DETERMINATION OF OPTIMUM SOWING WINDOWS OF MILLET (*Pennisetum glaucum* L.R.Br) VARIETIES IN NIGER REPUBLIC USING CERES-MILLET MODEL

BY

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SPS/14/PAG/00005

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FEBRUARY, 2020

DECLARATION

I hereby declare that this project work is the product of my own research undertaken by me under the supervision of Prof. J. M. Jibrin, and Dr. M. Garba. It has not been presented elsewhere for the award of a degree or certificate. All sources of reference materials had been duly acknowledged.

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CERTIFICATION

This is to certify that this research work and the subsequent preparation of the thesis by ALI MALAM LABO MOHAMED (SPS/14/PAG/00005) were carried out under our supervision.

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APPROVAL

This thesis titled ‘’Determination of Optimum Sowing Windows of Millet (*Pennisetum glaucum* L. R. Br.) Varieties in Niger Republic Using CERES-MILLET MODEL’’ by ALI MALAM LABO MOHAMED has been examined and is approved for the award of the Degree of Doctor of Philosophy (Ph. D) in Agronomy (Crops and Cropping System in the Drylands).

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DEDICATION

This research work is dedicated to my parents, Grandparents and to my entire family for what they all meant to me.

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ABSTRACT

Field experiments were conducted at N'Dounga Research Station during the 2016 and 2017 rainy seasons and on farmers field during 2017 rainy season to determine the optimum sowing windows and select appropriate pearl millet variety adaptable to the study area. The data on days to 50 % flowering, physiological maturity, above ground biomass and grain yields were collected to calibrate and evaluate the CERES-Millet model for simulating sowing windows in Niger Republic. The treatments for the on station trial consisted of two sowing windows (late June and mid-July) and four varieties (HKP, ZATIB, CIVT and H80-10 GR). These were arranged in split plot design with three replications. Sowing window was allocated to the main plot while variety in the subplot. However, for the on farm field trial, the same varieties were sown at four different sowing windows (mid-June, Early-July, mid-July and late-July) in twelve farmers' field being replicates. Data were collected on plant height, days to 50 % flowering, above ground biomass, number of panicles harvest index and grain yield. These were subjected to analysis of variance using JMP software. Significantly different means were separated using Student New-mankeuls (SNK) Test. On the other hand, the DSSAT model was calibrated to predict the growth and yield of millet in Niger Republic using 2016 data on station trial and subsequently, it proceeded with the evaluation with independent data (2017) on station. The model was run for nine sowing windows using long term historical weather data from 1983 to 2017 to determine the optimum sowing windows. Results of the study showed that sowing had significant effect on above ground biomass, plant height and grain yields. Similarly, higher plant height was recorded from plants that were sown in late June. However, higher grain yield was recorded from the crops that were sown in mid-June on farmers field. Higher growth, yield components and grain yield were also recorded from ZATIB compared to all other varieties. Based on the results outcome, it is suggested that ZATIB be sown in mid-June for a desired yield on farmers' field. The results for model calibration showed that simulated growth, development and yield of millet were in a good agreement with their corresponding observed values. The results for the calibration and evaluation showed that normalized root mean square error (RMSEn) were less than 10 %. The values of d-index were also within the acceptable range for all the parameters. Therefore, CERES-Millet model is robust to satisfactorily simulate millet growth and yield in Niger Republic. Seasonal analysis revealed that sowing should be done from early June to mid June for ZATIB and H80-10 GR varieties. However, it should be done from early June to late June for CIVT and mid June to early July for HKP.

CHAPTER ONE
1.0 INTRODUCTION

1.1 BACKGROUND

Pearl millet [*Pennisetum glaucum* (L.) R. Br.] (also known under synonyms: *P. americanum* (L.) Leeke or *P. typhoides* (Burm.) Stapf and C.E. Hubb.), an important cereal of traditional farming systems in tropical and subtropical Asia and Sub-Saharan Africa. It was one of the most important cereal crops in the 1980s and early 1990s classified as the sixth most important crop after wheat, rice, maize, barley and sorghum regarding annual global production (FAO, 1992). Recent literature has shown a decline in millet production worldwide, currently ranked out of the 8 most important cereal crop in the world (Statista, 2018). Pearl millet is an annual, allogamous, cross-pollinated, diploid belonging to the Poaceae family, subfamily Panicoideae, tribe Paniceae, subtribe Panicinae, section Penicillaria and genus Pennisetum. The genus Pennisetum contains about 140 species (Brunken *et al*., 1977). The origin of pearl millet is estimated to be located in the central part of the Sahara Desert in West Africa. Archeological evidence for this is the discovery of a large number of seeds in the ruins of Villini in northern Ghana. The result of dating by radioisotope carbon has enabled the estimation that the plant may have been cultivated in this region about 2500 to 3500 BC (JAICAF, 2009). In Africa, the crop is grown in the Sahelian and Sudanian zones, especially in Nigeria and Niger Republic, although it has local importance in many other countries including parts of Southern Africa. Millet is a staple food and a major source of energy and protein for millions of people. It has many nutritional and medicinal functions (Yang *et al.,* 2001). It is extremely tolerant to drought and is well adapted to poor soils. (IRD, 2009). The major millet producing countries in West Africa in 2017 were Nigeria (54%), Niger (20%) and Mali (9%) of total production in the region.

Niger in the Western Sahel relies for much of its food production on rain-fed pearl millet cultivation, which is still carried out in an extensive system. Pearl millet been the main staple food remain dominant in agricultural production systems, contributing about 75% of national production (Amadou *et al.,* 1999). Even with minimal rainfall, millet will typically still produce reasonable yield (Ravelo, 2000). In many areas where pearl millet is the staple food nothing else will grow to provide food for humans.

The use of pearl millet as a food crop is limited to the developing countries in Asia and Africa. It is estimated that over 93% of pearl millet grain is used as food, the remainder being divided between animal and poultry feed (7%). Other uses include bakery products and snacks, to a very limited extent. The crop residue (stover) after grain harvest is a valuable source of fodder for livestock (ICRISAT, 2007). As a feed, grain pearl millet is comparable to maize but superior to sorghum (Andrews and Kumar 1993). Pearl millet was 1 to 2 percentage point higher in crude protein, 35 % more lysine and deficient in essential amino acids compared with sorghum (Rooney and McDonough, 1987).

The Decision Support System for Agro-technology Transfer (DSSAT) (Hoogenboom *et al*., 2004) is a comprehensive decision support system (DSS) for assessing management options. The Decision Support System for Agro-technological Transfer (DSSAT) is a highly-ranked crop model capable of simulating different cropping strategies in semi-arid agro-climatic regions. The cropping system simulation (CSM) (Jones *et al*., 2003; Hoogenboom *et al*., 2004), is process-oriented, dynamic and simulates growth, development and yield for more than 25 different crops. The crop simulation models simulate growth, development and yield, the soil and plant water, nitrogen and carbon balances. DSSAT and its crop simulation models have been used for a wide range of applications, including on-farm and precision management to regional assessments of the impact due to climate change. Within DSSAT, the relevant models are CERES, which includes the dryland cereal crops and CROPGRO for grain legumes (Jones *et al*., 2003). CERES and CROPGRO differ considerably in their level of detail, degree of modularity and underlying physiological assumptions. Both CERES and

CROPGRO models have undergone some testing and application in semi-arid West Africa (Hoogenboom *et al*., 2004).

1.2 PROBLEM STATEMENT

The issue of low crop productivity is a serious challenge affecting sub Saharan African countries particularly Niger Republic where the annual rainfall ranges between 250- and 650-mm. Niger is the third highest millet producing country in the world with production figures of 3,790,028 t, which occurs as result of increase of land areas rather than intensification (FAOSTAT, 2017). These areas are further characterized by variable and irregular rainfall, short rainy season and high evaporative demand (Mohamed *et al*., 2002). The variable rainfall and the short rainy season are identified as the most important reasons for the loss of food self-sufficiency in Niger. Pearl millet is generally produced in Niger on sandy soils, which are inherently low in fertility.

Drought is perhaps the most important abiotic stress limiting crop productivity in rainfed agriculture around the world (Nguyen, 2008). Since drought affect very large areas for period of months or years, it has devastating effects on agricultural production, leading to food shortages and food insecurity, which leads to famine and hunger. In Niger Republic, agriculture is the major driver of the economy. Drought causes yield reductions, which affects money flow from agriculture to other sectors thereby leading to not just hunger but total collapse of the economy. Dry spells at the beginning of the season usually result in multiple plantings and low or no yields leading to low food security index. In the same vein, end of season drought could bring about water stress at critical periods of need during the reproductive stages of most crops thus resulting in crop failures and shrinking of yield.

Most of the farmers harvest low yield in Niger Republic because they do not have access to improved, drought and heat tolerant cultivars that can give good yield in the face of climatic exigencies.

Farmers do not adopt appropriate sowing dates in the context of the irregular rainfall distribution, this is worrisome to the small producers in general. A major problem of rain-fed agriculture in the semi- arid regions with the short rainy season is how to determine the optimum sowing date for individual crop (Bashir *et al*., 2015).

1.3 JUSTIFICATION OF THE STUDY

The main staple crop in Niger is pearl millet. If a harvest of this major crop fails, Niger faces several problems with regard to food security. Sowing date is one of the most important management factors affecting cereal production and quality (Ferrise *et al*., 2010). Sowing on time ensures that vegetative growth occurs during a period of satisfactory temperature and high levels of solar radiation, and guarantees that grain filling occurs when milder autumn temperature is more likely, hence good grain quality is achieved (Gaire *et al*., 2013). Farmers are mainly poor and as such rely heavily on rainfed agriculture. Crop yields are strongly dependent on, and constrained by what has been recently recognized (after many decades of blaming only water stress) as the most important asset-soil fertility. The unfavorable climate and low fertility create intense pressure on land even at relatively low population densities (Reardon *et al*., 1997).

Crop simulation can be an alternative research tool for determining optimum sowing dates and other management practices. Farmers need to decide in order to plant and manage their farms efficiently. Strategic and tactical decisions such as when to plant, what cultivar to use, when and in what manner to fertilize and irrigate and when to harvest are frequently made based on rule of thumbs and years of growing experience and advice from agricultural consultants. However, identifying major yield limiting factors and appropriate crop management practices require many years of experimentation in order to be able to make meaningful deductions. This can be expensive and very time consuming (MacCarthy *et al*., 2010). This situation calls for tools that can support decision-making. Such decision support tools (DSTs) can assist with the diagnosis and analysis of problems and opportunities related to water. Crop modelling can assist in exploring the production risks and the yield uncertainty associated with rainfall variability but requires empirical data suitable for model testing within a specific system and environment. Crop modelling offers an effective way to understand and analyze the consequences of management options under variable climatic conditions. For example, the Agricultural Production Systems Simulator (Keating *et al*., 2003) has been used successfully to simulate crops growth and development for a wide range of climatic conditions (Fosu-Mensah *et al*., 2012; Archontoulis *et al*., 2014) and management practices (Fosu-Mensah *et al.*, 2012). Crop simulation models are reliable and robust tools to understand the influence of biophysical rainfall variability on crop yield. This can be used to simulate various planting scenarios, which will assist decision makers, farmers, and extension agents to know which varieties to plant and at what time. Knowing this will increase the productivity of millet despite the variability. However, the models like DSSAT if well calibrated and validated can be used by researchers to solve pearl millet farming problems including climate change impacts in Niger Republic.

1.4 OBJECTIVES OF THE STUDY

The objectives of the study were to:

1 evaluate the effect of sowing windows on the growth and yield of millet varieties;

2 calibrate and evaluate CERES-Millet model for simulating sowing windows of millet varieties;

3 carry out a seasonal analysis with CERES-Millet model to establish the optimum sowing window of millet varieties at N’Dounga.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BOTANY AND DEVELOPMENT OF PEARL MILLET

Pearl millet (*Pennisetum glaucum* (L) R. Br) is an annual cereal. It belongs to the PACMAD (Panicoidae, Arundinoideae, Chloridoideae, Micrairoideae, Aristidoideae and Danthonioideae) clade (Edwards, 2012). The wide variability existing amongst the pearl millet species led to the early classification of different forms across species. It is now well known that all these forms belong to a single species, in the sense of inter fecundity, but history left a few names by which the pearl millet species are called in old publications. The most common are: *Pennisetum typhoides, Pennisetum americanum, and Pennisetum glaucum* the latter being the actual binomial name of the species. The plant height varies from 0.5 to 3 meters at maturity and can even reach 4 meters in wetlands (Guigaz, 2002). Wild relatives have many tillers and tillering is still frequent in domesticated millet. The leaves are lance-like and are 20 to 100 cm long 5 to 50 mm wide. The Spike called panicle that held the seeds, often measuring 10 to over 100 cm long. Seed size is generally around 2 to 5 mm with a large existing variability. Seed shape varies from globular to lanceolate and its weight goes from 5 to 20 mg (Andrew and Kumar, 1992). The growth potential of any crop is a function of its growth rate and cycle. Pearl millet is a monocot, short cycled and small seed size crop. The growth and phenology of pearl millet is usually divided into three phases indicating growth stages (GS1, GS2 and GS3). The first growth phase (GS1) includes seedling establishment, tillering and panicle initiation. Seedling development occurs from two to four weeks followed by development of stalk. Primary tillers development is started after 20–25 days of germination and then secondary tillers raised from primary at all stages of apical development. The second growth phase (GS2) includes elongation of leaves, floral initiation in tillers and stem elongation. Flowering is occurred in 45 and 59 days after germination, respectively. While flag leaf becomes visible after 50 days of germination. The third growth phase (GS3) starts with fertilization of florets, seed setting/grain filling and maturity of plant. Seed setting/ grain formation is started from 60–65 days after germination and completed within 9–10 days. The crop accomplishes its physiological maturity from 90–95 days after germination depending upon weather conditions and variety (Ullah *et al*., 2016).

2.2 CULTIVATED AREA OF PEARL MILLET

The total area cultivated with pearl millet worldwide is 26 million ha, mainly by millions of resource-poor and subsistence farmers in Asia and Africa (Rai *et al*., 2009; Upadhyaya *et al*., 2011) and accounting for 95% of the production and acreage (Basavaraj *et al*., 2010). Pearl millet area in Africa is 14 million ha with annual production of 10.5 million tones. Millet production is distributed differentially among a large number of African countries; largest producers being in West Africa led by Nigeria, Niger, Burkina Faso, Mali, Senegal and Sudan. Niger is the third highest millet producer in the world with 3,790,028 tons but the production is still low because of the variability of rainfall pattern (FAOSTAT, 2017). The agricultural land area in Niger Republic allocated to millet production has increased from one million to about seven million hectares from 1961 to 2016 (Figure 1). The increase of millet production was attributed to increase of agricultural land area. (FAOSTAT, 2017). A great increase in population during the last 40 years resulted in land pressure which makes alternative crop production like fallow and shifting cultivation systems no longer possible (Takanori *et al*., 2002). Maradi region has the highest acreage of millet followed by Tillabery, Tahoua and Zinder, Dosso, Diffa, Niamey and Agadez (International Finance Corporation, 2013).

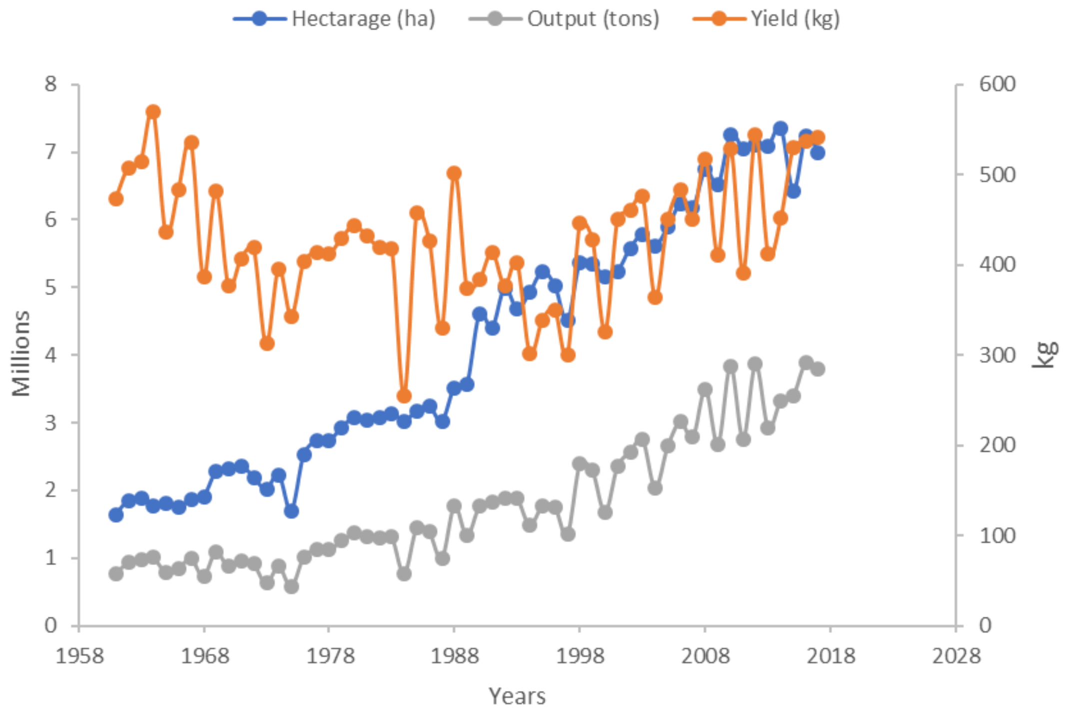

Figure 1: Long Term Trend of Millet Yield and Land Area from 1961 to 2016 in Niger Republic (FAOSTAT, 2017).

2.3 NUTRITIONAL VALUES AND MEDICINAL USES

Pearl millet has an excellent nutritional composition and is a rich source of energy (361 Kcal/100g) as compared to staple cereals like rice (345 Kcal/100g) and wheat (346 Kcal/100g) (Malik, 2015). Furthermore, it is generally equivalent to maize and superior to sorghum in terms of protein content, quality efficient ratio, and metabolizable energy (Vadez, 2012). Although it is deficient in essential amino acids, it contains 35% more lysine as compared to sorghum (Rooney and McDonough, 1987). Added to that, it also does not contain condensed polyphenols which are a major cause of decrease digestibility, for example tannins in sorghum (Jambunathan and Subramanian; 1988, Malik 2015). Pearl millet grains contains 5-6% oil and also rich in important micronutrients like iron and zinc (Jambunathan and Subramanian; 1988, Malik 2015).

Hence, Pearl millet significantly contributes towards protein, iron, and zinc uptake as well as serves as the cheapest source of energy to low-income consumer groups of semi-arid tropic including India. Millet is a very rich source of phytochemicals and micronutrients (Singh *et al.*, 2012) as compared to other major cereals such as wheat and rice. Pearl millet is reported to be found clearly rich in resistant starch, soluble and insoluble dietary fibers, minerals and antioxidants. The high fiber content of pearl millet can make it a potential component in the diets of patients suffering from constipation, obesity, and gallstones (Malik, 2015). Since pearl millet grains are gluten free and have low glycemic index, they can be very beneficial for persons with celiac disease. With diabetes, hypertension and cardiovascular disease becoming more prevalent, as gifts of newly acquired life-styles and food habits, millets have returned as a viable option to live healthy life and can reduce the incidence of these lifestyle diseases. Millets have many nutritional, nutraceutical and health promoting properties especially the high fiber content, nature of starch has major role in reducing the risk of diabetes other related diseases. Indeed, millets act as a prebiotic feeding micro-flora in our inner ecosystem. Millet will hydrate our colon to keep us from being constipated. The high levels of tryptophan in millet produce serotonin, which is calming to our moods. Niacin in millet can help lower cholesterol. Millet consumption decreases triglycerides and C-reactive protein, thereby preventing cardiovascular disease. All millet varieties show high antioxidant activity. Thus, pearl millet grains have immense medicinal value and should be aggressively promoted dieticians and nutritionist so that large section of society could be benefited (ICAR-Indian Institute of Millets Research 2018).

Due to its rich composition of minerals and proteins, Pear millet has many health benefits. Pearl millet has the highest protein content. It contains many essential minerals like magnesium, phosphorus, zinc etc. It contains amino acids and vitamins also which contribute to its therapeutic properties.

- Beneficial in treating stomach ulcers: pearl millet is recommended for curing stomach ulcers. The most common causes for stomach ulcers is excess acidity in the stomach after food intake. Pearl millet is one of the very few foods that turns the stomach alkaline and prevents formation of stomach ulcers or reduces the effect of ulcers.
- Beneficial for Heart health: The lignin and phytonutrients in millet act as strong antioxidants thus preventing heart related diseases. This is why, pearl millet is considered good for heart health. High amounts of magnesium present in pearl millet have been shown to control blood pressure and relieve heart stress.
- Beneficial due to high amount of magnesium: Pearl millet contains high concentration of magnesium, which helps reduce severity of respiratory problems for asthma patients and is effective in reducing migraine attacks.
- Helps in bone growth development and repair: Pearl millet has a large amount of phosphorus. Phosphorus is very essential for bone growth and development as well as for development of Adenosine triphosphate (ATP) which is the energy currency of our body.

• Reduces cancer risk: All millets are known to reduce the risk of cancer occurrence and pearl millet is no exception. Though scientists are not sure how this is, they believe it has something to do with the high amount of magnesium and the compound phytates.

• Helps in weight loss: The biggest challenge faced by people trying to lose weight is controlling their food intake. Pearl millet can aid the process of weight loss, as it is high in fiber content. Owing to its fiber content it takes longer for the grain to move from the stomach to the intestines. This way, pearl millet satiates hunger for a long period of time and thus helps in lowering the overall consumption of food.

• Beneficial for diabetes: Pearl millet is very effective for controlling diabetes. Because of its high fiber content, it digests slowly and releases glucose into the blood at a slower rate as compared to other foods. This effectively helps in maintaining the blood sugar level constant in diabetes patients for a long period of time.

• Beneficial for Celiac Disease: Celiac disease is a condition in which a person cannot tolerate even a small amount of gluten in his/her diet. Unfortunately, most of the common grains like rice, wheat, etc have gluten present in them. Millets are the only type of grains, which do not have any gluten present. Thus, this is suitable for people with celiac disease.

• Reduces Cholesterol: It is common knowledge that Pearl Millet is suggested for people suffering from high cholesterol levels. Pearl millet contains a type of phytochemical called phytic acid, which is believed to increase cholesterol metabolism and stabilize the levels of cholesterol in the body (Miller, 2001; Edge *et al*., 2005)**.**

2.4 PEARL MILLET AS FEED AND FOOD

Foods prepared from millets are several and differ from country to country and occasionally from region to region. In West Africa, the main food dishes from pearl millet vary by country. The stiff or thick porridges are the most popular, commonly consumed dishes in all the Sahelian countries across the region. The steam-cooked product ‘Couscous’ is more commonly consumed in the Francophone countries including Senegal, Mali, Guinea, Burkina Faso, Niger and Chad. The thin porridge ‘bouillie’ is also popular in these countries. Three countries among others have unique foods from pearl millet specific to them. In Nigeria and Niger, the thin porridge ‘Fourra’ is very popular while ‘Soungouf; ‘Sankhal’ and ‘Araw’ are very popular in Senegal (ICAR-Indian Institute of Millets Research, 2018). In Niger, pearl millet [*Pennisetum glaucum* (L.) R.Br.], the main staple food, dominates in the agricultural production system and contributes about 75% to the national cereal production constituting up to 90% of the cropped area (Ben-Mohamed *et al*., 2002).

Pearl millet is used by livestock producers for grazing silage, hay, and green chop (Newman *et al.,* 2010). It is the preferred choice for forage when compared to similar warm-season millet such as brown top, Japanese, and proso millet. Pearl millet production for grain is mainly for use in poultry feed (Myers, 2002). It is considered equal to or better than corn-soybean broiler chicken feed (Gulia *et al.,* 2007). Unlike sorghum, pearl millet does not produce prussic acid or have tannins, so is safe to feed horses (Newman *et al.,* 2010). Swine have been shown to reach slaughter weight earlier on pearl millet than on a corn diet (Gulia *et al.,* 2007). Terril *et al.,* (1998) found that pearl millet could be effectively used as substitute for corn feed in goat diets.

Pearl millet is the staple diet for farm households in the world’s poorest countries and among the poorest people. It supplies 80-90% of the calories for several million of the poor people in the semi-arid tropics of world (Burton *et al,*. 1972).

2.5 WEEDS, PESTS AND DISEASES

Weed: Striga (*Striga hermonthica*), is very important weed in pearl millet cultivation. Unlike other weeds, which compete for water and nutrients *Striga*, as a root parasite literally sucks the life out of pearl millet plants. In doing so, growth is stunted and yields are greatly reduced. Its incidence increases with phosphorus deficiency and the shortage of this element for the crop is therefore a double punishment because, on top of lacking an essential micronutrient, it is also more likely to be parasitized. Striga has a strong impact on yield, going up to 100% of yield loss, and it affects about 40% of the cereal-producing area in sub-Saharan Africa (Gurney *et. al*,. 2006). The parasitic plant Striga (*Striga hermonthica*) is a widespread problem for smallholders growing millet and sorghum in the Sahel (Aliyu and Emechebe, 2006).

An important constraint on agricultural intensification is the impact of pests and disease on crops. Few farmers in Africa can afford to use chemical herbicides or pesticides so their farms are consequently at risk of damage. Pests can also cause significant damage, particularly if the climatic conditions are favourable for the development of large swarms. For example, locust swarms caused widespread local damage to crops across West Africa in 2004 (FAO, 2004).

Pearl millet production is confronted with relatively few biotic stresses as compared to other crops. Among the diseases, downy mildew (*Sclerospora graminicola*) is the most important constraint, especially on genetically uniform hybrids. Other diseases include smut (*Moesziomyces penicillariae*), rust (*Puccinia substriata* var. *indica*), blast (*Pyricularia grisea*) and ergot (*Claviceps fusiformis*). Bacterial diseases as bacterial spot (*Pseudomonas syringae*).and bacterial leaf streak (*Xanthomonas campestris pv. Pennamericanum*).

2.6 ABIOTIC STRESS

Pearl millet is mostly (>92 %) cultivated under rainfed conditions in the arid and semi-arid regions of country where annual rainfall ranges from (300 to 600 mm), most of which is received during June to September (Shapiro and Sanders, 1998; Abdoulaye and Sanders, 2005). Owing to its cultivation in rainfed systems, its cultivation is challenged by several abiotic stresses. Among abiotic constraints, drought is the most important abiotic stress limiting crop productivity in rainfed agriculture in Niger Republic. The rainfall in Niger is usually inadequate, short in duration, poorly disturbed and highly variable between and within the seasons. Hence, the development of pearl millet cultivars suitable for rainfed and unpredictable low-rainfall situations has been a priority area in crop management. Average rainy season maximum and minimum air temperatures (°C) in India are around 35 °C and 25 °C, respectively. The maximum air temperature around 43 °C is common in the beginning of rainy season crop. The soil surface temperatures during germination may reach 60–62 °C in the Indian arid zone. Formation of crust is also common in soil with high-silt contents. The low millet yields have been attributed to limited annual rainfall considering the high annual potential evapotranspiration (2000-2300 mm) associated with frequent drought spells and high inter-annual rainfall variability (Shapiro and Sanders, 1998; Abdoulaye and Sanders, 2005). Poor soil fertility management high evaporation demand and low native soil fertility limit millet production in Niger. Changing the climate may cause larger losses of nitrogen leaching. Pearl millet is mostly grown in areas where the rainfall does not exceed 800 mm per year the lower limit being around 150 mm per year. The soil is usually sandy and therefore drains water quickly, deep, with low soil organic matter (SOM) content and with low phosphorus (P) level. It is often grown in areas where no other cereal would grow. A number of abiotic or biotic factors limit pearl millet yield.

2.7 MILLETS ARE CLIMATE RESILIENT CROPS

Millets being C4 crops are efficient users of water and nutrients for growth. They are highly tolerant to warmer temperatures and to some extent flooding. Their tolerance to salinity results in germination and seedling stages results in very good plant stand. As millets possess physiological mechanisms for rapid recovery from abiotic stresses like drought and heat, they are most promising sources for food during climate change.

2.8 EFFECT OF SOWING DATES

With prolonged dry spells at the beginning of the rainy season, the risk of the re-seeding and crop failures during the first stage of plant development is still a major concern of the small holder farming system in Niger republic. Consequently strategic, agricultural decision such as planting dates help reduce the need for crop re-seeding and crop failures and are, therefore the key element in agricultural decision support (Waongo *et al*., 2014).

Appropriate crop sowing window estimation is crucial for rainfed agriculture and a challenging task for scientists in Sub Saharan Africa. Efforts have been made to estimate the suitable time for planting crops. approaches which use crop-generic assumptions in combination with the onset of the rainy season are the most often used in SSA. Waongo *et al.,* (2014) highlighted that appropriate planting date aims to minimize water stress during the entire growing period to significantly increase the crop production. Waongo *et al.* (2014) stressed that optimized planting dates (OPDs) have the potential to improve crop production in Sub Saharan Africa.

Studies have shown that planting too early leads to uneven seedling emergence because of limited soil moisture content and high temperatures during the dry season (Beiragi *et al*., 2011). Norwood, (2001), suggested that farmers should plant on more than one planting date in order to safeguard against unpredicted seasons.

Leila *et al.* (2008) reported that delaying planting from 15th June significantly decreased panicle weight in millet. A decrease in panicle weight for late planting dates can be attributed to changes in the duration of light interception. Early sowing is associated to long day-lengths (photoperiods) and high air temperatures that may affect millet growth and production. In fact, photoperiods are long (13h12mn to 13h40mn) during the reasonable sowing period and decrease significantly only after the end of July (Sivakumar, 1990).

Abd–El-Lattif (2011), reported that decline in both temperature and length of photoperiod over successive sowing dates from July to September had a drastic effect on phonology and yield potentials of the pearl millet cultivars. Meanwhile, Maas *et al.* (2008) found that planting dates was significant for yield and height. Planting date affected not only the time from planting to flowering but from flowering to physiological maturity of grain (Clark, 1997).

Siddig *et al*. (2013) indicated that sowing date had significant effect ($P \leq 0.05$) on 1000 - grain weight. Whereas, yield was significantly influenced ($P \leq 0.05$) by sowing date, early planting resulted in best yield (316.9 and 355.6 kg ⁄ fed) compared with late planting (244.8 and 289.4 kg ⁄ fed) Wailare *et al* (2009) observed that sowing date did not have significant influence on plant height, panicle weight, number of panicles per plot, panicle length, panicle diameter, and weight of 1000-grains but stover yield and grain yield per hectare were both significantly influenced by sowing date. Similar results were reported by Deshmukh *et al*., (2009) that the different dates of sowing significantly influenced the grain yield of pearl millet during all the years of experimentation and on pooled basis. In a study, it was shown that late planting influenced the yield and distribution of pearl millet forage. In addition, early planting increased seed number per unit area without reducing its weight and improved yield.

Khan (2003) observed a negative effect of delayed sowing on yield components of maize. They noted that delayed sowing resulted in reduced number of grains per row, 100-grain weight and grain yield. The planting date can have an important influence on the growth of a crop and the final yield particularly in locations with strong seasonal climates. In the Sahel planting too early can result in poor establishment of the crop, while planting too late can lead to drought stress during grain filling (Omer *et al.*,1988). Hanna and Wright (1995) looked at the effects of planting date on three hybrids differing for maturity and rust resistance. Date of planting was significant for both height and yield with June plantings having lower yields than May plantings. Much of this yield reduction was attributed to rust susceptibility as rust inoculum becomes more prevalent later in the season (Wilson *et al.*, 1995). Planting date influences sorghum through temperature and soil available water at seed germination vegetative and reproductive success, and hence, yield and yield components.

Heiniger *et al*. (1997) stated that early planting may result in an unfavorable soil environment, which may affect emergence rate, and result on poor stand establishment and possibly replanting. (Meaking, 1979). Crop sown late is normally affected by moisture stress hence the attempt to know the best time for planting the crop and the best planting method and sowing date. In the Northern Guinea savanna of Nigeria sowing date and planting method affect the crop population, which must be optimal in order to compete with weeds and absorb nutrient and moisture for good growth and development. Sowing time is the most important non-monetary input influencing crop yield. Sowing at optimum time improves the productivity by providing suitable environment at all the growth stages (Upadhyay *et al.*, 2001).

Earlier planting dates tended to extend the time from planting to growing point differentiation as well as the time from growing point differentiation to half bloom (Kambal and Webster, 1965), but reduce the time from half-bloom to physiological maturity of grain and expand the total number of days from planting to physiological maturity of grain (1961).

Soler *et al.* (2008) reported that the CSM-CERES-Millet model was able to accurately simulate growth, development and yield of millet grown in these two contrasting environment and under different management practices that included several genotypes and different nitrogen fertilizer application rate, the optimum planting date to obtain the maximum yield was between 13 and 23 May for variety HKP, while for the other varieties the planting dates were between 23 May and 2 June, the planting date analysis showed that the highest simulated yield was obtained, on average, between 23 May and 2 June, the planting date analysis showed that the highest simulated yield was obtained, on average, between 19 and 29 June for hybrid 59022A 89-083 and 1361M 6rm.

Adnan *et al*. (2017) stated that the CERES-MAIZE Model suggests that both early and extra-early varieties yield higher when planted in mid to late June in Sudan Savanna (SS), and mid-late July in Northern Guinea Savannas (NGS). While both varieties yield higher when planted in mid to late July in the NGS of Nigeria. Delays in planting to August can result in significant yield reductions. In both SS and NGS, planting in May and August are quite risky and could lead to total crop failure. Delaying the sowing date beyond the optimum sowing date led to reduced fodder and grain production because of the existence of low temperatures during vegetative stage which decreases the crop growth rate as it was simulated by the CSM-CERES-models of maize, millet and sorghum. The simulation of phenological response to different sowing dates was relatively poor, particularly for flowering time. This might be due to the use of fixed thermal time targets for each of the phases before flowering in the APSIM model. These thermal time targets are not directly linked to leaf initiation and appearance.

CSM–CERES-Pearl millet model was able to simulate accurately growth, development, and forage accumulation for four forage pearl millet cultivars grown in three Brazilian semi-arid locations under rainfed conditions

2.9 THE MOST COMMON PEARL MILLET VARIETIES USED IN NIGER

The variety HKP (90-95 days) was developed by INRAN. It is a variety with long panicles (55 to 60 cm) widely popular in all the millic zones of Niger. It is more particularly suited to the Northern Sahelian Zone of Niger where its potential grain yield reaches 1.300 to 1.800 kg ha^{-1}. Variety ZATIB (100-105 days) which derived from a cross made by INRAN between two varieties locally called ZANFARWA and TCHININ BAJININ in the region of Maradi in Niger. It is a semi-late variety which is popularly cultivated in fairly well-watered areas of Niger. It is characterized by such long panicles, but a slightly larger than those of HKP. It is better suited to southern Sahelian zone and offers a potential grain yield generally higher than that of HKP (1500 to 2000 kg ha^{-1}). The variety MTDO (120 to 150 days) is adapted to the North zone of Sudan. It produces panicles that are longer than those of HKP and ZATIB (85 to 95 cm). It has the best potential grain (2000 to 2500 kg ha^{-1}) of all the varieties of Millet cultivated in Niger, if the length of growing season rain allows it to complete its life cycle in good water conditions. SOSAT variety (90 days) is grown in the area where annual rainfall is about 350 to 600 mm on sandy and semi-clay soil. The panilces is about 28 cm and yield is about 1.5 to 2 t ha$^{-1.}$ The H80 10 GR variety (80 to 85 days) is grown where the rainfall is about 300 to 400 mm and yield is about 2.5 t ha^{-1}.

2.10 CONSTRAINTS TO ADOPTION OF DROUGHT TOLERANT MILLET VARIETIES

Constraints to the adoption of drought tolerant millet variety are in no way limited to physical and biological factors but socio-economic and cultural factors could have direct effect on adoption (Jibrin, 2010). Factors like education could enhance adoption of agricultural technologies through greater access to information. Guendel (1998) studied selected factors affecting adoption millet varieties by small-scale farmers in the semi-arid Mogotio district of Kenya. The study reported that farmers would choose to adopt a new technology when certain type of information is available either from other farmers, extension staffs and media among others. Information from extension workers are particularly important for the adoption of new technologies but not all extension agents are motivated to do their jobs well due to limiting facilities that affect their performance. Okeke and Onogwu (2014) reported that distance to source of technology (where the improved seeds are purchased) had a negative and significant influence on the adoption of improved pearl millet varieties by farmers. This implies that farmers who live closer to the source of technology are more likely to adopt the technology compared to farmers who are farther away from the sources of technology. They further reported that this trend is expected, since most of farmers were rural farmers who can hardly travel to distant centre where the technologies are available.

2.11 CROP MODELING

Modeling is the use of equations or sets of equations to represent the behavior of a system. In fact, crop models are computers programmes that mimic the growth and development of crop (Patricia *et al*., 2012). A model may be defined as a representation of the essential aspects of an existing system or a system to be constructed which presents knowledge of that system in a usable form.

2.11.1 Types of Models

The models are classified into different group among them:

Empirical models: These are direct descriptions of observed data and are generally expressed as regression equations (with one or a few factors) and are used to estimate the final yield. This approach is primarily one of examining the data, deciding on an equation or set of equation and fitting them to data.

Mechanistic models: describes the behavior of the system in terms of lower-level attributes. It can mimic relevant physical, chemical or biological processes and used to describe how and why a particular response occurs

Stochastic models: When variation and uncertainty reach a high level, it becomes advisable to develop a stochastic model that gives an expected mean value as well as the associated variance. However, stochastic models tend to be technically difficult to handle and can quickly become complex. Hence, it is advisable to attempt to solve the problem with a deterministic approach initially and to attempt the stochastic approach only if the results are not adequate and satisfactory.

2.11.2 Reason for Using Models

In order to understand and manage agroecosystems, models are used for the following reasons:

i) To reduce site specific, long-term field experiment.
ii) To interpret climatological records in term of production potential and limitations,
iii) To evaluate expected returns from soil and crop management practices,
iv) To evaluate risk associated with management practices,
v) To communicate research results between locations,
vi) To enhance understanding of biological and physical systems, and
vii) To conceptualize multidisciplinary activities.

2.12 CHARACTERISTICS OF A MODEL

Models are designed to solve specifics problems. In order to make their use under diverse purposes and location, the model should have the following characteristics (Ritchie *et al*., 1986)

- Use readily available genetic, soil and weather inputs.
- Be written in a familiar and widely used computer language
- Require minimum computational time
- Be adaptable for use on both mainframe and micro-computer

2.13 SIMULATION MODELLING IN CROP PRODUCTION

Simulation is an intimation of the behavior of a system. It generally involves some kind of model or simplified representation. During the course of a simulation, the model minimizes important processes of the system. To perform simulation using a mathematical model, the calculation indicated by the model equation are performed repeatedly to represent the passage of time (Robert *et al*., 1983). Simulation allows the synthesis of knowledge of scientists from different disciplines into a holistic description of the system, providing a common communication medium for the different disciplines (Mc Kinion, 1992).

Crop Simulation modelling has emerged as a concept, which is used to study the interactive response of various growth factors on crop yields. A crop simulation model may be perceived as a black box in which a minimum data set relating to crop, soil, weather etc.is fed. The model utilizes this input data set in calculating various growth processes using established quantitative relationship and gives the required information regarding the daily growth and development of the crop, water, nutrient balance information and the simulated final yield of the crop. For a lay man, the model itself behaves like a true plant right from the time the seed is sown, to the germination of the seed, to the vegetative growth of crop, to the flower formation and ensuring reproductive development of the plant, and finally to the harvest maturity stage. Though crop simulation models appear very fascinating, making them operational is a very laborious and time-consuming task. Initially detailed field data of several years on the crop is required. So, if we start working on a crop simulation model today, it may take several years of patient experimentation and computer exercises to get a fully operationalized model which predicts the growth, development and yield of the crop. The system approach provided a framework in which research is conducted to understand how the system and its components function. This understanding is then integrated into model that allow one to predict the behavior of the system for given condition. After one is confident that the model simulate the real world adequately, computer experiments can be performed hundreds or even thousands of times for given environment to determine how to best manage or control the system. DSSAT was developed to operationalize this approach and make it available for global application. The DSSAT helps decision makers buy reducing the time and human resources required for analyzing complex alternative decision (Tsuji *et al*., 1998).

2.14 MODEL CALIBRATION

Different crop cultivars are planted across locations, hence, it is necessary to calibrate crop models to account for difference in crop phenology and growth-related factors. Simulations will aim to portray most recently released high-yield crop cultivars, grown in pure stands. The following preference list will be followed to determine the preferable source of data for model calibration:

1- Elaborate calibration: this requires field experiments where crops were grown without evident nutrient limitations and no incidence of biotic adversities and where all weather, soil, and management data required to run the field-year specific simulation are available for the data requirements and procedure for a complete model calibration. If such experiments are not available for a specific country or region within a country, crop growth data may be used from experiments in which crops are grown with optimal management for very similar regions in terms of climate and soils-hopefully from the same climate zone (Van Wart *et al*., 2013a).

2- Simple (only phenology) calibration: if (1) is not possible, use the methodology in (Van (Wart *et al.*, (013b) to calibrate the simulated crop phenology for each crop-buffer zone. Briefly, it proposed to optimize model coefficients (related to phenology) until the simulated physiological maturity matches the actual physiological maturity date reported by the country agronomist. This phenology calibration is preferably done based on the buffer-specific weather data and sowing and maturity dates specified by the country agronomist. In those countries or regions where calculated sowing-to-maturity growing-degree days (GDD) vary little among crop-buffer zones (CV=5%), the same GDD value will be used for all crop-buffer zones. This should also be followed by a calibration of the flowering dates. If actual flowering dates are not reported by country agronomists, it can be determined using generic rules (for example, in maize the GDD before and after silking are typically the same) or data reported in the literature. In case there is no other alternative, we may use more generic calendars for calibrating phenology. If experimental data are lacking to do an elaborate calibration to derive the yield related coefficients, we may use initially for the model simulations the generic model parameters reported in the literature and derived in previous modelling studies (Van Heemst, 1988).

2.15 MODEL EVALUATION

According to Jones and Ritchie (1990), evaluation of a model is a verification of the model's performance with measured data so that users can run them with confidence. It may not be possible for a model to predict plant performance correctly under all situation since many of the factors that influence crop growth processes are not included in the models. The application of the model lies in it being evaluated under diverse conditions as it would allow the imperfections and weaknesses of the model to be exposed leading to its refinement.

Generally, model evaluation is done by comparing simulated results with observed results from experiments, demonstration plots or on-farm trials. A model should not be evaluated with the same result from which it was developed or parametrized. Evaluation with experiments from many sites improve confidence in the model. A model is scientifically valid if its assumptions confirm to basic scientific principles.

Leman (1977) defined evaluation as a comparison of a verified model to the real world and determination if it is suitable for its intended purpose.

2.16 SENSITIVITY ANALYSIS

Many input variables are needed for comprehensive mechanistic models. If one takes an individual input variable and changes it, holding all other constant, this called sensitivity testing, or sensitivity may be defined as relative change in output per unit relative change in model parameter. Computer simulation and analytical techniques (direct methods) and statistical techniques indirect approach) are some of the techniques used in sensitivity analysis. Indirect approach where indicator to sensitivity is determined, should be adopted only when it is not possible to use direct methods. This analysis guides the modeler with regard to accuracy in model parameters (Mahey and Mathauda, 2002).

2.17 DSSAT MODEL

The Decision Support System for Agrotechnology Transfer (DSSAT) was originally developed by an international network of scientists, cooperating in the International Benchmark Sites Network for Agrotechnology Transfer project (Jones *et al.*, 1998). The major focus of the IBSNAT project was to facilitate the application of crop models in a systems approach and use them for agronomic research. Its' initial development was motivated by a need to integrate knowledge about soil, climate, crop, and management for making better decisions about transferring production technology from one location to others where soils and climate differed (Uehara, 1998).

DSSAT has been in use for the past 15 years by researchers all over the world, for a variety of purposes, including crop management Fetcher *et al.*, (1991), climate change impact studies (Alexandrov and Hoogenboom, 2001), sustainability research.

The DSSAT crop models have been used for yield forecasting in several simulation studies (Duchon, 1986; Thornton *et al.*, 1997; Bannayan *et al*., 2003). These forecasts can be conducted prior of planting or during the actual growing season. In both cases, the information obtained can be used by the farmers for crop management such as scheduling of fertilization or irrigation, or by governments for agricultural planning (Hoogenboom, 2000). The simulations that are conducted during the growing season for yield forecasting normally use the most recently recorded weather data and for future weather (climate scenarios) daily weather data sets derived, and past weather recorded from General Circulation Models (GCMs) (Duchon, 1986; Thornton *et al*., 1997, Soler *et al*., 2007).

2.18 MINIMUM DATA SET NEEDED FOR DSSAT MODEL

2.18.1 Weather Data

The minimum required weather data includes:

•Latitude and longitude of the weather station,

•Daily values of incoming solar radiation (MJ/m²-day),

•Maximum and minimum daily air temperature (ºC), and

•Daily total rainfall (mm).

2.18.2 Soil Data

Desired soil data includes soil classification (SCS), surface slope, color, permeability, and drainage class. Soil profile data by soil horizons include:

• upper and lower horizon depths (cm),

• percentage sand, silt, and clay content,

• 1/3 bar bulk density,

• organic carbon,

• pH in water,

• aluminum saturation, and

• root abundance information.

2.18.3 Management and Experiment Data

Management data includes information on planting date, dates when soil conditions were measured prior to planting, planting density, row spacing, planting depth, crop variety, irrigation, and fertilizer practices. These data are needed for both model evaluation and strategy analysis. In addition to site, soil, and weather data, experimental data include crop growth data, soil water and fertility measurements. These are the observed data that are needed for model evaluation.

2.19 OVERALL DESCRIPTION OF THE DSSAT CROPPING SYSTEM MODEL

The DSSAT-CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in water the cropping system over time. The DSSAT-CSM is structured using the modular approach described by (Jones *et al*., 2003) the most important features of our approach are:

- It separates modules along disciplinary lines,
- It defines clear and simple interfaces for each module,
- It enables individual components to be plugged in or unplugged with little impact on the main program or other module, e.g for comparison of different models or model component,
- It facilities documentation and maintenance of code,
- It enables modules written in different programming languages to be linked together,

- It allows for easy integration into different types of application packages due to the well-defined and documented interface to the modules,
- It allows for evolution to integrate other components such as livestock and intercropping, through well-defined module interfaces, and
- It facilitates cooperation among different model development group where each can focus on specific modules as building blocks for expanding the scope and utility of the CSM (Figure 2).

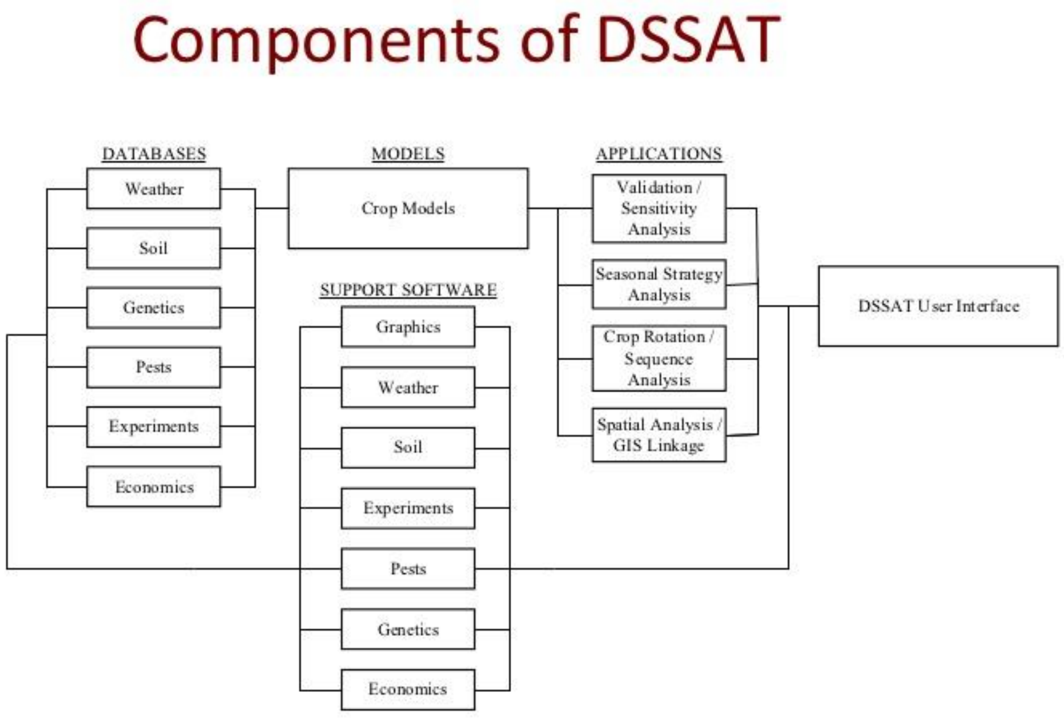

Figure 2: Overview of the Component and Modular Structure of the DSSAT-CSM

2.20 CERES-MILLET MODEL

The Decision Support System for Agrotechnology Transfer (DSSAT) is a comprehensive decision support system for assessing management options (Tsuji *et a*l., 1998; Jones *et al*., 2003; Hoogenboom *et al.*, 2015). This system includes the Cropping System Simulation Model (CSM)-CERES-Pearl Millet (Jones *et al*., 2003; Hoogenboom *et al*., 2015), which is a process-oriented, dynamic crop simulation model that simulates crop growth, development, and yield. The crop growth simulation model CERES-Millet was developed at Michigan State University USA. The model incorporates a thermal time estimation similar to growing degree days, taking into account the optimum upper and lower limit of temperature in which the plant development rates increase linearly with rise in temperature. This model simulates the effect of weather, soil, water, cultivar and nitrogen dynamics on crop growth biomass development and yield. Thornton *et al*., (1997) developed a prototype pearl millet yield estimation system for 30 provinces in Burkina Faso using CERES-Pearl millet model and remotely sensed rainfall in real time, embedded in Geographic Information System (GIS). Ram Niwas *et al*. (1996) tested the CERES-Pearl Millet model using three pearl millet cultivars at New Delhi, India and the predicted days to anthesis showed a deviation from 1 to 4 days with a mean deviation of 2.3 days for all the varieties and 2 seasons. The number of days required for maturity varied from those observed by 5 to 8 days. The predicted biomass and grain yield agreed with observed data. The author concluded that CERES-pearl millet can be used to study the suitability of genotype in a particular region.

A detailed description of the CERES-Millet model, the predecessor of the CSM–CERES-Millet, is provided by (Ritchie and Alagarswamy 1989). Fechter *et al*. (1991) conducted an evaluation of the CSM–CERES-Millet model for south-west Niger, The CSM–CERES-Millet was also evaluated for four regions in Niger by (Ravelo and Planchuelo (1993); the model predicted growth and development accurately, while the yield estimates had an average relative error of 0. 07. Although these studies are considered very valuable, the evaluation of the CSM–CERES-Millet model for different regions of the world has been minimal compared to other crop models. This reflects the need for further modelling studies, especially pearl millet, as it is such an important crop for resource-poor farmers, especially in the semi-arid tropics where environmental conditions for crops are harsh. The goal of the present study was to evaluate the performance of the CSM–CERES Millet model for two contrasting environments, including Mead, Nebraska, USA and Kollo, Niger, West Africa and to determine the optimum planting dates for these two environments using a modelling approach.

2.21 GENETIC COEFFICIENT OF MILLET

The CSM-CERES-Pearl-Millet model includes nine cultivar-specific coefficients that require modification for new cultivars not previously used with the crop model. Six specific cultivar coefficients were adjusted for pearl millet during the evaluation process: P1-Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 10°C) during which the plant is not responsive to changes in photoperiod; P5 – Thermal time (degree days above a base temperature of 10°C) from beginning of grain filling (3–4 days after flowering) to physiological maturity; G1 – Scaler for relative leaf size on main stem; GT–Tillering coefficient; G4–Scaler for partitioning of assimilates to the panicle (head) and PHINT–Phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances (Hoogenboom *et al*., 1992).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL SITES

On-station trials were conducted in N'Dounga Research Station situated at 30 km South-West of Niamey, (Figure 3) capital city of Niger Republic (2°18' 28" E 13° 15' 00" N); while on-farm trials were carried out on various farmers' fields with N'Dounga province. The mean annual precipitation at the station is around 500 mm, with long dry season from October to May. The annual temperature is approximately 28°C. The natural vegetation type in the area is dry savannah with shrubby trees, dominated by *Guiera senegalensis* J.F. Gmel., *Piliiostigma reticulum* (DC.) Hochst. and *Faidherbia albida* (Del.) Chev. (Larwanou, 2005).

3.2 TREATMENTS AND EXPERIMENTAL DESIGN

3.2.1 <u>On Station Field Trial</u>

Four (4) pearl millet varieties used in the experiment were CIVT, H80-10 GR, HKP and ZATIB. The crop was sown at two different sowing windows 25th June (late June) and 13thJuly (mid-July) in 2016 and 26th June (late June) and 19 July mid-July in 2017. The experiment was conducted in split-plot design with three replications. The main plot treatment were sowing dates. The subplot treatments were the four different millet varieties (CIVT, H80-10 GR, HKP and ZATIB).

3.2.2 <u>On Farmers' Field Trial</u>

The experiment was conducted in the same location at N'Dounga in 2017 but on farmers'field. The crop was sown at four level of different sowing dates 14th June (Mid-June), 04 July (Early July), 19th July (Mid-July) and 27th July (Late July) with four varieties (ZATIB, H80-10 GR, HKP and CIVT), in an incomplete factorial design with 12 farmers.

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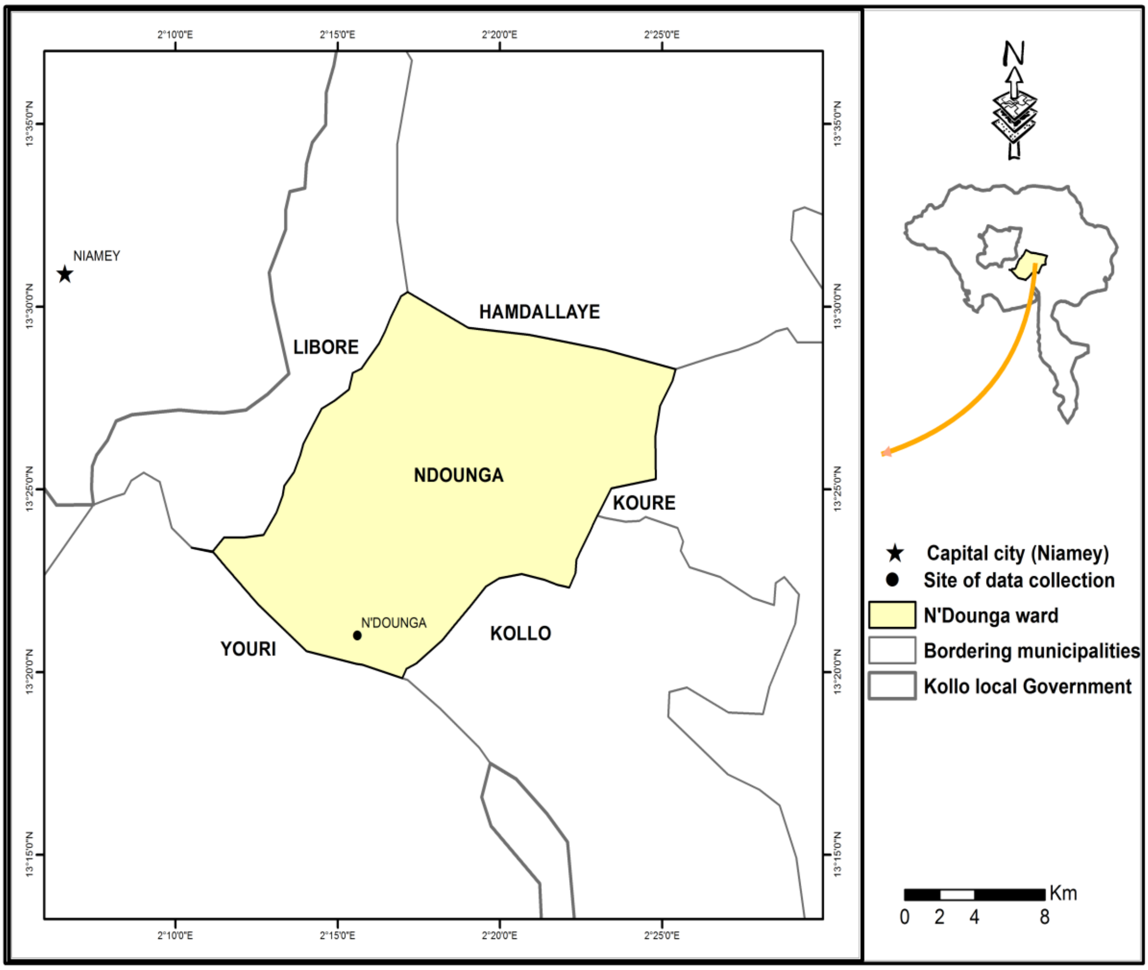

Figure 3: Study Location in Niger Republic

3.3 PLOT SIZES

The gross plot size consisted of six rows, 1 m apart and 10 meters long giving a total area of 60 m2. Data were collected from net plot made up of two innermost rows, which was 10 m x 2 m (20 m2). The other outside rows were used as border to minimize the impact of adjacent treatment or factor from outside experiment. An alley of 1m was left between the plots and 2 m between the replications

3.4 CULTURAL PRACTICES

3.4.1 Land Preparation

The land was cleared of debris, harrowed, and ridged at 1m between ridges before laying out the experiment.

3.4.2 Source of Seed and Sowing

The seeds were obtained from National Institute for Agronomic Research of Niger. At sowing, all the seeds were treated with an insecticide-fungicide thioral at a dose of 25 g per 10 kg of seeds. Five seeds were placed in each hole at the depth of 3 cm and covered. Thinning to three plants per hill at 20 days after emergence.

3.4.3 Fertilizer Application

One hundred (100) kg of NPK (15:15:15) was applied at sowing. Then 50 kg of urea was applied before flowering. This is equivalent to 38 kg N/ha, 15 kg P_2O_5/ha and 15 kg K_2O/ha.

3.4.4 Weed Control

Hand weeding was done to remove all weeds. No herbicide was applied to control weeds. Hand weeding was done at two weeks after sowing, just before the day of first top dressing, and repeated at flowering stage.

3.4.5 Pest and Disease Control

These were not encountered at all during the experimental period. Therefore, no control measure was taken.

3.4.6 Harvesting and Threshing

The crop was harvested when more than 80% grains of panicles were fully matured and moisture content of the grain was about 20-25 per cent. That was done from the net plot. After threshing, the grains were dried in the sun for two weeks.

3.5 SOIL SAMPLING

Soil samples were collected from soil profile dug on the experimental station at N'Dounga from 0-14, 14-31, 31-61, 65-85, 85-129. The soil samples were air-dried, sieved and prepared for both physical and chemical analyses in the laboratory.

3.5.1 Soil Physical Properties**:**

The analysis of particle size was done by the Hydrometer method as outlined by (International Institute for tropical Agriculture, 1979)

3.5.2 Soil Chemical Properties

- ***Total Nitrogen***

Total nitrogen was determined using the micro-Kjeldhal digestion method (Bremner, 1996).

- ***Available Phosphorus and exchangeable cations***

Available phosphorus, available exchangeable cations (K, Ca, Mg and Na) were analysed based on the Mehlich-3 extraction procedure (Mehlich, 1984).

- ***Soil pH***

This was determined using the glass electrode pH meter in 1:1 soil to distilled water (soil: water) ratio 10g Soil sample were weighed into a 100 ml beaker. To this distilled water was added from a measuring cylinder, stirred thoroughly and allowed to stand for 30 minutes. After calibrating the EUTECH pH meter with buffer solution at pH 4.0 and 7.0, the pH was read by immersing the electrode into the upper part of the suspension (Gee and Or, 2002).

- ***Soil organic carbon***

The modified Walkley and Black procedure as described by Nelson and Sommers (1982) was used to determine organic carbon. The procedure involved a wet combustion of the organic matter with a mixture of potassium dichromate and sulphuric acid after which the excess dichromate was titrated against ferrous sulphate. Two grams of soil sample was weighed into a 500 ml Erlenmeyer flask. A blank was included. Ten millilitres of 0.1667 M (1.0 N) potassium dichromate solution was added to the soil and the blank flask followed by 20 ml of concentrated sulphuric acid. The mixture was swirled and allowed to stand for 30 minutes on an asbestos sheet. Distilled water (200 ml) and 10 ml concentrated orthophosphoric acid were added and allowed to cool. One millilitre of diphenylamine indicator was added and titrated with 1.0 M ferrous sulphate solution.

3.6 METEOROLOGICAL DATA

Weather data for both years 2016 and 2017 were obtained from weather station at N'Dounga, including daily maximum and minimum temperatures, precipitation and solar radiation. These data were used for the model calibration and evaluation. However, for the model application we have used climatic data from 1983 to 2017 at Sadore Station which is very close to N'Dounga.

3.7 DATA COLLECTION

3.7.1 Plant Height (m)

This was measured from 5 randomly tagged plants within the net plots at physiological maturity. The height was measured using a graduated meter rule from the ground base to the tip of the terminal leaf, then their means were recorded.

3.7.2 Panicle Length (cm)

Five plants randomly selected and measurement were taken from the base to the tip of the panicle with a meter at physiological maturity.

3.7.3 Number of Panicles (m^{-2})

This was determined by counting the number of panicles per net plot.

3.7.4 Days to 50% Flowering

The actual days from sowing to when 50% flowering occur in each plot were noted and recorded.

3.7.5 Number of Days to Maturity

The number of days from date of sowing to when 95% of the panicle in the net plot reached physiological maturity were counted and recorded

3.7.6 Harvest Index

The total dry matter produced by a crop is known as biological yield and a fraction of the biological yield which is useful for human beings is known as economic yield. Harvest index may be defined as the ratio between economic yield and the biological yield. It is generally expressed as fraction and sometimes as percentage (Donald, 1962)

$$Harvest\ Index\ (H.I) = \frac{Economic\ Yield}{Biological\ Yield} = \frac{Dry\ Grain\ Yield}{Total\ dry\ weight}$$

3.7.7 Above Ground Biomass (kg ha-^{1})

Above ground biomass was determined at physiological maturity. All the plants in the net plots were harvested and weight was recorded these were chopped, weighed and oven dried at 70°C for 48 hours.

3.7.8 Grain Yields (kg ha-1)

After threshing, grains were dried in the sun until the constant weight was obtained and then grains were weighed and converted into kilograms per hectare using the formula:

$$Grain\ Yield\ (Kg/ha) = \frac{\boldsymbol{Grain\ \ yield\ /net\ plot\ (Kg)X10000}}{\boldsymbol{Net\ plot\ area\ (m^2)}}$$

3.8. DATA INPUT FOR DSSAT MODEL

The basic input data required to run the DSSAT model V 4.7 include daily weather data (maximum and minimum temperature, rainfall and solar radiation); soil characterization data (by soil layer); a set of cultivar coefficients characterizing the variety being grown; and crop management information, such as emerged plant population, row spacing, seeding depth and fertilizer and irrigation schedules.

3.8.1 Weather

Daily weather data were obtained from meteorological station at the experiment site. These included maximum and minimum temperature (°C), rainfall (mm), and solar radiation ($MJ.m^2$). The weather records for the periods of experimentation are presented in Figures 4 and 5. Records for long-term weather data used for long-term sensitivity analysis are shown in (Figure 6).

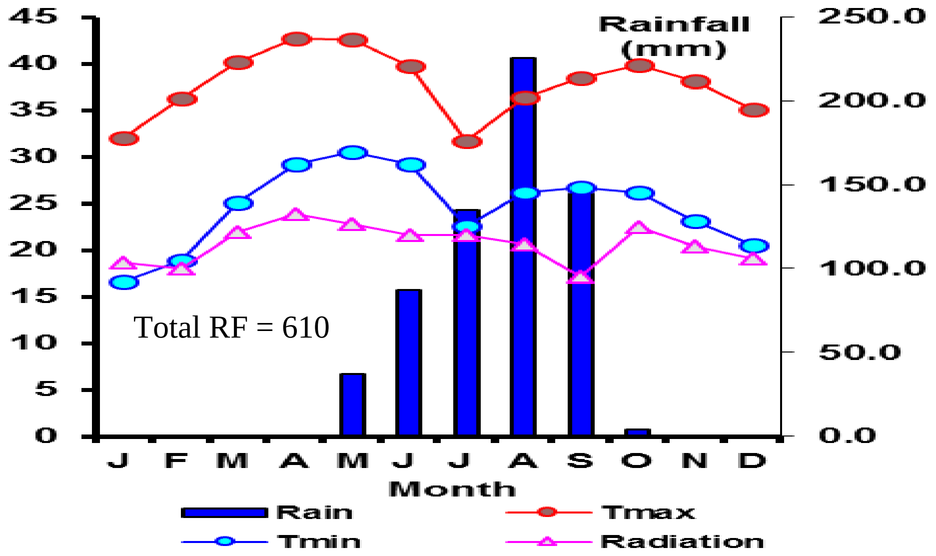

Figure 4: Weather Data for N'Dounga 2016 Rainy Season

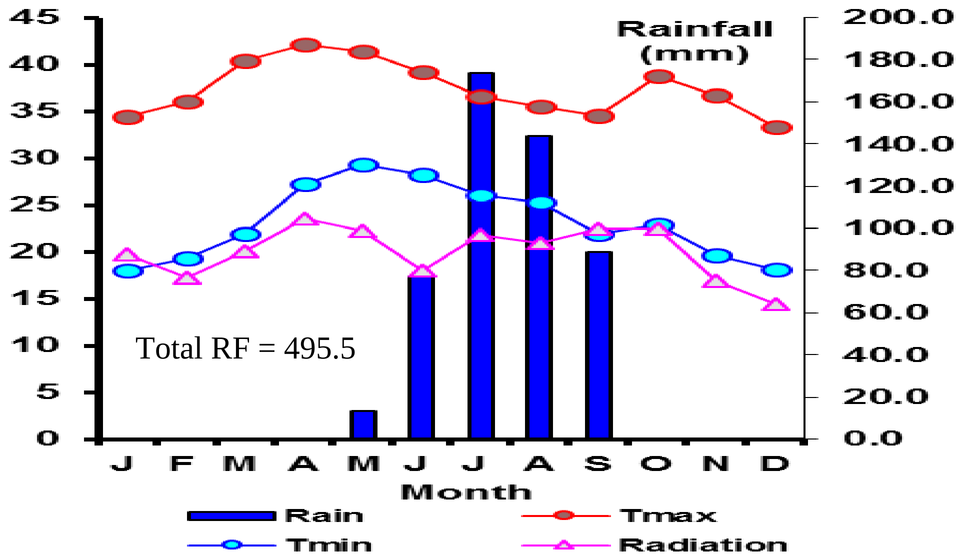

Figure 5: Weather Data for N'Dounga 2017 Rainy Season

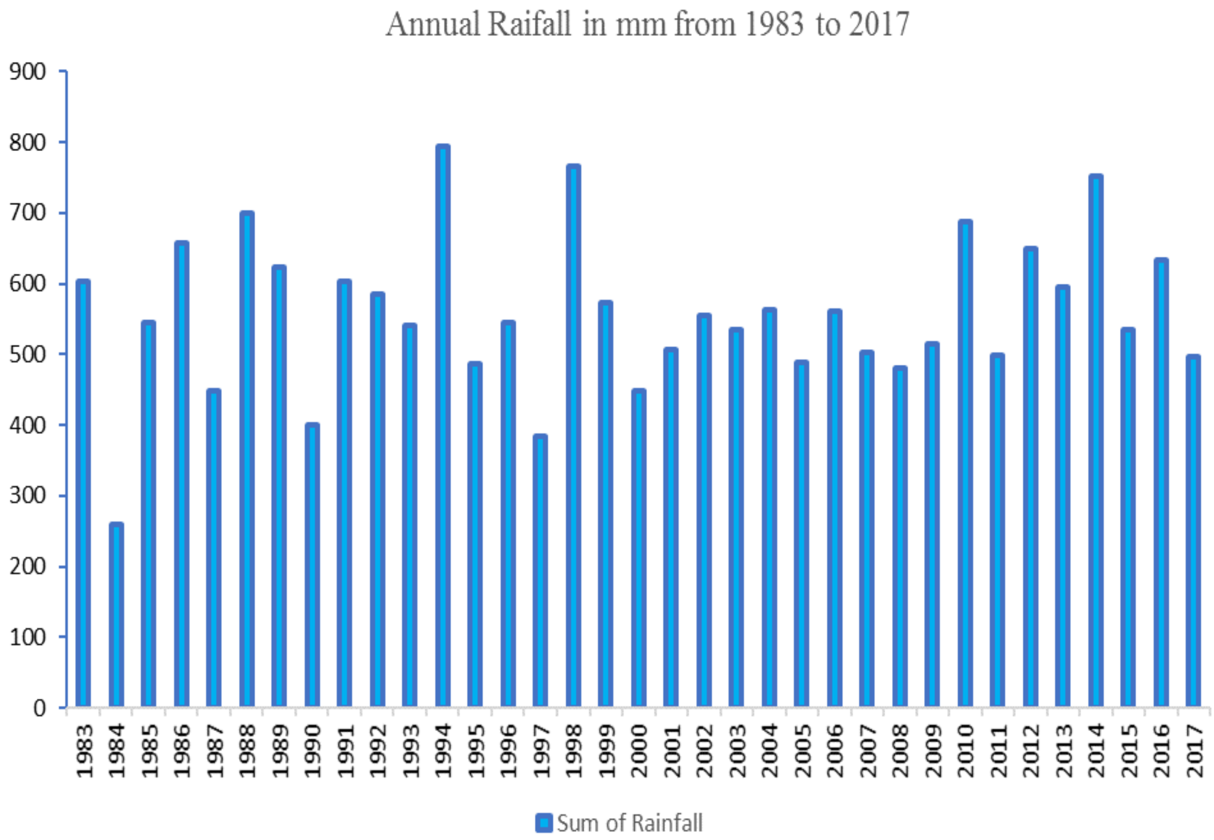

Figure 6: Thirty Years (1983-2017) Total Annual Rainfall for N'Dounga Station

3.8.2 Soil Data

The following soil information were collected for each soil horizon: pH (water), organic carbon, total N, exchangeable bases, available P, silt, clay, sand, and bulk density.

3.8.3 Management and Experiment Data

Management data included information on sowing date, planting density, row spacing, sowing depth, crop variety, and fertilizer practices. The major agronomic measurements on days to 50% flowering, physiological maturity, above ground biomass, yields and harvest index were used for model calibration and evaluation.

3.9 CALIBRATION OF CERES-Millet model

Model calibration or parameterization can generally be defined as an adjustment of some parameters and functions of a model so that predictions are the same or at least very close to data obtained from field experiments (Penning de Vries *et al*., 1989). To do this, data of weather were collected from N'Dounga. Pre-sowing soil samples were collected from soil profile from different horizons and analyzed for (clay %, Silt %, sand %), organic carbon, soil pH (water) total N%, the soil hydraulic parameters such as permanent wilting point (lower limit LL), field capacity (Drained upper limit DUL) and saturation were estimated using pedo-transfer function available in DSSAT. For calibration of DSSAT model, 2016 data set on flowering, maturity dates, grain yields, above ground biomass and harvest index were used. We selected four millet cultivars which are the most grown and used by the farmers in the area. Three out of the four (CIVT, ZATIB, HKP) were existing cultivars in the DSSAT model calibrated by (Akponike, 2008). The genetic coefficients of these varieties were recalibrated by running the generalized likelihood uncertainty estimation (GLUE) several times until the fit was observed between the simulated and observed. However, the cultivar H80-10 GR was not in the DSSAT model, we created it in the genetics file (MLCE046.CUL) of DSSAT-CSM. Initial values of the genetic coefficient were obtained from the variety ¾ HK already available in the DSSAT. The computed crop specific parameters values for ¾ HK were copied into MLCE46.CUL file to run the simulation. We simulated several times to estimate the values of the H80-10 GR genetic coefficients by using GLUE method after determining the parameter of crop (Millet). The details of the genetic coefficients are given in (Table 1).

3.10 MODEL EVALUATION

Model performance was evaluated by comparing the simulated versus observed values from the experiment of 2017. Data for model evaluation include anthesis date, physiological maturity date, grain yields, above ground biomass, and harvest index. Model evaluation was done using data not previously used in the calibration exercise. The evaluation is done to compare model simulated values from the calibrated genotype coefficients with actual observations. This exercise is done to evaluate the quality of the calibrations, it presents insight into how well the model is calibrated. The goodness of fit of the model is evaluated using a set of model statistics.

3.11. SEASONAL ANALYSIS

A long-term seasonal analysis was conducted to determine the effect of different sowing windows on pearl millet varieties in N'dounga using 30 years cliamtic records from 1983 to 2017. Nine different sowing windows (Early May, Mid-May, Late May, Early June, Mid-June, Late June, Early July, Mid-July and Late July) were simulated using seasonal analysis tools of DSSAT V 4.7. The sowing started from May 10 and repeated every 10 days until 30 July. Cumulative frequency plot were used to represent the result of simulated yield over 30 years.

3.12 MODEL STATISTICS

To assess the goodness of fit of the simulated and measured comparaisons, four different statistical indices were employed, including coefficient of determination, Root mean square error, normalized root mean square error and index of agreement (d-index).

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(m_i - S_i)^2}{\sum_{i=1}^{n}(m_i - \bar{m})^2} \quad (1)$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(m_i - S_i)^2}{n}} \quad (2)$$

$$RMSEn = \frac{RMSE \times 100}{\bar{m}} \quad (3)$$

$$d = - \frac{\sum_{i=1}^{n}(m_i - S_i)^2}{\sum_{i=1}^{n}(|S_i| + |m_i|)^2} \quad (4)$$

Where S_i = simulated value, m_i = measured value, and n = number of observations.

The index of agreement is defined by Willmott, (1982) as shown in equation (4)

The computed values of RMSE and value determine the degree of agreement between the simulated values with their respective measured values, the lower the RMSE value the better the simulation of the model.

Normalized RMSE (RMSEn) was used to give a measure (%) of the relative difference of simulated versus measured data. The simulation was considered excellent with a normalized RMSE less than 10%; good if the normalized RMSE was greater than 10 and less than 20%; fair if the normalized RMSE was greater than 20% and less than 30%, and poor if the normalized RMSE was greater than 30% (Loague and Green, 1991).

Table 1: Genetic Coefficient of four Millet Cultivars Used in DSSAT Simulation Model

Coefficient description
P1 Thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 10°C) during which the plant is not responsive to changes in photoperiod
P2O- Critical photoperiod or the longest day length (in hour) at which development at a maximum rate
P2R-Extent to which phasic development leading to panicle initiation (express in degree days) is delayed for each hour increase in photoperiod above P2O
P5- Thermal time (degree days above a base temperature of 10°C) from beginning of grain filling (3-4 days after flowering) to physiological maturity
G1-Scaler for relative leaf size on main stem
G4-Scaler for partitioning of assimilates to the panicle (head). interval; the interval in thermal time (degree days) between successive leaf tip appearances
PHINT-Phylochron interval; the interval time (degree days) between successive leaf tip appearances

CHAPTER FOUR
4.0 RESULTS AND DISCUSSION

4.1 RESULTS

4.1.1 Physical and Chemical Properties of the Soil at N'Dounga

The result of soil chemical and physical properties of the soil profile has been indicated in Table 2. The total sand were ranged from 73.4 to 83.4 %. However, for the total silt, it ranged from from 5.9 to 13.9 %. The soil pH in H_2O was ranged from 6.04 to 6.89 found in very moderately acidic. Total N were ranged from 0.035 to 0.7% the concentration of nitrogen was low; however the organic carbon ranged from 0.5 to 7.41 (g/kg).

4.1.2 Agronomic Trials

On-Station trials

Table 3 shows the effects of sowing windows on the plant height and above ground biomass of millet varieties in 2016 and 2017. Significant differences were observed in plant height between sowing windows in both years. Sowing in late June produced significantly taller plants than the mid July sowing in both instances. There were no significant differences in height between the four varieties in 2016 although CIVT had the highest mean value. In 2017 however, a significant difference in height was observed between the varieties where the variety HKP produced significantly shorter plants than the other varieties which remained at parity. The interaction of sowing window and varieties was not significant for plant height in both years.

Similar trends were observed for above ground biomass (Table 3) where sowing in late June led to the production of significantly higher above ground biomass than delaying sowing to early July in 2016 but not in 2017. Among the varieties, highest values of above

Table 2: Soil Properties of the on Station Field at N'Dounga in 2016 Used in Simulation Studies

Soil properties	Depth (cm)				
	0-14	14-31	31-65	65-85	85-129
Clay (%)	10.7	12.7	10.7	10.7	10.7
Silt (%)	9.9	13.9	11.9	5.9	13.9
Sand (%)	79.4	73.4	77.4	83.4	75.4
organic Carbon (g/kg)	7.41	0.5	5.53	3.65	3.02
Total Nitrogen (%)	0.035	0.07	0.035	0.035	0.07
pH	6.89	6.04	6.09	6.32	6.15
Na (cmol+/kg)	1.3	0.98	0.9	0.83	1.22
K (cmol+/kg)	1.82	1.31	2.4	1.7	2.1
Mg (cmol+/kg)	0.53	0.39	0.44	0.41	0.23
Ca (cmol+/kg)	4.00	3.26	2.5	3.63	3.25
E.A (cmol+/kg)	0.5	0.66	0.83	0.33	0.83
C.E.C (cmol+/kg)	7.9	6.6	7.1	6.9	7.6

Table 3: Effect of Sowing Windows on Plant Height and Above Ground Biomass of Millet Varieties in 2016 and 2017 Rainy Seasons at N'Dounga (on-station)

Treatment	Plant Height (m)		Biomass (kg ha^{-1})	
	2016	2017	2016	2017
Sowing Windows (S)				
Late June	2.50a	2.25a	7681a	7356
Mid-July	2.20b	2.11b	7162b	7074
SE±	0.08	0.04	179.72	299
Variety (V)				
CIVT	2.42	2.20a	7631b	7240b
H80-10 GR	2.39	2.22a	8340a	8161a
HKP	2.30	2.04b	6695c	6450b
ZATIB	2.29	2.26a	7020c	7009b
SE±	0.10	0.05	220	366
Interaction				
S × V	0.93	0.35	0.53	0.21

Means followed by the same letters within a treatment group are not significantly different at 5% level of probability using Student Newman Keuls (SNK) test.

ground biomass were observed for H80-10 GR in 2016 and 2017. In 2016, CIVT produced significantly higher above ground biomass than ZATIP and HKP, while in 2017 the three varieties produced statistically similar values for above ground biomass. All interactions were not significant.

Panicle length and panicle diameter showed similar trends in 2016 with respect to sowing window, where sowing in late June produced longer and thicker panicles (Table 4). In 2017 however, there were no significant differences between the sowing windows with respect to both panicle length and diameter.

Statistically similar panicle lengths were recorded among the varieties in 2016 and 2017, the longest panicle length was obtained with the variety ZATIB and the shortest was observed with the variety H80-10 GR in 2016 (Table 4). However, the longest panicle length was observed with H80-10 GR and the shortest was obtained with the HKP in 2017. For panicle diameter, similar responses were observed only in 2016 where the variety H80-10 GR produced the thickest panicle diameter, the thinnest panicle diameter was obtained with the variety ZATIB. In 2017 however, varieties CIVT, H80-10 GR, and ZATIB produced statistically similar panicle diameters which were all statistically higher than that produced by HKP. All the interaction between the sowing windows and varieties were not significant. Table 5 shows the effect of sowing windows and varieties on days to 50% flowering and days to physiological maturity. Significant difference was observed between the sowing windows for days to 50 % flowering in both years, where late June sowing window resulted in significantly higher number of days to 50% flowering. However, there were no significant differences between the sowing window on days to physiological maturity in 2016 and 2017.

Table 4: Effect of Sowing Windows on Panicle Length and Panicle Diameter of Millet Varieties in 2016 and 2017 Rainy Seasons at N'Dounga (on-station)

Treatment	Panicle length (cm)		Panicle Diameter (cm)	
	2016	2017	2016	2017
Sowing Windows (S)				
Late June	66.26a	63.77	28.13	25.47
Mid-July	60.58b	61.64	22.12	25.80
SE±	1.89	1.17	0.72	0.81
Variety (V)				
CIVT	65.42	63.42	25.20	25.67ab
H80-10 GR	59.92	63.82	25.31	26.56a
HKP	61.41	60.12	25.15	23.51b
ZATIB	66.93	63.55	24.86	26.79a
SE±	2.31	0.14	0.89	1.00
Interaction				
S × V	0.93	0.35	0.49	0.67

Means followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student Newman Keuls (SNK) test.

Table 5: Effect of Sowing Windows on Days to 50% Flowering and Day to Physiological Maturity of Millet Varieties in 2016 and 2017 Rainy Seasons at N'Dounga

Treatment	Days to 50% Flowering		Days to Physiological Maturity	
	2016	2017	2016	2017
Sowing Windows (S)				
Late June	62a	61a	84	84
Mid-July	60b	59b	83	83
SE±	0.76	0.58	1.09	0.7
Variety (V)				
CIVT	51d	50d	82b	81b
H80-10 GR	61b	62b	90a	91a
HKP	58c	55c	74c	72c
ZATIB	73a	73a	88a	90a
SE±	0.93	0.72	1.34	0.86
Interaction				
S × V	0.01	0.72	0.28	0.09

Means followed by the same letter within treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

There were significant differences between the varieties for days to 50% flowering in both years where the highest number of days to 50% flowering were observed for variety ZATIB, while the lowest number of days to 50% flowering was recorded for the variety CIVT in both years. Similar trend was observed on days to physiological maturity, where highest number of days to physiological maturity was recorded for the variety H80-10 GR and the lowest number of days were observed for the variety HKP. The interaction between sowing windows and varieties was significant in 2016 for the days to 50% flowering and in 2017 for the days to physiological maturity.

Table 6 shows the interaction between sowing windows and varieties on number of days to 50% flowering of millet. The highest number of days (76.5) to 50% flowering was recorded when ZATIB was planted in late June, while the lowest number (52.5 and 51.2) of days to flowering was recorded when CIVT was planted in late June and mid-July. The interaction between sowing windows and varieties on number of days to physiological maturity was not significant.

Result from Table 7 shows the effect of sowing windows on harvest index, number of panicles and grain yields. The results indicated that there was no significant difference between sowing windows with respect to harvest index. However, there was significant difference between the sowing window with respect to number of panicles in 2016. Planting in mid-July led to production of significantly higher number of panicles than late June. Similarly, there was significant difference in grain yield with respect to sowing windows in both years. Planting in late June produced significantly higher grain yields compared to mid-July.

A significant difference was observed between the varieties with respect to harvest index (HI) in both years (Table 7). The highest HI was observed for the variety ZATIB, and the lowest (HI) was recorded with the variety H80-10 GR in both years. However, there were

Table 6: Interaction of Sowing Windows and Varieties on the Number of Days to 50 % Flowering in 2016

Sowing Windows	Varieties			
	CIVT	H80-10 GR	HKP	ZATIB
Late June	52.50e	62.16c	57.16cd	76.50a
Mid-July	51.16e	61.16c	59.83d	69.50b
SE±		1.21		

Means followed by the same letter (s) are not significantly different at 5% level of probability using Student Newman Keuls (SNK).

Table 7**:** Effect of Sowing Window on Grain Yield, Harvest Index and Number of Panicles of Millet Varieties in 2016 and 2017 Rainy Seasons at N'Dounga (on-station)

	Harvest Index		Number of Panicles m^{-2}		Grain Yield $kgha^{-1}$	
Treatments	2016	2017	2016	2017	2016	2017
Sowing Windows (S)						
Late June	0.15	0.14	3.0b	3.5	1225.9a	1097.6a
Mid-July	0.14	0.13	4.2a	3.8	1059.5b	949.5b
SE±	0.010	0.01	0.23	0.18	51.49	33.85
Variety (V)						
CIVT	0.15a	0.13bc	3.8	3.7	1162.8	978
H80-10 GR	0.11b	0.12c	3.5	3.5	1075.3	1035
HKP	0.14ab	0.15ab	3.5	3.7	1038.5	975
ZATIB	0.17a	0.16a	3.6	3.7	1296.2	1105
SE±	0.013	0.01	0.28	0.22	72.83	41.46
Interaction						
S×V	0.47	0.75	0.41	0.003	0.6	0.04

Means followed by the same letter within treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

no significant differences in number of panicles and grain yields between the four varieties in both years.

Tables 8 and 9 showed interaction between sowing windows and variety on number of panicles and grain yields. Significant interaction was observed on number of panicles in 2017. The result indicated that sowing ZATIB variety in late June produced significant higher number of panicles which was at par with the variety HKP in late June, H80-10 GR and CIVT in mid-July (Table 8). The lowest number of panicles was observed when ZATIB and HKP were sown in mid-July. Similarly, a significant interaction was observed between variety and sowing window on grain yield. ZATIB sown in late June produced significantly highest grain yield. While sowing variety CIVT in late July produced the lowest grain yield (Table 9).

Table 10 shows the correlation matrix for growth and yield component at N'Dounga 2016 trial. A positive and highly significant correlation existed between grain yields and some growth and yields parameters such as: plant height, panicle diameter, and harvest index. However, no significant relationship was found to exist between the grain yield and some parameters which includes above ground biomass, number of panicles, panicle length, number of days to 50% flowering, number of days to Physiological maturity.

The result in Table 11 showed that at N'Dounga a positive and highly significant correlation existed between grain yields and yields component in 2017 at N'Dounga such as plant height and, also a positive correlation was found to exist between panicle length, number of days to 50 % flowering and harvest index. However, no significant correlation was found to exist between above ground biomass, panicle diameter, number of panicles and number of days to physiological maturity.

Table 8: Interaction of Sowing Windows and Varieties on the Number of Panicle in 2017

Sowing Windows	Varieties			
	CIVT	H80-10 GR	HKP	ZATIB
Late June	3.43bc	2.90bc	3.40ab	4.32a
Mid-July	4.03ab	4.13ab	4.15c	3.20c
SE±		0.29		

Mean followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

Table 9: Interaction of Sowing Windows and Varieties on the Grain Yields in 2017

Sowing Windows	Varieties			
	CIVT	H80-10 GR	HKP	ZATIB
Late June	1061.52b	1037.10bc	1034.18bc	1257.85a
Mid-July	895.35c	1033.18bc	917.18bc	952.35bc
SE±		53.53		

Mean followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

Table 10: Correlation Matrix for Growth and Yield Components at N'Dounga 2016 Trial

	1	2	3	4	5	6	7	8	9
1									
2	0.32								
3	0.61**	0.35							
4	-0.15	-0.45	-0.26						
5	0.29	-0.13	0.25	-0.13					
6	0.29	0.09	0.15	-0.03	0.49**				
7	0.12	0.49**	-0.03	-0.21	0.02	0.5**			
8	0.48*	0.81**	0.39	-0.71**	0.02	0.05	0.44**		
9	0.81**	0.01	0.56**	-0.01	0.24	0.01	-0.45**	0.16	

1=Grain Yield, 2 Plant Height, 3= Panicle Length, 4= Number of Panicle, 5= Day to 50% Flowering, 6=Day to Physiological Maturity, 7= Above Ground Biomass, 8=Panicle Dimeter, 9= Harvest Index

** Correlation is significant at 0.01
*Correlation is significant at 0.05

Table 11: Correlation Matrix for Growth and Yield Components at N'Dounga 2017 Trial

	1	2	3	4	5	6	7	8	9
1									
2	0.55**								
3	0.40*	0.19							
4	0.23	0.17	0.025						
5	0.46*	0.3	0.21	-0.005					
6	0.35	0.48**	0.4*	-0.04	0.65**				
7	0.28	0.29	0.51**	0.08	0.1	0.49**			
8	0.12	0.12	0.36	-0.1	0.36	0.58**	0.46		
9	0.47*	0.17	-0.18	0.07	0.31	-0.11	-0.7**	-0.29	

1=Grain Yield, 2 Plant Height, 3= Panicle Length, 4= Number of Panicle, 5= Day to 50% Flowering, 6=Day to Physiological Maturity, 7= Above Ground Biomass, 8=Panicle Dimeter, 9= Harvest Index

** Correlation is significant at 0.01
*Correlation is significant at 0.05

On-farm trials

The results on Table 12 showed the effect of sowing windows on plant height, above ground biomass and panicle length of the on-farm experiments. A significant difference was observed for plant height with respect to sowing window. Sowing in mid-June produced significantly taller plants than other sowing windows. Similar trend was observed for above ground biomass, where significantly higher above ground biomass was recorded from the mid-June sowing window. However, the smallest above ground biomass was recorded when sowing was done in late July. Similarly, a significant difference in panicle length was observed between the sowing windows, where late July produced shorter panicle lengths than other sowing windows which remained at parity.

All the varieties produced similar plant heights and above ground biomass. ZATIB variety produced statistically taller plants and higher above ground biomass than the other varieties which were at par for the two parameters (Table 12). For the panicle length, there was significant difference among the varieties where the variety ZATIB produced longer panicles. The interaction between sowing window and variety was only significant on plant height.

Table 13: shows the interaction between sowing windows and varieties on plant height. The results showed that sowing ZATIB in mid-June was observed to produce significantly tall plants, while sowing in late July produced the shortest plant.

The result of number of panicles, number of days to 50 % flowering, and number of days to physiological maturity are presented in Table 14. A significant difference was observed between the sowing windows for number of panicles. Millet sown in mid-June and early July produced the highest number of panicles which were at par. The lowest number of panicles was observed when millet was sown in late July. However, there was no significant difference between the sowing window on days to physiological maturity. Sowing on late July produced the

Table 12: Effect of Sowing Windows on Plant Height, Above Ground Biomass, and Panicle Length of Millet Varieties in 2017 Rainy Seasons on Farmers'Field at (N'Dounga)

Treatments	Plant Height (m)	Biomass ($kg\ ha^{-1}$)	Panicle Length (cm)
Sowing windows (S)			
Mid-June	2.24a	6110.35a	64.88a
Early July	2.23a	4772.35b	62.27a
Mid-July	1.70b	3042.02c	57.13a
Late July	1.54c	1148.77d	39.96b
SE±	0.06	409.54	3.62
Varieties (V)			
CIVT	1.80b	3387.10b	52.92bc
H80-10 GR	1.94b	3697.77b	60.08ab
HKP	1.80b	2733.44b	49.48c
ZATIB	2.16a	5255.18a	62.21a
SE±	0.06	409.54	3.62
Interaction			
S×V	0.003	0.31	0.12

Mean followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test

Table 13: Interaction of Sowing Windows and Varieties on the Plant Height (m) in 2017 on Farmers' Field Trial

Sowing Windows	Varieties			
	CIVT	H80-10 GR	HKP	ZATIB
Mid-June	1.82de	2.23c	2.34abc	2.56a
Early July	2.01cd	2.07cd	2.24bc	2.55ab
Mid-July	1.65ef	1.87de	1.42fg	1.88de
Late July	1.69ef	1.58ef	1.21g	1.67ef
SE±	0.11			

Mean followed by the same letter (s) are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

Table 14: The Effect of Sowing Windows on Number of Panicles, Days to 50% Flowering and Days to Physiological Maturity of Millet Varieties in 2017, Rainy Season on Farmers'Field.

Treatments	Number of Panicles (m^{-2})	Days to 50 Flowering (Days)	Days to Maturity (Days)
Sowing windows (S)			
Mid-June	3.59a	71	89a
Early July	3.18a	70	89a
Mid-July	1.84b	75	92a
Late July	1.02c	70	71b
SE±	0.19	1.98	6.95
Varieties (V)			
CIVT	2.05c	71bc	80
H80-10 GR	2.79b	73ab	93
HKP	1.41d	77a	86
ZATIB	3.38a	66c	82
SE±	0.19	1.98	6.95
Interaction			
S×V	0.01	0.33	0.78

Mean followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

lowest number of days to maturity. However, sowing in Mid-June, early July and mid-July produced the highest number of days to physiological maturity which were statistically at parity.

There were significant differences in number of panicles among the four varieties. ZATIB variety produced the highest number of panicle than other varieties (Table14). There were also significant differences among the varieties with respect to days to 50 % flowering. ZATIB variety flowered earlier than the other varieties which were statistically at par with CIVT, while HKP flowered late. However, there were no significant differences among the varieties with respect to days to physiological maturity. The interaction between sowing window and variety was not significant only with number of panicles.

The effect of sowing window on panicle diameter, harvest index and grain yield are presented in Table 15. The result indicated that there was no significant difference between the sowing windows on harvest index. However, sowing window affected panicle diameter. Sowing in mid-June recorded larger diameter than the other sowing windows. While sowing in early July and late July were at par and recorded the thinnest diameter. Similarly, sowing window affected grain yields, in which sowing in mid-June recorded the highest grain yield than the others. While sowing in late July produced the lowest grain yields.

The varieties had affected the harvest index (Table 15), in which ZATIB produced the highest percentage of harvest index than the other varieties. The variety HKP was at par with CIVT and produced the lowest percentage of harvest index. Similarly, varieties had significantly affected panicle diameter, in which ZATIB produced the bigger panicle diameter, which was closely at par with H80-10 GR. While variety HKP was at par with CIVT and both produced a thinner panicle diameter. However, there were no significant differences between the variety with respect to yield. The interaction between sowing window and variety was not significant on panicle diameter, grain yield and harvest index.

Table 15: The Effect of Sowing and Varieties on the Panicle Diameter, Harvest Index, and Grain Yields of Millet Varieties in 2017 Rainy Season on Farmers'Field at (N'Dounga)

Treatments	Panicle Diameter (mm)	Harvest Index -	Grain Yields (kg ha^{-1})
Sowing windows (S)			
Mid-June	26.10a	0.17	1086.86a
Early July	24.57c	0.16	825.31b
Mid-July	20.00b	0.14	458.69c
Late July	15.35c	0.24	345.31d
SE±	1.36	0.03	84.99
Varieties (V)			
CIVT	20.25bc	0.16	579.73bc
H80-10 GR	22.41ab	0.20	676.40b
HKP	18.37c	0.16	471.46c
ZATIB	24.99a	0.19	988.65a
SE±	1.36	0.03	84.99
Interaction			
S×V	0.12	0.94	0.42

Mean followed by the same letter (s) within a treatment group are not significantly different at 5% level of probability using Student New Man Keuls (SNK) Test.

Table 16 shows the correlation Matrix for Growth and Yield Characters on Farmers' Field in 2017. A highly significant and positive relationship existed between the grain yield and plant height and a negative relationship existed between grain yield and number of days to 50 % flowering. A positive and highly significant relationship was observed between grain yield and parameters like: above ground biomass, harvest index, panicle length, panicle diameter, number of panicle (Table 16).

Genotype Specific Parameters

Genotype Specific Parameters (GSPs) of the millet varieties are shown in Table 17. The values of P1 for CIVT and H80-10 GR were 180 and 290 respectively while that of ZATIB and HKP were 400 and 328 degree days, respectively. The P20 was 12.56 for ZATIB, 12.20 for CIVT, 11.00 for H80-10 GR and 11.30 for HKP. The highest value for the coeficient P2R (446.1) was observed for ZATIB which was followed by CIVT (180) and H80-10 GR (130). The lowest value for P2R (102) was obtained for HKP. The value of the coefficient P5 had large variations, ranging from 114.8 degree days for cultivar HKP to 342 for the cultivar H80-10 GR. There was also high variation among the cultivars for the coefficients G1 and G4. The phyllochron interval coefficient (PHINT) value for all four cultivars was 43 degree.

CERES-Millet model Calibration

The CERES-millet model was calibrated using data on number of days to anthesis, days to physiological maturity, above ground biomass at harvest, grain yields and harvest index to estimate the eco-physiological coefficient in running the CERES-Millet model. The details of the genetic coefficient of CERES-millet model generated from the calibration experiment are presented in the Table 17.

Table 16: Correlation Matrix for Growth and Yield Components in 2017 on Farmers' Field Trial

	1	2	3	4	5	6	7	8	9
1									
2	0.75**								
3	0.56**	0.55**							
4	0.8**	0.77**	0.68**						
5	- 0.36**	-0.26	-0.20	-0.36*					
6	0.16	0.22	0.6**	0.21	0.09				
7	0.86**	0.77**	0.57**	0.80**	-0.33*	0.16			
8	0.72**	0.71**	0.87**	0.74**	-0.30*	0.64**	0.72**		
9	0.16	-0.02	0.16	0.01	-0.18	0.30*	-0.24		

1=Grain Yield, 2 Plant Height, 3= Panicle Length, 4= Number of Panicle, 5= Day to 50% Flowering, 6=Day to Physiological Maturity, 7= Above Ground Biomass, 8=Panicle Dimeter, 9= Harvest Index

** Correlation is significant at 0.01
*Correlation is significant at 0.05

Table 17: Genetic Coefficients of four Millet Cultivars Used in Model Calibration

Cultivars	P1	P20	P2R	P5	G1	G4	PHINT
	° C day	(hour)	°C days	°C days	-	-	° C day
CIVT	180	12.20	180	326.0	0.50	0.61	43
ZATIB	400	12.56	446.1	120.8	2.50	12.0	43
HKP	325	11.30	102	114.8	2.50	1.66	43
H80-10 GR	290	11.00	130	342.0	0.50	0.56	43

Table 18 shows the results of simulated and measured days to anthesis. A good agreement was obtained between the observed data and model simulations for days to anthesis with values of RMSE, Normalized RMSE (RMSEn), d-index and R^2 of 1.27 days, 2.09 %, 0.99 and 0.98 respectively. Similarly, there was a close match between simulated and observed days to physiological maturity (Table 18). The values of RMSE, RMSEn, d-index and R^2 were: 2, 2.41%, 0.97 and 0.90 respectively.

Simulated values of grain yields were very close to the observed data as shown in Table 19. Low values of RMSE (64.21 kg) and RMSEn (5.51%) as well as high values of d-index (0.93) and R^2 (0.81) were recorded. There was also close match between simulated and observed harvest index with RMSE value of 0.01 and RMSEn values of 8.04%. The values of d-index and R^2 were 0.91 and 0.92 respectively. A close match was noticed between the observed and simulated values for above ground biomass (Table 19), with RMSE value of 680.45 kg and RMSEn value of 8.57%. The values of d-index and R^2 were: 0.79 and 0.62 respectively.

Model evaluation

Result of simulation using the calibrated CERES-Millet model was evaluated with the field experiment data recorded from 2017 on station trials. The results of simulated and measured days to anthesis are presented in Figure 7. A good agreement was obtained between observed data of experiment and model simulated for days to anthesis with the values of RMSE, RMSEn, d-index and R^2 of 2.17 days, 3.60%, 0.98 and 0.96 respectively. Similarly, the model simulated well the number of days to physiological maturity (Figure 8), with RMSE, RMSEn, d-index and R^2 values of 2.44 days 2.97%, 0.97 and 0.92 respectively. The result showed that the simulated harvest index was in good agreement with the corresponding observed values, with RMSE value of 0.01. The values of RMSEn was 9.22 % and the values of d-index and R^2 were 0.77 and 0.41 respectively (Figure 9).

Table 18: Comparison of Observed and Simulated Days to Anthesis and Days to Physiological Maturity for Model Calibration

		Days to Anthesis		Days to Maturity	
Varieties	Sowing Windows	Observed	Simulated	Observed	Simulated
CIVT	Late June	52	53	81	80
	Mid July	51	51	83	78
ZATIB	Late June	76	73	90	90
	Mid July	69	69	86	86
HKP	Late June	57	58	74	75
	Mid July	59	59	75	76
H80-10 GR	Late June	62	61	91	89
	Mid July	61	62	89	89
RMSE (Days)		1.27		2	
RMSEn (%)		2.09		2.41	
d-index		0.99		0.97	
R^2		0.98		0.90	

Obs= Observed; Sim= Simulated

Table 19: Comparison of Observed and Simulated Grain Yields, Above Ground Biomass and Harvest Index for Model Calibration

Varieties	Sowing Windows	Grain Yields (kg ha^{-1}) Obs	Grain Yields (kg ha^{-1}) Sim	Above Ground Biomass (kg ha^{-1}) Obs	Above Ground Biomass (kg ha^{-1}) Sim	Harvest Index Obs	Harvest Index Sim
CIVT	Late June	1164	1162	7705	8119	0.155	0.143
	Mid July	1161	1163	7557	7822	0.150	0.149
ZATIB	Late June	1427	1382	7459	7965	0.191	0.178
	Mid July	1165	1247	6580	6760	0.172	0.157
HKP	Late June	1144	1129	6901	7160	0.186	0.167
	Mid July	933	944	6489	7199	0.146	0.131
H80-10 GR	Late June	1172	1154	8658	8914	0.128	0.130
	Mid July	978	1132	8028	8986	0.126	0.126
RMSE (kg ha^{-1})		64.21		680.45		0.01	
RMSEn (%)		5.51		8.57		8.04	
d-index		0.93		0.79		0.91	
R^2		0.81		0.62		0.92	

Obs= Observed; Sim= Simulated

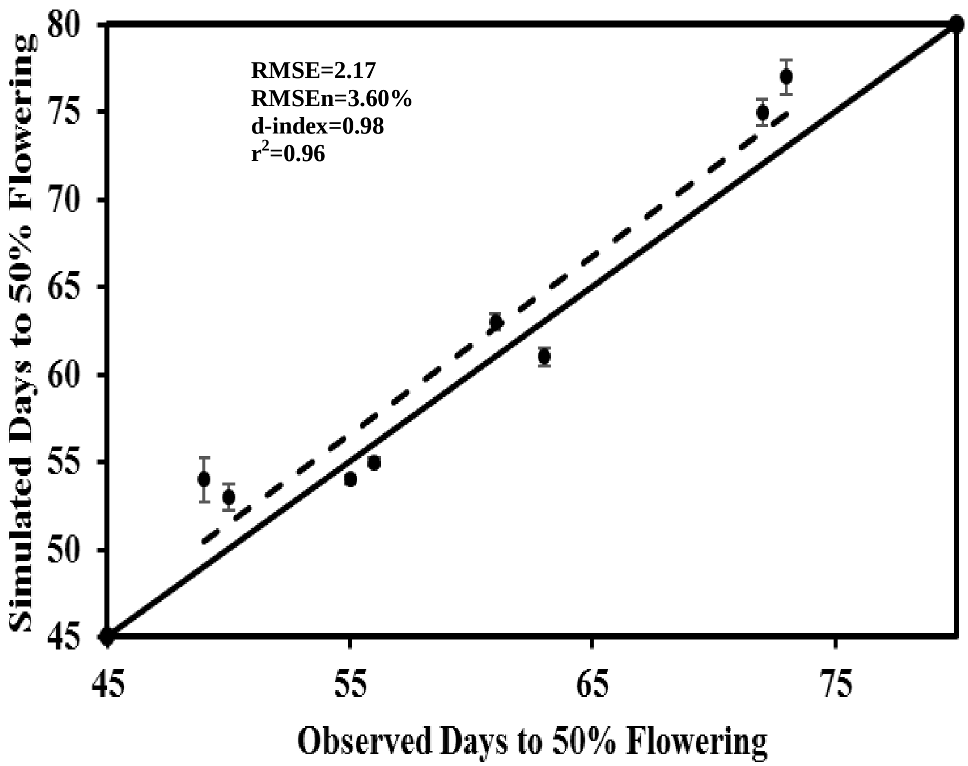

Figure 7: Comparison of Observed and Simulated Days to Anthesis for Model Evaluation

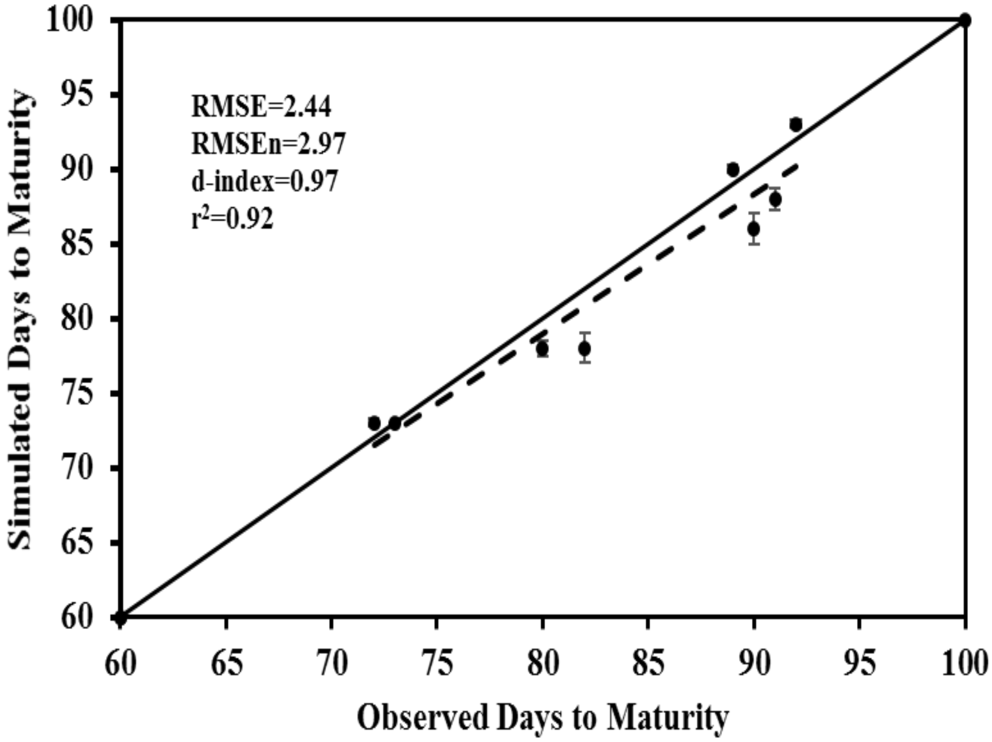

Figure 8: Comparisons of Observed and Simulated Days to Physiological Maturity of Millet for Model Evaluation

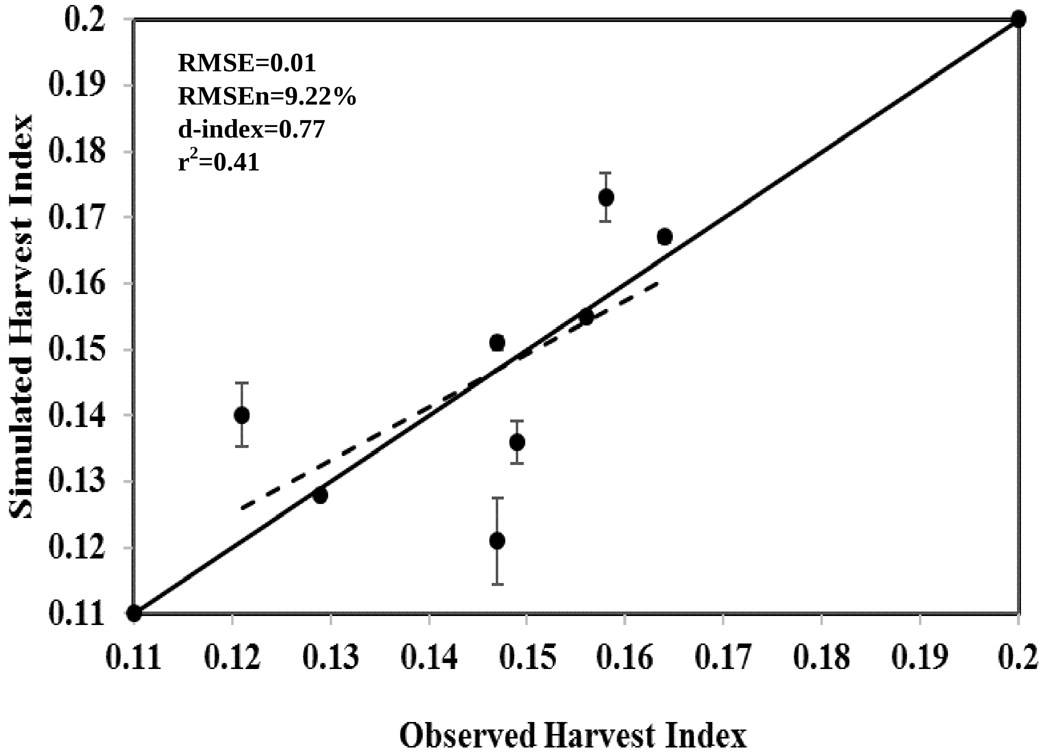

Figure 9: Comparisons of Observed and Simulated Millet Harvest Index for Model Evaluation

The results of the comparison of simulated and measured above ground biomass are presented in Figure 10. The RMSEn between the simulated above ground biomass and observed above ground biomass was 3.67 % with the value of RMSE of 264.16 kg ha^{-1} and the values of d-index, and R^2 were 0.94 and 0.89 respectively. Grain yield was well simulated by the CERES-Millet model (Figure 11). The RMSE, RMSEn, d-index and R^2 were 70.14 kg ha^{-1}, 6.80 %, 0.81 and 0.47 respectively.

Model Application

The cumulative probability plots for harvested grain yields of ZATIB variety is shown in Figure 12. Sowing ZATIB in late July produced the lowest grain yield of 0.4 t ha^{-1}.The highest grain yield was observed when ZATIB was sown in Mid-June, followed by sowing in late June. At 50% probability, ZATIB variety grain yield was below 0.7 t ha^{-1} for the early May, late June, early July and mid-July sowing windows, while the early June, mid-June sowing windows produced yields > 0.80 t ha^{-1}.

Figure 13 showed the cumulative probability for simulated grain yield of HKP. The minimum yield was observed when sowing was done in early May with almost 0.57 t ha^{-1}. Whereas, the highest grain yield was observed when sowing was done in mid-June. Yields below 0.5 t ha^{-1} was obtained with early-May, mid-May, and late July sowing windows and 0.6 t ha^{-1} for mid-July and late May sowing windows, with probability of 0.5. At 50 % of the probability the yield of HKP was above 0.73 t ha^{-1} for the late June and early July sowing window and above 0.8 t ha^{-1} for the mid-June sowing window.

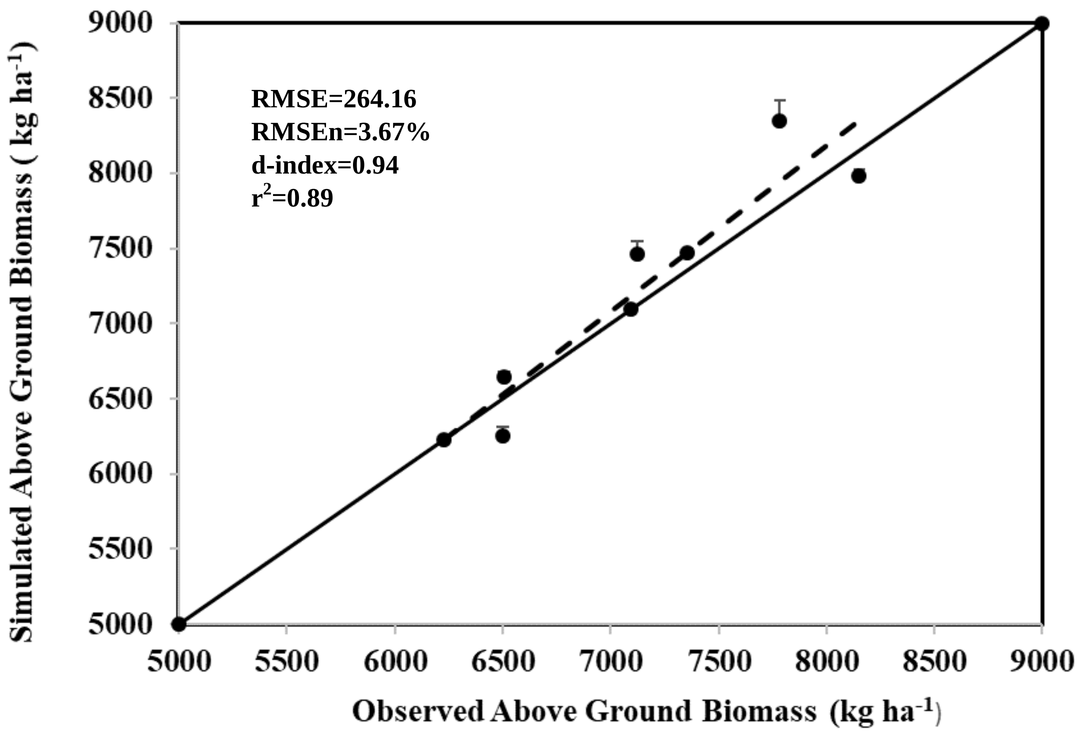

Figure 10: Comparison of Observed and Simulated Above Ground Biomass of Millet for Model Evaluation

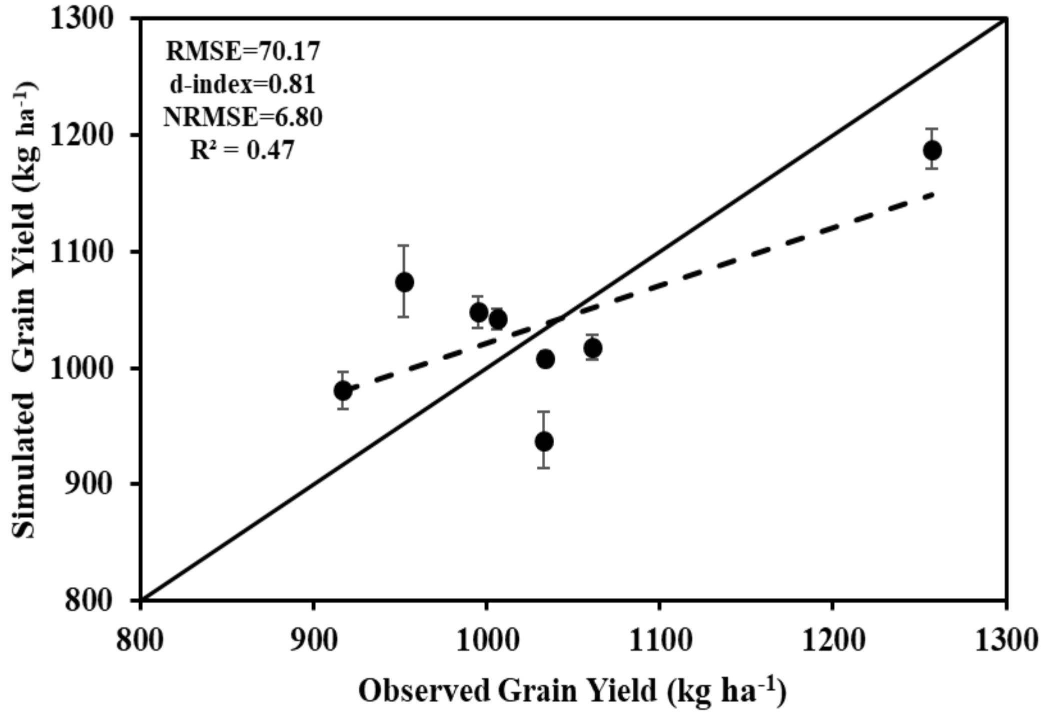

Figure 11: Comparison of Observed and Simulated Grain Yield for Model Evaluation

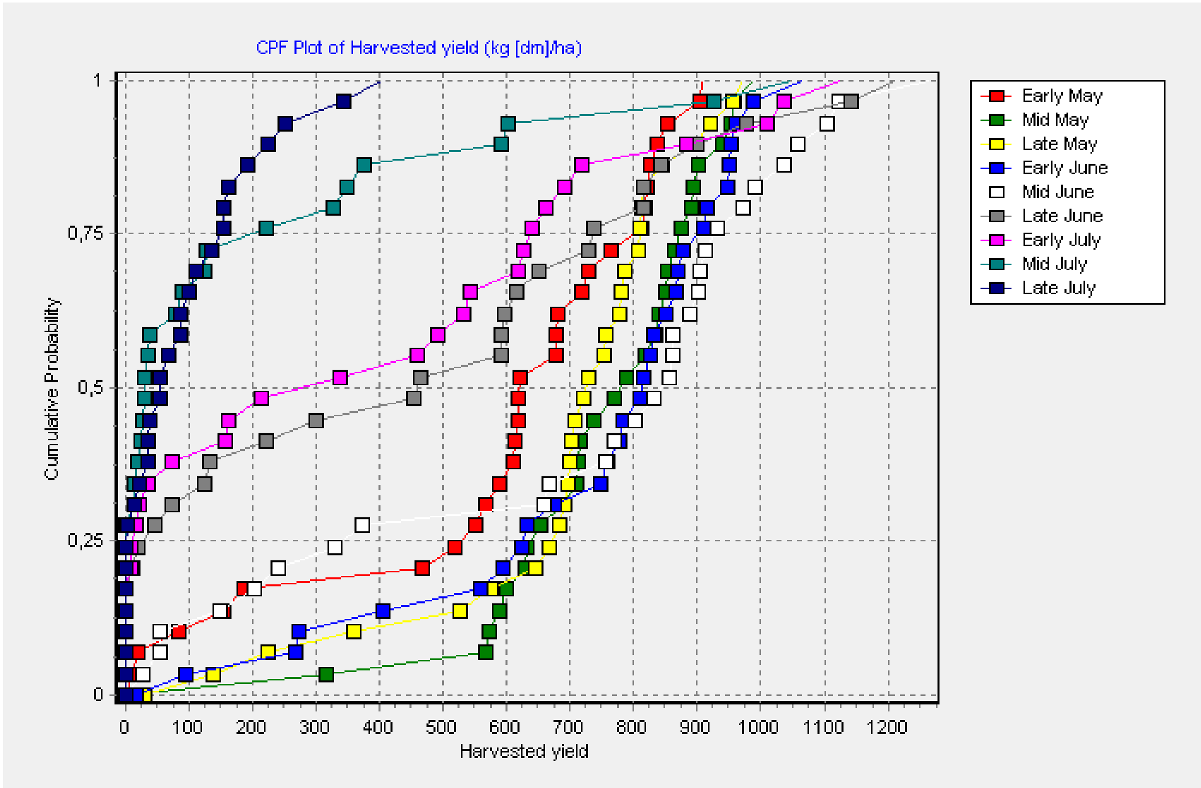

Figure 12: Cumulative Probability of ZATIB Millet Grain Yield (Kg ha^{-1}) per ha at Different Sowing Windows

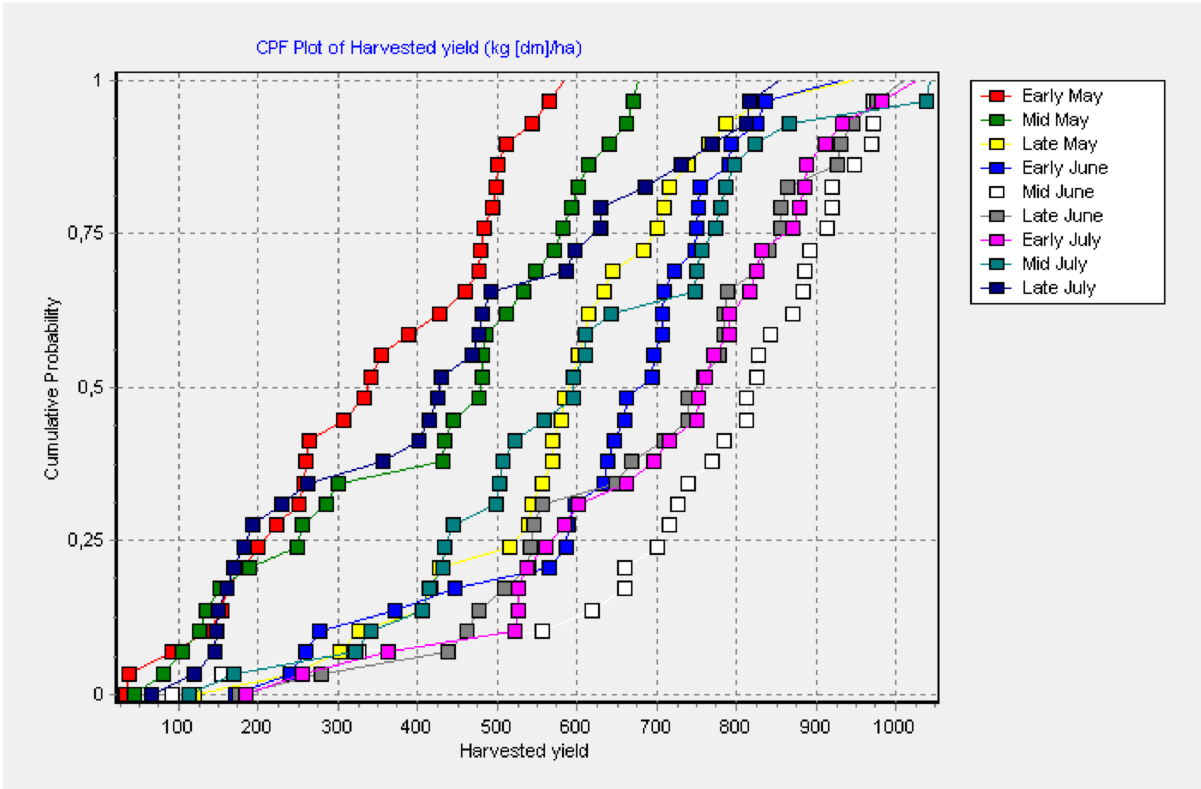

Figure 13: Cumulative Probability of HKP Millet Grain Yield (Kg ha^{-1}) at Different Sowing Windows

For the variety, CIVT the highest grain yield was above 1 t ha^{-1} when sowing was done in late June and early July (Figure 14). The cumulative probability analysis for harvested grain yield indicated that at 50% probability, CIVT was less than 0.4 t ha^{-1} for early May, late July. However, the yield was almost 0.70 t ha^{-1} when sowing was done in mid-June and late June.

Cumulative probability analysis over 30 years period (years) of H80-10 GR for grain yield indicated that at 50% probability, the harvest grain yield was less than 0.5 t ha^{-1} for early May, early July, mid-July and late July sowing windows. However, the yield of H80-10 GR was 0.7 t ha^{-1} tons when sown in mid-June and late June and 0.72 t ha^{-1} when sown in early-June (Figure 15).

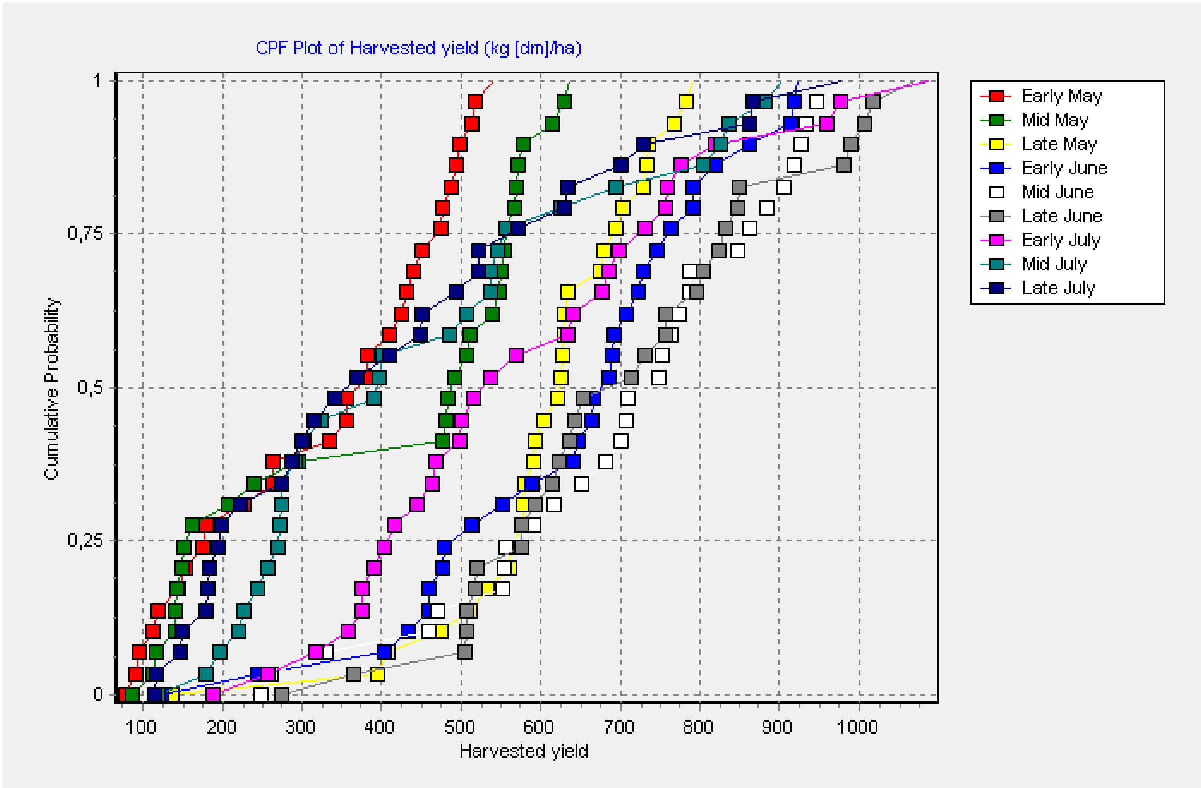

Figure 14: Cumulative Probability of CIVT Millet Grain Yield (Kg ha^{-1}) at Different Sowing Windows

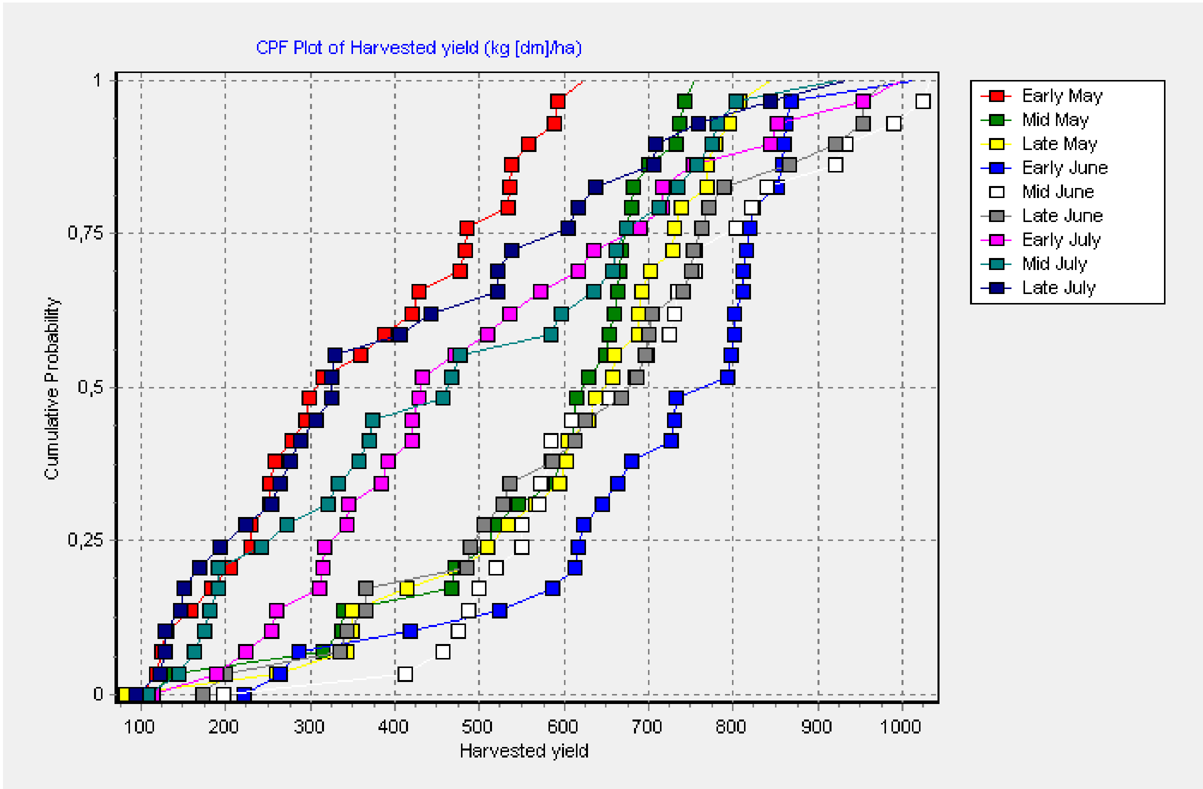

Figure 15: Cumulative Probability of H80-10 GR Millet Grain Yield (Kg ha^{-1}) at Different Sowing Windows

4.2 DISCUSSIONS

4.2.1 Effect of Sowing Windows on Growth of Pearl Millet

The result from this study showed significant differences between the sowing windows with regards to plant height both on station and on farmers' field. Early sowing window produced higher plant height than late sowing window. This could be explained by the fact that early sowing allows the crop to make full utilization of the available resources (water, nutrient, sunlight) that enable them to grow taller compared to late sowing. These results are in line with those of Maas *et al.* (2007) who reported that crop sown on 15th June produced significantly taller plants than that sown on 15th July, which produced dwarf plant. Juraimi *et al*. (2009), reported similar effects with tef grass (Eragrostis tef [Zucc.] Trotter) grown in Ethiopia. Strong reduction in plant height had been shown in previous studies when sowings were delayed on cereal crops (Razzaq *et al*., 1986).

Days to 50% flowering was shortened with delay in sowing in 2016 and 2017 in the on station trial. This was due to dry spell observed during this period which made the crop to prolong its days to 50% flowering (Dokuyucu *et al.,* 2004; Kamara *et al*., 2009; Aslani and Mehrvar, 2012). This is in line with the report of the study conducted in the Southeast of Senegal on fonio, where delayed sowing shortened the time to heading or time to flowering and that, led to a reduction of resource capture.

4.2.2 Effect of Sowing Windows on Yields and Yields Components of Pearl Millet

The yield differences between the sowing windows could have been because early sowing enabled the crop to receive well distributed rainfall uniformly which enabled it to cover their needs during flowering stage, which required a lot water (Beiragi *et al*., 2011). This indicated the overwhelming effect of sowing window on yield components. In all these studies, it is apparent that early sowing without dry spells performed better than late sowing. Deshmukh *et al*. (2009) reported that the different dates of sowing significantly influenced the grain yield of pearl millet during all the years of experimentation and on pooled basis.

Above ground biomass was significantly influenced by variation in sowing windows, where early sowing resulted in highest above ground biomass in 2016 in the on station trial and 2017 on farmers' field. The reason for differences in above ground biomass may be explained by the fact that the late sowing windows experienced more water deficit conditions as the rains ended early. This finding is in line with the report of Kamara *et al*. (2009) who noted considerable reduction in yield and yield component of maize when sowing was delayed in Northern Nigeria

4.2.3 <u>Effect of Varieties on Growth of Pearl Millet</u>

The varieties differed significantly with respect to plant height where ZATIB produced taller plants compared to the other varieties. This was due to the genetic make-up which enabled ZATIB to have taller plants. Similar results were reported by Bachir *et al.* (2015) who reported the variety to have taller plants in Sudan. The result from both experiments showed variations in numbers of days to 50% flowering among the varieties. It was found that CIVT variety reached 50% flowering earlier compared to others. This may be explained by the fact of its ability to tiller faster than other varieties.

4.2.4 <u>Effect of Varieties on Yields and Yield Components</u>

ZATIB produced the highest grain yields among the varieties in the on station trials of 2016 and on farmers' fields in 2017. This might be due to the adaptability of the variety to the soil and weather conditions of the experimental locations.

Similar results were recorded by (Ugur *et al*., 2005) who reported that yield of pearl millet varies with different varieties. There were significant differences among the varieties in respect of panicle diameter, number of panicles and above ground biomass in the on farmers'field trial. These results agreed with those reported by (Bachir *et al*., 2.15).

Equally, the variety H80-10 GR was found to have higher above ground biomass on the station in both years of the study compared to other varieties. The highest above ground biomass was observed with the ZATIB variety on farmers' field trial this situation showed that H80-10 GR could not perform well under farmers'field conditions as it does, on station. The differences in the above ground biomass of the varieties could be attributed to differences in their genetic make-up. This is in line with the findings of (Ugur *et al*., 2005).

4.2.5 Genetics Coefficient

For genetic specific estimation we used days to anthesis, days to physiological maturity, grain yield, above ground biomass and harvest index. There was very good agreement among both growth and phenology variables. The closeness of fit observed for the calibration data could be attributed first to several runs of GLUE but also to good weather data and better crop management (timely weeding, fertilizer application etc.).

4.2.6 Calibration and Evaluation of CERES-millet

For the model calibration step all the indices showed good agreement between the observed and simulated days to anthesis and days to physiological maturity. Thus, indicating that the model was able to accurately predict phenology well. A very good agreement was observed between simulated and observed grain yield and above ground biomass. All the indices for these parameters showed that the simulation was excellent. This could have been explained by the fact that the millet crop phenology was well simulated. Thus, Indicating that the CERES-Millet model was quite efficient in simulating the above ground biomass and grain yield. Similar finding was made by (Xevi *et al*., 1996) who used the CERES-Maize model to predict above ground biomass of maize and reported that this parameter predicted within the 95 percent confidence limit of the measured data. Accurate prediction of phenology is critical in model calibration (Archontoulis *et al*., 2014). When phenology is well simulated, it is expected to have good prediction with regards to yield and yield component (Robertson *et al*., 2002).

A close agreement was observed between the observed days to anthesis and days to physiological maturity. These results are in line with those of Adnan *et al.* (2017) who reported that CERES-Maize model was able to simulate phenology quite well.
The evaluation of CERES-Millet model for above ground biomass and grain yields showed the good agreement between the model prediction and measured data. The ability of the CERES-Pearl Millet model to predict biomass in the tropical, sub-tropical and temperate environment was verified by previous studies (Shivsharan *et al*., 2003; Soler *et al*., 2010; Hussaini and Halilu, 2013). These results are also in good agreement with those of those of Hunt and Boote (1998).

4.2.7 Long Term Sowing Windows Analysis

The recommended local sowing window in Niger Republic are outdated due to influence of rainfall variability. Recommendations for sowing are made from large-scale cropping experiment conducted across the regions (NAERLS, 2013). Often time the same sowing window is recommended for multiple locations without considering seasonal and spatial variations as well as soil and varietal differences. Long-term weather data was used for sowing window analysis to come up with better sowing window recommendations for the farmers. This analysis indicated the optimum sowing window for the ZATIB variety and H80-10 GR is from early June to mid-June. However, high yield variations were observed for sowing windows below and above the recommended. Lower yields were recorded for very early (mid and late May) and late (early and mid-July) sowing windows. This could be explained by the fact that the varieties will experience severe drought stress and high temperature at flowering stage which has detrimental effect on yields. Late planting also leads to a higher yield reduction and has the potential to result in total crop failure. Late planting results in yield reduction due to failure of the crops to mature if the rainfall ceases early before the end of the cropping season (Jibrin *et al.,* 2012; and Adnan *et al*., 2017). Planting the variety CIVT from early June to late June led to the highest grain yield. Sowing before, and particularly after these dates could be highly risky and farmers should be discouraged from sowing at this period, the yield is decreasing because of non-establishment of rainfall at the beginning of the season and stress at the end of season. Similar relationships between sowing windows and crop responses have been previously reported on many cereal crops under various conditions (Dokuyucu *et al*., 2004; Kamara *et al*., 2009; Aslani and Mehrvar, 2012). For the HKP variety the best time to sow it is from mid-June to early-July June because these varieties cannot tolerate stress during the end of their cycle.

CHAPTER FIVE
5.0 SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 SUMMARY

The effect of sowing dates and varieties on growth and yields of pearl millet was studied. The experiment was conducted at N'Dounga Research (2°18' 28" E 13° 15' 00" N) Station in 2016 and 2017 and on farmers' field in 2017. The objectives of the study were:

i) To evaluate the effect of sowing windows on the growth and yield of millet varieties;

ii) To calibrate and evaluate CERES-Millet model for simulating sowing windows of millet varieties;

iii) To carry out a seasonal analysis with CERES-Millet model to establish the optimum sowing windows of millet varieties at N'Dounga.

The treatment consisted of two sowing windows on station (Late June and Mid-July) with four varieties (HKP, ZATIB, H80-10 GR and CIVT). The treatments were laid out in split plot design with three replications. Sowing windows were assigned in the main plot. While the varieties in the subplot. The experiment was conducted in the same location at N'Dounga in 2017 but on farmers 'field. On the other hand, on the farmers'field, the crop was sown at four level of different sowing windows which were 14th June (Mid-June), 04 July (Early July) ,19th July (Mid-July) and 27th July (Late July) with four varieties (ZATIB, H80-10 GR, HKP and CIVT), in an incomplete factorial design with 12 farmers. The following data were collected during the experiments: plant height, days to 50 % flowering, days to physiological maturity, harvest index, above ground biomass and grain yields. The results revealed that there was significant effect of sowing windows both in 2016 and 2017 on station trial. Late June sowing window produced the higher grain yield compared to mid-July sowing window. However, for the on farm trial, mid-June sowing produced the highest grain yields compared to the other sowing window. ZATIB variety produced the highest grain yields in comparison to other varieties in the on station trial as well as the on farm trial.

The DSSAT CERES-Millet model was calibrated to predict the growth and yields of millet in Niger Republic using 2016 data from on station experiment and subsequently, it was proceeded with the evaluation with an independent data from 2017 on station. For the model calibration, lower values of RMSE were observed between the simulated and observed days to 50% flowering, days to physiological maturity, above ground biomass and grain yields. The RMSEn values for these parameters were less than 10%. The outcomes of the simulations for days to 50 % flowering and physiological maturity resulted in high d-index. Similarly, the values of d-index were high for above ground biomass and yields. For the model evaluation, the statistics revealed that the RMSEn for all the variables and d-index were within the acceptable range that shows that the model is able to simulate growth and yield of millet in Niger Republic. After the calibration and evaluation, the model was used for model application analysis

5.2 CONCLUSION

This experiment was conducted to determine the effect of sowing windows on growth and yields of pearl millet. The results of this study had shown that sowing windows had significant effect on growth and yields of pearl millet at N'Dounga in Niger Republic. On station trials in late-June sowing windows produced the higher grain yield compared to mid-July sowing window. On the other hand, for the on farm trial, mid-June sowing windows gave the highest grain yield compared to the other sowing windows. Despite the fact that mid-June sowing gave the highest grain yield in the on farm trial, yield cannot be as much as if the farmers had sown in late June therefore, late June is the best sowing dates at N'Dounga in Niger Republic. ZATIB variety had the highest grain compared to the others varieties under both on station and on farmers' field.

CERES-Millet model was first calibrated and evaluated to simulate sowing windows on yields of millet varieties. For both calibration and evaluation, the results showed the values of normalized root mean square error were less than 10 % for all the variables (days to anthesis, days to physiological maturity, above ground biomass, harvest index and grain yields) showing that the simulation was excellent. The simulated and measured values of variables (days to anthesis, days to physiological maturity, harvest index, above ground biomass and grain yield) fitted each other well. The values of d-index were also within acceptable range for all variables compared. Therefore, it can be concluded that the CERES-Millet is robust to satisfactorily simulate millet growth and yields at N'Dounga, Niger Republic. The CERES-Millet model can, therefore, be a useful tool for decision support to researchers and extension workers in Niger Republic to determine optimum sowing windows and compensate the need for years of costly multiplications on station and farm trial which are very expensive and time consuming.

5.3 RECOMMENDATIONS

Based on the findings of this study it can be recommended that:

- ✓ Late June sowing window is the best for the farmers to adopt when using the good cultivar ZATIB millet production as it gave the highest yield;

- ✓ ZATIB variety is recommended to the farmers in the study area as it gave the higher grain yield compared to the other varieties;
- ✓ Seasonal analysis revealed that sowing should be done from early June to mid-June for the ZATIB and H80-10 GR;
- ✓ It should be done from early June to late June for CIVT and mid-June to early July for HKP;
- ✓ Further model evaluation might be needed for other cultivars which are released in the area;
- ✓ These is a need to repeat this study in other benchmark soil located within the agro-ecological zones to capture variability that exist in soil.

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