.1
11254	13.1	28.5	22.0	0.9
11255	18.9	27.4	23.2	0.0
11256	21.0	26.9	23.3	1.0
11257	18.7	26.9	23.2	9.6
11258	12.7	26.2	22.6	0.3
11259	18.2	27.1	22.8	2.4
11260	21.2	26.6	23.0	4.5
11261	15.1	26.5	23.0	10.9
11262	20.0	26.5	23.0	17.7
11263	15.2	25.4	23.3	6.3
11264	13.3	26.9	23.4	4.4
11265	17.9	27.3	23.2	1.6
11266	17.0	27.9	23.3	0.0
11267	21.2	27.4	23.7	7.9
11268	17.6	27.4	23.8	3.5
11269	24.2	28.3	23.4	18.1
11270	15.9	27.2	23.7	20.8
11271	18.6	27.3	23.3	5.8
11272	18.7	28.9	23.0	23.7
11273	17.6	27.0	22.8	10.3
11274	8.4	26.5	23.4	15.9

11275	19.2	28.7	22.3	13.8
11276	12.1	29.1	23.1	1.7
11277	18.6	29.2	23.4	0.5
11278	20.2	28.6	23.7	1.7
11279	17.0	27.8	23.6	15.5
11280	13.9	27.3	23.7	17.8
11281	20.6	27.6	23.8	9.1
11282	20.1	27.7	23.8	0.8
11283	21.2	27.3	23.7	13.2
11284	19.4	27.6	23.4	15.7
11285	17.2	27.6	23.5	17.6
11286	16.2	29.0	23.2	9.1
11287	16.7	28.8	22.7	0.0
11288	6.6	27.8	23.1	9.1
11289	19.9	27.8	22.6	9.1
11290	20.8	28.9	23.4	7.9
11291	14.0	27.4	24.4	17.4
11292	23.3	27.8	23.9	0.0
11293	16.8	28.4	24.0	1.9
11294	18.3	27.9	23.8	6.7
11295	6.6	26.3	23.8	27.4
11296	20.3	27.5	22.6	3.4
11297	20.8	27.2	23.0	16.6
11298	14.7	26.3	23.4	0.3
11299	21.2	27.6	22.8	18.3
11300	21.4	28.2	22.9	3.3
11301	22.5	29.1	23.5	0.0
11302	17.4	29.7	22.5	0.0
11303	20.2	28.3	23.1	6.6
11304	19.5	28.4	23.6	0.4
11305	20.7	28.9	23.4	2.3
11306	19.2	28.0	23.3	13.8
11307	20.3	27.7	23.6	0.0
11308	21.0	28.1	23.9	0.5
11309	20.2	27.6	23.6	0.0
11310	20.3	28.4	23.1	0.2
11311	19.6	28.5	23.6	0.0
11312	19.6	28.6	23.4	0.0
11313	20.2	29.1	23.5	3.1
11314	20.5	29.2	23.5	0.0
11315	21.2	29.4	23.4	1.3
11316	21.2	28.6	24.3	3.3
11317	19.4	28.7	23.7	0.0
11318	21.7	28.9	23.9	0.0
11319	22.0	28.4	23.3	0.0
11320	14.5	28.5	23.6	1.9

11321	18.5	28.4	23.5	2.1
11322	19.3	27.8	23.9	0.0
11323	21.0	28.0	23.8	0.0
11324	21.1	28.5	23.5	0.0
11325	20.0	28.1	23.7	0.0
11326	18.3	27.9	24.1	0.0
11327	18.9	27.4	23.9	0.0
11328	21.1	29.6	23.1	0.0
11329	20.4	29.0	22.7	0.0
11330	20.7	29.6	23.3	0.0
11331	21.2	29.4	23.6	0.0
11332	21.6	28.7	23.5	0.0
11333	21.6	30.1	23.2	0.0
11334	21.9	29.6	23.5	0.0
11335	22.2	30.6	22.8	0.0
11336	22.4	32.1	21.0	0.0
11337	22.1	31.6	20.5	0.0
11338	21.3	30.8	20.3	0.0
11339	20.8	29.9	23.4	0.0
11340	21.1	30.3	22.8	0.0
11341	21.0	29.2	22.9	0.0
11342	21.1	29.8	23.1	0.0
11343	21.6	30.5	22.7	0.0
11344	21.7	30.8	19.3	0.0
11345	20.9	30.8	19.5	0.0
11346	21.9	30.5	17.9	0.0
11347	21.2	30.2	18.5	0.0
11348	21.5	30.7	20.1	0.0
11349	21.5	30.5	22.1	0.0
11350	21.9	31.1	20.6	0.0
11351	21.4	31.2	20.9	0.0
11352	20.8	29.7	21.9	0.0
11353	19.3	29.0	22.9	0.0
11354	19.7	28.4	23.6	0.0
11355	20.4	28.3	23.7	0.1
11356	21.0	29.2	23.6	0.0
11357	20.2	29.0	23.7	0.0
11358	20.4	29.0	24.5	0.0
11359	19.9	29.3	24.5	0.0
11360	20.8	30.0	23.4	0.0
11361	20.6	29.8	23.7	0.0
11362	20.1	29.2	24.1	0.0
11363	21.2	28.9	23.9	0.5
11364	21.2	29.2	23.5	0.0
11365	21.6	30.8	20.1	0.0
12001	21.5	31.3	20.6	0.0

12002	21.4	30.4	22.1	0.0
12003	21.3	29.9	23.6	0.0
12004	21.9	30.5	21.0	0.0
12005	21.0	30.2	21.6	0.0
12006	21.0	30.1	23.0	0.0
12007	21.5	30.4	21.1	0.0
12008	22.1	30.8	18.0	0.0
12009	21.7	31.7	20.8	0.0
12010	22.0	31.5	21.2	0.0
12011	21.9	30.9	21.6	0.0
12012	21.9	31.0	22.4	0.0
12013	22.2	30.7	19.5	0.0
12014	21.2	30.2	17.4	0.0
12015	21.5	31.4	17.7	0.0
12016	21.2	31.5	18.8	0.0
12017	21.9	31.2	20.8	0.0
12018	21.4	31.1	20.1	0.0
12019	20.8	29.6	22.6	0.0
12020	21.3	29.8	22.7	0.0
12021	18.6	28.7	23.1	0.0
12022	22.1	29.5	23.1	0.0
12023	20.8	29.8	23.3	0.0
12024	22.0	31.6	22.9	0.0
12025	22.3	31.1	21.3	0.0
12026	20.1	30.1	23.0	0.0
12027	19.3	29.8	23.8	0.7
12028	20.3	28.7	23.3	0.1
12029	19.9	28.1	23.5	0.0
12030	21.2	26.9	23.8	0.0
12031	21.7	27.6	23.5	0.0
12032	22.6	27.9	22.7	0.0
12033	20.8	28.6	23.8	0.4
12034	21.0	29.3	24.1	4.8
12035	20.6	30.4	23.4	0.0
12036	20.8	30.1	23.0	0.1
12037	21.9	28.1	24.0	0.3
12038	20.9	29.4	20.8	0.0
12039	21.8	32.1	20.8	0.0
12040	22.1	29.7	22.8	0.0
12041	21.8	30.2	22.2	0.0
12042	21.8	29.6	22.7	0.0
12043	22.5	28.9	23.6	0.0
12044	19.1	28.6	24.1	0.0
12045	19.2	28.4	23.6	0.0
12046	21.2	28.2	24.1	0.0
12047	21.3	27.8	23.4	0.0

12048	21.2	29.1	23.7	0.2
12049	17.3	28.9	24.2	12.7
12050	22.2	29.6	24.0	0.0
12051	19.7	29.1	23.4	16.6
12052	19.5	29.6	23.4	0.8
12053	13.8	27.4	23.8	0.4
12054	22.1	27.9	23.3	0.0
12055	22.0	28.9	23.1	0.0
12056	21.8	28.0	23.3	0.0
12057	21.8	28.5	23.6	2.9
12058	21.9	29.2	23.7	0.0
12059	22.6	28.5	24.2	9.6
12060	21.0	27.6	23.8	1.1
12061	20.8	27.5	23.5	8.6
12062	21.2	28.2	23.8	2.6
12063	24.4	29.9	23.1	6.7
12064	20.6	29.3	24.6	1.8
12065	18.3	28.7	24.3	2.7
12066	22.8	30.6	23.0	2.0
12067	21.8	29.0	24.3	0.0
12068	22.8	28.3	24.0	4.5
12069	21.6	28.1	24.0	4.3
12070	22.1	28.8	24.3	0.0
12071	22.8	29.2	23.5	0.0
12072	25.0	29.8	23.9	0.0
12073	25.1	29.4	24.1	0.0
12074	24.6	30.0	23.9	0.0
12075	23.9	31.6	23.8	0.0
12076	22.6	30.6	24.7	0.0
12077	24.2	30.8	24.7	0.0
12078	21.2	30.3	25.1	0.0
12079	21.6	30.4	24.9	0.0
12080	22.6	30.1	24.0	0.0
12081	23.2	30.1	25.2	0.0
12082	23.9	29.8	25.3	0.0
12083	22.5	29.6	25.1	0.0
12084	20.4	29.1	25.4	2.8
12085	6.9	29.1	24.9	11.0
12086	22.1	29.0	24.4	0.0
12087	20.8	31.1	24.1	0.0
12088	23.1	29.4	24.8	0.9
12089	22.4	28.4	25.5	2.2
12090	14.2	28.9	24.8	8.7
12091	22.0	29.2	24.6	0.0
12092	21.0	28.2	24.7	0.1
12093	21.5	28.9	24.8	3.7

12094	21.2	28.1	24.6	5.5
12095	23.3	27.8	23.9	7.6
12096	24.8	29.4	23.4	1.1
12097	15.6	28.8	24.6	5.6
12098	22.2	28.1	25.2	0.0
12099	21.8	28.5	25.2	11.3
12100	18.4	28.9	25.1	23.3
12101	19.8	28.7	24.5	0.5
12102	23.2	29.2	24.0	1.9
12103	20.9	27.7	24.9	3.3
12104	19.3	28.5	24.4	0.1
12105	12.8	27.6	24.5	7.3
12106	19.2	27.7	24.2	10.8
12107	6.9	27.6	24.9	15.8
12108	17.9	28.4	24.4	8.2
12109	24.6	29.2	23.3	0.0
12110	21.2	27.6	24.3	9.5
12111	21.7	27.9	23.7	0.0
12112	23.2	28.8	23.8	0.0
12113	17.7	27.5	24.1	0.0
12114	20.7	28.6	24.8	0.1
12115	22.5	29.0	24.1	7.1
12116	13.5	28.4	24.9	12.6
12117	23.8	29.7	23.0	0.0
12118	23.8	29.8	23.8	5.3
12119	18.6	28.9	24.2	0.0
12120	21.6	30.1	24.9	0.0
12121	22.9	29.2	25.1	2.1
12122	21.0	28.2	24.9	0.5
12123	20.9	29.4	23.9	9.3
12124	20.9	28.6	24.6	3.0
12125	18.9	29.4	24.9	0.0
12126	21.2	28.1	24.2	12.5
12127	23.4	29.6	23.6	0.0
12128	20.3	28.3	25.0	0.0
12129	14.8	27.5	24.9	8.4
12130	20.2	28.2	24.2	0.3
12131	23.6	27.8	24.2	0.4
12132	20.5	28.5	24.5	1.4
12133	10.2	26.7	24.4	5.6
12134	10.8	26.9	23.5	6.6
12135	18.1	28.5	23.1	4.8
12136	20.5	28.8	23.4	21.9
12137	17.1	27.1	24.1	9.4
12138	19.0	28.4	23.8	0.0
12139	19.9	28.5	24.2	0.0

12140	8.2	27.7	24.0	8.7
12141	21.1	28.8	23.8	0.0
12142	21.2	27.7	24.0	6.7
12143	17.6	27.6	23.6	0.0
12144	19.7	27.7	23.8	1.2
12145	21.0	27.9	24.4	17.2
12146	8.7	27.0	24.1	22.8
12147	19.3	28.3	23.5	0.0
12148	22.3	27.7	23.2	0.0
12149	12.5	27.8	23.9	15.0
12150	15.4	27.2	24.1	11.6
12151	12.8	27.7	23.8	2.4
12152	12.3	27.6	23.2	0.8
12153	20.8	28.8	23.3	11.0
12154	8.0	29.4	23.3	21.3
12155	18.3	28.0	23.1	0.4
12156	22.6	29.5	23.2	0.4
12157	10.8	26.8	23.9	34.2
12158	21.2	28.4	23.6	0.0
12159	14.8	27.7	23.6	0.0
12160	20.8	26.7	23.5	0.0
12161	17.8	28.7	23.7	7.7
12162	21.0	28.5	23.5	0.0
12163	20.2	28.5	23.8	3.0
12164	11.1	26.6	24.2	16.0
12165	14.9	28.0	24.1	2.5
12166	13.7	28.3	23.4	3.9
12167	15.7	26.7	23.9	0.0
12168	11.4	27.8	23.5	9.2
12169	10.1	26.3	23.6	0.6
12170	19.6	26.4	22.7	1.5
12171	18.3	27.6	23.2	0.1
12172	16.8	26.5	23.4	20.2
12173	16.8	27.0	23.1	1.2
12174	21.2	26.9	23.0	0.1
12175	18.8	27.2	23.1	0.8
12176	19.8	26.3	23.3	10.6
12177	14.1	26.8	23.0	0.7
12178	19.9	27.3	22.9	15.2
12179	15.2	26.6	23.1	21.9
12180	14.1	24.8	23.0	27.4
12181	17.5	26.6	22.4	0.3
12182	19.5	26.8	22.4	1.8
12183	11.3	26.0	23.2	4.3
12184	13.0	26.9	22.9	5.9
12185	17.6	27.7	22.7	12.7

12186	18.5	25.1	22.9	0.4
12187	18.6	26.7	22.6	0.1
12188	16.1	28.5	22.8	1.1
12189	13.1	25.9	22.5	5.7
12190	21.2	27.6	22.5	2.8
12191	20.3	28.2	21.9	0.0
12192	18.9	28.4	21.9	0.0
12193	16.2	27.1	22.3	0.0
12194	15.9	26.1	22.8	0.9
12195	15.3	28.2	22.4	0.4
12196	17.4	27.6	22.9	46.3
12197	10.5	25.6	22.6	5.5
12198	21.0	27.5	22.3	0.0
12199	17.7	28.5	21.5	0.0
12200	12.7	27.6	22.2	0.0
12201	17.3	28.0	22.2	0.0
12202	17.9	28.6	22.2	0.0
12203	15.0	27.1	21.8	0.0
12204	12.1	26.7	22.4	1.7
12205	13.8	28.2	22.2	0.0
12206	21.2	27.1	22.0	0.0
12207	14.1	27.2	22.2	1.0
12208	12.3	26.8	22.6	0.0
12209	8.0	27.3	22.6	0.0
12210	16.5	27.6	22.5	0.0
12211	16.3	26.8	22.7	0.0
12212	17.4	28.4	22.2	0.0
12213	5.5	26.8	22.1	11.4
12214	12.1	26.4	22.5	0.0
12215	11.5	27.2	21.3	0.0
12216	13.2	28.1	21.7	4.4
12217	11.4	26.2	21.9	0.8
12218	13.5	27.0	21.3	0.0
12219	11.7	26.8	20.9	1.0
12220	11.6	28.0	20.9	0.0
12221	14.6	28.6	21.7	0.0
12222	21.2	27.7	22.2	0.2
12223	11.2	27.6	22.2	0.2
12224	9.8	24.7	22.0	0.0
12225	18.3	27.9	21.1	0.0
12226	12.2	29.2	20.5	0.0
12227	9.9	25.8	21.1	3.8
12228	17.7	27.8	20.6	0.0
12229	17.7	29.1	20.1	0.0
12230	13.2	28.1	21.1	0.7
12231	7.3	28.2	21.7	17.2

12232	14.1	28.1	21.9	0.0
12233	19.2	26.3	22.3	0.0
12234	11.2	26.4	22.2	5.4
12235	10.4	26.1	22.2	3.9
12236	14.1	27.7	22.1	0.1
12237	15.2	27.1	22.4	1.5
12238	21.2	27.4	22.0	1.0
12239	14.4	29.2	21.4	0.1
12240	13.2	28.3	21.8	1.2
12241	14.2	27.1	22.5	0.1
12242	15.2	28.2	22.6	0.2
12243	17.3	28.0	22.3	0.0
12244	16.3	25.5	21.4	20.3
12245	13.0	27.8	22.0	0.0
12246	12.4	27.4	21.8	0.9
12247	17.1	27.9	22.4	0.0
12248	10.1	25.6	22.6	0.0
12249	17.7	26.9	22.6	1.6
12250	13.3	28.0	22.0	0.0
12251	18.5	27.2	22.4	0.0
12252	14.1	26.0	22.9	5.2
12253	13.9	27.0	22.7	1.6
12254	21.2	26.3	22.7	2.5
12255	12.6	26.7	22.4	1.4
12256	17.3	26.7	23.0	0.2
12257	12.3	26.6	22.5	0.1
12258	14.6	28.2	22.1	0.0
12259	16.2	28.2	22.8	0.0
12260	15.6	26.0	22.4	1.4
12261	14.9	26.5	22.5	1.6
12262	19.4	28.4	22.0	20.3
12263	16.8	26.8	22.4	26.7
12264	17.9	25.8	22.6	11.0
12265	20.3	28.3	22.2	16.6
12266	14.5	27.3	22.9	13.2
12267	20.2	26.9	23.0	0.7
12268	17.8	28.5	22.9	0.5
12269	15.6	28.1	22.8	0.0
12270	21.2	27.5	23.3	54.0
12271	18.5	25.7	23.3	1.4
12272	19.9	28.2	22.9	0.0
12273	6.1	27.1	23.1	42.8
12274	14.0	26.3	23.0	0.0
12275	16.6	26.1	23.1	0.0
12276	18.3	27.9	22.8	10.5
12277	14.9	28.2	23.1	0.0

12278	14.3	26.9	23.6	4.9
12279	16.1	28.3	22.9	3.4
12280	12.6	26.7	23.6	9.2
12281	19.7	28.4	23.3	0.6
12282	15.0	26.3	23.4	1.3
12283	17.0	27.8	22.9	0.0
12284	18.5	27.4	23.2	21.4
12285	19.7	28.3	23.5	1.1
12286	21.2	27.2	23.7	8.4
12287	20.4	28.7	23.4	6.2
12288	21.1	28.4	23.5	11.4
12289	14.9	27.2	23.6	6.2
12290	21.7	27.2	23.2	0.0
12291	15.6	27.0	23.5	0.7
12292	14.7	27.8	22.9	5.6
12293	12.7	27.4	23.2	10.5
12294	22.8	28.2	22.7	0.8
12295	17.7	28.2	22.9	4.3
12296	17.4	27.8	22.8	12.6
12297	19.7	27.6	23.2	28.6
12298	11.8	26.7	23.0	1.2
12299	20.4	28.6	22.6	0.1
12300	18.0	27.9	23.2	14.1
12301	12.2	28.1	23.2	7.0
12302	21.2	28.7	23.1	17.3
12303	20.5	27.9	23.2	5.4
12304	21.3	28.3	23.7	0.8
12305	20.3	27.7	23.5	0.5
12306	21.0	28.5	23.4	0.2
12307	19.5	27.6	24.5	1.8
12308	20.3	28.2	23.7	3.3
12309	20.1	29.1	23.7	0.4
12310	21.6	28.7	23.3	3.1
12311	20.2	27.9	24.3	0.2
12312	19.1	28.0	23.4	1.9
12313	19.9	28.1	23.8	2.0
12314	11.7	26.9	23.3	2.3
12315	21.6	27.8	23.0	8.3
12316	16.8	27.6	23.9	0.1
12317	13.0	28.0	23.6	9.9
12318	21.2	27.6	23.4	4.5
12319	19.0	29.6	23.7	0.2
12320	20.4	29.9	23.6	0.0
12321	20.7	29.9	24.0	0.0
12322	21.6	29.3	24.2	0.0
12323	20.1	29.0	24.3	3.5

12324	19.6	28.3	23.9	0.2
12325	19.7	27.3	24.2	0.0
12326	21.1	28.6	24.0	0.5
12327	19.8	28.8	24.2	0.3
12328	18.7	28.6	23.9	1.4
12329	19.4	28.7	23.5	0.1
12330	19.4	28.1	24.3	0.0
12331	8.9	26.9	24.0	1.6
12332	20.0	27.0	23.4	0.0
12333	18.4	28.1	23.8	0.5
12334	21.2	29.2	23.4	0.1
12335	21.0	28.5	24.1	0.0
12336	19.8	28.2	24.2	3.2
12337	19.8	27.8	23.6	2.0
12338	16.0	26.6	24.2	8.0
12339	18.8	27.7	23.5	0.2
12340	18.8	27.3	23.6	0.0
12341	18.4	27.5	23.6	1.4
12342	18.6	27.5	23.7	1.6
12343	18.0	26.8	23.4	0.8
12344	20.4	28.4	23.0	0.0
12345	19.2	28.3	23.6	0.0
12346	16.5	28.4	23.8	9.2
12347	19.2	28.9	24.1	0.0
12348	20.2	28.7	23.6	0.0
12349	20.5	28.7	24.0	0.0
12350	21.2	28.5	24.2	0.0
12351	20.4	28.7	23.2	0.8
12352	20.3	28.6	24.6	0.0
12353	20.3	28.6	23.2	0.0
12354	20.2	28.4	21.7	0.0
12355	21.0	27.7	22.8	0.0
12356	20.1	28.6	23.2	0.0
12357	19.7	28.9	23.7	0.0
12358	21.3	29.3	23.5	0.0
12359	21.2	29.2	23.4	0.0
12360	21.5	30.5	21.9	0.0
12361	21.1	30.0	19.5	0.1
12362	21.0	29.8	21.5	0.0
12363	20.8	29.9	23.4	0.0
12364	21.1	29.8	23.0	0.0
12365	20.2	28.5	24.2	0.0
12366	21.2	28.6	24.0	0.0

Appendix 4: Exp.Details: NGGB1001PN 2010 Variety x Sowing Date Experiment

```
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Agronomy Dept, LAUTECH, Ogbomoso
@SITE
Teaching and Research farm, LAUTECH, Ogbomoso
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
    486     9   1.5   -99    25   -99    .5     5     1 anual

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 0 0 0 10 DATE1 SAMNUT10          1  1  1  1  1  0  0  0  0  0  0  1  1
 2 0 0 0 10 DATE1 SAMNUT22          2  1  1  1  1  0  0  0  0  0  0  1  1
 3 0 0 0 10 DATE1 SAMNUT 23          3  1  1  1  1  0  0  0  0  0  0  1  1
 4 0 0 0 10 DATE1 KAMPALA           4  1  1  1  1  0  0  0  0  0  0  1  1
 5 0 0 0 10 DATE2 SAMNUT10          1  1  1  1  2  0  0  0  0  0  0  2  1
 6 0 0 0 10 DATE2 SAMNUT22          2  1  1  1  2  0  0  0  0  0  0  2  1
 7 0 0 0 10 DATE2 SAMNUT 23          3  1  1  1  2  0  0  0  0  0  0  2  1
 8 0 0 0 10 DATE2 KAMPALA           4  1  1  1  2  0  0  0  0  0  0  2  1
 9 0 0 0 10 DATE3 SAMNUT10          1  1  1  1  3  0  0  0  0  0  0  3  1
10 0 0 0 10 DATE3 SAMNUT22          2  1  1  1  3  0  0  0  0  0  0  3  1
11 0 0 0 10 DATE3 SAMNUT 23          3  1  1  1  3  0  0  0  0  0  0  3  1
12 0 0 0 10 DATE3 KAMPALA           4  1  1  1  3  0  0  0  0  0  0  3  1
13 0 0 0 10 DATE4 SAMNUT10          1  1  1  1  4  0  0  0  0  0  0  4  1
14 0 0 0 10 DATE4 SAMNUT22          2  1  1  1  4  0  0  0  0  0  0  4  1
15 0 0 0 10 DATE4 SAMNUT 23          3  1  1  1  4  0  0  0  0  0  0  4  1
16 0 0 0 10 DATE4 KAMPALA           4  1  1  1  4  0  0  0  0  0  0  4  1

*CULTIVARS
@C CR INGENO CNAME
 1 PN IB0039 SAMNUT 10
 2 PN IB0040 SAMNUT 21
 3 PN IB0041 SAMNUT 23
 4 PN IB0042 KAMPALA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGGB1001 NGGB       -99   -99 DR000   -99   -99  0000 SL      15  NGGB100001 Ogbomoso
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1              0               0         0                 0     0     0     0   -99   -99

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 10055 SA011 SA002 SA015  physicochemical properties
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    15   -99   .65   .06   6.4   -99   3.7    .2   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    PN 10055   100   -99     1     1   190  1000   .53     0     0    15 2010
@C  ICBL  SH2O  SNH4  SNO3
 1     5  .108   -99   -99
 1    15  .108   -99   -99
 1    30  .108   -99   -99
 1    45  .227   -99   -99
 1    60  .213   -99   -99
 1    90  .196   -99   -99
 1   113  .199   -99   -99

*SOWING DETAILS
@P  SDATE  EDATE    PPOP    PPOE    PLME    PLDS    PLRS    PLRD    PLDP    PLWT    PAGE    PENV    PLPH    SPRL
PLNAME
 1  10119  10126      63      60       S       R      50       0       2     -99     -99     -99     -99       0
10 DATE1 SAMNUT10
 2  10119  10126      63      59       S       R      50       0       2     -99     -99     -99     -99       0
10 DATE1 SAMNUT22
 3  10119  10126      63      60       S       R      50       0       2     -99     -99     -99     -99       0
10 DATE1 SAMNUT 23
 4  10119  10126      63      57       S       R      50       0       2     -99     -99     -99     -99       0
10 DATE1 KAMPALA
 5  10126  10133      63      61       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE2 SAMNUT10
 6  10126  10133      63      62       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE2 SAMNUT22
 7  10126  10131      63      59       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE2 SAMNUT 23
 8  10126  10131      63      62       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE2 KAMPALA
 9  10133  10141      63      56       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE3 SAMNUT10
10  10133  10141      63      57       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE3 SAMNUT22
11  10133  10140      63      58       S       R      50       0       3     -99     -99     -99     -99       0
10 DATE3 SAMNUT 23
```

```
12 10133 10143      63      58       S       R      50       0       3    -99    -99    -99    -99        0
10 DATE3 KAMPALA
13 10140 10147      63      58       S       R      50       0       4    -99    -99    -99    -99        0
10 DATE4 SAMNUT10
14 10140 10147      63      60       S       R      50       0       4    -99    -99    -99    -99        0
10 DATE4 SAMNUT22
15 10140 10146      63      61       S       R      50       0       4    -99    -99    -99    -99        0
10 DATE4 SAMNUT 23
16 10140 10146      63      61       S       R      50       0       4    -99    -99    -99    -99        0
10 DATE4 KAMPALA

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 10119   -99   -99   -99   -99   -99   -99   -99   -99   -99 -99

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 10100   -99   -99   -99   -99   -99   -99   -99   -99 -99

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 10259 GS016     H     M   100     0 SAMNUT10
 2 10239 GS016     H     M   100     0 SAMNUT22
 3 10219 GS016     H     M   100     0 SAMNUT 23
 4 10259 GS016     H     M   100     0 KAMPALA
 5 10266 GS016     H     M   100     0 SAMNUT10
 6 10246 GS016     H     M   100     0 SAMNUT22
 7 10226 GS016     H     M   100     0 SAMNUT 23
 8 10266 GS016     H     M   100     0 KAMPALA
 9 10273 GS016     H     M   100     0 SAMNUT10
10 10253 GS016     H     M   100     0 SAMNUT22
11 10233 GS016     H     M   100     0 SAMNUT 23
12 10273 GS016     H     M   100     0 KAMPALA
13 10280 GS016     H     M   100     0 SAMNUT10
14 10260 GS016     H     M   100     0 SAMNUT22
15 10240 GS016     H     M   100     0 SAMNUT 23
16 10280 GS016     H     M   100     0 KAMPALA

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 10056  2150 SAMNUT10                 CRGRO
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     Y     N     N     N     N     N     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     N     N     N     R
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     N     Y     Y     N     Y     Y     N     N

@  AUTOMATIC MANAGEMENT
@N SOWING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          10060 10140    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA          10233 10275   100     0
```

Appendix 5: Exp.Details: NGGB1001PN 2011 Starter N Experiment

```
*GENERAL
@PEOPLE
F. G. O. Oni
@ADDRESS
Agronomy Dept, LAUTECH, Ogbomoso
@SITE
Teaching and Research farm, LAUTECH, Ogbomoso
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
    476     9   1.5   -99    25   -99    .5     5     1 anual

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 0 0 0 11 DATE1 SAMNUT 23 0kgN    1  1  1  1  1  0  1  0  0  0  0  1  1
 2 0 0 0 11 DATE1 SAMNUT 23 5kgN    1  1  1  1  2  0  2  0  0  0  0  2  1
 3 0 0 0 11 DATE1 SAMNUT 23 10kgN   1  1  1  1  3  0  3  0  0  0  0  3  1
 4 0 0 0 11 DATE1 SAMNUT 23 20kgN   1  1  1  1  4  0  4  0  0  0  0  4  1
 5 0 0 0 11 DATE1 KAMPALA 0kgN      2  1  1  1  5  0  5  0  0  0  0  5  1
 6 0 0 0 11 DATE1 KAMPALA 5kgN      2  1  1  1  6  0  6  0  0  0  0  6  1
 7 0 0 0 11 DATE1 KAMPALA 10kgN     2  1  1  1  7  0  7  0  0  0  0  7  1
 8 0 0 0 11 DATE1 KAMPALA 20kgN     2  1  1  1  8  0  8  0  0  0  0  8  1
 9 0 0 0 11 DATE2 SAMNUT 23 0kgN    1  1  1  1  9  0  9  0  0  0  0  9  1
10 0 0 0 11 DATE2 SAMNUT 23 5kgN    1  1  1  1 10  0 10  0  0  0  0 10  1
11 0 0 0 11 DATE2 SAMNUT 23 10kgN   1  1  1  1 11  0 11  0  0  0  0 11  1
12 0 0 0 11 DATE2 SAMNUT 23 20kgN   1  1  1  1 12  0 12  0  0  0  0 12  1
13 0 0 0 11 DATE2 KAMPALA 0kgN      2  1  1  1 13  0 13  0  0  0  0 13  1
14 0 0 0 11 DATE2 KAMPALA 5kgN      2  1  1  1 14  0 14  0  0  0  0 14  1
15 0 0 0 11 DATE2 KAMPALA 10kgN     2  1  1  1 15  0 15  0  0  0  0 15  1
16 0 0 0 11 DATE2 KAMPALA 20kgN     2  1  1  1 16  0 16  0  0  0  0 16  1

*CULTIVARS
@C CR INGENO CNAME
 1 PN IB0041 SAMNUT 23
 2 PN IB0042 KAMPALA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGGB1101 NGGB1101   -99   -99 DR000   -99   -99  0000 SL      15  NGGB100001 Ogbomoso
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1              0               0         0                 0     0     0     0   -99   -99

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 11031 SA011 SA002 SA015  physicochemical properties
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    15   -99   .65   .06   6.4   -99   3.7    .2   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    PN 11135   100   -99     1     1   190  1000   .53     0     0    15 2011
@C  ICBL  SH2O  SNH4  SNO3
 1     5  .108   -99   -99
 1    15  .108   -99   -99
 1    30  .108   -99   -99
 1    45  .227   -99   -99
 1    60  .213   -99   -99
 1    90  .196   -99   -99
 1   113  .199   -99   -99

*SOWING DETAILS
@P  SDATE  EDATE    PPOP    PPOE    PLME    PLDS    PLRS    PLRD    PLDP    PLWT    PAGE    PENV    PLPH    SPRL
PLNAME
 1  11164  11173      63      60       S       R      50       0       2     -99     -99     -99     -99       0
11 DATE1 SAMNUT 23 0kgN
 2  11164  11172      63      59       S       R      50       0       2     -99     -99     -99     -99       0
11 DATE1 SAMNUT 23 5kgN
 3  11164  11171      63      60       S       R      50       0       2     -99     -99     -99     -99       0
11 DATE1 SAMNUT 23 10kgN
 4  11164  11170      63      57       S       R      50       0       2     -99     -99     -99     -99       0
11 DATE1 SAMNUT 23 20kgN
 5  11164  11169      63      61       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE1 KAMPALA 0kgN
 6  11164  11174      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE1 KAMPALA 5kgN
 7  11164  11168      63      59       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE1 KAMPALA 10kgN
 8  11164  11171      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE1 KAMPALA 20kgN
 9  11171  11178      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE2 SAMNUT 23 0kgN
10  11171  11182      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE2 SAMNUT 23 5kgN
11  11171  11179      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE2 SAMNUT 23 10kgN
12  11171  11180      63      62       S       R      50       0       3     -99     -99     -99     -99       0
11 DATE2 SAMNUT 23 20kgN
```

```
13  11171  11178      63      62       S       R      50       0       3    -99    -99    -99    -99        0
11 DATE2 KAMPALA 0kgN
14  11171  11181      63      62       S       R      50       0       3    -99    -99    -99    -99        0
11 DATE2 KAMPALA 5kgN
15  11171  11177      63      62       S       R      50       0       3    -99    -99    -99    -99        0
11 DATE2 KAMPALA 10kgN
16  11171  11178      63      62       S       R      50       0       3    -99    -99    -99    -99        0
11 DATE2 KAMPALA 20kgN

*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 11169 FE001 AP001     1     0     0     0   -99   -99   -99 11 DATE1 SAMNUT 23 0kgN
 2 11169 FE001 AP001     1     5     5     5   -99   -99   -99 11 DATE1 SAMNUT 23 5kgN
 3 11169 FE001 AP001     1    10    10    10   -99   -99   -99 11 DATE1 SAMNUT 23 10kgN
 4 11169 FE001 AP001     1    20    20    20   -99   -99   -99 11 DATE1 SAMNUT 23 20kgN
 5 11169 FE001 AP001     1     0     0     0   -99   -99   -99 11 DATE1 KAMPALA 0kgN
 6 11169 FE001 AP001     1     5     5     5   -99   -99   -99 11 DATE1 KAMPALA 5kgN
 7 11169 FE001 AP001     1    10    10    10   -99   -99   -99 11 DATE1 KAMPALA 10kgN
 8 11169 FE001 AP001     1    20    20    20   -99   -99   -99 11 DATE1 KAMPALA 20kgN
 9 11176 FE001 AP001     1     0     0     0   -99   -99   -99 11 DATE2 SAMNUT 23 0kgN
10 11176 FE001 AP001     1     5     5     5   -99   -99   -99 11 DATE2 SAMNUT 23 5kgN
11 11176 FE001 AP001     1    10    10    10   -99   -99   -99 11 DATE2 SAMNUT 23 10kgN
12 11176 FE001 AP001     1    20    20    20   -99   -99   -99 11 DATE2 SAMNUT 23 20kgN
13 11176 FE001 AP001     1     0     0     0   -99   -99   -99 11 DATE2 KAMPALA 0kgN
14 11176 FE001 AP001     1     5     5     5   -99   -99   -99 11 DATE2 KAMPALA 5kgN
15 11176 FE001 AP001     1    10    10    10   -99   -99   -99 11 DATE2 KAMPALA 10kgN
16 11176 FE001 AP001     1    20    20    20   -99   -99   -99 11 DATE2 KAMPALA 20kgN

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 11100   -99   -99   -99   -99   -99   -99   -99   -99 -99

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 11056   -99   -99   -99   -99   -99  -99

*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 11056 A   0 A   0 A   0 A   0 A 0.0 A   0 A   0 A   0

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 11284 GS016     H     M   100     0 SAMNUT 23 0kgN
 2 11284 GS016     H     M   100     0 SAMNUT 23 5kgN
 3 11284 GS016     H     M   100     0 SAMNUT 23 10kgN
 4 11284 GS016     H     M   100     0 SAMNUT 23 20kgN
 5 11284 GS016     H     M   100     0 KAMPALA 0kgN
 6 11284 GS016     H     M   100     0 KAMPALA 5kgN
 7 11284 GS016     H     M   100     0 KAMPALA 10kgN
 8 11284 GS016     H     M   100     0 KAMPALA 20kgN
 9 11291 GS016     H     M   100     0 SAMNUT 23 0kgN
10 11291 GS016     H     M   100     0 SAMNUT 23 5kgN
11 11291 GS016     H     M   100     0 SAMNUT 23 10kgN
12 11291 GS016     H     M   100     0 SAMNUT 23 20kgN
13 11291 GS016     H     M   100     0 KAMPALA 0kgN
14 11291 GS016     H     M   100     0 KAMPALA 5kgN
15 11291 GS016     H     M   100     0 KAMPALA 10kgN
16 11291 GS016     H     M   100     0 KAMPALA 20kgN

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 11100  2150 SAMNUT10                  CRGRO
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     Y     N     N     N     N     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     N     N     N     R
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     N     Y     Y     N     Y     Y     N     N

@  AUTOMATIC MANAGEMENT
@N SOWING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          11169 11365    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA          11293 11129    10     0
```

Appendix 6: Exp.Details: NGGB1001PN 2012 Starter N Source x Rate Experiment *GENERAL

```
@PEOPLE
F. G. O. Oni
@ADDRESS
Agronomy Dept, LAUTECH, Ogbomoso
@SITE
Teaching and Research farm, LAUTECH, Ogbomoso
@ PAREA  PRNO  PLEN  PLDR  PLSP  PLAY HAREA  HRNO  HLEN  HARM.........
    484     9   1.5   -99    25   -99    .5     5     1 anual

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 0 0 0 12 NPK 0kg SAMNUT 23       1  1  1  1  1  0  1  0  0  0  0  1  1
 2 0 0 0 12 NPK 0kg KAMPALA         2  1  1  1  1  0  2  0  0  0  0  1  1
 3 0 0 0 12 NPK 20kg SAMNUT 23      1  1  1  1  1  0  3  0  0  0  0  1  1
 4 0 0 0 12 NPK 20kg KAMPALA        2  1  1  1  1  0  4  0  0  0  0  1  1
 5 0 0 0 12 PWM 0kg SAMNUT 23       1  1  1  1  1  0  5  0  0  0  0  1  1
 6 0 0 0 12 PWM 0kg KAMPALA         2  1  1  1  1  0  6  0  0  0  0  1  1
 7 0 0 0 12 PWM 20kg SAMNUT 23      1  1  1  1  1  0  7  0  0  0  0  1  1
 8 0 0 0 12 PWM 20kg KAMPALA        2  1  1  1  1  0  8  0  0  0  0  1  1
 9 0 0 0 12 AOM 0kg SAMNUT 23       1  1  1  1  1  0  9  0  0  0  0  1  1
10 0 0 0 12 AOM 0kg KAMPALA         2  1  1  1  1  0 10  0  0  0  0  1  1
11 0 0 0 12 AOM 20kg SAMNUT 23      1  1  1  1  1  0 11  0  0  0  0  1  1
12 0 0 0 12 AOM 20kg KAMPALA        2  1  1  1  1  0 12  0  0  0  0  1  1

*CULTIVARS
@C CR INGENO CNAME
 1 PN IB0041 SAMNUT 23
 2 PN IB0042 KAMPALA

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX  SLDP  ID_SOIL    FLNAME
 1 NGGB1201 NGGB       -99   -99 DR000   -99   -99  0000 SL      15  NGGB100001 Ogbomoso
@L ...........XCRD ...........YCRD .....ELEV .............AREA .SLEN .FLWR .SLAS FLHST FHDUR
 1               0               0         0                 0     0     0     0   -99   -99

*SOIL ANALYSIS
@A SADAT  SMHB  SMPX  SMKE  SANAME
 1 12145 SA011 SA002 SA015  physicochemical properties
@A  SABL  SADM  SAOC  SANI SAPHW SAPHB  SAPX  SAKE  SASC
 1    15   -99   .65   .06   6.4   -99   3.7    .2   -99

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID ICNAME
 1    PN 12106   100   -99     1     1   190  1000   .53     0     0    15 2012
@C  ICBL  SH2O  SNH4  SNO3
 1     5  .108   -99   -99
 1    15  .108   -99   -99
 1    30  .108   -99   -99
 1    45  .227   -99   -99
 1    60  .213   -99   -99
 1    90  .196   -99   -99
 1   113  .199   -99   -99

*SOWING DETAILS
@P  SDATE  EDATE    PPOP    PPOE    PLME    PLDS    PLRS    PLRD    PLDP    PLWT    PAGE    PENV    PLPH    SPRL
PLNAME
 1 12153    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
NPK 0kg SAMNUT 23
 2 12153    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
NPK 0kg KAMPALA
 3 12153    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
NPK 10kg SAMNUT 23
 4 12153    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
NPK 10kg KAMPALA
 5 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
PWM 0kg SAMNUT 23
 6 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
PWM 0kg KAMPALA
 7 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
PWM 10kg SAMNUT 23
 8 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
PWM 10kg KAMPALA
 9 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
AOM 0kg SAMNUT 23
10 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
AOM 0kg KAMPALA
11 12153    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
AOM 10kg SAMNUT 23
12 11164    -99      63      60       S       R      50       0       2     -99     -99     -99     -99       0
AOM 10kg KAMPALA

*IRRIGATION AND WATER MANAGEMENT
@I  EFIR  IDEP  ITHR  IEPT  IOFF  IAME  IAMT IRNAME
 1     1    30    50   100 GS000 IR001    10 -99
@I IDATE  IROP IRVAL
 1 12101   -99   -99
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*FERTILIZERS (INORGANIC)
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMO  FOCD FERNAME
 1 12160 FE001 AP001     1     0     0     0   -99   -99   -99 NPK 0kg SAMNUT 23
 2 12160 FE001 AP001     1     0     0     0   -99   -99   -99 NPK 0kg KAMPALA
 3 12160 FE001 AP001     1    20    20    20   -99   -99   -99 NPK 20kg SAMNUT 23
 4 12160 FE001 AP001     1    20    20    20   -99   -99   -99 NPK 20kg KAMPALA
 5 12136 FE001 AP001     1     0     0     0   -99   -99   -99 OGN 0kg SAMNUT 23
 6 12136 FE001 AP001     1     0     0     0   -99   -99   -99 OGN 0kg KAMPALA
 7 12136 FE001 AP001     1     0     0     0   -99   -99   -99 OGN 20kg SAMNUT 23
 8 12136 FE001 AP001     1     0     0     0   -99   -99   -99 OGN 20kg KAMPALA
 9 12136 FE001 AP001     1     0     0     0   -99   -99   -99 ORM 0kg SAMNUT 23
10 12136 FE001 AP001     1     0     0     0   -99   -99   -99 ORM 0kg KAMPALA
11 12136 FE001 AP001     1     0     0     0   -99   -99   -99 ORM 20kg SAMNUT 23
12 12136 FE001 AP001     1     0     0     0   -99   -99   -99 ORM 20kg KAMPALA

*RESIDUES AND ORGANIC FERTILIZER
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP  RMET RENAME
 1 12136 RE006   -99  1.19   -99   -99   -99     5 AP001 Poultry watse manure, PWM
 2 12136 RE005   -99     3   2.5   1.5   -99     5 AP001 Aleshinloye organmineral fertilizer, AOM
 3 12150   -99   -99   -99   -99   -99   -99   -99   -99 Poultry watse manure, PWM
 4 12150   -99   -99   -99   -99   -99   -99   -99   -99 Aleshinloye organmineral fertilizer, AOM

*CHEMICAL APPLICATIONS
@C CDATE CHCOD CHAMT  CHME CHDEP   CHT..CHNAME
 1 12056   -99   -99   -99   -99   -99  -99

*TILLAGE AND ROTATIONS
@T TDATE TIMPL  TDEP TNAME
 1 12174   -99   -99 -99

*ENVIRONMENT MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND ENVNAME
 1 12056 A   0 A   0 A   0 A   0 A 0.0 A   0 A   0 A   0

*HARVEST DETAILS
@H HDATE  HSTG  HCOM HSIZE   HPC  HBPC HNAME
 1 12279 GS016     H     M   100     0 Sowing date 1
 2 12279 GS016     H     M   100     0 Sowing date 2

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME.................... SMODEL
 1 GE              1     1     S 12101  2150 DEFAULT SIMULATION CONTR  CRGRO
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL   CO2
 1 OP              Y     Y     Y     N     N     N     N     N     M
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM MESEV MESOL
 1 ME              M     M     E     R     S     L     R     1     G     S     2
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     N     N     N     R
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT VBOSE CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     N     Y     Y     N     Y     Y     N     N

@  AUTOMATIC MANAGEMENT
@N SOWING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          12153 12153    40   100    30    40    10
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10     1
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA          12279 12279    10    00
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