ASSESSMENT OF PHENOLOGICAL PHASES, MAXIMUM YIELD, AND WATER USE OF PEARL MILLET IN THE DSSAT MODEL

BY

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2000/9499EA

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

NIGER STATE, NIGERIA

NOVEMBER, 2006

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BEING A FINAL YEAR PROJECT SUBMITTED IN FULFILLMENT FOR THE REQUIREMENT OF THE AWARD OF BACHELOR OF ENGINEERING (B.ENG.) IN AGRICULTURAL ENGINEERING

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA.

NOVEMBER,2006

DECLARATION

I hereby declare that this project is a record of a research work that was undertaken and written by me Ogijo Samuel Idoko. It has not been presented before any degree or diploma or certificate at any university or institution. Information derived from personal communications, published and unpublished works of others were duly referenced in the text.

.... 10-11-2006.

Ogijo Samuel Idoko Date

CERTIFICATION

This project entitled "Assessment of Phenological Phase, Maximum Yield, and Water use of pearl Millet in the DSSAT Model" by Ogijo Samuel Idoko meets the regulations governing the award of the degree of Bachelor of Engineering (B.ENG) of the Federal University of Technology, Minna and it is approved for its contribution to scientific knowledge and literary presentation.

Engr. Dr. N.A. Egharevba
Project Supervisor.

10-11-2006
Date

External Examiner

02/11/2006
Date

Dr.(Mrs) Z. D. Osunde
Head, Department of Agricultural Engineering

13/11/2006
Date

DEDICATION

This project is dedicated to Professor Gerrit Hoogenboom of the Department of Biological and Agricultural Engineering of the University of Georgia USA who assisted me greatly in this research and to all other ICASA members for their contributions.

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My wholesome gratitude and praise to God Almighty, the source and anchor of my life, without his mercies all this years of toiling would have fruitless. My sincere gratitude goes to the Head of the department of Agricultural Engineering, federal university of technology Minna Dr Z. D. Osunde for her leadership qualities in piloting the affairs of the department. My sincere gratitude to my supervisor Dr. N. A. Egharevba who spent his precious time in assessing the project when called upon and for inspiring me in soil/water Engineering options. To all other lecturers in the department worthy to mention; professor E A .Ajisegiri, Dr. M G Yisa, and Dr. O. Chukwu who inspired me in many ways.

To Professor Gerrit Hoogenboom, Cecelia Tojo, who assisted me with journal and papers when I started the research. To Mr. Alilu who also assisted me throughout the research, I say thank you.

To my parent Mr. and Mrs. Gabriel Ogijo, who invested on me a long time project by making me somebody today, they will eat the fruit of their labor and to my sister Ajuma who assisted me financially, I owned you a million thanks.

In a special way I appreciate Bar. And Mrs. Benjamin Okolo .without your assistant, the journey would have been hard. You are actually God's sent.

To Emeka Madueke, you are more than a friend, Avong, you are thoroughly a friend who understands and to all CCR brethren who are always there in prayers and encouragements, God have used you to bless me.

To my sweet Angel Anna. I leave this portion for you only. You are the Angel of my life. Nothing is more important to me.

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ABSTRACT

The Decision Support System for Agro technology Transfer (DSSAT) has been in use for the last 15years by researchers worldwide. This package incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purposes. For this research pearl millet is used in order to evaluate the phonological phase, maximum yield and water use. An experimental field of 27 × 19 m² was used, divided into 18 plots or replicate of 6 × 3 plot design. The two varieties used are Ex-Borno and Niger local, planted at different dates. Parameters used for the simulation of this crop in the model were collected. These are; millet phenology data yield and yield data, daily record of weather parameters, detailed soil profile description, determination of upper and lower limits of available water at different depths and bulk density. After simulation result shows that the simulated field is 3623 Kg/ha and the measured field is 130 Kg/ha.

The physiological maturity of the simulated value is 94 while the measured is 76. This research is recommendable to commercial farmers involved in exportation and brewery industries

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CHAPTER ONE

1.1 INTRODUCTORY BACKGROUND

Pearl millet (*Pennisetum glaucum L. R. Br*) is an important tropical food cereal with 26 hectare being grown mostly in semi and West Africa and India (Andrews *et al.*, 1993, Andrews and Bramel-cox, 1994). It is the most droughts tolerant of all domesticated cereals and can yield grain under rainfall an amount as low as 200 to 250mm (Bidinger and hash, 2003). This is an added advantage to millet, making it one of the reliable productive cereals in the direct rain fed regions of the arid and semi-arid tropics. It is second only to sorghum as a staple in the savanna areas of Nigeria (Ikwelle, 1998). Pearl millet is a diploid annual (2n =2x = 14) and is part of the group of species within penniselum that also includes the perennial p, purpureum Napier or elephant grass (Purseglove, 1976).

In Africa, pearl millet is commonly grown in semi-arid regions where it is the primary food source for millions of people. The main millet producing countries in West Africa in 2000 were Nigeria (54%), Niger (20%) and Mali (9%). Pearl millet may be considered as a single species but it includes a number of cultivated races. The height of the pearl millet may range from 0.5 to 4m and the grain can be nearly white, pale, yellow, brown, grey, slate blue or purple. The ovoid grains are about 3 to 4mm long, much larger than those of other millet and the 1000 – seed weight ranges from 2.5 to 14kg with a mean of 8g (FAO Corporate Document Repository, 2005). Purseglove (1972) listed 11 major morphological characters by which cultivars may be distinguished. Penology has been used as a criterion for broad grouping into early, medium and late maturity types: the boundaries between these groups in West are 95 and 130 days to maturity and in India 100 and 180 days (Purseglove, 1972). Pearl millet needs 500 – 600mm of rainfall per annum. It requires temperature above 20°C if the grain is to ripen. Pear millet stores very well and is resistant to most pest and diseases. It is a quick maturity crop which produces grain – bearing side shoots (tillers). It can be worked in a number of ways, fermented into beer for brewery or used as a forage crop by poultry industry (Amato and Forrester, 1995, Andrew *et al.,* 1996). After harvesting, the stalks are useful for fencing in local surroundings (dwellings) and as fuel for cooking or as beddings but it is labour intensive.

The DSSAT – Decision support system for Agro technology transfer model is designed to stimulate plant phonological processes (nutrient and water update, transpiration, photosynthesis, organogenesis and biomass partitioning) and predict growth, development and yield in daily time steps in a manner similar to the processes as they are thought to occur in the real plant (Jagtap *et al.,* 1992)

1.2 OBJECTIVE

The objective of this study is:

To quantify pearl millet phonological phases, maximum yield and water use with the aim of filing knowledge gap areas in DSSAT millet model for the West African semi – arid varieties and environment.

1.3 JUSTIFICATION

This study will show the possible relations between climates (weather parameters) and periodic biological phenomena as the crop grows from its emergence stage to flowering stage and maturity stage. Secondly it will show the actual use water consumed by the crop and the maximum yield it will produce. Based on the findings from this research, farmers can be advised on the best date for planting for maximum water use and fertilizer application, they can also be advised on the best land for maximum yield.

CHAPTER TWO

2.0 REVIEW OF LITERATURE

2.1 Origin, Evolution and Dispersal

Pearl millet is not known in the wild state. Chevalier (1934) noted that the cultivars of the Sahel zone of West Africa are very similar to local spontaneous and sub spontaneous forms and Purseglove (1972, 1976) considers this region the probable centre of domestication. Although a poly phyletic origin has been proposed (Krishpaswamy, 1951), Purseglove believes that only one or two wild species were domesticated and that subsequent races were domesticated and that subsequent races evolved by disruptive selection in new environments. Introgression and hybridization between cultivars and wild types coulinned, giving rise to new crop and weedy races. The weedy races have deciduous spikelets and small enclosed grains; cultivars have persistent spikelets and generally large exposed grains.

There is no evidence of the date of domestication. The crop spread to East Africa and thence to India probably at least 3000 years ago according to Purseglove (1976). Grains found in India are tentatively identified as pearl millet has been dated c. 3000BP (Auchin, 1969). In India, only cultivated races with morphological characters indicating degrees of past selection are found (Krishnaswamy, 1951), suggesting the entry of races already domesticated. Pearl millet was introduced to the USA in the 1850s, but it probably reached tropical America from Southern Europe at an earlier date (Rachie & Majmudar, 1980). In the USA it is grown only as forage and as a grain crops it is unimportant in the new world tropics.

2.2 Crop Development Pattern

Pearl millet is grown largely with 200 – 800mm AAR. As a consequence of this wide range in duration of growing season, genotypes vary in maturity from 55 to 180 days or more. In short season cultivars, development is divided into three approximately equal periods: floral initiation occurs at about DI = 0.3 and anthesis at DI =0.6 – 0.7 (Bindiger *et al.,* 1981). Floral initiation in most cultivars is simulated by short day length (Begg & Burton 1971, Patil, Reddy & Gill 1978). This affects time to maturity as demonstrated by serial plantings at high latitude (Ferrani, Norman & Andrews, 1973). Variation in development within long – season cultivars is mainly related to the timing of floral initiation and the period between initiation and anthesis.

Tillering is very important in pearl millet because crops are commonly grown at low populations under semi – arid rain fed conditions. Basal tillering occurs between the thirteenth and fortieth day after sowing and up to 40 tillers may be produced (Raymond 1968). Auxiliary tillering from upper nodes occurs in flushes throughout grain development under intermittent drought. These tillers form two or three leaves and an inflorescence within 10 -20 days (Bindiger *et al.,* 1981); they may contribute up to the total yield of pearl millet growing under natural rainfall (Rachie & Majmudar, 1980)

2.3 Crop / Climate Relations

The caryopsis of pearl millet is small (3 – 4mm; 5 – 12mg) which accounts for much of the field problems of establishment, especially in crusting soil. Seed viability and seedling vigor are not affected if seed development on the parent plant is terminated between mid – grain – filling and black region appearance (Fussel and Pearson, 1970); this is presumably an adaptation to ensure survival when early termination of the wet season interrupts grain development. High temperatures increase speed of germination and reduce variation about the model date of both germination and emergence (Pearson, 1975). Different levels of availability soil water between 50 and 75% of field capacity do not influence germination, whereas soil held at field capacity may kill seedling (Fawusi and Agboola, 1980).

Leaf photosynthetic and anatomical characteristics associated with a C4 photosynthetic pathway lead to high potential growth rates and sensitivity to low temperature (reviewed by Pearson in press). Lamina expansion increases linearly with increasing temperature (Monteith *et al.,* 1981) but because of low plant populating radiation interception is the primary constraint during vegetative growth.

Leaf area development water use and energy balance have been described throughout the life of an 85 – day crop at latitude 11°N in the northern Nigeria (Kassam and Kowai, 1975). Maximum LAI was reached at inflorescence emergence and leaf area declined throughout grain development (Fig 2.3). The seasonal growth rate of 265kg/ha "d" represented an average of 5% conversion of photo synthetically active radiation (400- 700mm). The ratio of evaporation (E/Ep) averaged 0.82 and was unity from floral initiation (at DI = 0.2) to anthesis (Di = 0.6) (Fig 2.3). Crop water use was relatively efficient 300mm or 148g water per gram top weight compared with 253g/g for maize. However, because of low partitioning of dry matter into grain, water use per grain weight was 863g/g in contrast to 747g/g for maize.

ensure survival when early termination of the wet season interrupts grain development. High temperatures increase speed of germination and reduce variation about the modal date of both germination and emergence (Pearson. 1975). Different levels of available soil water between 50

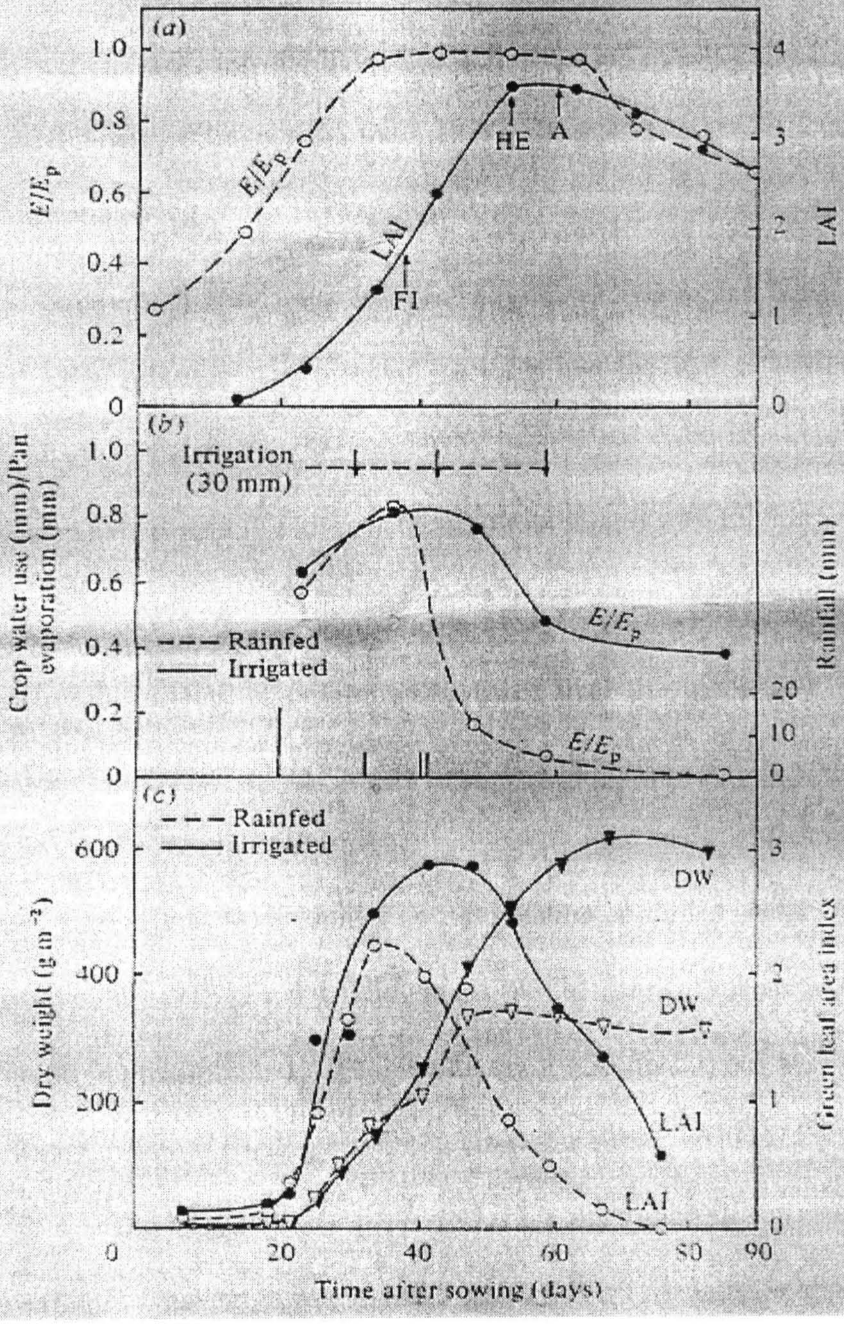

Fig.2.3 water use by pearl millet (a) Relative Evaporation and LAI of rainfed pearl millet at samaru, Nigeria.(b) and (c) E/Ep Ratio Dry Weight in Hyderabad , India

Studies of dry weight partitioning to roots indicate that under rain fed compared with irrigated conditions there are a fewer root axes, root weight is lower and a lower percentage of roots are found in the topsoil. (Gregory & Squire, 1997). Nonetheless, pearl millet has a reputation for drought tolerance owing to its apid and deep root penetration: e.g. to 1m depth within 33 days after sowing (Gregory &Squire, 1997). Root penetration has been recorded to 3.6m in north Australia (Begg *et al.,* 1978).

Although values of 1.2 – 1.5m are probably more common (Wetselaaw & Norman, 1960). As in other cereals, most of the roots and the widest lateral spread occur in the top 30 cm of the profile (Squire, 1979). Root length reaches a maximum at about an thesis in an experiment in India , maximum root length was 3500mm-² ground area, compared wit 2500mm-² ground area for groundnut (Gregory and Reddy, 1982).

Little is known of the effects of environment, other than the qualitative effect of daylenght, on floral initiation and inflorescence development before anthesis. In glasshouse studies, spiket number increases by 25% with increasing temperature from 19 to 31°c and time from floral initiation to heading declined with increasing temperature (Monteith, 1980). In the field, grain number and grain size contribute equally to variation in yield (45 and 42% respectively for 50 gene types at Hyderabad, India, Alagarswamy, Maiti & Bindinger, 1997). Grain number is reduced by abnormal temperature (Fig 2.3) and by high vapor pressure deficit, maximum flowering occurs at night and flowering is weakest between 15.00 and 18.00h (Ayangar, Vigiaraghavan and Pillai, 1933; Bhatnagar & Kumar, 1960).

Following anthesis, the "lag phase" of grain development lasts between 0 and 10 days and decreases by 2 days per 3°C increase in temperature (Fussel *et al*, .1980).

Rate of grain growth during the actual grain filling period (AGFP) varies substantially between genotypes (Fussel & Pearson, 1978). However, rate of grain growth appears to be constant over a range of temperatures duration of AGFP accounts for all the temperatures dependent variation in grain size.

2.40 Crop/Soil Relations.

2.41 Soil/Physical Properties

The main soils on which pearl millet is grown for grain occur in the wet-and- dry tropics. In West African they include Aridisols, Alfisols and Entisols.as classified in the D'Hoore (1964) legends of the soil map of Africa, the main millet soils of north Nigeria are juvenile soils approximately three-fifths of which are Aeolians sand, the remainder being riverine and lacustrine alluvium, also generally sandy (Klinkenberg and Higgins, 1968).in India pearl millet soils include Aridisols, Alfisols and Vertisols.

Pearl millet is preferred to sorghum on sandy soils (Norman and Berg,1968,Ferraris,1973) but grows best on light loams (Kowal and Kasam,1978).it is one of the few crops adapted to the deep sands of the Sahelian regions and similar area such as the Rajasthan desert and extreme western Punjab. the sandy soils favored for pearl millet in the drier zones of the west- and –dry climates may be prone to wind erosion and sand movement (e.g. in Niger,L.K fusel personal communication),which can result in severe damage to emerging seedling. Pearl millet is also grown extensively as a grain crop on shallow mixed black and red light-colored upland gravelly soils of the Deccan and South India (KAR, 1961, quoted by Ritchie and Majmndar, 1980).

Pearl millet does not tolerate water logging(Kowal and Kassam,1978).studies in tanks by wiliamson,willey and Gray1969) showed that water tables shallower tan 76cm affected plant yields and root distribution. Two days of flooding 4 weeks before first harvest reduced the first harvest yield by 40%, although it did not affect the second harvest. Table 2.1 gives a comparison with other crops of the effect of depth to water table.

Table 2.1 Relative Yields of Crop at Various Water Table Depths.

Crop	**Soil**	**Water Table Depth (cm)**						
		15	**30**	**40-50**	**60**	**75**	**80-90**	**100**
Maize	Silty Clay	45	55	67	70	-	100	-
Sorghum	Loam Clay[a]	73	86	93	100	93	-	-
Pearl Millet	Loam	41	69	80	87	98	100	93
Common Bean	Clay	-	-	79	84	-	90	-

After Williamson and Kriz (1978)

2.42 Soil Chemical Properties

A notable feature of pearl millet is its capacity to grow on soils of low chemical fertility. as a staple cereal, it has been grown on sands(as mentioned above) on marginal soils and other soils which has been declined severely in fertility (Ahn,1970).Smith and Clark(1968) found that pearl millet was able to extract greater quantities of nitrogen, phosphorus and potassium than sudan grass (sorghum Sudanese)in an acid sandy loam. The capacity of pearl millet to grow on infertile soils may be related to its ability to root deeply to rootly deeply and rapidly. Mineral uptake proceeds throughout vegetative growth (Theodoratos and Pearson, 1981) and was shown by Gregory (1979) to continue in an irrigated crop until crop until about 2 weeks after root growth ceased at about ahthesis.

However, the pattern of nutrient uptake can be greatly modified by climate, nutrient availability-particularly of nitrogen- and availability of water. In irrigated crop, nutrient uptake ceased at about 40days after sowing but continued for a further 7-21days in the rain fed crop probably explains why split fertilizer application of nitrogen, phosphorus and potassium did not increase yield under rain fed conditions at Samaru, Nigeria (Egharevba, 1978).

In wet-and-dry climates where rain fed crops are grown for grain, rates of nitrogen are usually quit low, vigorous early growth promoted by fertilizer nitrogen may consume water required for later crop development and grain maturation. Etasse(1977),on the basis of west Africa experience warned against nitrogen applications above 60kg nitrogenha-1,which may promote vegetative growth but depress grain yield. Yield depression in the Nigerian savanna is illustrated in the Table 2.2 the recommended rate of nitrogen application at Samaru is only 13kg ha-1 for rain fed grain production (Egharevba, 1978).

Table 2.2 Response of Rain fed Pearl Millet to Different Levels of Nitrogen and Phosphorus over Three Years at Samaru, Nigeria.

Fertilizer	Rate (kg/ha)	Grain Yield (kg/ha)
N	0	1398
	50	2150
	100	1940
P	0	1285
	66	2125
	132	1792

After Egharevba (1978)

Responses of pearl millet to phosphorus are not uncommon (Ferraris, 1973), but the phosphorus requirement of pearl millet does not appear to be high under rain fed farming conditions. While African savanna soils may respond to phosphorus, rates above 66kg phosphorus ha-a can depress yield(Table2.2).surface soil appears to be an important location for phosphorus uptake, Shriniwas (1980) found that the 0-15cm zone contributed 44-60%of total phosphorus taken up by five hybrids.

Pearl millet has a high requirement for potassium .in a total dry matter yield at the soft dough stage of 6749kgha-1,Mehta and Shah (1958) recorded 121kgha-1of potassium, in comparison with amounts for nitrogen, phosphorus, calcium and magnesium of 63,28,21 and 10kgha-1 respectively. Gregory(1979)showed that at maturity the quantity of potassium in pearl millet was about the same as that of nitrogen and over ten times a much as that of phosphorus.

Pearl millet appears as much to be very tolerant of soil acidity it has been found to be better suited as a forage crop to acid sandy soils of southeast USA than sorghum. In the same region, walker, Marhant and Ethredge (1975) found that forage yield of pearl millet was unaffected by pH rise between 4.8 and 6.4, whereas that of sorghum in the same soil increased by 2000kgha-1 of dry matter between pH 5.2 and 6.4.pearl millet took up aluminium readily and uptake was not reduced until the pH reached 7.1 whereas uptake of aluminium in sorghum was reduced at pH 5

2.5 The DSSAT Cropping System Model

The goal of the international Benchmark sites for Agro technology transfer (IBSNAT) is to accelerate the flow of agro technology and increase the success rate of technology transfer from agricultural research centers to farmers fields (Tsuji;Uehara;1998;

Jones *el al.*,1998).This is due to increasing information needs for agricultural decision making at all levels. The generation of new data through traditional agronomic research methods and its publication are not sufficient to meet these increasing needs demands for agricultural product and increased pressures on lands, water and other natural resources. Traditional agronomic experiments are conducted at particular points in time and space, making results site and season –specific time consuming and expensive. Thus IBSNAT developed a computer software which helps match crop requirements to land characteristics using crop simulation models, data bases, and strategy evaluation programs. The decision support system for agrotecthnology Transfer (DSSAT) is a comprehensive decision support system for assessing management options(Tsuji *et al.,*1994,Jones el al;2003; Hoogenboom *el al.,* 2004).it is a model used for the evaluation of different management practices options for a particular location, including fertilizer application rates, planting density, planting dates and others(Saseendran *et al.,*1998 Ruiz-Nogueria *et al*., 2001; Gijsman *et al*.,2002).The cropping system simulation Model(CSM), which is the main model of DSSAT version 4.0 (Jones *el al*.,2003;Hoogenboom *et al.,*2004), is a process- oriented , dynamic crop simulation model that simulates crop growth, development and yield for 27 food and other crops, including millet. Crop growth is simulated with a daily time step from planting to maturity, based on physiological processes that describe the crop's response to soil and aerial environment conditions. Potentials growth is independent on photosnythetically active radiation and its interception, whereas actual biomass production on any day is constrained by suboptimal temperatures, soil water deficits and nitrogen deficiencies.

The input data required to run the DSSAT model include daily weather information (maximum and minimum temperatures, 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, and seeding depth, and fertilizer and irrigation schedules. The soil water balance is simulated in order to determine potential yield reduction caused by soil water deficits and is simulated on a daily basis as a function of precipitation, irrigation transpiration, soil evaporation, runoff and deep drainage from the bottom of the soil profile. Soil water is distributed among the individual soil layers (Richie, 1998).a detailed description of the CERES-Millet Model, predecessor of the CSM-CERES-Millet, is provided by Ritchie and Alagarswamy (1989).

The CSM model has been used for determining the optimum planting dates for soyabean in India (Kumar et al; 2002; Mall el al 2004) and Spain(Ruiz-Nogerira *el al.,*2001),for rice in India (Saseedran *el al.,*1998) and Cuba (Rivero Vega *et al.,*2005) and for Cariola in Western Australia(Farre *el al*.,2002).previous studies that have used the CSM-CERES-MILLET include an evaluation for four regions in Niger,(Tabagati,Niamey, Sadore and Gaya) in which the model predicted growth and development accurately, while the yield estimates had an averages error of seven percent (Ravelo and Planchuelo,1993).Fetcher *el al.,*(1991) conducted another evaluation of the CSM-CERES-MILLET model for south- west Niger, while Thornton *et al*.,(1997)used the model for estimating millet production in Burkina Faso. 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 modeling studies, especially pearl millet crop, as it is such an important crop to resource farmers.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Study location

The study area will be crop production department Experimental farms at Gidan Kwano in the north Guinea savanna of Nigeria (latitude 9°45'North and longitude 6°15'East).the area is located at the western end of Minna township and within the main campus of the federal university of technology, Minna,Niger state, in the North Central Geo-political zone of Nigeria.

3.11 Climate and Vegetation

WARDA (1997) classified the vegetation in this study area as Guinea savanna grassland characteristic vegetation includes shrubs with scattered shear butter and locust bean trees. The climate is characterized by low rainfall. A temperature oscillates between 25°C and 40°C while rainfall ranges from between 600mm to 2650mm)The relative humidity ranges between 50-60%.

3.12 Soil Type

The soil belong to the Alfisols group (USDA system-Mobery and Esu, 1991) which has developed on deeply weathered pre-cambian basement complex rocks but overlain by Aeolian drift of varying thickness. The Ap horizon is predominantly loam in texture with fine sand and dominating the sand fraction and silt content as high as 46%. The clay content increases with depth giving rise to strong argillic horizons in the usltafs (Owonubi *et al.,* 1991). There is a sharp rise in the clay fraction creating a conspicuous bulge in the clay content. This explains sudden change in the textural class from loam to clay at Bt1/Bt2 (Ogunwole, 2000). The soil structures are dominantly moderately developed, medium sub angular block types (Ogunwole, 2000) resulting from high clay contents and the preponderance of bivalent cations (Ca^{2}+ and Mg^{2}+) over the monovalent cat ions (K+ and Na+) on the exchange complex and have caused the soil to be flocculated (Kparmwang *et al.*,1998).

3.2 Determination of Soil Properties

Soil samples would be collected from the field to planting and at harvest at soil profile described depths.undistrubed core samples will be collected from soil horizons on the farm for soil hydrological properties determination. Soil samples will also be air dried, sieved through a 2mm sieve for physical and chemical analysis.

3.21 Soil Analysis

Soil analysis collected would be analyzed for the following parameters:

{i}Physical Analysis, which includes:

- Bulk density will be determined by the gravimetric method as described by Blacke and Hartge (1986).

- Soil moisture content: a neutron probe will be used to measure soil moisture in the field with installed access tubes drilled into the soil with an auger.

{ii} Chemical Analysis, which include:

- Particle size distribution using hydrometer method as described by Gee and Bandar (1986)

- Soil pH will be determined in 1:2: 5 soil/ water ratio with a glass electrode pH meter according to McClean, 1982

- Organic carbon to be determined by dichromate (Nelson and Summers, 1982) - Extractable phosphorus by Bray No. 1 method (Grewelling and Peech, 1965).

3.3 Experimental Design

Treatment in this study will consist of two pearl millet varieties and three planting dates at one week interval from first week of June to 3rd week of June. Planting would be done at 75 X 50 (inter and intra row) spacing in a plot size of $27m^2$ (6m x 6m) by 19 m^2. Seeds would be sown into 3-5cm deep hole and would be thinned to 2 plants per stand. This is expected to give a population of 1025 plants after thinning. The experiment will be laid up in dividing the total plot into two sub-plots of which each contains nine sub plots arranged in a Randomized complete block design with three replication. Breeder's seeds of these varieties: Ex-Borno and Niger Local.

3.4 Millet Phenology Data

- Data to be collected include:
- Date of planting
- Date of emergence (>50%)
- Date of thinning
- Plant population after thinning
- Dates of successive leaf tip appearances and tiller appearances
- Number of leaves on main stem over time until harvest
- Dates of reproductive stages
- Dates of grain filling
- Date of maturity
- Date of harvest
- Total number of leaves on main stems and tillers at maturity
- Records of leaf senescence and tiller death.

3.5 Yield and Yield Parameter

The parameters to be considered include;

- Date of harvest

- Number of tillers per stand at harvest

- Days to 50% panicle initiation/plot

-Days to 50% flowering per plot

- Number of panicles per plot at harvest

- Number of leaves on main stem at harvest

- Panicle weight per plot at harvest

- Grain weight per plot at harvest

3.6 Weather Parameter

Daily records of weather parameters such as solar radiation/sunshine hours, maximum and minimum air temperature, and rainfall were collected from the Nigerian Metrological agency center Minna, Niger state, Nigeria.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 PRESENTATION OF RESULTS

After collection of the phenology data, soil analysis, and weather parameters from the site and the metrological centre, the data was imputed into the model, which gave out the following outputs as presented in Tables 4.1, 4.2 and Figures 4.1, 4.2, 4.3(a,b.c,) 4.4, 4.5, and 4.6 respectively

Table 4.1 Summary of Simulation of Pearl Millet

Date	Crop Age	Growth Stage	Biomass kg/ha	LAI	LEAVE NO	CROP M% kg/ha	H_2O	N
25th Jan	0	Start SIM	0	0.0	0	0	0	0
9th Jun	0	Sowing	0	0.0	0	0	0	0
10th Jun	1	Germinate	0	0.0	0	0	0	0
15th Jun	6	Emergence	0	0.0	0.5	6	0	0
3rd July	24	End juvenile	122	0.25	0.8	9	6.2	0
7th July	28	Floral initiation	327	0.62	16	14	0.3	0
31st July	52	End leave growth	4591	3.26	10.6	59	0	0.12
2nd Aug	54	Anthesis	4691	3.82	16.2	64	0	0.04
8th Aug	60	End panicle growth	5666	3.73	16.8	72	0	0
2nd Sept	85	End Mn FL	10384	1.20	17.2	72	0	0
9th Sept	92	End Trl FL	12461	0.6	14.3	72	0	0
10th Sept.	93	Maturity	12431	0.7	17.5	73 0		0

Table4. 2 Main Growth and Development

VARIABLE	SIMULATED	MEASURED
Anthesis Day (DAP)	56	49
Physiological Maturity	94	76
Yield at Maturity	3623 kg/ha	130 kg/ha
No.at Maturity (No/unit)	2683	-99
Unit Weight at Maturity kg(dm)/unit	0.0106	-99
Top weight at Maturity kg(dm)/ha	1964	-99
By Product Harvest kg(dm)/ha	4745	-99
Leave Area Index at Maturity	0.287	-99
Grain Weight at Maturity kg/ha	26	-99
Top Weight at Maturity kg/ha	6	-99
Stem Weight at Maturity kg/ha	56	-99
Grain Nitrogen at Anthesis kg/ha	0.6	-99
Top Wt At Anthesis kg/ha	2672	-99
Top Wt At Anthesis kg/ha	56	-99
Leaf No. Per Stand At Maturity	16.6	-99

Pearl Millet Yield: 3623 kg/ha (DRY WEIGHT)

RUN	TRT	FLO DAP	MAT DAP	TOP WT kg/ha	DNT kg/ha	RAIN (mm)	TIRR (mm)
1	ML 1	52	89	000	1224	629	0
2	ML 2	43	74	000	1420	548	0

LET (mm)	PESW	TNUP kg/ha	TSON kg/ha	TSOC
317	112	14	1552	16
352	124	14	1653	16

4.2 DICUSSIONS OF RESULTS

4.21 Growth Analysis and Development

From the growth data result obtained from the model (Table 4.1). The variation within the ages of the various growth where within the growth limit. For most millet varieties developmental stages falls within the life span of 3 – 4 months (Norman *et al.*, 1984). From literatures, expansion of leaf area depend on the number of leaves, the rate at which they expand and their final size; these are primarily affected by temperature, plant water stress and nutrient availability. From (Fig. 4.5), there is no water stress throughout its development stages and results from several experiments with cereals and grasses shows that in the absence of water stress, the rate of leaf extension is a linear function of mean temperature and there is no difference in the response to day and night temperature (Alan, 1989). .

4.22 Yield

The variation of the predicted values of 3623kg/ha and the measured value of 130kg/ha (Table 4.2) is attributed to nutrient deflection by the previous crops planted on the same land which is pearl millet, the nutrient has been used, leaving small amount for the present one, and the application of fertilizer was late. Secondly, the plot became waterlogged due to high rainfall intensity of 780mm which is against or greater than its annual need of 500 – 600mm of rainfall and land clearing operations carried out around the site which led to poor roof development, poor infiltration and nutrient supply during fertilizer application. In Fig. 4.21, the grain weight increases from 60 days to a maximum of 90. This is obtained from progressive weight measurement from grain filling to grain weight at maturity (i.e. weight of 100 grams).

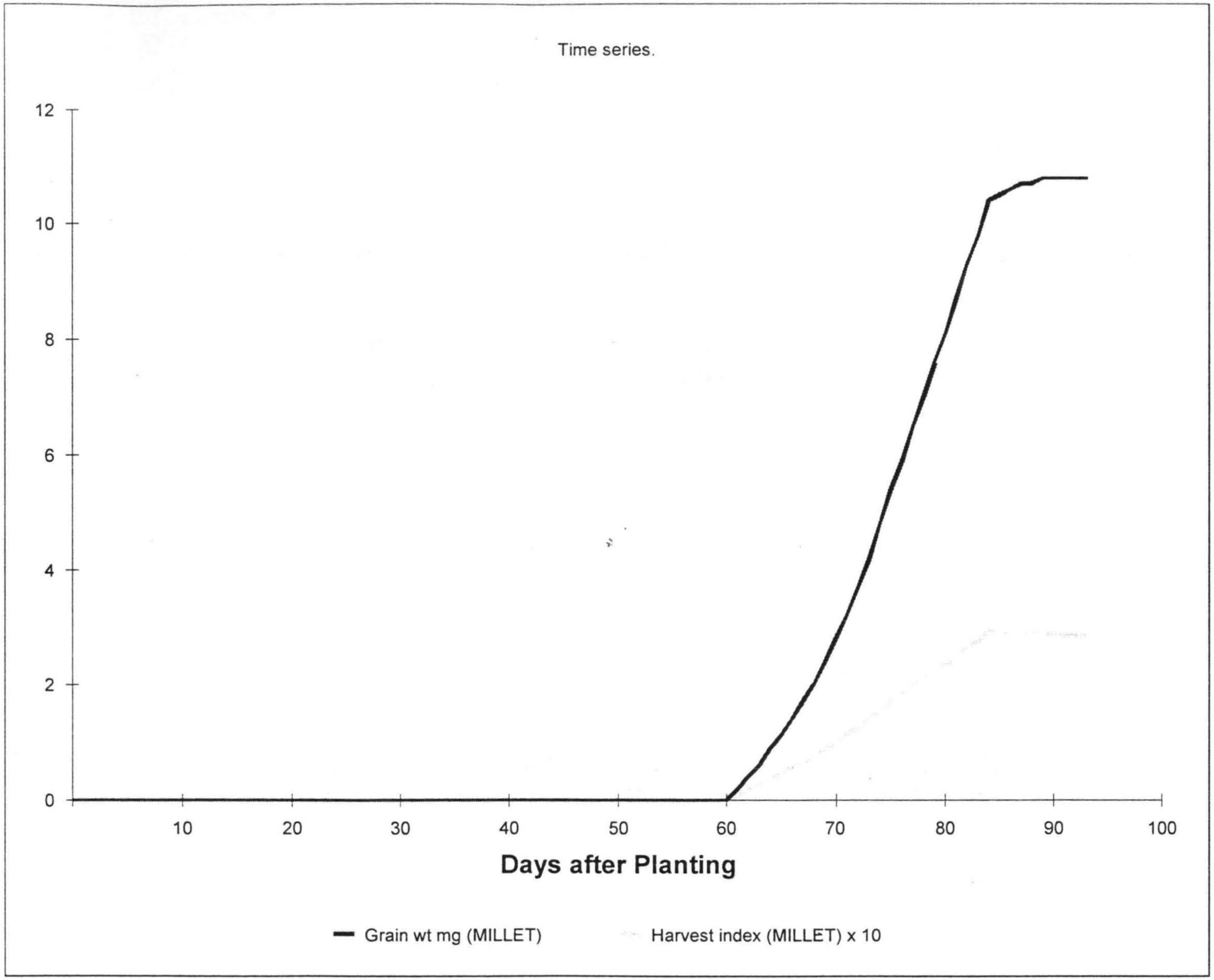

Figure 4.21 Grain Weight

4.3 Crop Water Use

The amount of water used by a crop is sometimes referred to as evapotranspiration or ET. It is composed of evaporation (the water that evaporates from wet soil and plant surfaces following a rain) and transpiration (the water that moves from the soil profile through the roots and stem, and out through the leaves to the air). The water level fluctuation within the plots where within sustainable root zone of the crop (shallow feeders' depth 100cm). (Halilu, 2005) and as shown by the soil water content in figure 4.3a, b, and c shows that the water content with depth (1 – 10) considered with maximum water reach at 32cm and minimum of about 7cm, where all within the sustainable root zone of pearl millet and other shallow feeders (Michael, 1980). This result is in conformity with the experiment carried out in Akron USA where Proso millet requires the least amount of water to grow the plant before grain production begins at 8.89cm (Nielsen, 2004).

Figure 4.3a shows initial constant values of 7cm, 9cm and 14cm due to insufficient rainfall. This gradually rises to a maximum of about 35cm and in figure 4.3b larger (8) water content was constant being close to the water table, while layers 5, 6 and 7 shows an initial constant value of 4cm and between 140 and 160 Dap there was a sharp rise due to rainfall activities while in figure 4.3c from days 0 – 250, the water content were also constant due to its closeness to the water table.

4.4 Extractable Water

This is the difference between the highest volumetric water content in the filed (after drainage) and the lowest measured water content when plants are very dry and leaves are either dead or formant (Ritchie, 1981). The stimulated extractable water in figure 4.4 value is 180mm which is in conformity with white French millet, which is a short season, but can

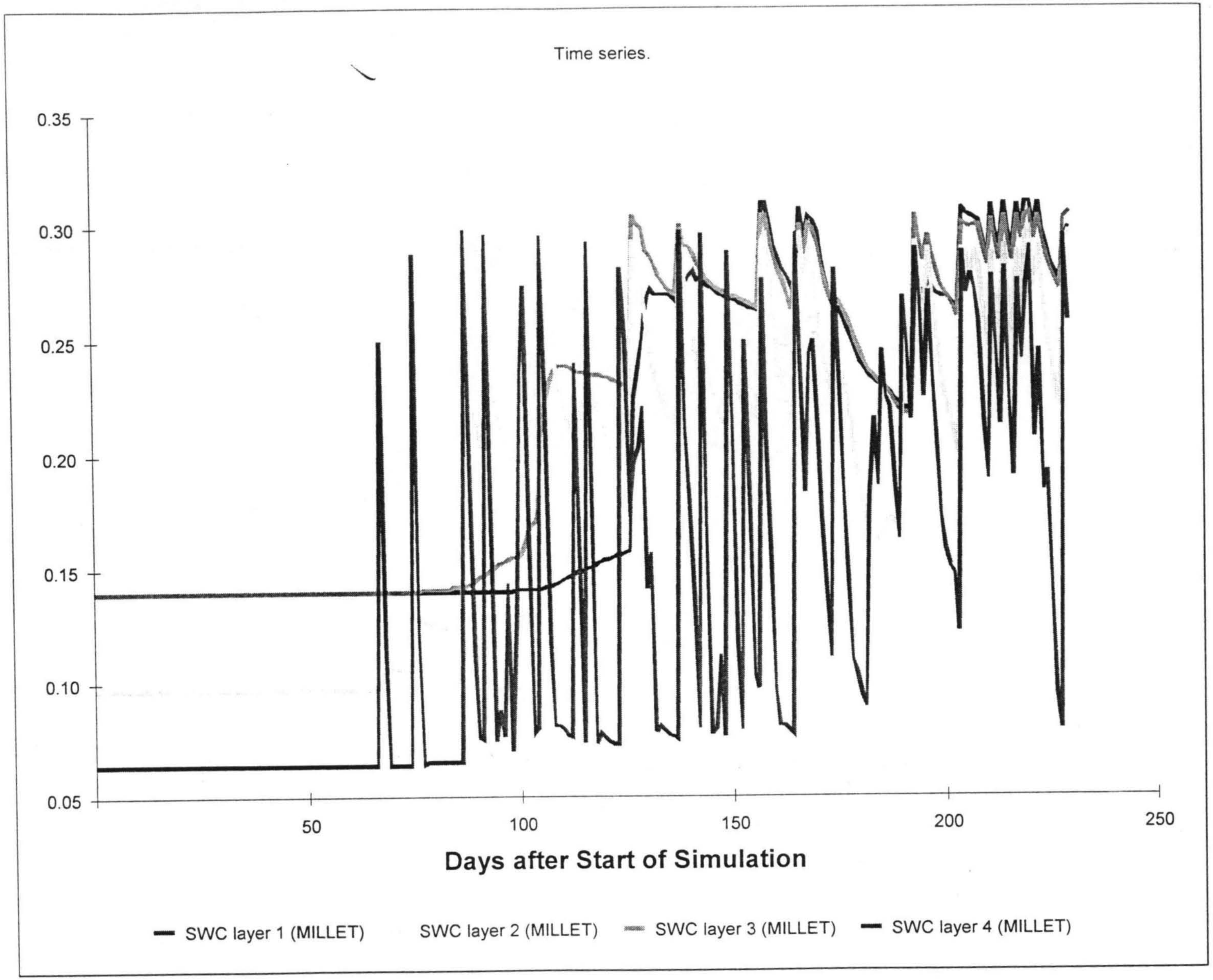

Figure 4.3a Soil Water Content

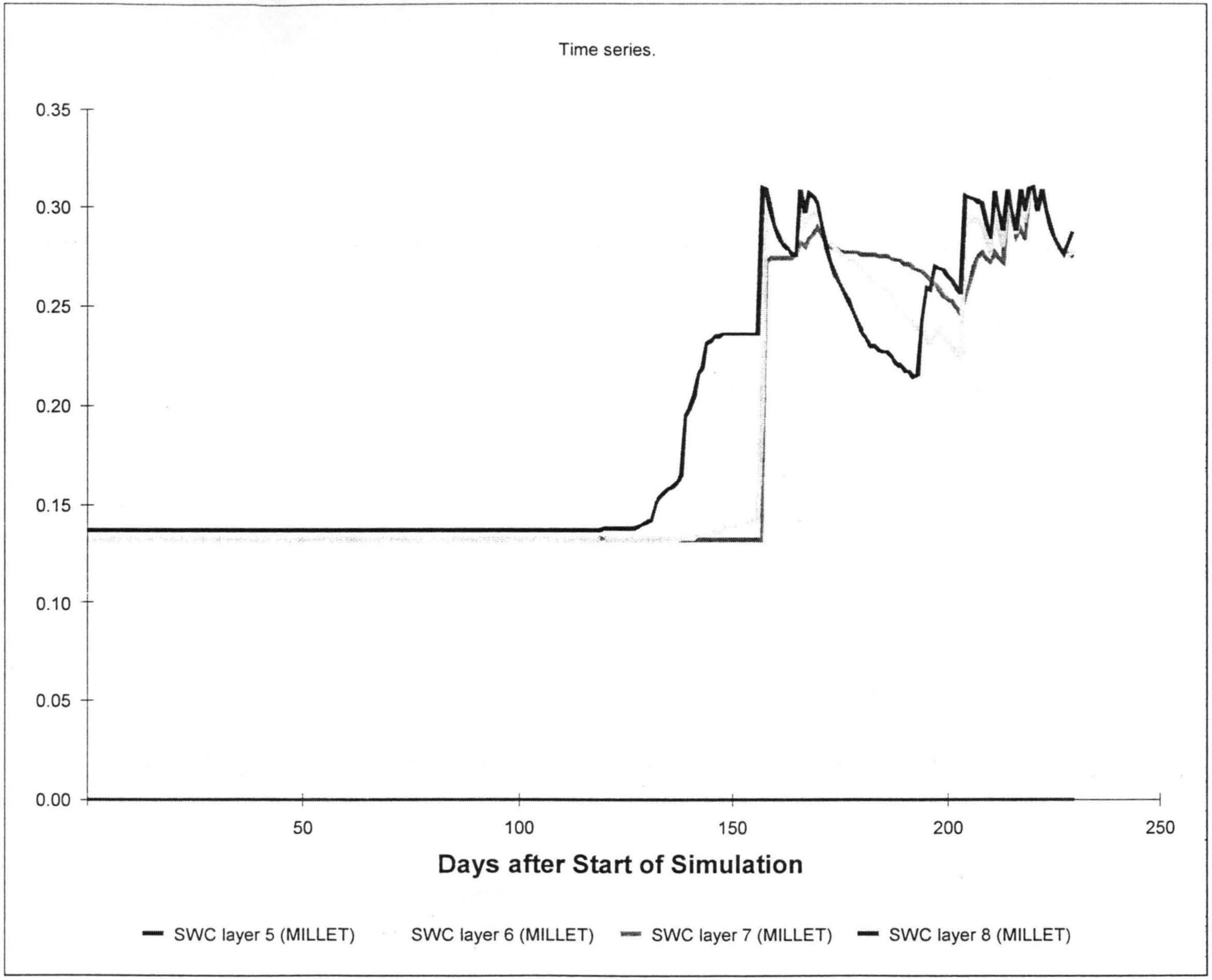

Figure 4.3b Soil Water Content

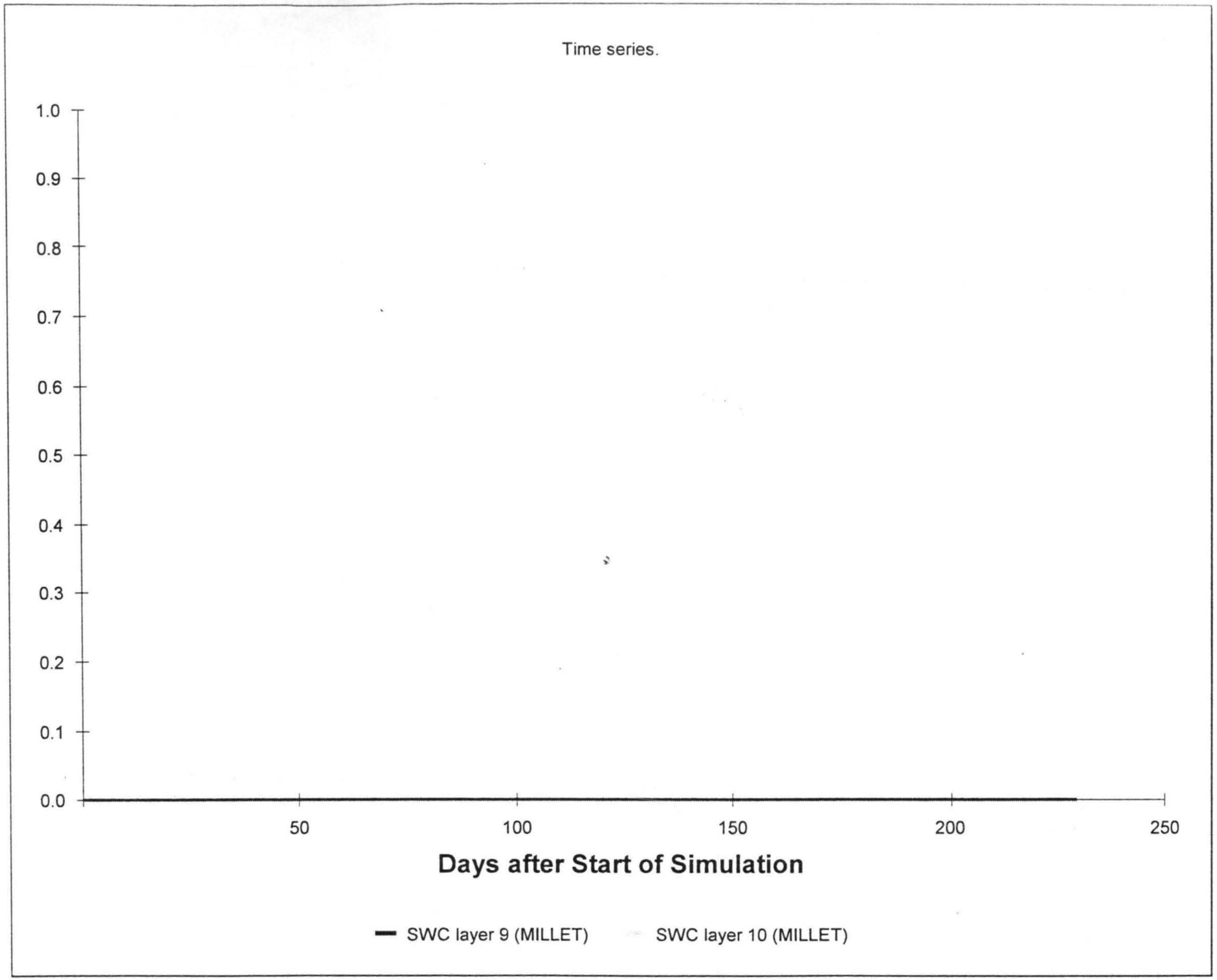

Figure 4.3c Soil Water Content

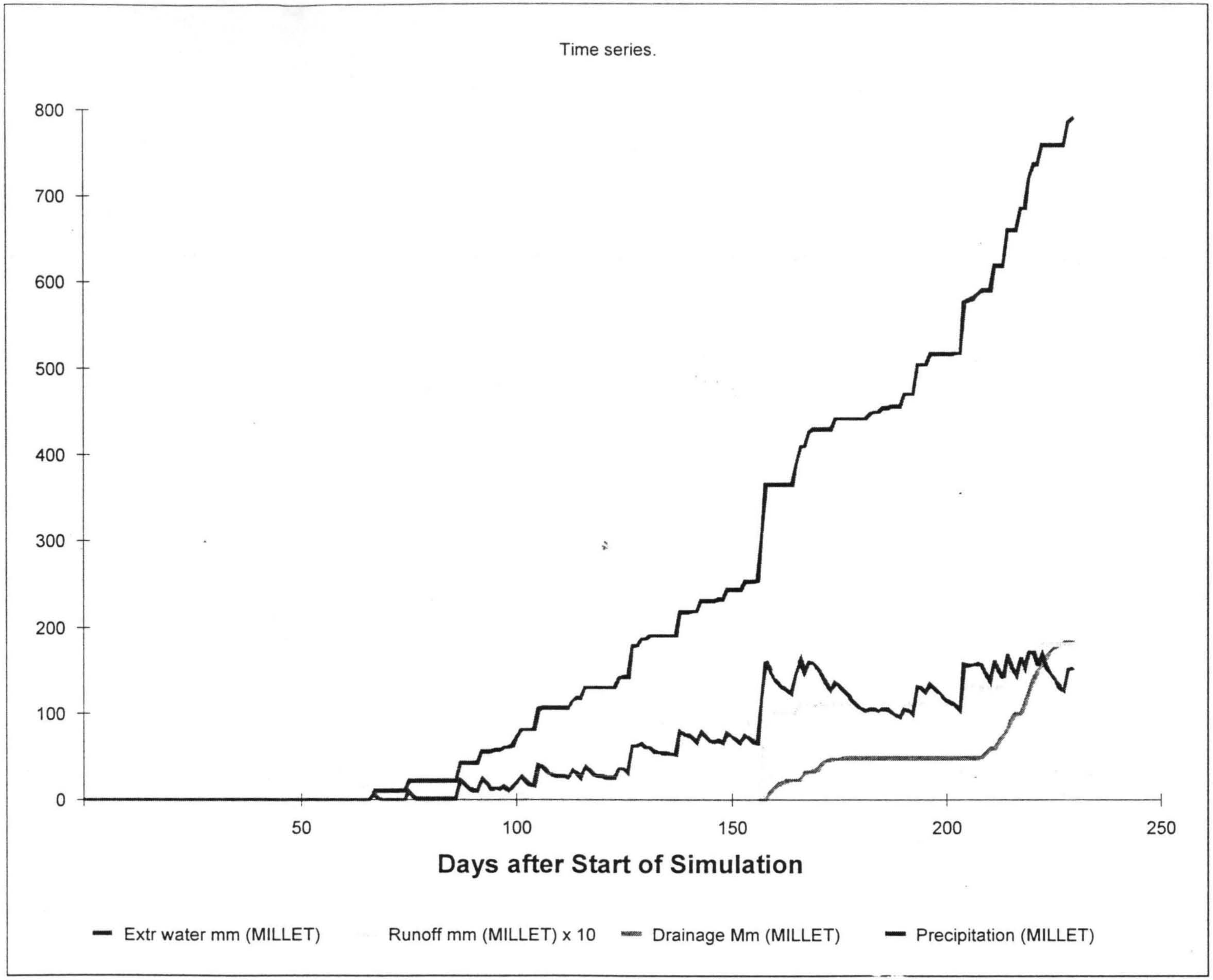

Figure 4.4 Extractable Water

extract more water up to 180mm carried out at the Eastern Darling Downs (Neal Dalghesh, 2003). Since at the beginning of the experiment, no water is extracted, the value of the extractable water starts fluctuating with minimum 0 in days 0 – 70, to maximum at 180 days. The extractable water curve in Fig 4.4 shows an increase with developmental stage.

4.5 Water stress/Nitrogen Stress Factor/Leaf Nitrogen %

Water stress accelerates leaf senescence and when it occurs late in the growing season is almost associated with nutrient stress. From figure 4.5, water stress was constant at zero since it is a rainfed experiment. The high demand for nitrogen by growing grains (grains of wheat frequently contain almost 70 percent and seeds of soyabeans 70 – 80 percent of total plant nitrogen at final harvest) means that if the demand cannot be met by uptake from the soil, nitrogen will be translocated from the green stems and leaves resulting stress factor occurs at the 33rd day of planting, fluctuating from its highest use of 4.5 to 0 at 70 dap.

Leaf nitrogen percent in Fig. 4.5 shows a greater leaf nitrogen uptake by the plant from days 7 to 9 maximum at 28 – 29 days, which could also affect the field, since little nitrogen is left for other physiological activities.

4.6 Leaf Number

For most of a crop's life, the leaves are the main plant organs intercepting sunlight and converting it to chemical energy and then to dry water by the process of photosynthesis. From Fig. 4.6 leaf number increases linearly from the day 5 DAP to day 47 DAP and maintained a constant number till its maturity day.

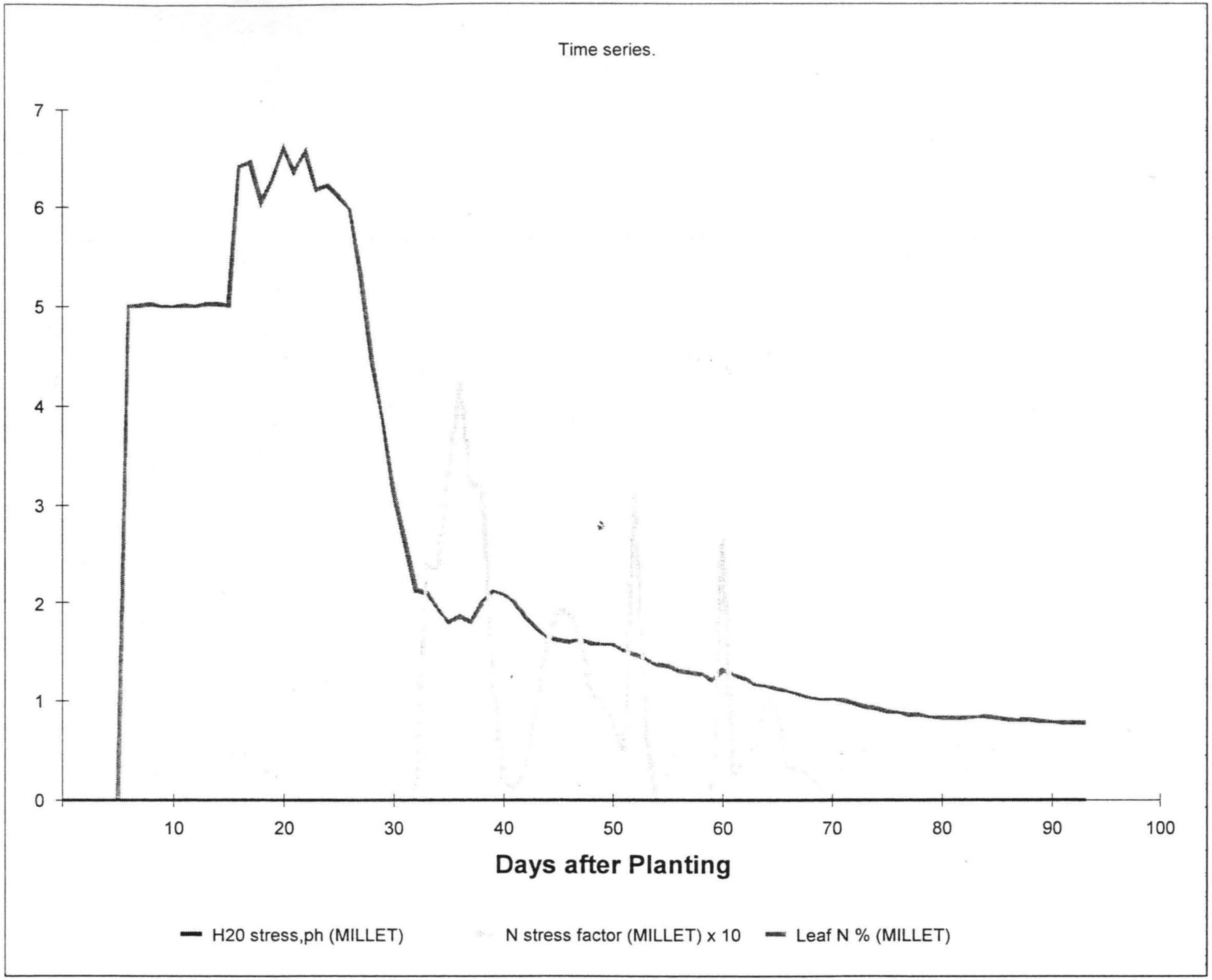

Figure 4.5 Water Stress

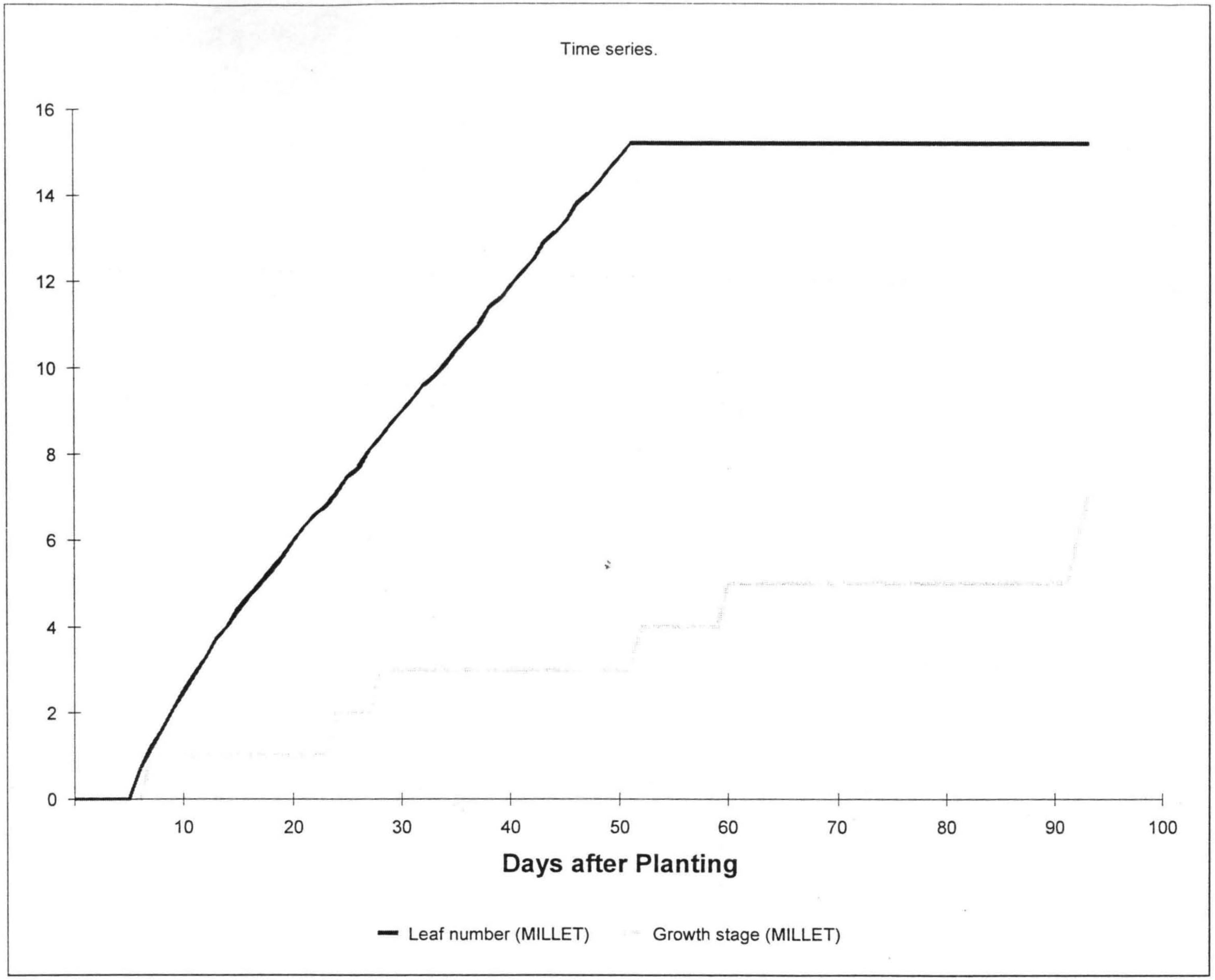

Figure 4.6 Leaf Number

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

From the output of the model. It shows that the following parameters could be predicted if all farming managements are used properly.

(1) The predicted yield is 3623 kg/ha and the measured yield is 130 kg/ha, this is due to high rainfall intensity of 780 mm. So proper drainage system should be installed if this occurs in the future use.

(2) The extractable water is 180mm

(3) Water stress was not experienced since the rain fall is sufficient. Nitrogen stress factor was experienced at 33 DAP which rises sharply to 4.3 level.

(4) From the growth data, the variation within the ages of the various growth stages where within the growth limit.

5.2 Recommendations

These research findings can be used by farmers' especially commercial ones that produce pearl millet in large scale for either brewery industries, poultry houses or for exportation.

It will aid them in the following:

(1) Determining the actual water use consumers of the crop when going into irrigation farming.

(2) Predicting the maximum yield if proper farming management is applied.

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APPENDIX A

File: C:\DSSAT4\Millet\NGGK0601.MLX 10/14/2006, 3:28:02PM

Experiment Details

```
*EXP.DETAILS: NGGK0601ML

*TREATMENTS                        -------------FACTOR LEVELS------------
@N R O C TNAME.................... CU FL SA IC MP MI MF MR MC MT ME MH SM
 1 1 0 0 2006 MN LOCAL              1  1  0  1  1  0  0  1  0  1  0  0  1
 2 1 0 0 2006 MN EXBORNO            2  1  0  1  1  0  0  1  0  1  0  0  1
 3 1 0 0 2006 MN local              3  1  0  1  1  0  0  1  0  1  0  0  1
 4 1 0 0 2006 MN EXBORNO            1  1  0  1  2  0  0  1  0  1  0  0  1
 5 1 0 0 2006 MN LOCAL              2  1  0  1  2  0  0  1  0  1  0  0  1
 6 1 0 0 2006 MN EXBORNO            3  1  0  1  2  0  0  1  0  1  0  0  1

*CULTIVARS
@C CR INGENO CNAME
 1 ML NIGER  LOCAL
 2 ML EXBRN1 ExBorno 93-95

*FIELDS
@L ID_FIELD WSTA....  FLSA  FLOB  FLDT  FLDD  FLDS  FLST SLTX   SLDP  ID_SOIL
 1 NGGK0601 NGGK     -99.0     0 DR000     0     0 00000 -99     170  NGGK060001

*INITIAL CONDITIONS
@C   PCR ICDAT  ICRT  ICND  ICRN  ICRE  ICWD ICRES ICREN ICREP ICRIP ICRID
 1    CP 06025   500     0  1.00  1.00 -99.0   000  0.80  0.00   100    15
@C  ICBL  SH2O  SNH4  SNO3
 1     5 0.050   1.0  01.0
 1    15 0.025   1.0  01.0
 1    30 0.025   1.0  01.0
 1    45 0.022   1.0  01.0
 1    60 0.022   1.0  01.0
 1    90 0.022   1.0  01.0
 1   120 0.027   1.0  01.0

*PLANTING DETAILS
!Planting was done at a row spacing of 75cm and millet sown at 50
!apart within rows and thinned to two plants per stand.
@P PDATE EDATE  PPOP  PPOE  PLME  PLDS  PLRS  PLRD  PLDP  PLWT  PAGE  PENV
PLPH  SPRL
 1 06162 06166   5.3   -99     S     R    75     0   5.0   6.0   -99 -99.0
2.0   0.0
 2 06162 06166   5.3   -99     S     R    75     0   5.0   6.0   -99 -99.0
2.0   0.0
 3 06169 06173   5.3   -99     S     R    75     0   5.0   6.0   -99 -99.0
2.0   0.0
 4 06169 06173   2.7   -99     S     R    75     0   5.0   3.5   -99 -99.0
2.0   0.0
 5 06176 06180   1.3   -99     S     R    75     0   5.0   2.0   -99 -99.0
2.0   0.0
 6 06176 06180   2.7   -99     S     R    75     0   5.0   3.5   -99 -99.0
2.0   0.0

*FERTILIZERS (INORGANIC)
!Fertilizer application was basal, hence got incorporated into the soil during
land
!preparation using hoE to a depth of 15cm. Top dress N fertilizer was side
placed in
!a shallow hole (5cm)at the base of the plant stand (AP007).
@F FDATE  FMCD  FACD  FDEP  FAMN  FAMP  FAMK  FAMC  FAMS  FOCL
 1 06165 FE005 AP002    15    00    00    00   -99   -99   -99
```

```
 2 06172 FE005 AP002     15     00     00     00    -99    -99    -99
 3 06182 FE005 AP007      5     22     00     00    -99    -99    -99

*RESIDUES AND OTHER ORGANIC
!Barnyard manure (RE003) and previous crops residue (RE001) were disk harrowed
into the
!soil before ridge making and sowing of crop
@R RDATE  RCOD  RAMT  RESN  RESP  RESK  RINP  RDEP
 1 06157 RE003  6000   0.3     1     8   100    15
 1 06157 RE001   800   1.0   0.1     3   100    15
 2 06160 RE003  6000   0.4     2    18   100    15
 2 06160 RE001  1000   0.8   0.2     4   100    15
 3 06149 RE003  4000   0.4     2    18   100    15
 3 06149 RE001  1300   0.8   0.2     4   100    15

*TILLAGE
!The tillage implements are HOE (TI002)
@L TDATE TIMPL  TDEP
 1 06161 TI002  0015

*ENVIRONMENTAL MODIFICATIONS
@E ODATE EDAY  ERAD  EMAX  EMIN  ERAIN ECO2  EDEW  EWIND
 1     0 A00.0 A00.0 S00.0 S00.0 M01.0 R0360 A00.0 A00.0

*SIMULATION CONTROLS
@N GENERAL     NYERS NREPS START SDATE RSEED SNAME....................
 1 GE              1     1     I 06025  2150 N X IRRIG., S.C. (CERES M1
@N OPTIONS     WATER NITRO SYMBI PHOSP POTAS DISES  CHEM  TILL
 1 OP              Y     Y     Y     Y     Y     N     N     Y
@N METHODS     WTHER INCON LIGHT EVAPO INFIL PHOTO HYDRO NSWIT MESOM
 1 ME              M     M     E     P     S     C     R     1     P
@N MANAGEMENT  PLANT IRRIG FERTI RESID HARVS
 1 MA              R     N     R     R     M
@N OUTPUTS     FNAME OVVEW SUMRY FROPT GROUT CAOUT WAOUT NIOUT MIOUT DIOUT
LONG CHOUT OPOUT
 1 OU              N     Y     Y     1     Y     N     Y     Y     N     Y
Y     N     N

@  AUTOMATIC MANAGEMENT
@N PLANTING    PFRST PLAST PH2OL PH2OU PH2OD PSTMX PSTMN
 1 PL          06090 06204     8    22    30    40    25
@N IRRIGATION  IMDEP ITHRL ITHRU IROFF IMETH IRAMT IREFF
 1 IR             30    50   100 GS000 IR001    10  1.00
@N NITROGEN    NMDEP NMTHR NAMNT NCODE NAOFF
 1 NI             30    50    25 FE001 GS000
@N RESIDUES    RIPCN RTIME RIDEP
 1 RE            100     1    20
@N HARVEST     HFRST HLAST HPCNP HPCNR
 1 HA              0 06097   100     0
```

APPENDIX B

Soil Analysis


```
*NGGK06001  NIGERIA       LS      130 MINNA - FUT
@SITE         COUNTRY           LAT      LONG SCS FAMILY
 FUTMINN    Nigeria          9.6170  6.550 OXIC HAPLUSTULT
@ SCOM  SALB  SLU1  SLDR  SLRO  SLNF  SLPF  SMHB  SMPX  SMKE
     Y  0.15  13.0  0.30  55.0  0.80  1.00 IB001 IB001 IB001
@  SLB  SLMH  SLLL  SDUL  SSAT  SRGF  SSKS  SBDM  SLOC  SLCL  SLSI  SLCF  SLNI
SLHW  SLHB  SCEC  SADC X1LLL X1DUL X2LLL X2DUL
    26    AP 0.097 0.237 0.325 1.000    -99  1.48  0.24   2.0  38.0   0.0  0.04
6.6   5.2   6.0 -99.0 -99.0 -99.0 -99.0 -99.0
    75    AP 0.140 0.270 0.320 0.800    -99  1.49  0.20   6.0  38.0   0.0  0.04
5.8   5.3   8.0 -99.0 -99.0 -99.0 -99.0 -99.0
   135    BC 0.140 0.272 0.327 0.200    -99  1.49  0.20  10.0  34.0   0.0  0.02
5.6   4.3   8.0 -99.0 -99.0 -99.0 -99.0 -99.0
   170    BT 0.132 0.274 0.324 0.100    -99  1.48  0.18   4.0  30.0   0.0  0.02
4.6   4.6   9.5 -99.0 -99.0 -99.0 -99.0 -99.0
```

APPENDIX C

Weather Data

File: C:\DSSAT4\Millet\NGGK0601.WTH.bak 10/14/2006, 3:10:09PM

*WEATHER DATA : MINNA_NIGERIA

@ INSI	LAT	LONG	ELEV	TAV	AMP	REFHT	WNDHT
MINN	09.650	06.470	300	28.4	10.4	1.00	1.0

@DATE	SRAD	TMAX	TMIN	RAIN
06001	25.1	30.0	13.0	0.0
06002	22.7	30.0	12.0	0.0
06003	16.2	30.0	12.0	0.0
06004	21.7	27.0	14.0	0.0
06005	22.9	30.0	13.0	0.0
06006	18.0	30.0	12.0	0.0
06007	17.1	30.0	12.0	0.0
06008	18.6	24.0	15.0	0.0
06009	18.4	28.0	14.0	0.0
06010	21.3	27.0	15.0	0.0
06011	22.7	28.0	14.0	0.0
06012	22.2	33.0	14.0	0.0
06013	23.8	35.0	14.0	0.0
06014	24.3	33.0	14.0	0.0
06015	25.7	33.0	16.0	0.0
06016	25.5	31.0	15.0	0.0
06017	22.5	28.0	14.0	0.0
06018	26.6	34.0	14.0	0.0
06019	25.3	34.0	16.0	0.0
06020	25.8	34.0	16.0	0.0
06021	24.1	34.0	15.0	0.0
06022	23.5	33.0	15.0	0.0
06023	26.6	35.0	15.0	0.0
06024	22.5	36.0	14.0	0.0
06025	25.0	38.0	16.0	0.0
06026	24.7	36.0	17.0	0.0
06027	25.6	36.0	18.0	0.0
06028	24.2	33.0	20.0	0.0
06029	23.1	26.0	18.0	0.0
06030	26.5	25.0	14.0	0.0
06031	23.9	25.0	13.0	0.0
06032	22.2	25.0	12.0	0.0
06033	20.6	26.0	12.0	0.0
06034	17.2	25.0	14.0	0.0
06035	23.2	26.0	14.0	0.0
06036	23.8	26.0	14.0	0.0
06037	27.0	28.0	15.0	0.0
06038	28.0	25.0	13.0	0.0
06039	30.7	26.0	13.0	0.0
06040	31.1	26.0	13.0	0.0
06041	31.2	26.0	12.0	0.0
06042	29.0	27.0	13.0	0.0
06043	28.9	28.0	13.0	0.0
06044	26.6	28.0	13.0	0.0
06045	29.4	27.0	13.0	0.0
06046	25.7	29.0	13.0	0.0
06047	27.8	29.0	14.0	0.0
06048	28.8	28.0	15.0	0.0
06049	23.5	30.0	14.0	0.0
06050	28.4	30.0	15.0	0.0
06051	27.5	32.0	15.0	0.0
06052	29.2	33.0	16.0	0.0
06053	19.7	35.0	18.0	0.0

06054	27.7	34.0	16.0	0.0
06055	27.7	34.0	17.0	0.0
06056	23.3	34.0	16.0	0.0
06057	25.1	27.0	18.0	0.0
06058	25.9	26.0	14.0	0.0
06059	25.7	26.0	17.0	0.0
06060	24.4	28.0	17.0	0.0
06061	24.4	28.0	16.0	0.0
06062	23.8	29.0	17.0	0.0
06063	19.4	30.0	17.0	0.0
06064	23.3	32.0	15.0	0.0
06065	11.4	34.0	20.0	0.0
06066	21.7	33.0	17.0	0.0
06067	22.0	33.0	18.0	0.0
06068	24.4	33.0	11.0	0.0
06069	25.6	32.0	12.0	0.0
06070	19.5	30.0	16.0	0.0
06071	23.5	30.0	16.0	0.0
06072	23.9	31.0	16.0	0.0
06073	26.7	32.0	18.0	0.0
06074	27.9	32.0	19.0	0.0
06075	22.3	32.0	16.0	0.0
06076	24.9	34.0	17.0	0.0
06077	28.7	37.0	17.0	0.0
06078	28.7	36.0	19.0	0.0
06079	26.7	39.0	19.0	0.0
06080	28.5	39.0	23.0	0.0
06081	18.5	38.0	20.0	0.0
06082	27.8	38.0	19.0	0.0
06083	26.7	38.0	21.0	0.0
06084	26.7	37.0	20.0	0.0
06085	24.9	36.0	23.0	0.0
06086	25.4	34.0	21.0	0.0
06087	28.0	35.0	21.0	0.0
06088	21.7	36.0	20.0	0.0
06089	26.1	38.0	22.0	0.0
06090	27.3	39.0	21.0	0.0
06091	21.3	40.0	19.0	0.0
06092	13.8	40.0	20.0	0.0
06093	24.1	40.0	18.0	0.0
06094	24.6	40.0	22.0	0.0
06095	25.9	40.0	23.0	0.0
06096	26.0	40.0	21.0	0.0
06097	22.7	41.0	23.0	0.0
06098	24.0	40.0	21.0	0.0
06099	23.2	40.0	22.0	0.0
06100	20.1	41.0	23.0	0.0
06101	21.6	42.0	23.0	0.0
06102	25.3	41.0	26.0	0.0
06103	26.4	39.0	27.0	0.0
06104	24.7	41.0	26.0	0.0
06105	25.3	41.0	25.0	0.0
06106	18.0	42.0	24.0	0.0
06107	14.8	42.0	25.0	0.0
06108	18.1	42.0	26.0	0.0
06109	26.6	42.0	25.0	0.0
06110	18.4	41.0	27.0	0.0
06111	24.2	39.0	29.0	0.0

06112	23.8	38.0	27.0	0.0
06113	26.2	40.0	25.0	0.0
06114	25.3	40.0	29.0	0.0
06115	26.0	40.0	25.0	0.0
06116	20.7	40.0	21.0	0.0
06117	20.7	41.0	22.0	0.0
06118	25.1	41.0	23.0	0.0
06119	17.6	41.0	27.0	0.0
06120	24.6	40.0	25.0	0.0
06121	26.3	41.0	26.0	0.0
06122	23.4	39.0	27.0	0.0
06123	24.6	41.0	26.0	0.0
06124	26.4	41.0	26.0	0.0
06125	14.1	41.0	25.0	0.0
06126	20.5	42.0	25.0	0.0
06127	23.7	39.0	27.0	0.0
06128	19.9	40.0	23.0	0.0
06129	19.2	41.0	22.0	0.0
06130	23.0	40.0	25.0	0.0
06131	19.5	40.0	21.0	0.0
06132	24.1	39.0	22.0	0.0
06133	26.3	39.0	24.0	0.0
06134	25.1	39.0	24.0	0.0
06135	24.1	40.0	24.0	0.0
06136	23.1	40.0	24.0	0.0
06137	20.4	40.0	26.0	0.5
06138	16.1	41.0	27.0	0.0
06139	20.1	40.0	26.0	0.0
06140	24.5	40.0	26.0	0.0
06141	24.9	40.0	25.0	0.5
06142	11.4	41.0	26.0	0.0
06143	24.4	40.0	26.0	0.0
06144	21.3	37.0	26.0	0.0
06145	19.0	37.0	22.0	0.0
06146	22.6	39.0	25.0	0.5
06147	14.6	38.0	24.0	7.6
06148	26.0	35.0	22.0	0.0
06149	23.2	37.0	24.0	19.8
06150	22.8	36.0	22.0	0.0
06151	25.0	37.0	24.0	0.0
06152	25.4	38.0	26.0	2.1
06153	22.9	37.0	24.0	0.0
06154	24.1	38.0	25.0	0.0
06155	21.7	34.0	24.0	41.5
06156	24.8	34.0	20.0	0.0
06157	23.6	32.0	23.0	23.0
06158	18.6	34.0	22.0	0.0
06159	23.8	35.0	24.0	0.2
06160	20.9	36.0	22.0	0.0
06161	24.3	37.0	25.0	0.0
06162	19.7	38.0	25.0	3.3
06163	22.9	34.0	22.0	0.0
06164	26.3	35.0	25.0	0.0
06165	21.3	38.0	26.0	0.0
06166	23.2	38.0	24.0	0.0
06167	20.6	33.0	24.0	0.0
06168	26.2	37.0	24.0	28.8
06169	26.1	31.0	20.0	0.0

06170	20.6	27.0	20.0	46.7
06171	22.5	31.0	21.0	0.0
06172	14.2	34.0	23.0	0.0
06173	26.0	35.0	24.0	0.0
06174	11.1	35.0	24.0	0.0
06175	24.2	33.0	23.0	0.0
06176	19.2	34.0	23.0	0.0
06177	25.9	34.0	24.0	5.1
06178	27.4	34.0	22.0	0.0
06179	24.6	33.0	23.0	0.0
06180	15.7	35.0	23.0	0.0
06181	23.8	34.0	23.0	0.0
06182	25.6	35.0	22.0	0.0
06183	22.3	33.0	24.0	0.0
06184	24.4	35.0	23.0	0.0
06185	25.9	36.0	23.0	17.6
06186	24.9	33.0	22.0	0.0
06187	22.0	33.0	22.0	14.5
06188	17.7	31.0	20.0	0.0
06189	21.4	34.0	24.0	0.0
06190	23.6	30.0	21.0	0.0
06191	24.8	30.0	20.0	0.0
06192	26.2	29.0	21.0	0.0
06193	16.1	29.0	20.0	0.0
06194	15.7	30.0	20.0	0.0
06195	23.0	27.0	22.0	0.0
06196	25.2	28.0	21.0	0.0
06197	21.9	26.0	21.0	0.0
06198	22.8	30.0	20.0	0.0
06199	17.6	27.0	22.0	0.0
06200	22.2	30.0	21.0	0.0
06201	22.8	31.0	22.0	0.0
06202	26.3	29.0	19.0	0.0
06203	12.6	30.0	22.0	0.0
06204	19.6	30.0	21.0	46.1
06205	25.5	30.0	20.0	21.6
06206	19.4	29.0	21.0	0.3
06207	25.4	29.0	20.0	0.6
06208	21.9	30.0	20.0	0.0
06209	22.7	27.0	22.0	0.0
06210	24.7	28.0	21.0	3.1
06211	23.1	26.0	21.0	9.4
06212	18.3	30.0	20.0	0.0
06213	26.1	27.0	22.0	0.0
06214	21.3	30.0	21.0	0.0
06215	24.5	31.0	22.0	19.0
06216	25.2	29.0	19.0	0.0
06217	14.5	30.0	22.0	17.3
06218	26.2	30.0	19.0	0.0
06219	23.4	31.0	19.0	0.0
06220	25.7	30.0	20.0	0.0
06221	17.3	27.0	20.0	10.4
06222	23.4	30.0	20.0	8.7
06223	21.6	30.0	20.0	0.0
06224	25.3	30.0	21.0	1.3
06225	25.4	32.0	20.0	17.0
06226	26.1	30.0	19.0	7.4
06227	23.3	29.0	20.0	0.0

06228	25.0	31.0	21.0	4.2
06229	17.2	30.0	21.0	0.0
06230	20.2	29.0	22.0	22.9
06231	17.1	29.0	19.0	0.0
06232	23.6	30.0	20.0	58.0
06233	22.9	30.0	20.0	0.0
06234	24.2	32.0	21.0	0.1
06235	20.8	33.0	20.0	5.8
06236	24.7	29.0	20.0	0.0
06237	23.7	30.0	21.0	0.0
06238	23.4	32.0	22.0	0.0
06239	18.8	32.0	22.0	49.6
06240	24.5	30.0	20.0	0.0
06241	20.0	32.0	22.0	3.1
06242	24.5	33.0	20.0	0.0
06243	21.2	33.0	22.0	1.6
06244	17.8	32.0	22.0	0.5
06245	23.6	34.0	24.0	0.0
06246	20.9	34.0	23.0	0.0
06247	21.8	35.0	22.0	1.0
06248	19.4	33.0	22.0	0.0
06249	17.3	34.0	24.0	0.0
06250	24.1	32.0	21.0	3.0
06251	24.4	32.0	21.0	0.0
06252	24.3	33.0	23.0	0.0
06253	24.3	33.0	24.0	0.0
06254	20.8	34.0	24.0	13.0
06255	21.7	30.0	24.0	0.5
06256	21.7	30.0	22.0	3.1
06257	24.9	32.0	21.0	13.1
06258	25.6	32.0	20.0	0.0
06259	23.9	33.0	21.0	0.0
06260	24.3	30.0	18.0	36.6
06261	24.5	31.0	18.0	0.0
06262	24.9	32.0	19.0	0.0
06263	20.9	33.0	23.0	0.0
06264	26.5	33.0	22.0	3.5
06265	24.7	33.0	21.0	0.0
06266	24.7	32.0	23.0	3.3
06267	20.9	32.0	20.0	0.0
06268	23.1	32.0	23.0	0.0
06269	23.3	33.0	22.0	0.0
06270	24.3	33.0	23.0	0.0
06271	23.1	33.0	23.0	8.4
06272	24.6	32.0	21.0	0.0
06273	22.8	33.0	23.0	0.0
06274	24.2	34.0	22.0	0.0
06275	22.6	34.0	23.0	0.0
06276	19.6	34.0	22.0	15.3
06277	21.4	34.0	23.0	0.0
06278	25.2	33.0	21.0	0.0
06279	24.8	34.0	22.0	11.0
06280	24.0	34.0	23.0	9.3
06281	24.2	32.0	22.0	0.0
06282	23.1	32.0	23.0	9.3
06283	24.1	32.0	22.0	2.9
06284	24.8	32.0	22.0	0.0
06285	24.9	33.0	23.0	0.0

06286	25.5	34.0	23.0	0.0
06287	24.6	35.0	23.0	0.0
06288	24.6	34.0	22.0	0.0
06289	23.3	35.0	23.0	0.0
06290	23.6	35.0	21.0	0.0
06291	21.8	35.0	21.0	0.0
06292	19.6	34.0	19.0	0.0
06293	21.8	35.0	19.0	0.0
06294	20.5	34.0	19.0	0.0
06295	24.8	34.0	19.0	0.0
06296	24.0	35.0	18.0	0.0
06297	24.2	34.0	18.0	0.0
06298	23.1	34.0	18.0	0.0
06299	24.1	35.0	17.0	0.0
06300	24.8	34.0	19.0	0.0
06301	24.9	32.0	20.0	0.0
06302	25.5	32.0	17.0	0.0
06303	24.6	33.0	16.0	0.0
06304	24.6	34.0	17.0	0.0
06305	23.3	35.0	16.0	0.0
06306	23.6	36.0	18.0	0.0
06307	21.8	36.0	16.0	0.0
06308	19.6	35.0	17.0	0.0
06309	24.8	33.0	17.0	0.0
06310	24.0	34.0	16.0	0.0
06311	24.2	32.0	17.0	0.0
06312	23.1	34.0	16.0	0.0
06313	24.1	35.0	15.0	0.0
06314	24.8	34.0	16.0	0.0
06315	24.9	34.0	16.0	0.0
06316	25.5	33.0	17.0	0.0
06317	24.6	33.0	16.0	0.0
06318	24.6	33.0	15.0	0.0
06319	23.3	33.0	15.0	0.0
06320	23.6	33.0	18.0	0.0
06321	21.8	34.0	17.0	0.0
06322	19.6	33.0	15.0	0.0
06323	21.8	35.0	15.0	0.0
06324	20.5	35.0	15.0	0.0
06325	-999	36.0	14.0	0.0
06326	-999	35.0	15.0	0.0
06327	-999	35.0	19.0	0.0
06328	-999	35.0	19.0	0.0
06329	-999	33.0	18.0	0.0
06330	-999	0.0	0.0	0.0
06331	-999	0.0	0.0	0.0
06332	21.2	0.0	0.0	0.0
06333	24.4	0.0	0.0	0.0
06334	24.6	0.0	0.0	0.0
06335	25.4	0.0	0.0	0.0
06336	24.9	0.0	0.0	0.0
06337	26.1	30.0	14.0	0.0
06338	26.6	30.0	15.0	0.0
06339	-999	30.0	14.0	0.0
06340	-999	29.0	14.0	0.0
06341	-999	28.0	14.0	0.0
06342	21.4	29.0	14.0	0.0
06343	22.1	29.0	14.0	0.0

06344	20.6	29.0	14.0	0.0
06345	23.4	27.0	13.0	0.0
05346	23.3	26.0	14.0	0.0
06347	23.0	26.0	15.0	0.0
06348	23.3	25.0	15.0	0.0
06349	23.1	27.0	13.0	0.0
06350	21.3	27.0	13.0	0.0
06351	20.8	28.0	13.0	0.0
06352	22.1	29.0	12.0	0.0
06353	24.3	31.0	13.0	0.0
06354	23.7	31.0	12.0	0.0
06355	24.7	33.0	12.0	0.0
06356	24.2	35.0	13.0	0.0
06357	25.3	34.0	14.0	0.0
06358	25.3	33.0	13.0	0.0
06359	24.0	33.0	13.0	0.0
06360	23.7	33.0	12.0	0.0
06361	24.5	33.0	12.0	0.0
06362	24.8	32.0	13.0	0.0
06363	26.5	32.0	14.0	0.0
06364	23.9	32.0	12.0	0.0
06365	23.5	32.0	11.0	0.0
06366	24.9	32.0	12.0	0.0

APPENDIX D

EXPERIMENT DETAILS CODES

Header used in the line to identify variables are listed first, codes to identify methods, chemicals, etc. are listed next in sections that relate to specific aspects (Chemicals Crop and weed species; Diseases and pests; Drainage; environmental modification factors; Fertilizers, inoculants and amendments; Harvest components Harvest size categories; Methods, fertilizer and chemical applications; Method, irrigation and water management; Methods-soil analysis; Planting materials; Plant distribution; Residues and organic fertilizers ; Rotations ; Soil texture ; and Tillage implements).

The fields in the file are as follows:

CDE The 'universal' code used to facilitate data interchange.

DESCRIPTION A description of the code, with units.

SO The source of the codes (IB-IBSNAT). Codes added by a user should be referenced in this field and the name and address of the person adding the code should be entered as a comment (i.e.with a '!' in column 1) below this note. This is important to ensure that information from different worker can be easily integrated. Users adding codes should also ensure that those constructed by adding a number to section code (eg. FE001, CH001) are clearly identified with a letter in this position (eg. FEK01 for a fertilizer code added by someone with a family name beginning with K).

Headers

OCDE	**DESCRIPTION**
ADDRESS	Contact address of principal scientist
C	Crop component number (default = 1)

CDATE	Application date, year + day or days from planting
CHAMT	Chemical application amount, kg-ha-1
CHCOD	Chemical material, code
CHDEP	Chemical application depth, cm
CHME	Chemical application method, code
CHNOTES	Chemical notes (Target, chemical name, etc.)
CNAME	Cultivar name
CNOTES	Cultivar details (Type, pedigree, etc.)
CR	Crop code
CU	Cultivar level
ECO2	CO2 adjustment, A,S,M,H vpm
EDATE	Emergence date, earliest treatment
EDAY	Daylength adjustment, A,S,M,R+ h
EDEW	Humidity adjustment, A,S,M,R + OC
EMAX	Temperature (maximum) adjustment, A,S,M,R +OC
EMIN	Temperature (minimum) adjustment, A,S,M,R +OC
ERAD	Radiation adjustment, A,S,M,R + MJ m-2day-1
ERAIN	precipitation adjustment, A,S,M,R + mm
EWIND	Wind adjustment, A,S,M,R + km day - 1
FACD	Fertilizer application/placement, code
FAMC	Ca in applied fertilizer, kg ha-1
FAMK	K in applied fertilizer, kg ha-1
FAMN	N in applied fertilizer, kg ha-1

FAMO	Other elements in applied fertilizer, kg ha-1
FAMP	P in applied fertilizer, kg ha-1
FDATE	Fertilization date, year, day or days from planting
FDEP	Fertilizer incorporation/application depth, cm
FL	Field level
FLDD	Drain depth, cm
FLDS	Drain spacing, m
FLDT	Drainage type,
FLOB	Obstruction to sun in degrees
FLSA	Slope and aspect
FLST	Surface stones
FMCD	Fertilizer material, code
FOCD	Other element
HAREA	Harvest area, m^2
HARM	Harvest method
HCOM	Harvest component
HDATE	Harvest date, year + day from planting
HL	Harvest level
HLEN	Harvest row length
HPC	Harvest percentage
HRLO	Harvest row number
MC	Chemical application level
ME	Environment modification level

MF	Fertilizer application level
MH	Harvest level
MI	Irrigation level
MP	Planting level
MR	Residue level
MT	Tillage level
PAGE	Transplant age
PAREA	Gross plot area
PCR	Previous crop code
PDATE	Planting date
PENV	Transplant environment
PLAY	Plot layout
PLDP	Planting depth in cm
PLMA	Planting method
PLRS	Row spacing
PPOE	planting population at emergence
PPOP	Plant population at seeding
RCOD	Residue material
RDATE	Incorporation date, year + days
RESK	Residue potassium concentration
RESN	Residue nitrogen concentration
RESP	Residue Phosphorus concentration
SA	Soil analysis level

SABD	Bulk density, moist
SABL	Depth, base of layer
SADAT	Analysis Date
SAHB	pH in buffer
SAHW	pH in water
SANI	Total nitrogen
SAOC	Organic carbon
SLDP	Soil depth
SLTX	Soil texture
SM	Simulation control level
TDATE	Tillage date
TDEP	Tillage depth
TL	Tillage level
T1002	Tandem disk
RE001	Crop residue
ML	Pearl millet

WEATHER DATA CODES

DATE	Date, year + days from Jan. 1
IN	Institute code
LAT	Latitude
LONG	Longitude
RAIN	Rainfall

REFHT	Reference height for weather measurement in m
SRAD	Solar radiation
TMAX	Temperature maximum
TMIN	Temperature minimum
WNDHT	Reference height for wind speed measurement

DSSAT MILLET MODEL PARAMETERS 2006

PHENOLOGY DATA	1A LOCAL	1B EXBORNO	2A LOCAL	2B EXBORNO	3A LOCAL	3B IMPROVED	4A LOCAL	4B EX-BORNO	5A LOCAL	5B EXBORNO	6A LOCAL	6B EX-BORNO	7A LOCAL	7B EX-BORNO	8A LOCAL	8B EX-BORNO	9A LOCAL	9 E B
1. Date of Planting	161	161	161	161	161	161	175	175	175	175	175	175	168	168	168	168	168	16
2. Date of Emergence (750%)	164	164	164	164	164	164	181	181	181	181	181	181	181	171	171	171	171	17
3. Date of Thinning	176	176	176	176	176	176	196	196	196	196	196	196	183	183	183	183	183	18
4. Plant Population after Thinning	108	90	102	85	106	93	98	82	104	86	106	80	115	95	106	85	98	82
5. Dates of Successive leaf tip appearance	179-184	180-185	179-184	180-185	179-184	180-185	199-203	200-204	199-203	199-203	199-203	200-204	185-188	185-188	185-188	185-188	185-188	1
6. Dates of Successive tiller appearance	181-188	182-186	181-188	182-186	181-188	182-186	200-202	201-206	200-205	201-206	200-205	201-206	200-205	201-206	186-191	186-191	186-191	
7. No. of leaves on main stem over time till harvest (two week interval)	7,8,9,12	6,7,8	7,8,10,12	6,7,8	8,9,12	6,7,8	10,12	6,8,10	6,8,10,12	6,8,9	6,8,10	8,10	8,10,12	6,8	6,8,10	6,8	6,8,10	
8. Date of Reproductive stages	281-282	230-233	281-282	230-233	281-282	230-233	284-286	233-235	284-286	233-235	284-286	233-235	284-286	232-234	284-286	232-234	284-286	

9. Dates of Grain tilling	283-287	240-243	283-287	240-243	283-287	240-243	289-293	246-247	289-293	246-250	289-293	246-250	290-294	244-247	290-294	244-247	290-294	24
10. Dates of Maturity	292-294	252-254	292-294	252-254	292-294	252-254	292-294	258-261	292-294	258-261	292-294	258-261	292-294	254-256	292-294	254-256	292-294	25
11. Dates of Harvest	302	254	302	254	302	254	304	262	304	262	304	262	304	258	304	258	304	25
12. Total No. of leaves on stem and tillers at maturity	12	8,4	12	8,4	10	8,4	10	8,4	10	8,4	12	8,4	10	8,4	12	8,4	10	8,4
13. Dates of tillers Death	306-309	259-263	306-309	259-263	306-309	259-263	309-311	269-271	309-311	269-271	309-311	269-271	309-311	265-268	309-311	265-268	309-311	26

YIELD AND YIELD PARAMETERS

YIELD AND YIELD PARAMETERS	1A LOCAL	1B HYBRID	2A LOCAL	2B HYBRID	3A LOCAL	3B HYBRID	4A LOCAL	4B HYBRID	5A LOCAL	5B HYBRID	6A LOCAL	6B HYBRID	7A LOCAL	7B HYBRID	8A LOCAL	8B HYBRID	9A LOCAL	9B HYBRID
1. Days to 50% panicle initiation	277-281	226-229	277-281	226-229	277-281	226-229	279-282	228-232	279-282	228-232	279-281	228-232	279-281	229-233	279-281	229-233	279-281	229-239
2. Days to 50% flowering (Anthesis)	281-282	230-233	281-282	230-233	281-282	230-233	284-286	233-235	284-286	233-235	284-286	233-235	284-286	232-234	284-286	232-234	284-286	232-234
3. Date of Harvest	302	254	302	254	302	254	304	262	304	262	304	262	304	258	304	258	2	258
4. Plant stand per plot at harvest	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5. No of tillers per stand at harvest	2	2	1	2	1	3	2	2	1	1	2	3	1	2	3	1	2	1
6. No of panicles per plot at harvest	12	8	15	9	12	14	13	3	6	4	7	6	5	4	9	6	5	4
7. No of leaves on main stem at harvest	12	8	10	9	12	8	12	8	10	8	12	8	12	9	10	8	12	8
8. Panicle weight per plot at harvest																		
9. Grain weight per plot at harvest	10	20	5	10	10	5	20	9	8	10	5	5	9	5	3	-	-	-

APPENDIX F

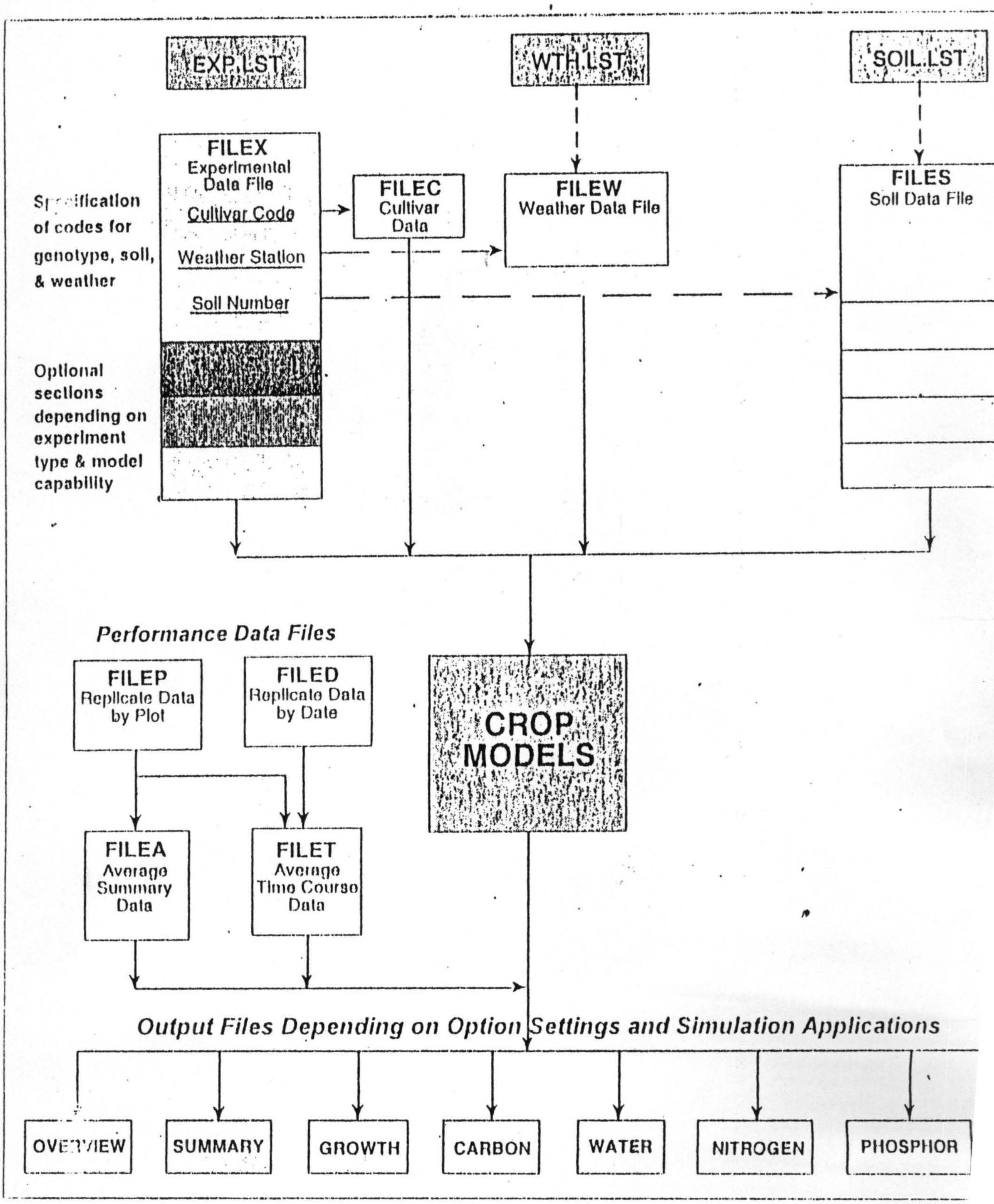

FIGURE 1. OVERVIEW OF INPUT AND OUTPUT FILES USED BY CROP MODEL