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Modeling the Time Elapsing from Seed Sowing to Emergence in Some Vegetable Crops

Sezgin Uzun¹, Dilek Marangoz¹ and Fikret Özkaraman²

¹Ondokuz Mayıs University, Faculty of Agriculture, Department of Horticulture, Turkey

²Ondokuz Mayıs University, The High School of Profession of Samsun, Turkey

Abstract: A simple regression model based on mean temperature was developed to be used for predicting the time elapsing from seed sowing to seedling emergence for some vegetable crops, namely tomato (*Lycopersicon esculentum*, Mill.), pepper (*Capsicum annum*, L.), aubergine (*Solanum melongena*, L.), pea (*Pisum sativum*, L.), carrot (*Daucus carota*, L.), sweet corn (*Zea mays*), cabbage (*Brassica oleracea* L. var. *capitata* (L.) Alef), cauliflower *Brassica oleracea* L. var. *botrytis* (L.), onion (*Allium cepa*, L.), celery (*Apium graveolens*, L.), lettuce (*Lactuca sativa*, L.), parsley (*Petroselinum hortense*), garden beet (*Beta vulgaris*, L.), cucumber (*Cucumis sativus*, L.), melon (*Cucumis melo*, L.), runner bean (*Phaseolus vulgaris*, L.), watermelon (*Citrullus lanatus*, Thunb.), okra (*Hibiscus esculentus*, L.), asparagus (*Asparagus officinalis*, L.), spinach (*Spinacia oleracea*, L.), radish (*Rhaphanus sativus*, L.) and turnip (*Brassica rapa*, L.). The prediction performance of the model with respect to the data used was highly acceptable. R² values of regression coefficients for each crop varied from 0.94 to 0.99 depending on the species. Plotting the actual days from seed sowing to emergence for all the crops against the predicted ones showed that the prediction performance of the model was good explaining 98% of the variation for combined data from all the crops. The present model also predicted optimum temperatures (To) for tried vegetables in the limits of acceptability.

Key words: Regression Model, time to emergence, temperature, vegetable crops

Introduction

In recent years, there is an increasing interest for quantitative studies of plant phenology. A great number of study on this subject have concentrated on the determination of different plant developmental phases describing plant development (Ellis *et al.*, 1990). Plant development includes the period from seed sowing to preceding to reproductive stage and from this stage to maturity. The time elapsing from seed sowing to seedling emergence can be given as a parameter to the development in plants (Ellis *et al.*, 1990). To date, many studies have been carried out on the relations between temperature and plant development. In practice, the concept of thermal time that has a close relation with temperature has been used for determination of suitable seed sowing time for many crops (Pearson *et al.*, 1994).

The rate of change in the developmental state of a plant often appears to be sensitive to temperature (Charles-Edwards, *et al.*, 1986). The speed of development is measured by the duration of a given phase of development and developmental processes are often arithmetic function of thermal time (Ellis *et al.*, 1990). As a direct consequence of observations of the apparent temperature dependence of many aspects of plant development, a considerable point of attention focused on the phase development of plants has been given to developing mathematical models based upon the overall effects of changing ambient temperature and light on the rate of plant development (Pearson, 1992; Pearson *et al.*, 1993 and 1994; Hadley *et al.*, 1994; DeKoning, 1995 and Uzun, 1996).

In order to germinate successfully, seeds must have moisture, air and a suitable temperature. In practice, the germination of seeds covers the entire process, from subjecting a resting seed to suitable conditions to cause it to develop to the stage at which the seedling produces true leaves and establishes as a young plant (Kenneth, 1992).

All growth processes within the seed are chemical reactions activated by the addition of water, subjecting to a moderate temperature and oxygen presence. The higher the temperature raised the faster will be the rate of chemical reactions. But there are biological limitations as to how the temperature can be raised. The upper limit of rising temperature varies with plant species (Bayraktar, 1976; Sevgican, 1989; Ellis *et al.*, 1990; Beckett, 1992; Günay, 1992; Kevseroglu and Çalkan, 1995).

The majority of greenhouse plants germinate at 15-18°C. Some of the plants raised under glass for setting outside germinate at lower temperatures, around 10°C or less, while many tropical plants need 24-26°C. Although some vegetable seeds germinate above a temperature threshold of 0 °C, some of the others can only begin to germinate at temperatures above 8 to 10 °C. For summer vegetable crops, germination temperatures are between 8 and 40 °C. Germination of some cultivars of celery (particularly at temperatures above 15 °C) tomato and lettuce (particularly when freshly harvested) is reduced in the dark. Light is unable to penetrate more than about 5mm into the soil and the performance of light-sensitive cultivars of celery is markedly reduced when they are direct seeded. But light requirement can be overcome by soaking seeds in a mixture of gibberellins (GA4/7) before sowing (Thomas *et al.*, 1972).

To date, some models have been developed by many workers to predict the time from planting to anthesis and the time from anthesis to fruit maturity (Pearson, 1992; Pearson *et al.*, 1993 and 1994; DeKoning, 1995; Uzun, 1996). These types of models help the grower in making decision. The previous studies on the effect of temperature on emergence have concentrated on producing models for field crops such as Sethi *et al.* (1985) and Sethi and Aggarwal (1986) in wheat; Cutforth *et al.* (1987) in corn; Benesh Arnold *et al.* (1989) and Brar *et al.* (1992) in Sorghum halepense L.; Charles *et al.* (1991) in tall fescue (*Festuca arundinacea* Schreb) and white clover (*Trifolium repens* L.); Cousens *et al.* (1992) in wild oats (*Avena fatua*), winter barley (*Hordeum sativum*) and winter wheat (*Triticum aestivum*); Forcella (1993) in velvetleaf; Weaich *et al.* (1996) in maize; Prostko *et al.* (1998) in johnsongrass (*Sorghum halepense*). A few emergence predicting models in vegetable crops such as Bierhuizen and Wagenvoort (1974) in onion and leek; Finch and Phelps (1993) in onion (*Allium cepa* L.); Finch *et al.* (1998) in carrot (*Daucus carota* L.).

Materials and Methods

Plant cultivation: This study was carried out in a glasshouse in Agricultural Faculty of Ondokuz Mayıs University in Turkey during 1997 and 1998. The seeds of cultivars from different species (lettuce (cv. Arapsacı), parsley (cv. İri yapraklı), radish

(cv. Kestane), tomato (cv. B5X052), cauliflower (cv. Snowball), aubergine (cv. Bonica), pepper (cv. Yalova 15) and melon (cv. Titan F1) were sown in wooden seed trays filled with 50 % sand and 50 % perlite as germination media. Seeds were sown in a depth equal to three-fold of seed diameter for the cultivars of each species. Seed sowing was made in lines prepared 10 cm apart in each tray. An average of 100 and 50 seeds were sown in each seed tray for small and large-seeded species, respectively. Experiment was designed according to randomized block design with three replications. Care was taken in watering seed trays so that equal water was given to the trays at each time. The time elapsing from seed sowing to seedling emergence was calculated by counting the seedlings emerging over the sowing medium and reaching to an amount of 50 % of the sown seed number (Bayraktar, 1976). The same study was repeated five times over the year to obtain required temperature variations.

Temperature measurements: The temperature of seed sowing media in a depth of sowing level was measured at a seven-hour intervals namely, at seven o'clock in the morning, at two o'clock in the afternoon and at nine o'clock in the evening to obtain daily mean temperature. In addition to the data obtained from the present study, the data from Bayraktar (1976) and Fordham and Biggs (1985) were also used in producing the present model.

Modelling procedure: The data from the present study and above mentioned previous studies were combined to carry out multiple regression analysis in order to produce the model predicting the time elapsing from seed sowing to seedling emergence based on temperature changes, $D = a - b \cdot T + c \cdot T^2$. Here, D represents the time elapsing from seed sowing to seedling emergence, T represents daily mean temperature and a, b and c are co-efficients of the parameters. All data were analyzed by using the EXCEL 5.0 computer program. Co-efficients a, b and c were calculated separately for every crop. Temperature variations obtained from the present study over the year ranged from 4 to 40 °C.

Results

Model production: In the present study, the data obtained were analysed as explained in the section of Material and Methods in order to obtain a regression model. The model is of the form;

$$D = a - b \cdot T + c \cdot T^2$$

Hence rate of change in duration of emergence with temperature is

$$dD / dT = -b + 2 \cdot c \cdot T$$

The optimal temperature T_o for emergence is then given when the rate of change is zero. Therefore;

$$T_o = b / 2 \cdot c$$

Multi regression analysis were performed until the lowest sum of squares of the mean was obtained. The prediction performance of the model with respect to the data used was highly acceptable such that r^2 values of regression co-efficients for each crop varied from 0.94 to 0.99 depending on the species (Table 1).

Regression models are reported to be attractive management tools for production agriculture because they are relatively easy to develop and, if carefully defined under the prevailing environmental conditions, they can accurately forecast long term crop responses (Krug, 1985). Warnock and Isaacs (1969) suggested a linear heat-unit system using a 6 °C base temperature to control the development of processing tomato crops in California. However, using processing tomatoes in Portugal, Stillwell and Portas (1978) found no predictable relationships between temperature and either emergence rate or the period from emergence to flowering.

On the other hand, Pearson *et al.* (1994) suggested a model

predicting thermal time from planting to curd initiation and from curd initiation to maturity in cauliflower. Hence, there is an inclination for the application of regression models for planning and this may be expected to spread all over the world in the near future.

Model validation: When the predicted days from seed sowing to emergence were plotted against the actual days for all the crops examined in the present study it was seen that there was a very close relationship between these parameters with a r^2 value of 0.98 (Figure 1). Relative error analysis which can be calculated through dividing the difference between predicted and actual days from seed sowing to seedling emergence by predicted days varied between 0.0008 (for sweet corn) and 0.26 (for turnip). However, in general, the model underestimated the days from seed sowing to emergence. It was also found that the model overestimated the days from seed sowing to seedling emergence for aubergine, sweet corn, cabbage, cauliflower, lettuce, parsley and okra while there was an underestimation of the actual days to emergence for the other species.

The time elapsing from seed sowing to emergence predicted by the present model for all the crops examined was found to be in accordance with those reported by many workers. Such as the tomato seeds were reported to germinate at a range of temperature of 10-35°C (Sevgican, 1989). Seniz (1992) reported that tomato seeds need an average of 10°C to emerge in 42.7 days after sowing and 30 and 35°C to emerge in 6.1 and 10.1 days after seed sowing, respectively. At optimum temperature range (20-25°C), tomato seeds were also reported to germinate in 8 to 10 days after seed sowing. These findings are also in accordance with the result of the present study. The results from the studies by Sam *et al.* (1994) in water melon, Sevgican, (1989) in cucumber, pepper and aubergine,

Cavero *et al.* (1996) in tomato and pepper, Seniz (1992) in tomato, aubergine and pepper who reported that aubergine seedlings emerged in 10 to 15 days at a temperature range of 25 to 30 °C. On the other hand, the days predicted by the model from the present study were also found to be in accordance with the results of Forkes and Watson (1992). Minimum and optimum temperatures for sweet corn seeds to germinate were found to be 8 to 10 °C and 32 to 35 °C, respectively. Sweet corn seeds could germinate in 11.25 days at 16 °C, in 3.25 and 30 days at 19 and 12 °C, respectively. On the other hand, Kevseroglu (1997) reported that minimum temperature range for sweet corn seeds were 9 to 10 °C and optimum temperature for the same event was above 18 °C. Moreover, it was revealed that sweet corn seedlings could emerge in three weeks at 10 to 13 °C and in one week at 20 °C. Lettuce types vary in response to high temperature with smooth heat types failing to germinate above 25 °C while crisp-head types still germinate well at 30 °C (Fordham and Biggs, 1985). High temperatures cause some vegetable seeds to get into dormancy called 'thermo-dormancy'. For example; crisp head lettuce seeds can not germinate at temperatures above 25 °C. Seeds of a few vegetable crops are unable to germinate without presence of light. On the contrary, onion seeds show the same response to the presence of light (Günay, 1992). Celery, onions and leeks will germinate very well over a very narrow range while brassicas, peas and broad beans are very adaptable. Cucumbers, peppers French and summer beans, sweet corns and tomatoes do not like low temperature and crop failures often result from sowings made in cold seasons, especially if the conditions are also wet (Fordham and Biggs, 1985).

When the predicted optimum temperatures for emergence in the vegetables tried in the present study were compared with those indicated in literature (Table 1), it was seen that in general, there was a highly acceptable closeness between

Table 1: The co-efficients a, b and c for the model ($D = a - b \cdot T + c \cdot T^2$), their standard errors (S.E) and optimum temperatures calculated by the model ($T_o = b/2c$) and those indicated in literature according to the plant species used in this study

Plant Species	Co-efficients			r2	Predicted optimum	Optimum Temperature
	A	B	C		Temperature ($T_o = b/2c$) (° C)	Indicated in literature (° C)
Tomato	62.42	3.97	0.068	0.94***	29,2	29
S.E	(3.99)***	(0.43)***	(0.010)***			
Pepper	77.27	4.70	0.078	0.98***	30,1	29
S.E	(3.42)***	(0.28)***	(0.005)***			
Aubergine	62.02	3.54	0.057	0.94***	31,0	29
S.E	(3.89)***	(0.31)***	(0.006)***			
Pea	55.28	4.45	0.094	0.98***	23,6	24
S.E	(1.49)***	(0.19)***	(0.051)***			
Carrot	71.04	5.01	0.093	0.98***	26,9	27
S.E	(2.45)***	(0.27)***	(0.006)***			
Sweet Corn	44.89	2.82	0.047	0.99***	30,0	29
S.E	(2.91)***	(0.28)***	(0.006)***			
Cabbage	29.69	1.83	0.032	0.99***	28,6	29
S.E	(1.31)***	(0.14)***	(0.003)***			
Cauliflower	42.76	2.97	0.057	0.98***	26,0	27
S.E	(2.56)***	(0.27)***	(0.007)***			
Onion	80.63	6.12	0.120	0.94**	25,5	27
S.E	(10.88)***	(1.06)**	(0.023)**			
Celery	70.50	7.12	0.201	0.96***	17,7	21
S.E	(6.12)***	(1.11)***	(0.044)***			
Lettuce	46.63	4.07	0.089	0.98***	22,8	24
S.E	(1.31)***	(0.19)***	(0.006)***			
Parsley	55.81	3.38	0.065	0.98***	26,0	27
S.E	(2.89)***	(0.31)***	(0.007)***			
Garden Beet	58.68	4.09	0.074	0.97***	27,6	29
S.E	(2.41)***	(0.28)***	(0.006)***			
Cucumber	31.65	1.63	0.023	0.98***	35,4	35
S.E	(2.79)***	(0.23)***	(0.004)***			
Melon	37.92	2.26	0.038	0.94***	29,7	35
S.E	(6.91)***	(0.54)***	(0.010)**			
Runner Bean	40.76	2.12	0.032	0.99***	33,1	30
S.E	(1.84)***	(0.15)***	(0.003)***			
Watermelon	68.87	4.23	0.067	0.97***	31,6	35
S.E	(7.04)***	(0.55)***	(0.010)***			
Okra	68.36	3.50	0.049	0.99***	35,7	35
S.E	(2.09)***	(0.16)***	(0.002)***			
Asparagus	92.71	6.15	0.112	0.98***	27,4	24
S.E	(2.97)***	(0.26)***	(0.005)***			
Spinach	49.01	3.98	0.086	0.97***	23,1	21
S.E	(2.31)***	(0.30)***	(0.008)***			
Radish	42.20	3.30	0.068	0.98***	24,3	29
S.E	(2.11)***	(0.26)***	(0.007)***			
Turnip	10.51	0.66	0.011	0.99***	30,0	29
S.E	(0.34)***	(0.03)***	(0.0006)***			

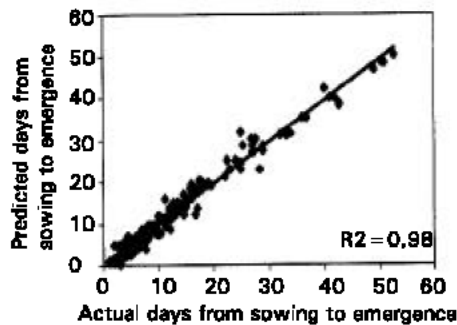


Fig.1: Relationship between actual days from sowing to emergence and days to emergence simulated by the present model ($D = a - b \cdot T + c \cdot T^2$; D: Time to Emergence (day), T: Temperature (°C)). The solid line is the line of identity. Data were gathered from all the crops used.

them. However the model markedly underestimated the optimum emergence temperature for celery (17.7-21 °C), watermelon (31,6-35 °C), melon (29,7-35 °C) and radish (24,3-29 °C) while there was a marked overestimation for asparagus (27,4-24 °C) and runner bean (33,1-30 °C) (Table 1).

Discussion

In recent years, vegetable market outlets increasingly demand programmed crop production to meet specific demands. This is obviously very important for processing crops but supermarket chains and other fresh market outlets are also requiring vegetables to be grown to schedules. Crop models have a wide range of potential application in greenhouse culture for research, planning, climate control, design, and support. The model will also enable the people running commercial seedling factories to plan their annual activities such as these factories will need this kind of models for planing and design their schedules. Scheduling crop development has been more successful with seeding and fruiting vegetables. For example, a base temperature of 4.5 °C was used for pea and successive sowings were made after intervals of the appropriate number of day- degrees. Crop development is slow during periods of low temperature but so

is day degree accumulation and the intervals between sowings are longer than at high temperature (Salter, 1972). Consequently, we can suggest that crop models have many current and potential uses for answering questions in research, crop management, and policy. They can assist in pre-season and in-season management decisions on cultural practices. Models only recently are seeing use as grower decision support tools. Despite considerable potential, producers and their consultants have made little use of crop models for pre-season or in-season strategic decisions. Specially, careful planning is required to harmoniously arrange for a successful greenhouse crop by the efficient operation of all its supporting systems. From the potting operation to the wholesale marketing procedures, greenhouse systems are closely linked. Understanding of these relationships and the factors which affect them is invaluable for design, operation and management of a greenhouse system. Attempts to maintain continuity of supply are frequently based on sowings and plantings made at regular intervals with a range of cultivars (Fordham and Biggs, 1985).

We believe that the present model will contribute to the other combined models predicting plant growth, development and yield and is open to be evolved by workers involved in this subject.

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