DEGREE-DAYS AS A TOOL IN DECISION MAKING AND CROP MONITORING

By

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Abstract
The objective of this study was to demonstrate how degree-days can be used in decision making and crop monitoring. The results obtained include monthly mean degree-days total, cumulative monthly degree-days , mean annual cumulative degree-day map and graphs, mean monthly temperature graphs for selected stations and the Beitbridge example that illustrates the use of degree-days as a decision making tool in agriculture. The cumulative degree-day map shows the magnitude and temporal distribution of heat units for Zimbabwe. The graphs show high values of degree-days in the low lying areas decreasing with altitude. Near zero values are found over the Eastern Highlands. This means that for base temperature 18 ° C, temperate crops are unsuitable for this area. Values of 2000 and more degree-days in the low lying areas mean that tropical crops can be grown in these areas all year round. The middle and high velds can only support tropical crops in the summer season. The map drawn goes further to confirm this trend. The example graph for Beitbridge illustrates how to determine dates for attainment of critical phenological stages and harvesting using degree-days where warmth is the only limiting factor.

Introduction

Plants require energy for growth and development and some of this energy is in the form of heat. A lot of work/research has been done on rainfall and its effects on the spatial distribution of cropping systems in Zimbabwe. On the other hand, despite the fact that temperature data/ information is readily available and the fact that temperature is the single most important weather element that affect plant response, not much research has been done to effectively utilize the thermal resources of Zimbabwe.

The concept of degree-days or heat units has evolved and is being used in other countries. These (degree-days) have been found to be a better way of relating plant growth, development and maturity to temperature than temperature alone. The degree-day concept assumes that each plant has its own base and thresh hold temperatures and these vary with the phenological stage.

The rates of most plant developmental processes and hence the timing of phenological phases are strongly temperature dependent. Take for example a given phenological stage that takes k days, the corresponding rate of development (R_d) is 1/k. So this means that there is an inverse proportionality between the time taken to complete a developmental stage and the corresponding rate of development (R_d). In a constant environment then ;

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$1/k. = R_d = f(T)$ ………………………………1.1

where T is the temperature. Within a growing temperature range for a plant , increasing the temperature will result in decreased number of days taken to complete a particular stage and vice versa.

Objectives
This research has been done with the following objectives in mind;

- Demonstrating how degree-days can be used to monitor crop growth and development.

- Demonstrating how degree-days can be used in pest management.

- Demonstrate how degree-days can be used for strategic planning for example, determining dates for harvesting and dates for attainment of critical phenological stages.

- Establishing the spatial distribution of degree-days in Zimbabwe and how this can be used in decision making.

Definitions of important terms or concepts:

- **Base temperature**: This is the lowest threshold temperature below which growth ceases for a plant.

- **Upper critical temperature**: This refers to the highest temperature beyond which growth is curtailed or stops for a plant due to heat stress

- **Optimal temperature:** This is the temperature range where maximum growth rate is realised for a plant. This is between the base temperature and the upper critical temperatures

- **Phenological stage**: This is a particular stage of plant/crop development for example, flowering and maturity stages

- **Degree-day**: This is excess temperature above a given threshold, below which growth and development ceases. In this research the threshold temperatures were 15° C and 18° C.

Temperature and Agriculture

"Climate is the dominant natural characteristic in all parts of Zimbabwe and is the most important single factor influencing land use. It sets the pattern of agricultural production through its direct and indirect effects upon crops and animals" (Vincent and Thomas, 1956). Combinations of climatic factors such as rainfall, radiation, humidity, temperature and wind just to mention a few are needed for optimum development and production.

Although there are many weather elements that are of vital importance to agriculture, only temperature and degree-days will be discussed in this article, and in particular the role of temperature and its derived parameter degree-day will be discussed. The main aim is to bring out the importance of degree-days and temperature to crop and animal production.

Temperature is the second most important meteorological element in agricultural production(after rainfall). Temperature directly affects plant functions of photosynthesis, respiration, cell-wall permeability, enzyme activity and protein coagulation. For a seed to be able to germinate and grow, it has to absorb moisture. The ease with which it can do this is determined by temperature and the level of available moisture. Temperature is therefore one of the factors determining growth rate, level of bacterial or fungal activity, duration of the growing period, mineral and nutrient uptake rate and the time to flowering.

In crop production and animal husbandry, there is a range of temperatures in which growth and development are realised. At each phenological stage in crop growth and development, there is a threshold lowest temperature at which growth ceases called the lower critical temperature or the base temperature. There is also the highest temperature beyond which growth is curtailed due to heat stress which is called the upper critical temperature. Between the upper and the lower critical temperatures is found a temperature or temperature range where maximum growth rate is realised. This is the optimum temperature.

It is important to note that the maximum temperature for plant life is about 54 °C and the minimum temperature for plant growth is 5 °C. These values vary from cultivar to cultivar. The following is a table indicating the average base temperatures for selected crops in general.

Table 1: Average base temperatures for selected crops

Crop	Base temperature in ° C
Spinach	2.2
Lettuce	4.4
General plant growth	5.5
Peas	5.5
Asparagus	5.5
Corn	10.0
Beans	10.0
Pumpkins	13.0
Tomatoes	13.0

Source: Jones H.G (1992)

For animals, the thermo-neutral zone is very important in the maximization of the efficiency of metabolism. For both plants and animals, temperature is important in the emergence, development and propagation of pests and diseases. Most plant viruses, unless they are very infectious and easily transmitted by contact like tobacco mosaic virus, are transmitted by anthropoids, and some insects. So viruses spread fastest under conditions optimal for insect multiplication and activity. Aphids and leafhoppers are the principal vectors of plant viruses. The optimal temperatures for aphid reproduction is 26°C (Taylor, 1967). Winged aphids cannot fly when the temperature is below 13°C and above 30°C. Temperature has a major role in the over- wintering of pests and aphids. Very cold temperatures mean few pests and viruses over-winter.

The delineation of frost-areas, hot-areas and areas with optimal temperatures for growth can be achieved easily with temperature maps. Determination of degree days, growing period, vernalization time, time for abscission and dormancy all depend on temperature in combination with light (Jones, 1992). In cold countries like Russia the heat index plays a very crucial role in crop and animal production.

Sivakumar et al (1993) describes the temperature of a locality as a manifestation of the radiation and energy balance and that thermal regime analysis of a place are essential to evaluate the rates of activity of temperature dependent developmental processes such as leaf initiation, leaf expansion, photosynthesis and respiration.

Degree-days and their importance to Agriculture

In plant growth and development each phenological stage requires a specific number of thermal units or heat units that vary with plant type and the stage of development. These thermal units are often referred to as degree-days. There are three ways to calculate degree-days namely, the mean temperature method, the triangulation method and the sine curve method (Chmielewski et al, 1995). Despite their differences, the mean temperature method gives results that are not significantly different from the other two methods. In the mean temperature method degree-days are given by:

$$DD = \sum_{d=0}^{n} (T_{mean} - T_t) \text{ for } T_t \leq T_{mean} \leq T_o \quad \dots\dots\dots 1.2$$

Where DD is the accumulated degreedays.

DD = 0; for $T_{mean} \leq T_t$ (Jones, 1992), where T_{mean} = mean temperature calculated from (Tmax + Tmin)/2, T_t or T_{base} = threshold temperature for development to occur, T_o = optimum temperature.

Hergarty (1973), in his studies of field performance of crops in temperate climates indicated that temperature accounted for far more of the total variation in the relative growth rate than did any other climatological factor. Temperature influences all enzyme controlled chemical reactions in the plant from germination onwards. The timing of phenological phases, dormancy and leaf abscission all depend on temperature and degree-days.

In crop production degree-days are important in a number of ways. These include assessment of crop growth and development, crop production strategies and policies. Degree-days are a better way of assessing thermal units than temperature, for they take into account the growing temperature conditions for a crop or plant.

In animal husbandry and industry, the concept of degree-days has been used in the assessment of the development of both homeotherms and poikilotherms. Insects also experience a temperature - mediated (controlled) "time scale," which is the dominant driving variable in their population dynamics (Allsopp et al , 1987).

Uses of the growing degree-days concept in crop production include the following:
* scheduling of planting and harvesting for many cash crops for example peas, beans and corn
* monitoring growth and development progress for plants, for example bloom date and fruit development
* yield forecasting
* prediction/indicator of oil quality for soya beans and other legumes.
* site selection for crop or crop selection for a locality
* prediction of dates for insect activity related to agriculture and forestry

Use of heat units (degree-days) in pest management
Living organisms, like plants have upper and lower critical temperatures for growth and development. The accumulated degree-days for a given organism to complete development are constant. This measure of accumulated heat is known as physiological time. As temperature increases, the time taken to develop decreases and vice- versa. Physiological time is measured in degree-days. The date to begin accumulating degree-days is called the biofix and is mostly based on specific biological events such as planting date, first trap catch and first occurrence of the pest.

Population and development models based on degree-days have been used to pin point biological events. In pest management these degree-day- based models can be used to achieve the following:
* to determine when to start applying the pest control measures;
* to minimise the conflict between cultural and pest control operations such as irrigation and pesticide application;
* to determine the situational position in the development of a generation of pests;
* to schedule and time efficiently pesticide application;
* to determine whether the outbreak is false or peak;
* to determine when to do extensive scouting and sampling; and
* to maximise production through reduced cost and damage by pests

Use of degree-days in the management of energy resources
The need to conserve energy has led some cities to use degree-days in their energy resources management strategies. Base temperature 18.3°C and any cumulative units above this base temperature are referred to as cooling units whereas cumulative units below this temperature are

called heating units. Given temperature data, city engineers can determine the energy requirements for heating or cooling on daily , weekly, monthly and even on annual bases. (Internet)

Methodology
The objective of this study was to demonstrate how degree-days can be used for strategic planning such as monitoring crop growth and development, determining dates for planting, harvesting, critical phenological stages attainment and also pest management. Degree-days which are derived from temperature data are the second most important weather parameter in agricultural production after rainfall. Pest management's main source of decision making information is obtained from degree-days. Degree-days are an indicator of warmth or cold which are important parameters in pest population dynamics.

Temperature information that was used to calculate the degree-days was obtained from the Meteorological Department for 43 stations period 1951-2000. Daily maximum and minimum temperatures were collected and monthly mean maximum and minimum temperatures for each of the 43 stations were calculated.

Degree-days were calculated using the following formular;

$$DD = \sum_{d=0}^{n} (T_{mean} - T_t) \text{ for } T_t \leq T_{mean} \leq T_o \qquad \text{............1.3}$$

Where DD is the accumulated degree days.

DD = 0; for $T_{mean} \leq T_t$ (Jones, 1992), where T_{mean} = mean temperature calculated from (Tmax + Tmin)/2, T_t or T_{base} = threshold temperature for development to occur, T_o = optimum temperature.
        In the **mean monthly temperature method** the formular given above for the calculation of degree days can be simplified to:

DD = (T$_{mean}$ - T$_{base}$) x M 1.4
Where DD = monthly degree day total
T$_{mean}$ = monthly mean temperature calculated from (Tmax + Tmin)/2, M = number of
days in the month. The choice of this method was necessitated by the fact that daily or
hourly temperature data is hard to find for most places

Where daily maximum and minimum temperatures were available, INSTAT was used for calculations. SURFER 4 and SURFER 32 were used to draw maps while graphs were drawn using EXCEL

 The results obtained include monthly mean degree-days , cumulative degree-days(annual totals) for each of the 43 stations. This data was used to draw the annual mean cumulative degree-day

total map, monthly mean degree-days graph for selected stations and the Beitbridge example illustrating the use of degree-days as a decision making tool in agriculture.

The other methods that can be used are the double sine, single triangulation and the double triangulation. All these are linear methods. Non-linear complicated methods are available and are often used for research.

Mean temperature calculations

The aspect of temperature investigated in this research is the mean temperature. This is because mean temperature and degree-days are highly correlated , in fact degree-days are derived from mean temperature. There are two methods that can be used to calculate mean temperatures namely:

1) using the daily/monthly maximum and minimum temperatures as shown by equation 1.4
2) using the thermograph to calculate the twenty four hour mean temperatures
   The first method has been preferred to the second for a number of reasons , some of which are that thermographs are not reliable and that they are very few stations with this facility as compared to stations that record maximum and minimum temperatures.

The mean temperature data obtained from the calculations were then used in the calculation of degree-days, the drawing of monthly mean temperature graphs and monthly cumulative degree-days graphs for selected stations in Zimbabwe.

Results and Discussion

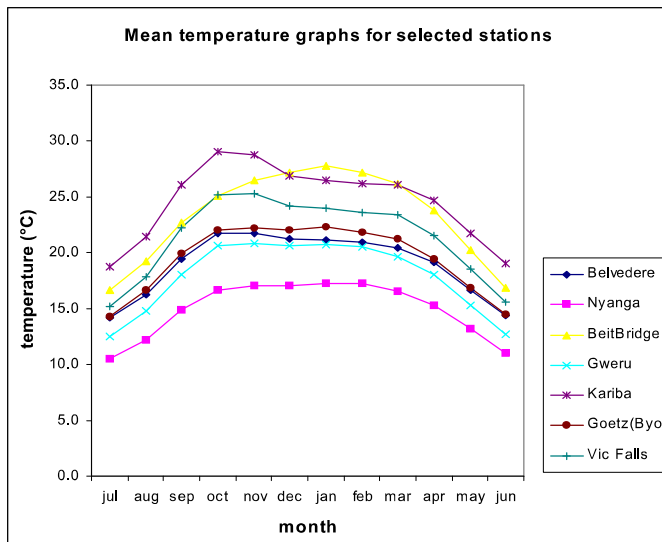## Figure 1.0 : Mean monthly temperature graphs for selected stations

Figure 1.0 shows the selected stations on one graph. From this graph it can be observed that all the stations show a gradual rise from July to a maximum in October and a decrease towards June. From October to December, there is steep cooling attributed to summer convection and cloudiness. Peak values of nearly 30 °C are at Kariba and lowest values of 12°C are at Nyanga.

Degree Days

Mean monthly degree-day totals and monthly mean cumulative totals were calculated from the maximum and the minimum temperatures for base temperatures 18 ° C. Equations 1.4 and 1.3 were used for these calculations. The calculated degree-day data were then used to:

a) Draw monthly mean degree-day totals bar graphs for selected stations
b) Draw the Annual mean cumulative degree-day map for Zimbabwe
c) Draw multiple line graphs for selected stations, showing monthly mean temperatures
d) Draw multiple line graphs for the cumulative monthly mean degree-day total for a selected group of stations

Monthly degree days mean total graphs for selected stations

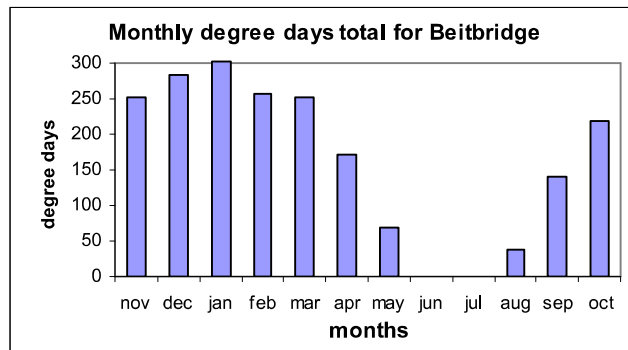**Figure 2(a): Monthly mean degree days total for Beitbridge**

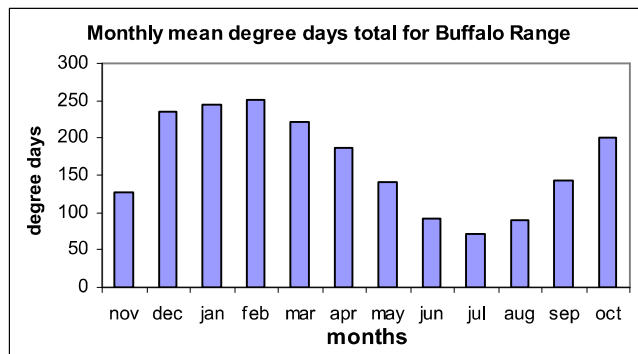**Figure 2(b):Monthly mean degree days total for Buffalo Range**

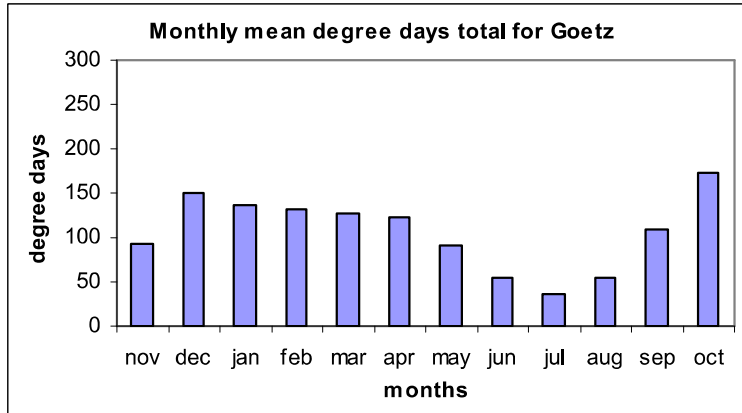**Figure 2(c): Monthly mean degree days total for Goetz**

Monthly mean degree days total for Goetz

Figure 2(d): Monthly mean degree days total for Victoria Falls

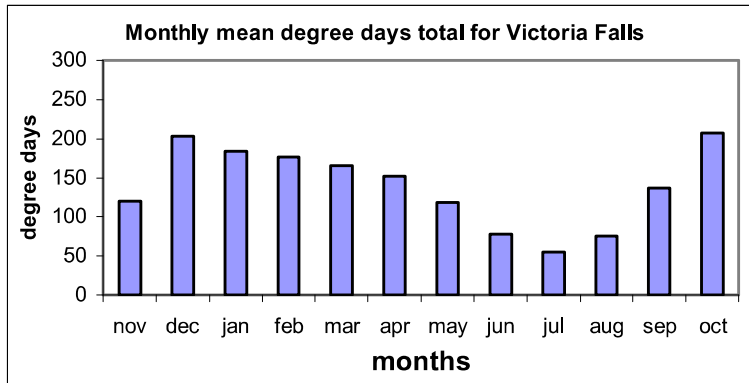Monthly mean degree days total for Victoria Falls

Figure 2(e): Monthly mean degree days total for Belvedere
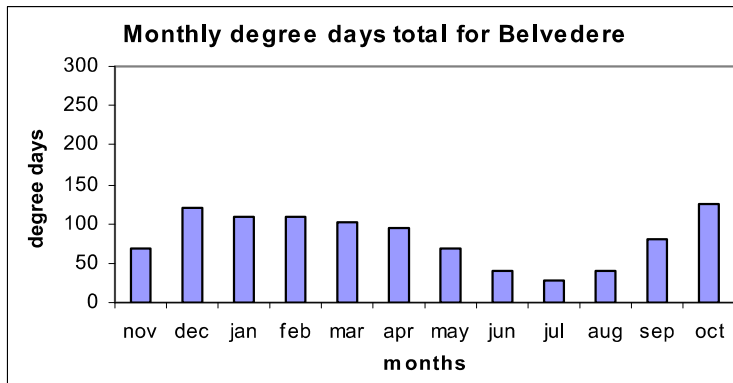

Monthly degree days total for Belvedere

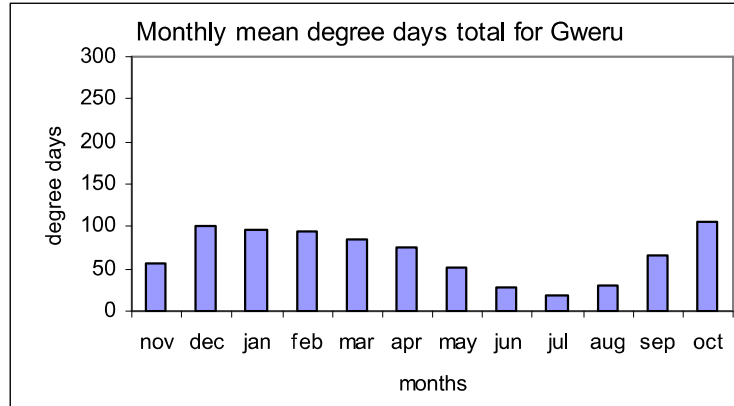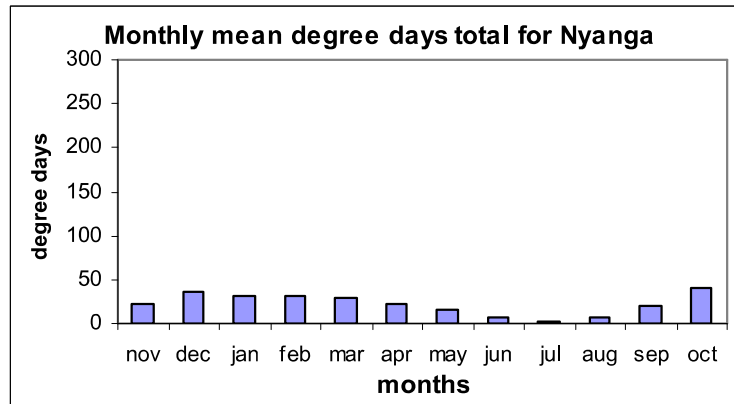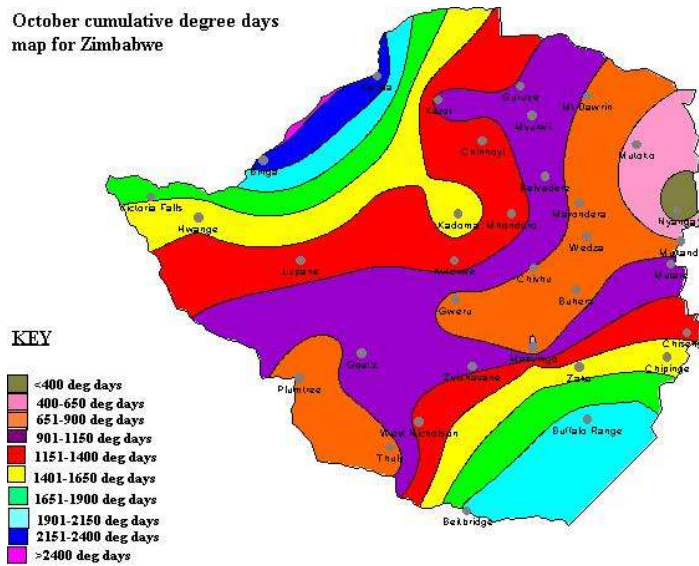**Figure 2(f): Monthly mean degree days total for Gweru**

Figure 2(g): Monthly mean degree days total for Nyanga

Figures 2(a) to 2(g) show monthly mean degree-day totals for selected stations. The graphs resemble the monthly mean temperature graphs with highest values over the Limpopo and the Zambezi valleys where Beitbridge, Buffalo Range and Victoria Falls have 300, 280 and 260 units respectively. These values were calculated for the growing season which stretches from mid October to March .

The lowest values are 5, 45 and 20 units for Nyanga, Gweru and Belvedere respectively. Nyanga has near zero values for all the three winter months, remaining low even in summer and the hot season with 50 units being hardly received. Moderate values range from 100 to 150 units in summer and the hot season.

October cumulative degree days map for Zimbabwe

KEY

- <400 deg days
- 400-650 deg days
- 651-900 deg days
- 901-1150 deg days
- 1151-1400 deg days
- 1401-1650 deg days
- 1651-1900 deg days
- 1901-2150 deg days
- 2151-2400 deg days
- >2400 deg days

The map above shows the spatial distribution of the added monthly totals starting in November to October the following year. This calender year is ideal because the growing season is not divided into two like what happens if the calender year starts in July. Nyanga has an annual total of 400 or less units. On the other hand low lying areas have 2000 or more units. These units are actual high values ideal for tropical crops such as sugar cane. The middle veld has moderate values ranging from 900 to 1900 units. This can support crop growth especially in summer.

Figure 4(a):Cumulative monthly mean degree-class total multiple line graphs for a selected
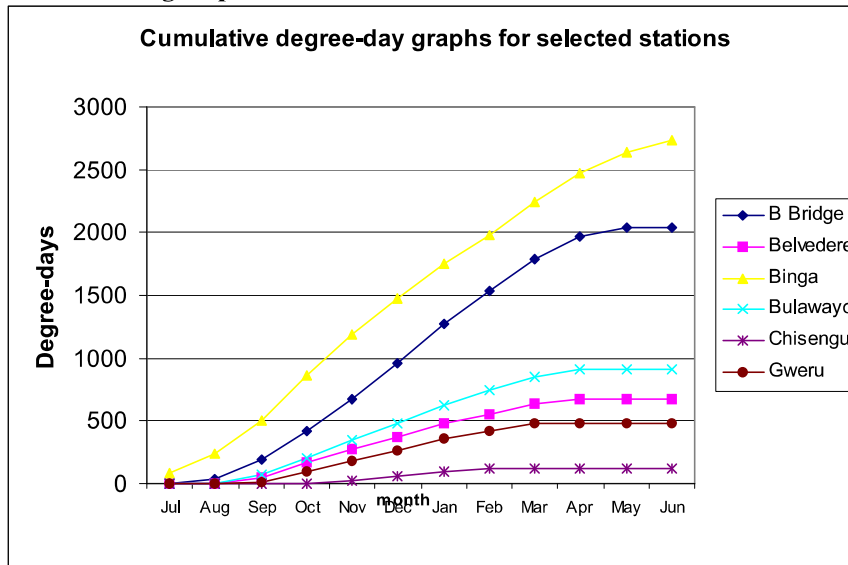
group of stations

Figure 4(b):**Cumulative monthly mean degree-day total multiple line graphs for a
selected group of stations**

Figure 4(c): **Cumulative monthly mean degree-day total multiple line graphs for a
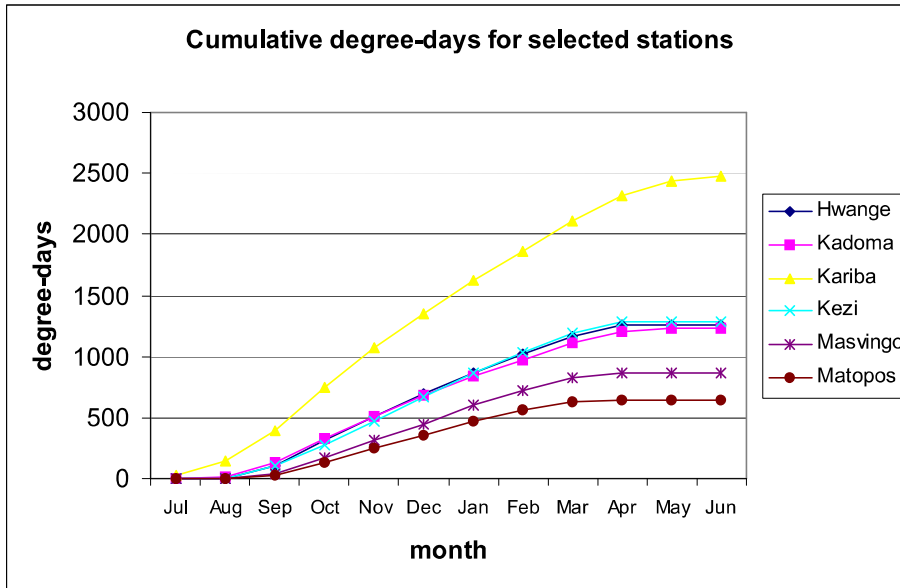selected group of stations**

Figure 4(d): **Cumulative monthly mean degree-day total multiple line graphs for a selected group of stations**

Figure 4(e): **Cumulative monthly mean degree-day total multiple line graphs for a selected group of stations**
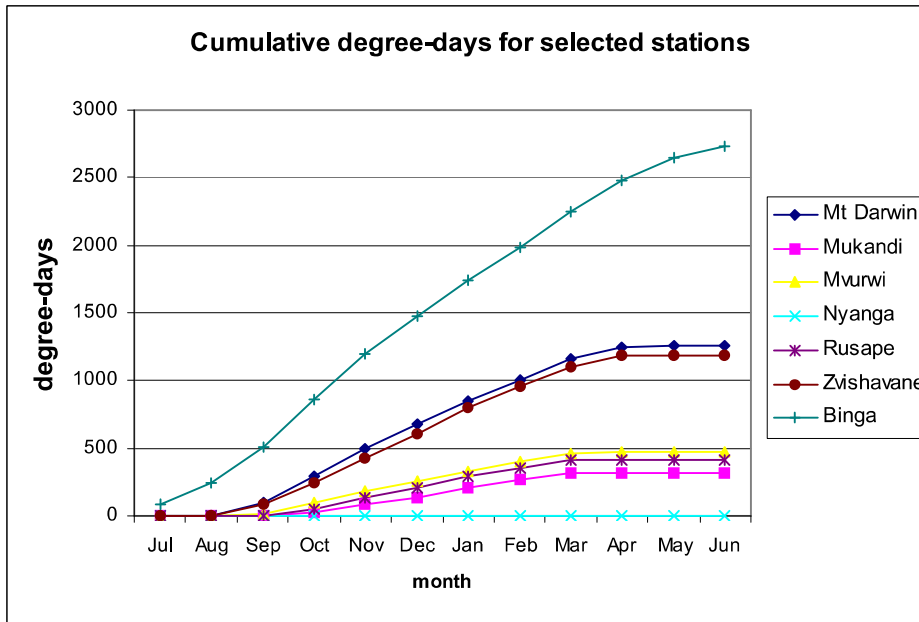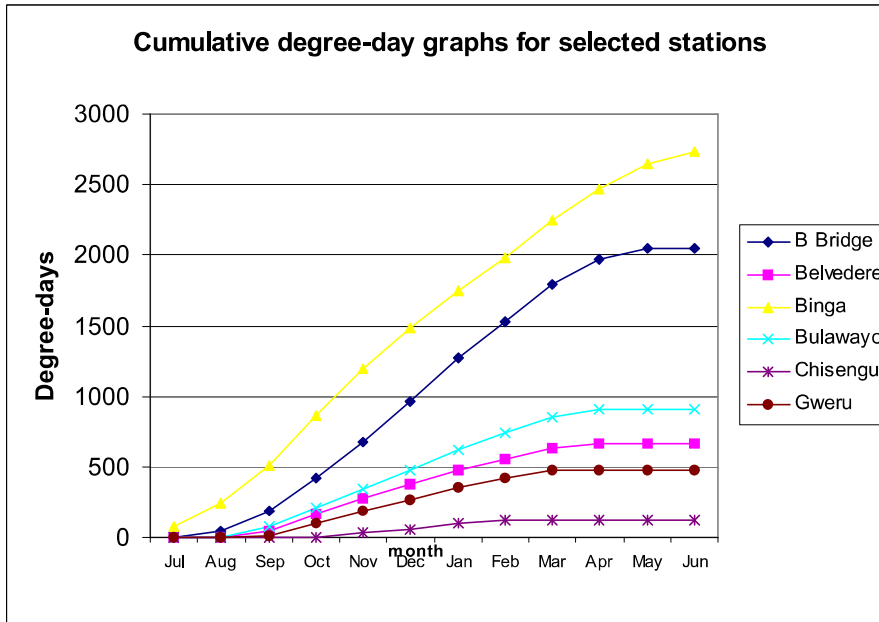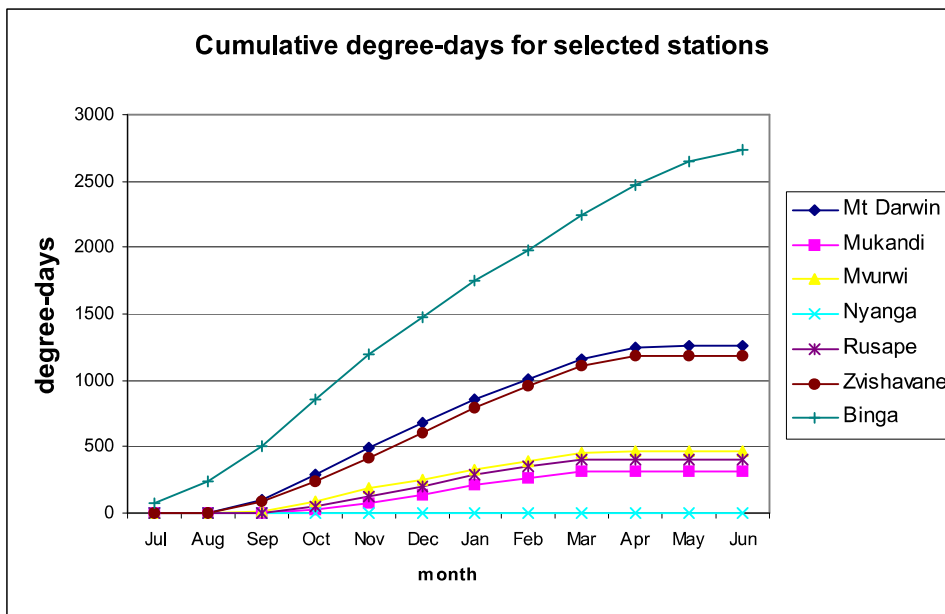
Figures 4(a) to 4(e) are groups of graphs for selected stations. These graphs are very useful. The values indicate the magnitude of thermal units the station is capable of attaining. This information used in conjunction with the growing degree-days for a particular crop or agricultural operation can be a useful tool in crop selection for sites and site selection for crops or plants. The graphs indicate very high values of 25000 at Binga, Beitbridge and least values ranging from zero to 400 units are at Rusape, Mukandi, Chisengu and Nyanga. This means that only crops with thermal units of 400 degree-days or less can thrive in these areas. These are temperate crops such as wheat and apples for example.

An example of how to use growing degree-days to forecast /determine harvesting and dates of attainment of the various phenological stages.

Method

Steps

1. Calculate long-term monthly cumulative degree-day totals for the place in question
2. Plot a graph of long-term monthly cumulative degree-days against the corresponding month of the year. Figure 5.0 shows an example of such a graph using the degree-day data for Beitbridge for base 10 ° C . The line marked by large squares (blue) and the line marked by smaller squares (red) are the normal and the actual cumulative degree- days.

Figure 5.0: **Cumulative normal and actual degree days graphs for Beitbridge**.
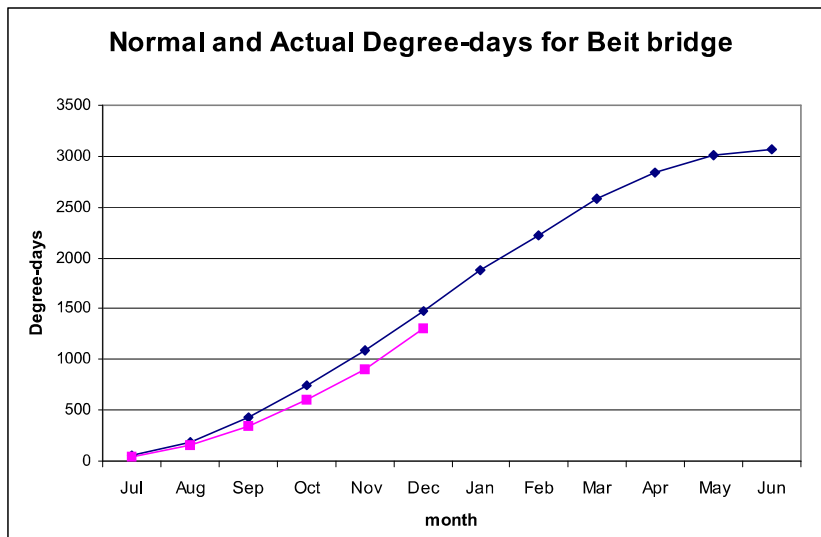
3. Assume the planting date was 31st October and the maize variety in question takes 2000 degree-days to reach harvesting date. If the temperature throughout the season   was normal then harvest date will be at(2000 + 748)=2748 degree-days. From the graph this date is 19th April.

4. If temperature conditions deviate from the normal, then the harvest date can change as well and this should be adjusted as the season progresses. To do this the actual daily temperatures are used to compute the degree-days accumulated up to the date that the calculation is to be done. From the theory that we have learnt a deficiency or surplus either delays or hastens the harvest from its predicted date. Suppose one plants on the 31st of December, to find the new harvest date resulting from this variation in the planting date. From the actual graph, 1300 degree-days will have accumulated up to this date, 600 of which will have elapsed on planting day. So the plant has acquired 700 degree-days. The plant still needs 1300 degree-days to be ready for harvesting.

5. From 1300 degree-days on the actual cumulative graph on 31st December, draw a line Parallel to the normal accumulation curve continuing to count for a further 1300 degree-days. This should count up to 2600 degree-days with a corresponding maturity date of 13th May. This is the new harvest date.

Note: The example given above assumes that all other growing conditions are not limiting and that temperature is the only variable element. Cooler than normal temperature has delayed the harvest date by 25 days and the reverse would be true for warmer than normal temperatures.

Given growing degree-days for various stages of a plant/crop and the daily temperatures for a place, apart from harvest date one can monitor the following:
  * Appropriate planting dates
  * Rate of plant/crop development
  * Determine the growing period for a location for a particular crop/plant
  * Crop selection for an area and site selection for a crop/plant

For pest management given the physiological times for various stages of pest development and the daily temperatures for a particular area apart from detection of peak infestation periods one can obtain the following information from the degree-day graph shown in Figure 5.0;
  * Determine when to start applying the pest control measures
  * Determine the situational position in the development of generation of pests
  * Determination of whether the outbreak is false or peak
  * When to do extensive scouting and sampling
  * Delineation of pest prone areas

Conclusion
The study and discussions in this paper have illustrated or highlighted areas where degree-days can be used for various purposes. These areas include suitable site or areas for a crop or the selection of a suitable crop for a particular area, strategic agricultural planning like designing of crop callenders, pest and livestock management.

The map for the mean annual(cumulative) degree-days shows that the low lying and hot areas can support maize production all year round where as areas like the high-veld only offer the right

growth conditions in summer. The eastern highlands are the least suitable for maize growth and development. In fact the degree-days in this area are ideal for temperate crops like tea, apples etc which require small amounts of degree-days.

Recommendation
The study is suggesting a simple method that can be used for strategic planning which only requires, temperature data, agroclimatic data like phenological stage and corresponding degree-days. Where the method is used for pest management, information such as the number of degree-days required for various stages in development dynamics of the pest is required.

The study therefore recommends that there be the following;
- adequate research on heat requirements in terms of degree-days of local pests and crop cultivars. This information should include degree-days required for each phenological stage of a particular crop up to maturity. Where the method is used for pest management, warming or chilling units expressed as degree-days for problem pests should be researched on. This information is essential in the management of the pest populations and scheduling of pesticide application.
- an efficient network for the dissemination of this agrometeorological data to grassroots users.
- a good network of agrometeorological stations in the country to provide a good coverage of agrometeorological data.
- research stations where all other growth factors are not limiting apart from temperature.

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