Heat sum calculation in forecasting maize phenological stages and harvesting date
Lagos South West, Nigeria.
(A case study of Oshodi Agro-met experimental farm, NIMET)

Abstract

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 for the period between 2005 and 2010, from the crop production section of Oshodi Agro-met experimental farm. 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 used to show the correlation between these parameters rainfall, temperature and crop yield data between (1995 and 2010) was used. Heat sum calculation (HSC) was employed as a forecasting guide of growing phase of maize crop and harvesting date in the study area. The graphs of the yield are 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 further determine the number of times maize crop could be grown within the use of crop weather calendar in a year in the study area. However, 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.

Key words: Heat sum calculation (HSC), Maize Crop, Temperatures (°C), Rainfall (mm), Agro-met, phenological, Yield, Oshodi, Lagos, NIMET.

1.0 INTRODUCTION

Heat sum is a measure of heating. It is the departure of mean air temperature above the minimum threshold temperature, or “biological zero” of a plant. Totalized heat sum from an appropriate starting date are used to plan the planting of crops and management of pests and pest control timing. Weekly or monthly heat sum figures may also be used within an energy monitoring and targeting scheme to monitor the heating and cooling costs of climate controlled environment, while annual figures can be used for estimating future costs. Heat sum is computed as an integral of a function of time that generally varies with temperature. The function is truncated to upper and lower limits that vary by organism, or to limits that are appropriate for climate control. The function can be estimated or measured by one of the following methods, in each case by reference to a chosen base temperature. A large number of studies have been undertaken to show the direct effect of meteorological factor on maize crop yield. But
as noted by Penman, (1962), most workers have approached their various relationships from either an empirical/statistical, experimental or theoretical standpoint. 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. (1973) 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, (1986) 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 Mornu, (1986) 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. 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. (Kassam, 1975), 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, (Adejokun, 1999). Ilesanmi (1972), identified the time of onset of rain at any station in Nigeria as the first point of maximum curvature on a plotted graph of the cumulative percentage of computed five-day intervals through the year. He found out that, his point coincides with 7 – 8 cumulative percentages, meaning that the onset of rain at every station begins with an accumulated 7 – 8 per cent of the annual rainfall. Virmani (1975), defined the start of the rain as being that week, which had more than 20 mm of rain in one or two consecutive days, provided that, the probability of at least 10 mm of rain in subsequent week is greater than 0.7 mm. This definition attempts to rule out false start of rains resulting from occasional heavy rainfall which might be followed by a prolonged dry spell. As investigated by Adejokun (2010), 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, this study is to relate the number of days of growth of maize crop with the use of heat sum (HS) and the length of growing periods of different maize varieties grown at Oshodi Agro-met experimental farm, with the total number of days of growing season. Also, this study intends to provide forecast for phenological stages and harvesting date of maize crop and to determine the number of times that maize crop could be grown in a year in the study area.

Maize (Zea maize) is one of the most edible crops throughout the world and it is grown world-wide. Today, maize is one of the most staple food crops that sustain the ever increasing world population (Adejokun, 1999). Maize plant originates in the Andean region of Central America, about 5,000 years ago, (IITA, 1982). It is one of the most
important cereals both for human and animal consumption and is grown for grains and forages. And the Present world production is about 594 million tons grain from about 139 million ha (FAOSTAT, 2000). According to Van Eijina ten (1964), maize from central and South America is introduced to Europe in 1492 by Columbus and then later spread to Africa in 1900 and finally got to Nigeria in the early 20th century. Maize seed is composed of outer layer called pericarp and of two inner components, the endosperm and the embryo. The entire pericarp and the testa and usually the aleurone layer collectively termed bran are removed in milling. The bran that includes the embryo has a higher protein than the carbohydrate rich endosperm between the embryos. This is because the concentrations of enzymes (protein) in the embryo are essential for germination, growth and development (Adejokun, 1999). 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. Depending on one’s tribe, maize is processed and taken in so many forms. The Hausa process maize grains and take it as 'Tuwo ', the Ibos process it and eat it as 'Agiyi ' or 'Akamu ', while Yoruba process it as 'Eko '. And generally, maize is commonly taken in roasted or boiled form. On a wider range maize is processed and sold as baby food. It is usually the first solid food for infants, from the age of four month upwards.

Plate A: Establishment period
Plate B: Late Vegetative period
(Sowing phase to 3rd leaf phase)(3rd leaf phase to 9rd leaf phase)
Plate C: Maturity period (Soft dough to hard dough)

2.0 MATERIALS AND METHODS

2.1 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 06° 30’ North and Longitude 03° 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 6° 27’ and 6° 40’ North of the equator and Longitude 2° 32’ and 6° 40’ 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 180km of the Atlantic Ocean Coast line and by the Bight of Benin and in the West by the Republic of Benin, (Duze, 1978). 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 (James Grant, 1960).

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.

Figure 2.1: Map showing position of Oshodi (pink) in Lagos State (brown) and Nigeria (green)

2.2 THE HEAT SUM (HS) 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: cereals (0-10°C), sunflower (7-8°C), potato (8°C), Maize, beans, millet, tomatoes etc. (10°C), Cucumber (13°C), rice and cotton (14-15°C).

Note that extremely high temperature is harmful to the roots, while low temperature impedes the plant mineral nutrient intake and below 10°C, the soil moisture ceases to be available to plants. Persistently cold soil results in to dwarfted growth of plant.

Heat sum calculation (HSC): can be used to assess the suitability of a region for production of a particular crop; estimate the growth-stages of crops, weeds or even life stages of insects; predict maturity and cutting dates of forage crops; predict best timing of fertilizer or pesticide application; estimate the heat stress on crops; plan spacing of planting dates to produce separate harvest dates. 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. (Jasper Womach 2005).

Phenological Phases of Maize Crop

The growing phase of maize crop from sowing to harvesting stage was observed as shown below:

Sowing 
↓
Germination 
↓
Emergence 
↓
3rd leaf 
↓
9th leaf 
↓
Tasseling 
↓
Flowering
Milky ripening/ Soft dough
↓
Wax ripening/Hard dough
↓
Harvesting

2.3 METHODS OF DATA COLLECTION, MANAGEMENT AND ANALYSIS

All data were collected from Oshodi Agro-meteorological Observatory of Nigerian Meteorological Agency (NIMET) located at Longitude 03°23’ East and Latitude 06°03’ North with altitude of 19m above mean sea level in Oshodi Lagos State of Nigeria. Maize phenological records were collected for the period between 2005 and 2010, from the crop production section of Agro-met experimental farm Oshodi. 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. The graphs of the yield are plotted against temperature and rainfall. Therefore, Heat Sum (HS) is given by:

\[
\text{HS}_{\text{Season}} = \sum_{t=1}^{T} \text{HS}(t)
\]

\[
\text{HS} = T_{\text{observed}} - T_{\text{mean}}
\]

\[
\text{HS} = T_{\text{observed}} - \text{Critical}
\]

\[
T_{\text{critical}} = \text{Optimum growth of temperature.}
\]

0°C – 10°C is the negative growth of maize crop.

10°C is the base temperature of maize (below this, the growth will be zero).

25°C – 38°C is the optimum temperature i.e. (best or highest yield).

40°C is the maximum temperature i.e. (above this, the crop will be negatively affected).

Heat Sum (HS) calculation:
Heat sum (HS) is typically measured from the winter low. Any temperature below $T_{base}$ is set to $T_{base}$ before calculating the average. Likewise, the maximum temperature is usually capped at 30 °C 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 30 °C to mature fruit or seeds (Jasper Womach, 2005).

3.0 RESULTS AND DISCUSSION

Data was collected from the Nigerian Meteorological Agency (NIMET) on Agromet experimental farm Oshodi Lagos State Nigeria spanning six (6) years Data from 2005 to 2010. Microsoft Excel was used to show the correlation between these parameters rainfall, temperature and crop yield data between (1995 and 2010) was used. 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.

Figure (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.
Results show that the year 1995 recorded highest rainfall distribution of 180 mm due to significant variations in monthly rainfall peak values in order to meet the needs of the crop during the growing season. As investigated by Adejokun (2010), the growing length of maize varieties grown in Nigeria is between 75 and 85 days. However, 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.

Figure 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 (IITA, 1982). 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.

Figure 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 rain days 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.
Figure 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 (Kassam, 1975), 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, (Adejokun, 1999).
Figure 4.1: Result shows that maize will not thrive well under a high temperature but requires a moderate value of 25°C – 38°C because it is the optimum temperature i.e. for best or highest yield. However, extremely high temperature is harmful to the roots. Above this 40°C 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 10°C, the soil moisture ceases to be available to plants.
Figure (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.

![Graph showing average rainfall (mm) and crop yield per m² for maize farm at Nimet Oshodi (1995-2009).]

![Graph showing average temperature (°C) and crop yield per m² for maize farm at Nimet Oshodi (1995-2009).]
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 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 10°C to get the temperature effective. The addition of temperature effective gives the heat sum calculation. From the phonological records of maize farm at NimetOshodi, cumulative rain was calculated by the addition of each phenological 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.
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 3\textsuperscript{rd} leaf phase is very important. Maize being the 2\textsuperscript{nd} 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 grown with 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.

**RECOMMENDATION**

For irrigation maize planting, suman 1 open pollinated maize variety is recommended in the study area. Most importantly, I will 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.

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