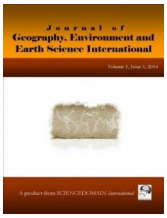

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Heat-Sum Calculation in Forecasting Maize Phenological Stages and Harvesting Date in Lagos South West, Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author GAA designed the study, Authors GAA and VNO performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors GAA, VNO, BAO and VFA managed the analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Maize production is of primary importance in the world, especially considering that its cultivation takes up one of the greatest ratios of land used for agricultural production.Based on analysis of rainfall pattern and thermal regime, maize phenological stages and harvesting dates has been investigated with the use of heat-sum calculation along with the seasonal rainfall forecast by NIMET in relation to maize crop production. Data were collected from Agro-meteorological Observatory of Nigerian Meteorological Agency (NIMET), Oshodi Lagos, Nigeria. Maize phenological records were collected during the period between 2005 and 2010. Also, information obtained includes

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phenological records for ten different period of maize crop forecast. The monthly mean values of all parameters were further averaged to obtain the annual mean. Microsoft Excel was used to show the correlation between these parameters rainfall, temperature and crop yield data between 1995 and 2010. Heat-sum calculation was employed as a forecasting guide of growing phase of maize crop and harvesting date in the study area. Graph of the yield were plotted against temperature and rainfall. Results show the length of growing-period with use of heat sum calculation and harvesting date of maize crop grown was forecasted. Results show that maize crop could be grown with the use of crop weather calendar considering life history and mean dates of important epoch of crop growth and development of maize phonological stages, sowing to germination, germination to emergence, emergence to 3rd leaf, 3rd leaf to 9th leaf, 9th leaf to tasselling, tasselling to flowering, flowering to soft dough, soft dough to hard dough, hard dough to harvesting dates with total number of 73 days. Heat units, expressed in growing days are frequently used to describe the timing of biological processes. The basic equation used was HS = [(TMAX + TMIN)/2]−TBASE, where T_{MAX} and T_{MIN} are daily maximum and minimum air temperature, respectively, and T_{BASE} is the base temperature. The methods of interpreting this equation for calculating heat-sum is if the daily mean temperature is less than the base, it is set equal to the base temperature or if T_{MAX} or $T_{MIN} < T_{BASE}$ they are reset equal to T_{BASE}. Average rainfall observed was 30mm in 10 days with duration of wet spell > 4 days. High wind exceeded 40knot. The minimum temperature recorded was 10ºC at night with maximum temperature of 40^0C during the day. Furthermore, result show that 10ºC is the base temperature of maize below this, the growth will be zero. 25º ─ 38ºC is the optimum temperature for best or highest yield.

Keywords: Heat-sum (HS); heat unit;maize crop;temperatures (ºC);rainfall (mm);agro-met; phonological;yield; Lagos, South West, NIMET.

1. INTRODUCTION

The significance of maize is due to the fact that it is utilized for direct human consumption, as raw material in the food industry as a result of its high energy content and good digestibility. On the other hand, its utilization as animal forage also has great significance. The whole plant is utilized as silo or green forage worldwide. Its significance is further increased by its widespread industrial processing and utilization. As a result of the above mentioned facts, making production efficient is of decisive importance to farms. Temperature is arguably the most important environmental factor that affects plant development, growth, and yield. All biological processes respond to temperature, and all responses can be summarized in terms of three cardinal temperatures: a base or minimum (T_{min}), an optimum (T_{opt}), and a maximum (T_{max}). However, the nature of the response to temperature between these cardinal points is important for calculating the phenology, adaptation, and yield of various crops [1-4]. The precise knowledge of climatic requirements for maize is essential for profitable maize production. Considering climatic conditions, we have taken into account that various climatic elements have different effects on the yield of maize [5]. Regarding weather, it can be concluded that maize can be mainly characterized by the following requirements: high amount of winter precipitation, which requires large water storages in the soil. Relatively high average temperature in April is required, which is a condition of early sowing and even, rapid germination. In May, high precipitation and relatively low temperatures and sunlight are favorable. In June, high sunlight length and temperature and relative low precipitation requirement is favorable. The optimal conditions of July and August are high precipitation, temperature and sunlight requirement. Warm, humid and wet weather favorably influences fertility and seed fixation. Optimal September is dry, and can be characterized by warm and sunny weather which promotes processes of assimilation, grain filling and ripening. Considering the above mentioned, it is clear that heat sum calculation plays an important role in maize production [6]. Heat-sum calculations form a transition from this aspect, since temperatures occurring during the growing season cannot be influenced by man. However, the method of calculation and evaluation and thus the crop weather calendar to improve planting and harvesting dates is in the life history and mean dates of important epoch of crop growth and development of maize phonological stages. A large number of studies have been undertaken to show the direct effect of meteorological factor on maize crop yield [7]. Most workers have

approached their various relationships from either an empirical/statistical, experimental or theoretical stand point. The empirical /statistical method has been employed most frequently for yield forecasting, but the recent rise in scientific farming activities has complicated the use of this method. Kowal *et al* [8] investigated the effect of water on maize yield at Sumaru. They concluded that the pre-sowing moist period is sufficient to allow for easy cultivation of the soil. This is because water in the soil is in excess of evaporative demand. Bello, [9] investigated mean annual rainfall and length of growing period of maize among other tropical crops grown in Nigeria. In his conclusion, maize growth length is between 100 and 140 days. Rainfall decreases Northwards in Nigeria, hence Buba, [10] in his work concluded that with the exception of parts of the middle-belt areas, a systematic decline in maize crop production Northwards is noticeable. Maize yield was also lower than expected (1.1 ton/ha). The production of maize crop in the Northern Nigeria is sporadic. In Zaria, maize crop is produced on less than 1% cropped land. Maize plant is an efficient user of water in terms of total dry matter production and among the cereals; it is potentially the highest yielding grain crop [11]. For maximum production, a medium maturity grain crop requires between 500 and 800 mm water depending on climate. But recent studies show that rainfall of 400 – 600 mm if well distributed to meet the needs of the crop during the growing season is also adequate. Maize (*Zea mays L*) is one of the most edible crops throughout the world and it is grown world-wide. The present world production is about 594 million tons grain from about 139 million ha [12]. In Nigeria, maize is taken as one of the staple food crop and it is the most commonly affordable food crop in many household today.

1.1 Aim and Objectives

The aim of this study was to determine maize phenological stages and harvesting date with the use of heat-sum calculation along with the seasonal rainfall forecast by NIMET in relation to maize crop production.

The specific objectives are;

(1) To determine growing degree days, cumulative rainfall and number of raindays using crop weather calendar in the study area.
(2) To determine the correlation between rainfall, temperature parameters and Maize yield data in the study area.
(3) To forecast the length of different phases of maize development.
(4) To determine the optimum growth of temperature required for best yield, base temperature of maize and maximum temperature.

1.2 The Study Area

NIMET Oshodi Agro-meteorological station is located in Lagos State in the South Western part of Nigeria. Oshodi is geographically located on latitude 06º 30’ North and Longitude 03º 23’ East with an altitude of 19 meters. Lagos State lies in the Tropical rain forest of south western part of Nigeria. It is approximately located between Latitude 6º27' and 6º40’ North of the equator and Longitude 2º32' and 6º40' East of the Greenwich Meridian. It is bounded in the East, North and Northwest by Ogun State of Nigeria, in the South, it is bounded by 180 km of the Atlantic Ocean Coast line and by the Bight of Benin and in the West by the Republic of Benin. Lagos is the smallest in the federation of Nigeria with total land mass of 3,577 square kilometres. Tourist attraction: Lagos State consists of a strong narrow strip of land which passes a line of creeks and lagoons almost parallel to the coast. These inland water-ways play an important role in the transportation system of the state as well as the livelihood of the inhabitants of the state. The State is endowed with water body of which occupies about 20% of the land mass [13].

Occupation: The main occupations in Lagos State are Trading, cloth and mat weaving, fishing and farming. Fishing is the major occupation of the people at the coastal areas of the State, while farming is mostly practiced by the people at the mainland areas. However, trading is common within the whole areas of the State.

Climate: Lagos State as a result of its tropical origin has the climate which is characterised by high temperature throughout the year. Its temperature distribution is uniform with little variations between the seasons.

Drainage: Lagos State is well drained with several big streams, notably river Ogun, Oshun, Ibu, and Yelwa as the main ones.

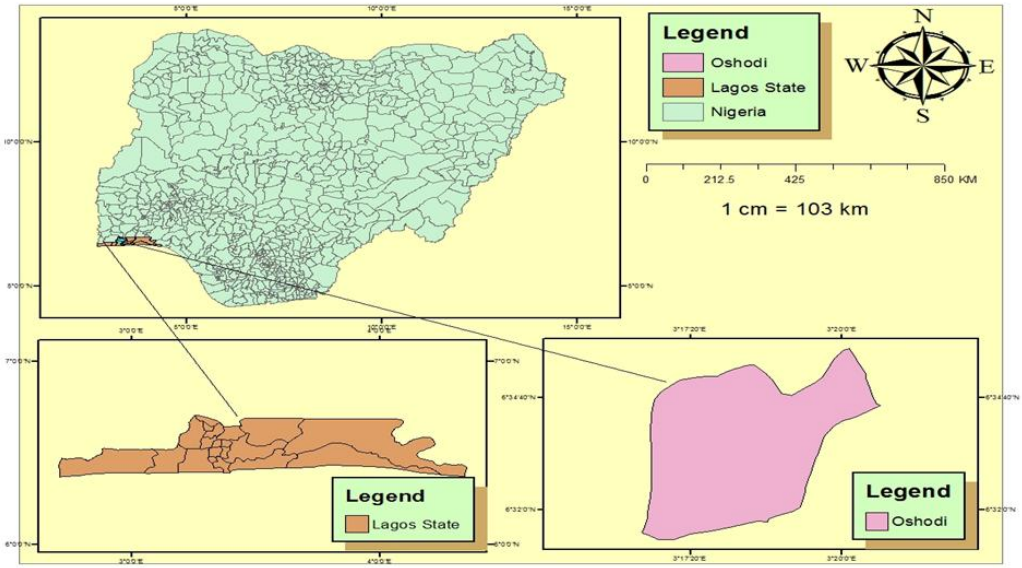

Fig.1.2.1 Map showing position of Oshodi (pink) in Lagos State (brown) and Nigeria (green)

2. MATERIALS AND METHOD OF DATA COLLECTION

The information obtained includes phenological records for ten different period of maize crop forecast. The monthly mean values of all parameters are further average to get the annual mean. Microsoft Excel was also used to show the correlation between these parameters. The main types of data used were the rainfall, temperature and crop yield data between 1995 and 2010.Maize crop was planted and observed using heat sum calculation to forecast the phenological phase and harvesting date, along the seasonal rainfall issued by NIMET. The graphs of the yield are plotted against temperature and rainfall.

Therefore;

Heat-Sum (HS) is given by;

$$HS_{(Season)} = \sum_{t=1}^{t=T} HS(t)$$

$HS = T_{observed} - T_{mean}$
$HS = T_{observed} - Critical$
$T_{critical}$ = Optimum growth of temperature.
0º – 10ºC is the negative growth of maize crop.
10ºC is the base temperature of maize (below this, the growth will be zero).
25º – 38ºC is the optimum temperature i.e. (best or highest yield).
40ºC is the maximum temperature i.e. (above this, the crop will be negatively affected).
Consequently;

$$HSC = \int (T - T_{base})dt$$

$$HSC = \frac{T_{max} + T_{min}}{2} - T_{base}$$

Where;

T_{max} = Daily maximum temperature
T_{min} = Daily minimum temperature
T_{base} = Base temperature

However, if the daily mean temperature is less than the base, it is set equal to the base temperature, or (2) if T_{MAX} or $T_{MIN} < T_{BASE}$ they are reset equal to T_{BASE}.

HSC are typically measured from the start of growth in spring for a particular crop. Any daily mean temperature below T_{base} is set to T_{base} before calculating the average giving a zero value. Likewise, the maximum temperature is usually capped at 30ºC because most plants and insects do not grow any faster above that temperature. However, some warm temperate and tropical plants do have significant

requirements for days above 30ºC to mature fruit or seeds [14].

2.1 The Heat-Sum Concept

Heat-sum concept holds to the total amount of heat to which a plant is subjected to during its growth. Heat sum is the measurement of departure of the mean day temperature above the minimum threshold for a plant. Assumption of the concept: is that the relationship between growth and temperature is linear.

Critical temperatures: These are three meteorological factors which control plant growth and development, they are: temperature or heat, moisture or rainfall and light. But regardless of how favourable light and moisture condition may be, plant growth ceases when temperature drops below a certain minimum value or exceeds a certain maximum value. Between these two limits, there is an optimum temperature at which plant growth proceeds with greatest rapidity. These are the cardinal temperatures:

- Minimum below which crop growth ceases.
- Optimum crop grows at its best.
- Maximum beyond which crop growth declines.

Biological Zero: This is a temperature below which the physiological process in a plant ceases examples; maize (10^0C). Note that extremely high temperature is harmful to the roots, while low temperature impedes the plant mineral nutrient intake and below 10ºC, the soil moisture ceases to be available to plants. Persistently cold soil results in to dwarfed growth of plant. Crop specific indices that employ separate equations for the influence of the daily minimum (night time) and the maximum (daytime) temperatures on growth are call crop heat units [14].

2.2 Phenological Phases of Maize Crop

The growing phase of maize crop from sowing to harvesting stage was observed; life history and mean dates of important epoch of crop growth and development of maize phenological stages as shown in Table 1.

3. RESULTS AND DISCUSSION

Fig. 1a and 1b Result shows that before going for planting the soil must be wet at least with a rainfall of 30mm, because decadal of rains must be considered. Excessive rain may negatively affect the leaf area index of maize crop because leaf area index is not high enough to accommodate the water.It was observed that during the wet season, rainfall was at its peak in June for the mean monthly variations of Rainfall while the mean monthly variation of temperature peak in March as a result of high insolation during the winter period preceding the summer months.

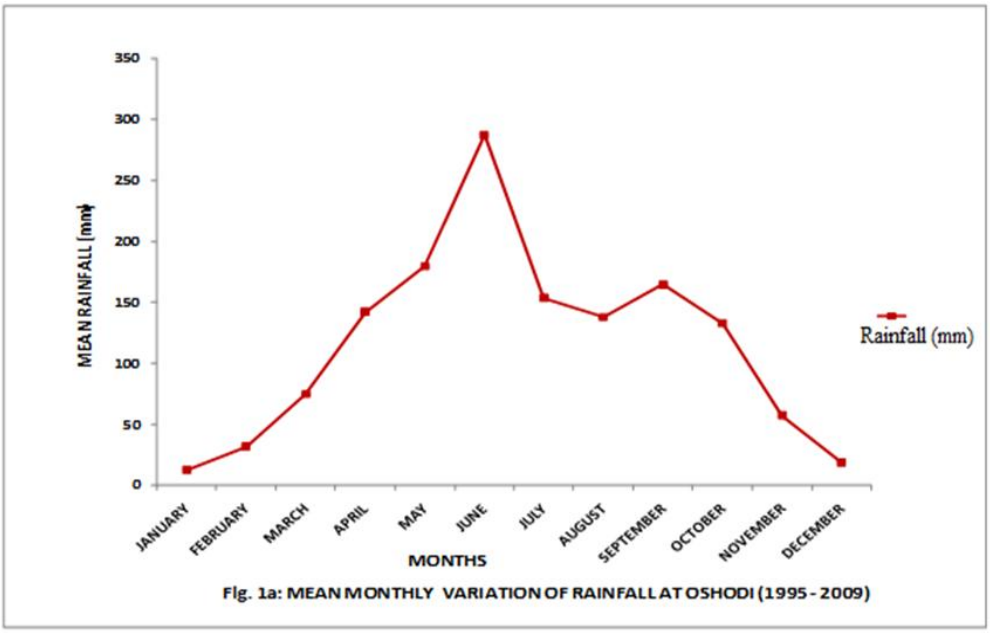

Fig. 1a: MEAN MONTHLY VARIATION OF RAINFALL AT OSHODI (1995 - 2009)

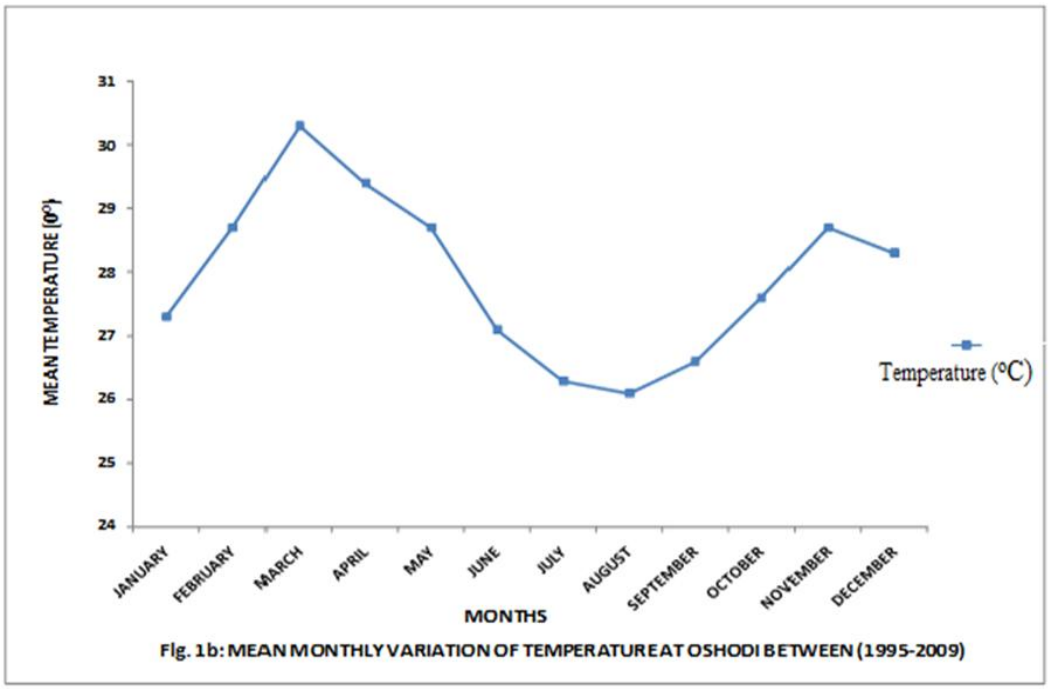

Fig. 1b: MEAN MONTHLY VARIATION OF TEMPERATURE AT OSHODI BETWEEN (1995-2009)

Table 1. Phenological phases of maize crop

Sowing to germination	Germination to emergence	Emergence to 3rd leaf	3rd leaf to 9th leaf	9th leaf to tasselling	Tasselling to flowering	Flowering to soft dough	Soft dough to hard dough	Hard dough to harvesting	Total
3	1	3	15	15	8	10	9	9	73

Source: Agromet Experimental Farm, Nimet Agency, Oshodi Lagos: (2010)

Fig. (2a and 2b) Results show that the year 1995 recorded highest rainfall distribution of 180 mm due to significant variations in monthly rainfall peakvalues in other to meet the needs of the crop during the growing season. As investigated by Adejokun [15], the growing length of maize varieties grown in Nigeria is between 75 and 85 days. But, there is a wide variation in the growing length of maize crop of the same variety grown on high and low altitude. However, the year 1998 recorded highest insolation from the atmosphere, as a result of mean annual temperature maximum occurrence for that year.

Fig. 3.1 Result shows that there is no specific upper limit of temperature for maize crop production, but yield usually decreases with too high temperature [16]. If the temperature is ok, we observe germination at the third day. Emergence will come up a day after germination. Result show that the highest yield was observed in 2006 as a result of even distribution of rainfall and temperature in the study area. However, lowest yield was observed in 2010 as a result of excessive rain that negatively affect the leaf area index of maize crop because leaf area index is not high enough to accommodate the water.

Fig. 3.2 Result show that heat sum calculation (HSC) is the reflection of the number of growing days considering the temperature effect. Relating the total number of days of growing season of maize crop and output, shows that 2009 recorded highest output of maize due to even distribution of sufficient amount of raindays to meet the needs of the crop during the growing season, while 2010 recorded lowest output of maize because water in the soil is in excess of evaporative demand during the growing season in the study area.

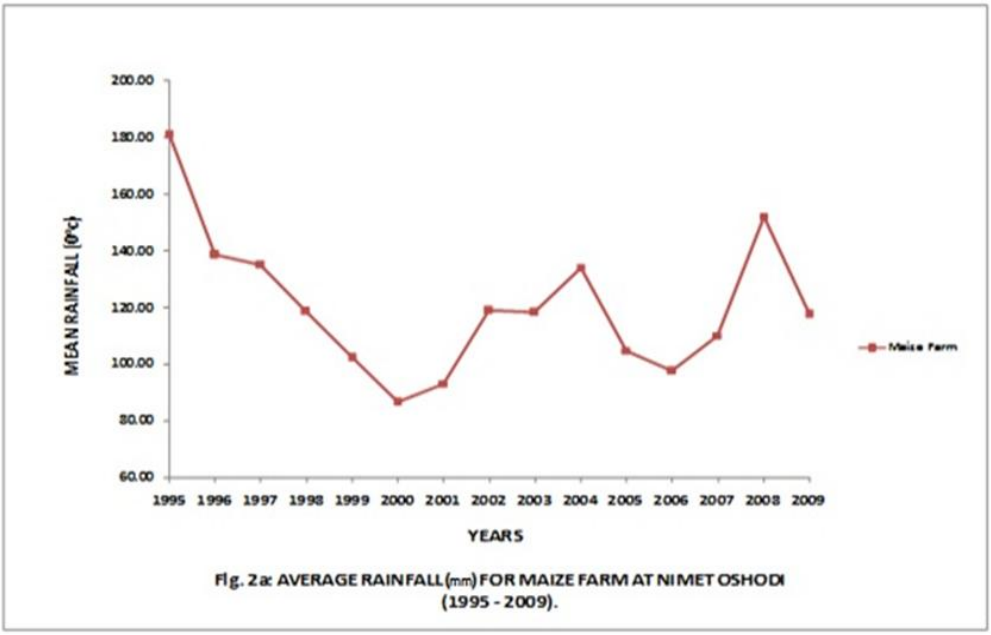

Fig. 2a: AVERAGE RAINFALL (mm) FOR MAIZE FARM AT NIMET OSHODI (1995 - 2009).

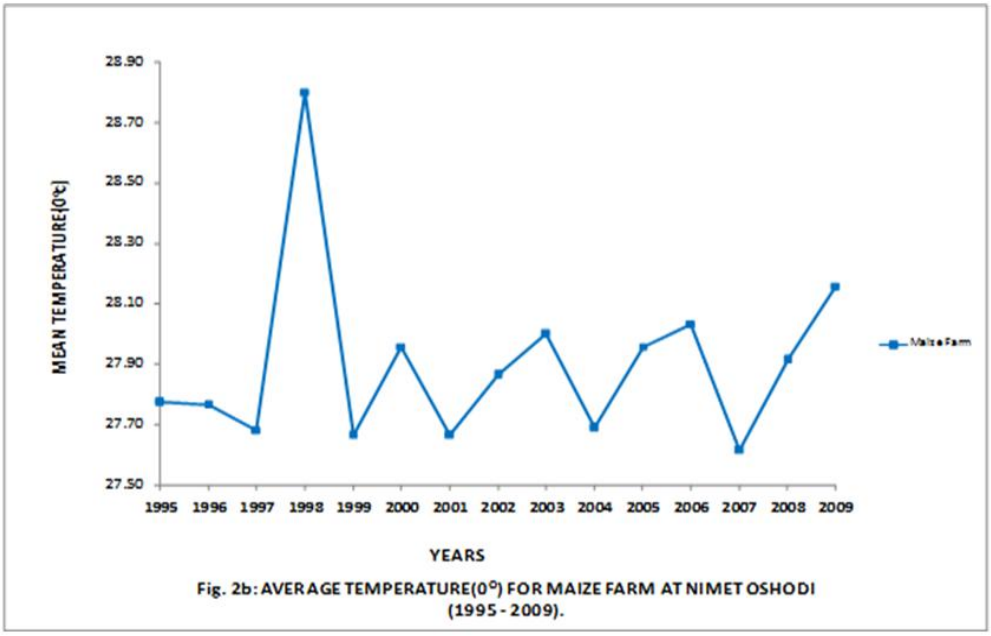

Fig. 2b: AVERAGE TEMPERATURE(0°) FOR MAIZE FARM AT NIMET OSHODI (1995 - 2009).

Fig. 3.3 Result shows that growth of maize crop is dependent on temperature and water. The controlling factor is water for the 3rd leaf phase. Consequently, after two or three days of flowering fruiting set in because flowering coincide with fruiting or grains filling. Moreover, adding the number of days we look for length of days from sowing to ripening phase is the length of growth. Wax ripening or hard dough is the end product of the crop. Result shows that cumulative rainfall with the phonological phases of maize crop grown in 2010 was at its peak as a result of high rainfall amount of raindays while 2007 exhibits lowest rainfall amount of raindays [11]. For maximum production, a medium maturity grain crop requires between 500 and 800 mm water depending on climate. But recent studies show that rainfall of 400–600 mm if well distributed to meet the needs of the crop during the growing season is also adequate [17].

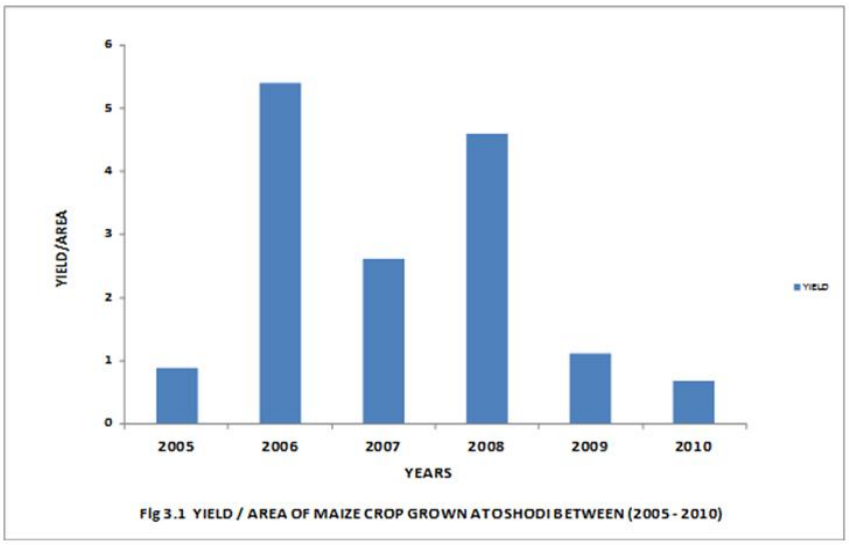

Fig 3.1 YIELD / AREA OF MAIZE CROP GROWN AT OSHODI BETWEEN (2005 - 2010)

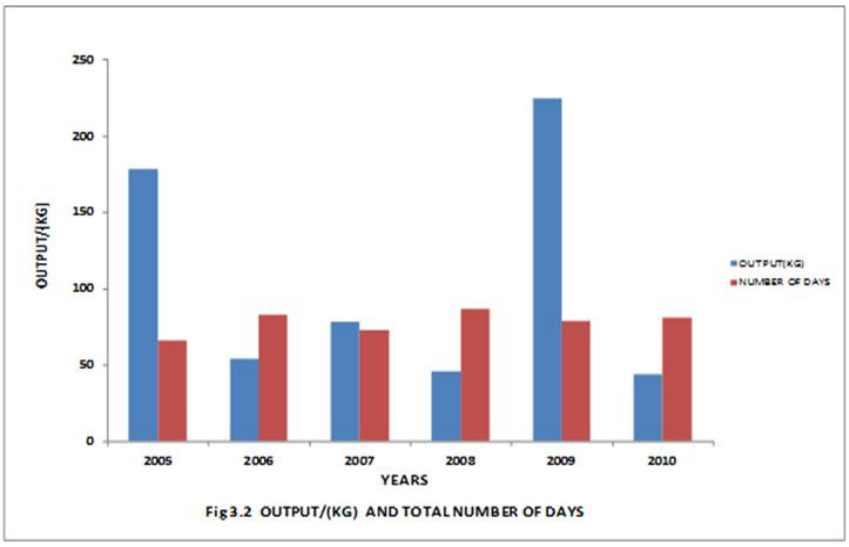

Fig 3.2 OUTPUT/(KG) AND TOTAL NUMBER OF DAYS

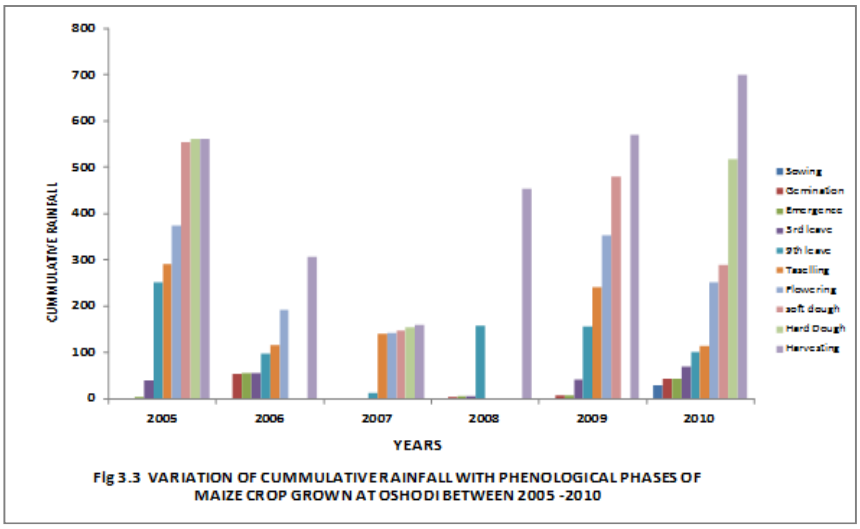

Fig 3.3 VARIATION OF CUMMULATIVE RAINFALL WITH PHENOLOGICAL PHASES OF MAIZE CROP GROWN AT OSHODI BETWEEN 2005 -2010

Fig. 4.1. Result shows that maize will not thrive well under a high temperature but requires a moderate value of 25º ─ 38ºC because It is the optimum temperature i.e. for best or highest yield. However, extremely high temperature is harmful to the roots. Above this 40ºC maximum temperature, the maize crop will be negatively affected which may result to daunted growth of plant. While low temperature impedes the plant mineral nutrient intake and below 10ºC, the soil moisture ceases to be available to plants.

Fig. 4.2 and 4.3 Result shows that rainfall is the major factor that determines the yield of maize. It was observed that at high rainfall and temperature value for the mean rainfall amount; highest yield was recorded in 2006 and 2008 respectively due to mean annual variation in the meteorological parameters especially during the growing season in the study area.

3.1 Preparation of Crop Weather Calendar

To get the average total number of days from sowing phase, the numbers of days were added all together and divide it by the number of growing phase. Heat sum is calculated by the addition of maximum temperature and minimum

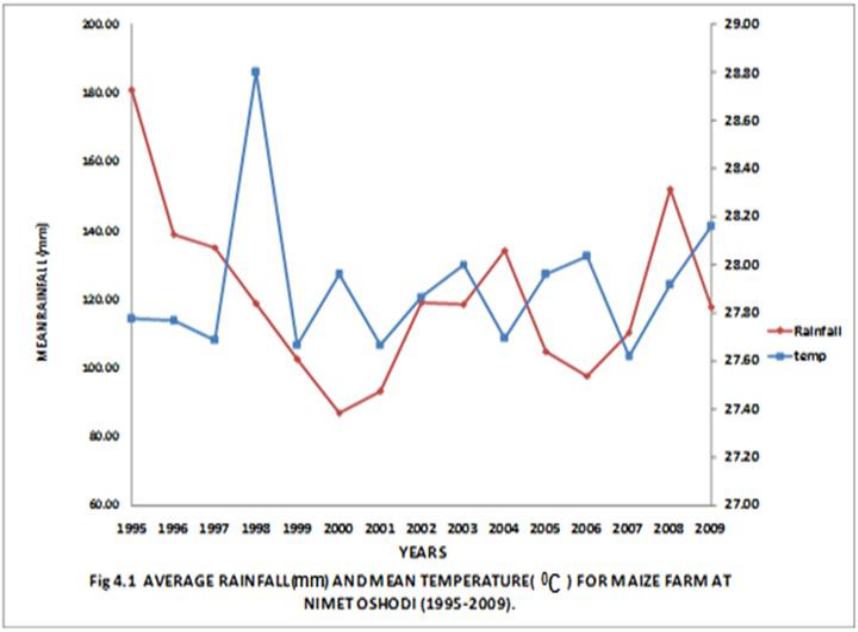

Fig 4.1 AVERAGE RAINFALL(mm) AND MEAN TEMPERATURE(^0C) FOR MAIZE FARM AT NIMET OSHODI (1995-2009).

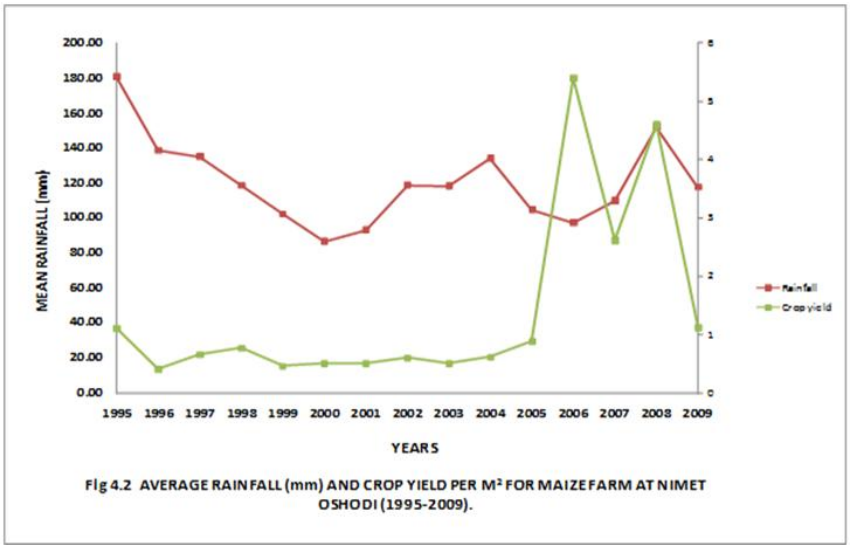

Fig 4.2 AVERAGE RAINFALL (mm) AND CROP YIELD PER M^2 FOR MAIZE FARM AT NIMET OSHODI (1995-2009).

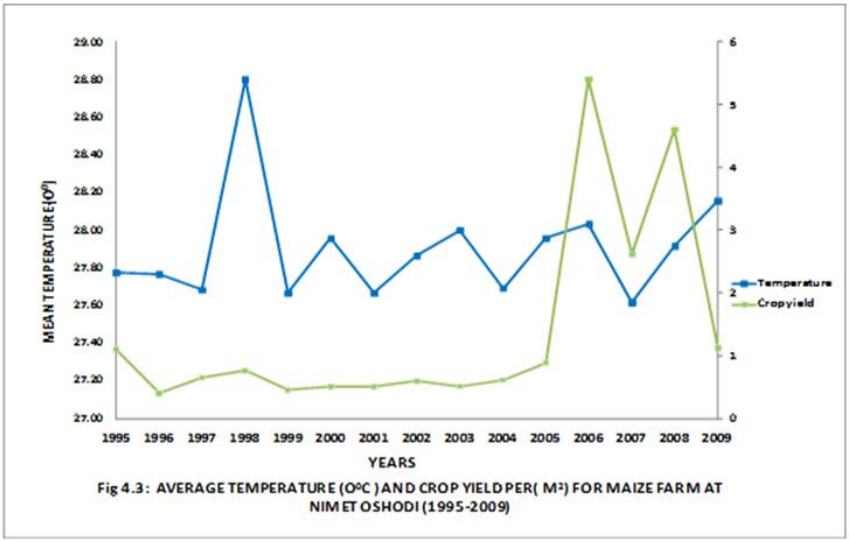

Fig 4.3: AVERAGE TEMPERATURE (O°C) AND CROP YIELD PER(M²) FOR MAIZE FARM AT NIMET OSHODI (1995-2009)

temperature which was divided by two (2) which gives the mean temperature for that day. The mean temperature is been subtracted from the base temperature of maize which is 10ºC to get the temperature effective. The addition of temperature effective gives the heat sum calculation. From the phonological records of maize farm at Nimet Oshodi, cumulative rain was calculated by the addition of each phonological stage in each year and divided by the total number of cumulative rainfall. Furthermore, the raindays was calculated by the addition of each phonological stage in each year and divided by the total number of raindays.

CROP WEATHER CALENDAR

STATE: Lagos
STATION: Agromet Exp. farm, Oshodi
PERIOD: 2005 - 2010 **CROP:** Maize

ZONE: Humid (Rain) Forest:
Reference: AGROMET FARM, NIMET AGENCY, OSHODI

Weather warning to be noted.	Rain	[30mm in 10 days]									
	Duration of Wet spell	[> 4 days]									
	Cloudy Weather										
	Drought										
Normal Weather Requirements	Highwinds	[exceeding 40 knots									
	Temperature	[< 10°c] < 10°c at night, > 40°c during the day									
	Hail Storm	[Hail storm									
											Total
✓	Degree days	54.5	73.4	134.1	433.6	725.2	867.1	1,119.3	1,213.2	1,429.5	1,429.5
✓	No of rain days	2	2	3	12	17	20	25	28	34	34
Life history and mean dates of importants epochs(phases) of crop growth and development	Cummulative rainfall	19.15	20.41	36.16	130.98	193.22	263.58	369.25	412.1	459.3	459.3
✓											
✓	main phenological stages	Sowing to Germination	germination to Emergence	Emergence to 3" leaf	3" leaf to 9" leaf	9" leaf to Tasselling	Tasselling to Flowering	Flowering to Soft dough	Soft dough to Hard dough	Hard dough to Harvesting	TOTAL NO.
✓	No of days	3	1	3	15	15	8	10	9	9	73

4. CONCLUSION

Maize phonological stages and harvesting dates has been investigated with the use of heat sum calculation along with the seasonal rainfall forecast by Nimet in relation to maize crop production based on analysis of rainfall pattern and thermal regime. Result obtained, shows that knowing the average temperature for that area to determine the number of crop to be planted along seasonal forecast by Nimet. Maize phenological records were collected for the period between 2005 and 2010, from the crop production section of Agromet experimental farm Oshodi.

Maize crop can be grown on varieties of soils, but performs well on well drained, well aerated warm loams and silt loams containing adequate organic matter and well supplied with available nutrients. Results show the length of growing period with use of heat sum calculation and harvesting date of maize crop grown in the study area is forecasted. For the purpose of having a good yield, the water applied at the emergence and 3rd leaf phase is very important. Maize being the 2nd most staple food crop in the world, to make the farmers know when to grow their crops with the help of crop weather calendar in the part of the country. Also, results further necessitate the preparation of crop weather calendar and development of strategies for farmers to make provision for availability of food for the people and the nation because, when there is no food there is no peace. Results show the length of growing period with use of heat sum calculation and harvesting date of maize crop grown was forecasted. Result further determines the number of times maize crop could be grownwith the use of crop weather calendar in a year in the study area.

In conclusion, results from this study provide valuable baseline information for planting and harvesting dates with the use of crop weather calendar for both small and large scale farmers in relation to maize crop production.

5. RECOMMENDATION

For irrigation maize planting, suman 1 open pollinated maize variety is recommended in the study area. Most importantly, we recommend that government should encourage the use of meteorological data and the heat sum calculation information on maize production in the part of the country. Also, that incentives should be given to researchers of this nature, so that good result will be obtained as this in a large sense determines the profit and limit the level of risk bearing by the farmers.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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