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An arithmetic method to determine the most suitable planting dates for vegetables

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ABSTRACT

Optimum crop yield is greatly affected by proper planting and sowing times. The objective of this research was to develop an algorithm that uses the heat unit concept to determine the most suitable planting times for vegetable crops. The developed algorithm was programmed in a database environment with sample climatic data for the Kingdom of Saudi Arabia. The model was tested by validation (comparison to experts' estimations), verification (statistical comparison to formal published data), and evaluation (by professionals, landowners, and farmers). The overall results of the model were highly acceptable. The model needs more verification and validation in different environments and with various crops.

1. Introduction

Food security and water scarcity urge researchers to maximize crop yields with minimum possible water consumption. Maximizing crop yields involves several practices, including the selection of a proper planting time that matches the crop species and the region's environment throughout the entire growing season. Temperature plays a central role in a plant's life cycle, affecting its growth, development, and yield (Adam et al., 1994). Since it was developed, the heat unit concept has been widely used to determine the length of the growing season for vegetables and field crops (McMaster and Wilhelm, 1997; Chen, 1973). Most of the research on field crops has been for Maize (e.g. Gesch and Archer, 2005; Nielsen et al., 2002), Wheat (e.g. Haider et al., 2003; Pal and Murty, 2010), and Sunflower (e.g. Qadir et al., 2007; Kaleem et al., 2011). Studies for vegetables include: Potatoes (Yuan and Bland, 2005; Alsadon, 2002), Tomatoes (Perry et al., 1997), Cucumber (Perry and Wehner, 1990, 1996; Perry et al., 1986), and others (Bossie et al., 2009; Petkeviciene, 2009; Filho et al., 1993).

The concept of heat units (HUs) is expressed in growing degree-days (GDDs), which is calculated (Chen, 1973; Pal and Murty, 2010) as:

$$\mathrm{HU} = \sum_{i=1}^{cSL} \mathrm{GDD}_i \tag{1}$$

$$\mathrm{GDD} = \left(\frac{T_x + T_n}{2}\right) - cT_b \tag{2}$$

where T_x and T_n are the maximum and minimum daily temperatures respectively, cT_b is the crop base temperature, i indicates the growing day in the crop's season, and cSL is the season length in days.

Several investigations had been performed to enhance the biological meaning of GDD (McMaster and Wilhelm, 1997), helping to avoid the errors that occur if the GDD formula returns a negative number. The most spread method considers the following correction:

$$\mathrm{GDD} = \mathrm{MAX}\ \{0\ ,\ (T_x + T_n)/2 - cT_b\} \tag{3}$$

where the 'MAX' function returns the maximum value of either zero or the value returned from Eq. (2) which ensures no negative value from the equation. The other method takes a deeper look at the formula and considers the following:

$$\mathrm{GDD} = \mathrm{MAX}\begin{bmatrix} & (cT_b + T_n)/2 - cT_b & T_x < cT_b \\ 0, & (cT_b + T_x)/2 - cT_b & T_n < cT_b \\ & (T_x + T_n)/2 - cT_b & T_n \geqslant cT_b \end{bmatrix} \tag{4}$$

Although the two correction methods seem similar, in some cases the difference between them may reach 83% (McMaster and Wilhelm, 1997). Several comparisons and reviews of GDD

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calculation methods were achieved for some vegetable crops (Perry et al., 1986, 1997; Perry and Wehner, 1996, 1990), indicating that the optimum method varies according to crop and regional climate.

Overall, the concept of heat units has succeeded in predicting a reliable approximate harvest time (Haider et al., 2003; Salassi et al., 2002; Black et al., 2008; Chen, 1973; Alsadon, 2002). Most vegetable crop species have a well-known approximate life duration (LD) from sowing to harvest. Hence, working backwards the sowing/planting date (SPD) can also be determined using the HU concept. The degree of confidence of the predicted SPD depends on the validity of the estimated/known LD of the crop.

The aim of this work is to develop a combined algorithm that uses the HU concept to predict a satisfactory estimation of the SPD for vegetable crops.

2. Materials and methods

2.1. The arithmetic model development

A computer model was developed to benefit from the historical weather data in prediction of suitable or optimal sowing/planting dates. The algorithm is simplified in the following steps:

1. For each crop/crop species, we have the following thermal characteristics:
   - Base temperature cT_b.
   - Optimum growing temperature cT_{opt}.
   - Maximum tolerable temperature cT_x.
   - Minimum tolerable temperature cT_n.
   - Optimum seasonal heat units HU_{opt}, calculated by the following formula:

$$HU_{opt} = (cT_{opt} - cT_b) \times cSL_h, \quad (5)$$

where cSL_h is the season's length for the crop obtained from historical data (days).

   - Maximum tolerable heat units HU_x, calculated as:

$$HU_x = (1 + H_{tol}/100)HU_{opt}, \quad (6)$$

where H_{tol} is the percent heat tolerance above optimal [%].

2. For each region, there are some basic climatic loggings for each Julian day j:
   - Maximum daily dry bulb temperature T_x.
   - Minimum daily dry bulb temperature T_n.
   - Average daily dry bulb temperature T_a.
3. For any day within the cSL_h duration, if $T_x > cT_x$ then the crop has a heat shock, and the 'heat' flag parameter (F_h) should be increased by 1.
4. For any day within the cSL duration, if $T_n < cT_n$ then the crop has a cold shock, and the 'cold' flag parameter (F_c) should be increased by 1.
5. For the known cSL_h duration, starting from the suggested SPD in Julian format (j), HU_{SL} is calculated as:

Table 1
Thermal parameters of vegetable crops.

Common name	Binomial/trinomial name	cT_x (°C)	cT_n (°C)	cT_b (°C)	cT_{opt} (°C)	cSL_h (days)	H_{tol} (%)
Bell pepper	*Capsicum annum L.*	35	15	10	24	100	30
Cabbage	*Brassica oleracea var. capitata L.*	30	10	4	20	105	30
Carrot	*Daucus carota L.*	28	6	4	19	120	30
Cauliflower	*Brassica oleracea var. botrytis L.*	30	10	4	21	90	30
Celery	*Apium graveolens var. dulce (Mill.)*	24	10	4	17	105	30
Chard	*Beta vulgaris var. cicla L.*	35	4	4	19	60	30
Chicory	*Cichorium intybus L.*	27	5	4	18	90	50
Common beans	*Phaseolus vulgaris L.*	35	15	10	25	90	30
Cowpea	*Vigna unguiculata L. Walp.*	35	10	10	24	90	30
Cucumber	*Cucumis sativus L.*	35	16	10	25	105	30
Eggplant	*Solanum melongena L.*	35	15	10	24	105	30
Faba bean	*Vicia faba L.*	30	10	4	18	130	30
Garlic	*Allium sativum L.*	30	8	4	18	210	30
Leek	*Allium ampeloprasum* var. *porrum* L.	33	10	5	23	180	30
Lettuce	*Lactuca sativa L.*	27	5	4	16	100	50
Melon	*Cucumis melo L.*	38	15	10	26	100	30
Mulukhiyah	*Corchorus olitorius L.*	35	15	10	27	60	25
Muskmelon	*Cucumis melo var. Reticulatus L.*	35	15	10	26	100	30
Okra	*Abelmoschus esculentus L. Moench.*	35	15	10	30	75	20
Onion	*Allium cepa L.*	35	2	2	20	150	20
Parsley	*Petroselinum crispum (Mill.)*	27	10	4	17	90	50
Peas	*Pisum sativum L.*	29	4	4	16	105	30
Potato or Irish potato	*Solanum tuberosum L.*	27	7	6	16	100	70
Pumpkin	*Cucurbita maxima Duch.*	38	15	10	25	120	30
Purslane	*Portulaca oleracea L.*	30	10	10	21	60	30
Radish	*Raphanus sativus L.*	30	10	4	18	60	30
Rocket (salad)	*Eruca sativa (Mill.)*	38	5	4	14	45	30
Snake cucumber	*Cucumis melo var. flaxuosus L.*	40	15	10	30	100	20
Soya bean	*Glycine max L. Merr.*	35	15	10	25	85	35
Spinach	*Spinacia oleracea L.*	25	4	4	18	60	30
Sweet corn	*Zea mays saccharata L.*	40	10	10	26	105	30
Sweet potato	*Ipomoea batatas L. Lam*	32	15	12	25	150	30
Table beet	*Beta vulgaris var. Crassa L.*	35	10	4	18	90	30
Tomato	*Solanum lycopersicum L.*	35	14	10	24	100	30
Turnip	*Brassica rapa* var. *rapa L.*	35	10	4	18	75	30
Watermelon	*Citrullus lanatus (Thunb.)*	37	15	10	30	105	20
Wild leek	*Allium ampeloprasum L.*	30	10	5	20	180	30
Yam	*Discorea alata L.*	35	20	15	28	120	30
Zucchini	*Cucurbita pepo L.*	38	15	10	25	75	35