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General Article ______________________________ *Chapter –14*

HEAT UNIT REQUIREMENT FOR MATURATION OF DIFFERENT CROPS

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Abstract

The heat unit concept was developed to study plant temperature relationships and to provide a method for more precisely measuring the intervals between growth stages (i.e. emergence to maturity).Plants, insects and other organisms lack the ability to maintain constant internal temperatures. As a result, their rates of growth and development are closely related to temperature changes in their respective environments.GDD/HU are a measure of heat accumulation used to predict the growth stages including the date when a flower will bloom or a crop will reach to the maturity.Plants grow in a cumulative stepwise manner which is strongly influenced by temperature (except in the extreme conditions like unseasonal drought or disease).Growing degree days take aspects of local weather into account and allow to predict or even to control (in greenhouses) the plants' tendency towards maturity. Many developmental events of plants and insects depend on the accumulation of specific quantities of heat.Accumulation of GD occurs by adding each day's Growing Degrees.

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History and Concept

The idea of Heat Unit was introduced almost 300 years ago, in 1730, by the French scientist Rene A. F. de Reaumur.Since that time, Heat Unit has been used as a means to predict the growth stages of many living organisms.Growing Degree Days (GDD) are also called Growing Degree Units (GDUs) or Heat Units (HU).

The Heat Unit Concept Is Based on The Following Assumptions

(a) Growth or development occurs only when the average daily temperature (AT) exceeds the certain temperature *i.e.* base temperature- below which the organism does not grow or grows very slowly.
(b) Growth and development are closely related to daily temperature mean accumulations above the base temperature.
(c) The number of accumulated heat units between growth stages for a given species is constant across years, locations and climates.
(d) A certain amount of heat is required to provide enough energy for the organism to move to the next development stage, which depends on weather conditions, the amount of time can vary.

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Definition

1. Degree days (DD) are computed from each day's mean temperature(max+min/2). A day's mean temperature is below or above a certain temperature is counted as one degree day*e.g.*the amount of fuel burnt for heating or cooling home up to one unit is a DD for that day.
2. Heating Degree Days (HDD) is determined by subtracting the mean temperature for the day from the certain (Base) temperature.

   If the mean temperature for a day is 50F and the reference temperature is 65F, there would be 15 (65-50) heating degree-days on that day. The lower the average daily temperature requires more heating degree days. On days when the mean temperature is equals to the certain reference temperature, there are no heating degree days. If the mean temperature for a day is 65F and the reference temperature is 65^{o}F, there would be zero (65-65) heating degree-days on that day.

3. **3.** Cooling Degree Days (CDD) is used during hot/ warm weather to estimate the energy needed to cool indoor air to a comfortable temperature.

   For example, a day with a mean temperature of 80F and a reference temperature of 65F would correspond to (80-65), or 15 CDD.Higher values of CDD indicate warm weather and result in high power consumption for cooling.
4. **4.** Growing Degree Days (GDD) or HU are the number of temperature degrees above a certain threshold base temperature within consecutive 24 hrs period. The GDD varies among crop. ORA growing degree day is defined as a mean daily temperature one degree above the certain (base) temperature.So, GDD= Mean DailyTemperature - Certain (Base) Temperature.

Use of Heat Unit (HU) in Agriculture

1. To decide optimum sowing time of crops.
2. To guide various agricultural operations and planning the land use.
3. To assess the suitability of a region for production of a particular crop.
4. To estimate the growth stages of crops, weeds or even life stages of insects.
5. To predict maturity and cutting dates of forage crops.
6. To forecast the maturity date of a crop.
7. To predict best timing of fertilizer or pesticide application.
8. To estimate the level of heat stress on crops.
9. To determine spacing among plants and plan dates to produce harvest on separate dates.
10. To plan the sowing date to fetch good price in the markets and to meet export markets.
11. Useful to escape from the problems of insect and plant pathogens affecting growth and development.
12. To modify the microclimate to produce optimum conditions at the development cycle of an organism.
13. As an index for making crop zonation.
14. It is easy to compute and simple to use for various aspects of agriculture.

Base Temperature (BT)

The base temperature is the temperature required by the plant to produce enough energy to go to the next consecutive development stage, below which plant growth is zero or very slow. The base temperature is fixed for every crop. The base temperature is determined experimentally, based on the life cycle of the plant. HU/GDD only have meaning, if BT and starting date are specified.Though, 10°C (50^{o}F) is the most common base temperature for GDD calculations. The formula for the conversion is^{o}F = ^{o}C x 1.8+ 32.

Table 1. Base Temperature of Some Crops

Base Temp.	Crop and Insects
5.0°C	Wheat, barley
5.5 °C	Potato, rye, oats, sugarbeet, flaxseed, lettuce, asparagus
6 °C	Stalk borer moth
7 °C	Corn rootworm
8 °C	Sunflower, groundnut
9 °C	Alfalfa weevil
10 °C	Maize (including sweet corn), sorghum, rice, soybeans, tomato, Black cutworm, European Corn Borer, standard baseline for insect and mite pests of woody plants
11 °C	Green Clover worm
13 °C	Tobacco
30 °C	The USDA measure heat zones in GDD above 30 °C; for many plants this is significant for seed maturation, *e.g.* reed (Phragmites) requires at least some days reaching this temperature to mature viable seeds

Table 2. GDDs of Different Crops at BT 10°C

Common name	Latin name	Number of GDD at BT 10 °C
Witch-hazel	*Hamamelis*spp.	begins flowering at <1 GDD
Red maple	*Acer rubrum*	begins flowering at 1-27 GDD
Forsythia	*Forsythia* spp.	begin flowering at 1-27 GDD
Sugar maple	*Acer saccharum*	begin flowering at 1-27 GDD
Norway maple	*Acer platanoides*	begins flowering at 30-50 GDD
White ash	*Fraxinusamericana*	begins flowering at 30-50 GDD
Crabapple	*Malus*spp.	begins flowering at 50-80 GDD
Common Broom	*Cytissusscoparius*	begins flowering at 50-80 GDD
Horsechestnut	*Aesculushippocastanum*	begin flowering at 80-110 GDD
Common lilac	*Syringa vulgaris*	begin flowering at 80-110 GDD
Beach plum	*Prunusmaritima*	full bloom at 80-110 GDD
Black locust	*Robiniapseudoacacia*	begins flowering at 140-160 GDD
Catalpa	*Catalpa speciosa*	begins flowering at 250-330 GDD
Privet	*Ligustrum*spp.	begins flowering at 330-400 GDD
Elderberry	*Sambucuscanadensis*	begins flowering at 330-400 GDD
Purple loosestrife	*Lythrumsalicaria*	begins flowering at 400-450 GDD
Sumac	*Rhustyphina*	begins flowering at 450-500 GDD
Butterfly bush	*Buddleia davidii*	begins flowering at 550-650 GDD

Table 3. Base Temperature & Heat Units of Fruit Crops

Sr. No.	Fruits	Cultivar	Base Temperature	HU for maturity
1	Mango	Kesar	17.9 °C	780-796
		Banganpally	18 °C	1426-1445
2	Banana	-	9.8 °C	1930
3	Ber	Gola	7.2 °C	1980-2236
		Kaithali	7.2 °C	2236-2566
		Umran	7.2 °C	2516-2290
4	Litchi	Shai	15 °C	813
5	Citrus	-	13 °C	1600-1900
6	Papaya	-	12 °C	2000
7	Pecan nuts	-	10 °C	2700-3000

Calculation of Heat Unit

Daily temperature readings can be used to calculate GDDs, which is a measure of accumulated heat.The formulation of GDD calculations is developed from a general base of knowledge inherent to the environment. GDDs are calculated by measuring accumulated heat within 24 hrs.

A. Average method:

GDD are calculated by taking the average of the daily maximum and minimum temperatures compared to a base temperature, T_{base} (usually 10 °C).The formula for the calculation is $(T_{max}+T_{min})/2- T_{base.}$

Example: 1. A day with a high temperature of 23°C and a low temperature of 12°C (and a base temperature of 10°C) would contribute 7.5 GDDs. So, (23+12)/2-10= 7.5.

Example: 2. A day with a high temperature of 13°C and a low temperature of 10°C (and a base temperature of 10°C) would contribute 1.5 GDDs. So, (13+10)/2-10= 1.5.

B. Modified average method:

This method is used to calculate GDD when temperature falls below T_{base}/ lower threshold. The temperature is set to T_{base}or in general 50°F for the calculations of GDD, because plants can not grow negative.When temperature stands more than upper threshold the temperature is set to upper threshold before calculating the average,because usually above 86°F temperature most plants and insects do not grow any faster above that temperature.However, in warm temperate and tropical plants upper threshold is not considered because those plants do have significant requirements for temperature above 86°F to mature fruit or seeds.

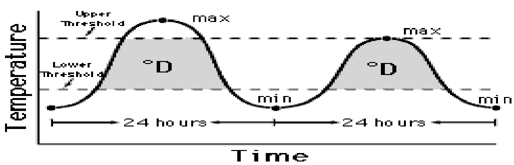

Figure: 1 Threshold and Degree Days

Here are some examples for the calculation of heat units as per modified method.

T_{min} °F	T_{max} °F	Formula	GDD	Notes
77	85	[(77+85)/2]-50 =81-50	31	
48	63	[(50+63)/2]-50 =56.5-50	6.5	48 is less than 50 so 50 used as T_{min}
38	49	[(50+50)/2] -50 =50-50	0	BothT_{max} and T_{min} are less than 50.
78	98	[(78+86)/2] -50 = 82-50	32	98 s greater than 86 so 86 used as T_{max}

The formula is [(T_{min}+T_{max})/2 – 50 °F] because plant growth cannot be negative, the lowest temperature used in the formula is 50°F. There is some evidence that corn growth shows at temperature above 86 °F, so it is considered as the highest.

Accumulated Degree Days:

Number of degree days of each calendar day accumulated during a specified time interval.*e.g.* since the beginning of the flower blooming to maturity. Below depicted table showing the accumulations of degree days.

Calendar Day	Base Temp.	Maximum (°F)	Minimum (°F)
1	40	57	40
2	40	64	40
3	40	70	44

Here, $GDD_{day\ 1}$ = (57 + 40)/2 - 40 = 8.5; $GDD_{day\ 2}$ = (64 + 40)/2 - 40 = 12; $GDD_{day\ 3}$ = (70 + 44)/2 - 40 = 17. So $GDD_{accumulated}$ = 8.5 + 12 + 17 = 37.5. Each growing stage of plant requires accumulation of certain DD to move to the next phase of growth.

Table 4. Growing Degree Day Requirements for Different Stages of A 2700 GDD Corn Hybrid.

Phase	Development Stage	GDD
Vegetative	Planting (Cut off date)	
	Two leaves fully emerged	200
	Four leaves fully emerged	345
	Six leaves fully emerged (growing point above soil)	476
	Eight leaves fully emerged (tassel beginning to develop)	610
	Ten leaves fully emerged	740
	Twelve leaves fully emerged (ear formation)	870
	Fourteen leaves fully emerged (silks developing on ear)	1000
	Sixteen leaves fully emerged (tip of tassel emerging)	1135

Reproductive	Silks emerging/pollen shedding (plant at full height)	1400
	Kernels in blister stage	1660
	Kernels in dough stage	1925
	Kernels denting	2190
	Kernels dented	2450
	Physiological maturity	2700

Source: Neild and Newman. Growing season characteristics and requirements in the Corn Belt. National Corn Handbook.

Table 5. Requirements of Accumulated GDD for Different Crops

Crop	Latin name	Requirements of Accumulated GDD
Dry beans	*Phaseolus vulgaris*	1100-1300 GDD to maturity depending on cultivar and soil conditions
Sugar Beet	*Beta vulgaris*	130 GDD to emergence and 1400-1500 GDD to maturity
Barley	*Hordeumvulgare*	125-162 GDD to emergence and 1290-1540 GDD to maturity
Wheat	*Triticumaestivum*	143-178 GDD to emergence and 1550-1680 GDD to maturity
Oats	*Avena sativa*	1500-1750 GDD to maturity

Relevance

The history of agriculture involves a continuous series of adaptations to a wide range of factors. Environmental conditions related to soil, water, terrain, and climate impose constraints and provide opportunities for agricultural production.Extreme weather events have taken a substantial toll on human livelihoods and lives around the globe, and have often detrimentally affected food production and security.Questions arise about the capacity of agri-food systems to handle changed climate and weather in the future.Climate change is already having an effect on farming, thereby increasing the need for research and programs to assist adaptive decision making.

The research community seeks to improve the understanding of the implications of climate change for the agri-food sector and to provide a sound basis for making decisions about adaptive strategies.Patterns of temperature, moisture and weather conditions greatly influence plant and animal performance, inputs, management practices, yields, and economic returns. This could be beneficial if it results in production opportunities from an extended growing season and increases in available heat unit.More heat unit and a longer crop season allow for increased flexibility in timing of operations and choice of crops or varieties. In general, recommendations are made on the basis of date/ calendar days. In today's changed climatic conditions follower/ farmers may generally be sufferer due to the sowing of seeds/ planting of crops on the basis of date. By using heat unit concept one can plan their harvest date of crop at the time of sowing/ planting and can be early player or the only player at the end in the market to fetch good prices of their produce. Selection of suitable crops and cultivars is possible for the area.Temperature, humidity and bright sunshine hours are the most important factors affecting plant life after soil, moisture and nutrients.

Related Studies

According to Ma and Subedi (2005), different cultivars of the same crop having variation in the HU requirements to reach to the physiological maturity at the specified location.

It was stated by Bob *et al.*(2002) that specified variety of cotton at San Joaquin Valley required maximum 2350 GDD which is fixed for that variety at that location year after year and information will be useful to perform agricultural operations.

Information for synchronized maturity of different varieties. Work back from a desired harvest date to use the data to determine the likely period available for fruit production.One can estimate how long it will take to accumulate degree days to open that last harvest.One can assume date of harvest by using data 850 GDD (Acala), 940 GDD (Pima) and 817 GDD required for the late season flower to mature, Bob *et al.* (2002).

David *et al.* (2007) revealed that GD Hours are more precise to use than GDD, which is specific for different varieties for a particular location.

Sandra hardy and Khurshid (2007) calculated the heat unit according to modified method of GDD calculation for citrus crop in Australia. They revealed that the heat unit accumulation for the summer and winter season is different. Though in winter season the heat unit comes to negative value but the accumulation has been taken as zero, because plant grow negative.

Milatovic*et al.* (2010) noticed that date of full bloom and date of maturity is different for every variety in Apricot. Cultivar Senetate (82 days from Full Bloom and 1056 GDD) can be planted for early crop and for late crop cultivar Kecskemet Rose (112 days from Full Bloom and 1648 GDD) is useful. The noticeable difference of 20 days and 592 GDDs between two varieties was observed. Long term experimental data gives more accuracy.

Bob *et al.*(2002)given an example, if you select October 31 as a target harvest date, the last fruiting site should try to mature out(requiring about 850 degree-days for late-season Acala boll) would be expected to flower on about Aug. 16(using right-hand column 90+122+175+227+262 = 876 degree days).

"Date of sowing influence the accumulation of GDD, Grain yield, Straw yield and days to maturity" according to Prabhakar*et al.* (2007). They also revealed that avoid late sowing or select the variety requiring less GDD.

Shinde*et al.* (2001) selected two different locations and revealed that atVengurla, extra HU are received by all three varieties so earlier maturity observed. They also revealed that for early maturity of fruits Alphonso (103.33 days) variety of mango is suitable at Vengurla, Maharashtra and for more average fruit weight Ratna (316.66 g/fruit) variety of mango is suitable at Vengurla, Maharashtra.

Debnath and Mitra (2006) conducted an experiment and found that packaging materials effects at micro climates. Due varied accumulation of heat unit it effects on the maturity days.

Physical or Physiological Changes in Plant Development Affected By Temperature/ Number of Heat Units

More number of degree days increases the saturation deficit of plant. It accelerates photosynthesis and ripening of fruits.The maximum production of dry matter occurs when the temperature ranges between 20 to 30 ^{o}C (more heat unit). High night temperature (more GDD) increases respiration. It favours the growth of the shoot and leaves.It governs the distribution of photosynthates among the different organs of the plants, favouring those which are generally not useful. High night temperature (More GDD) also benefited the metabolism.Day temperature seldom produces any difference in responses in flower initiation, size of leaves or rate of leaf production. Night temperature, on other hand, has in general a pronounced effect on the state of leaf production as well as upon the leaf size.Low temperature can modify soybean reproductive potential by influencing flower and pod abscission.High night temperature increases leaf growth, inflorescence than low night temperature.

Limitations of Degree-Days

1. Except for the modified equations, a lot of weightage is given to high temperature, although temperature above 27 ^{o}C may have detrimental effects.
2. No difference can be made among the different combination of a warm spring and a cool summer.
3. The daily range of temperature is not taken in to consideration and this point is often more significant than the mean daily temperature.
4. No allowance is made for the threshold temperature changes with the advancing stage of crop development.
5. Net responses of plant growth and development are to the temperature of the plant parts themselves and they may be quite different from temperatures measured in a Stevenson's screen. Though this difference at a particular time may be small but the cumulative effects though an entire growing period can be very large.
6. The effects of topography, altitude and latitude on crop growth cannot be accounted for.
7. Plant, leaf or canopy temperature is more important for the plant growth and development rather than the screen temperature measured in the observatory.
8. Wind, hail, insect and diseases may influence the heat unit, but these cannot be accounted for in this concept.
9. Soil fertility may effect the crop maturity. This cannot be explained here.
10. A single threshold temperature is used throughout the crop season.
11. Insect response to temperature is not linear.
12. Lower temperature threshold known for very few species.
13. Measured temperatures not the same as those experienced by the pest.
14. Degree-days are cumbersome to track.

In spite of these limitations, the degree day or heat unit concept, with a slight modification, seems to answer a number of questions in forecasting crop growth and maturity.

Future Prospects

1. The heat unit concept has found application in numerous cropping systems and related industries. The system has been used by producers, processors, merchants and scientists in practical farm applications, for scheduling work forces and the flow of raw materials, in projecting commodity market fluctuations and in conducting research studies.
2. It can be used to assess the suitability of a region for production of a crop.
3. It can be used to estimate the growth stages of crops, weeds or stages of insects.
4. It can be used to predict maturity and cutting dates of forage crops.
5. It can be used to predict best timing of fertilizer or pesticide application.
6. It may be helpful for precision farming of different fruit crops.
7. Crop map can also be generating for the country to predictsuitability of the crops in the region.
8. Effect of uncertainty of climatic conditions due to climate change may be minimized by precise planning by the use of HU.

Conclusion

1. GDD provides information to growers with a more scientific way of understanding how the daily warmth provided by the sun and plant growth is related.
2. Growers can use the number of heat units required for a given crop and variety to reach maturity and to estimate when to be ready for harvest.
3. One can easily predict the performance of the particular crop based on the studies of the Growing degree days/ heat requirement of the crop.
4. In this changing environment conditions planning, selection and policy decisions can be made.

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