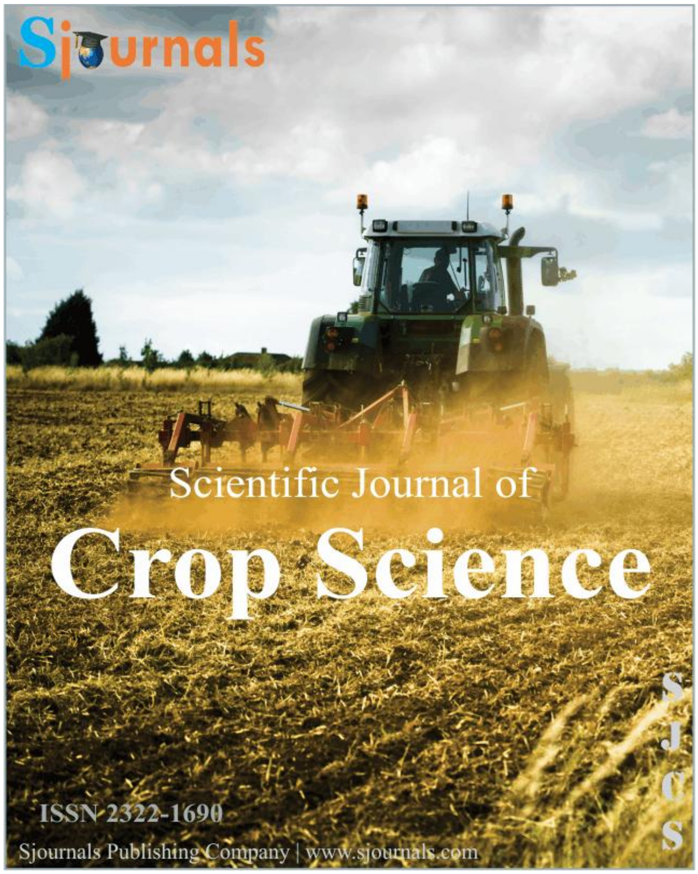
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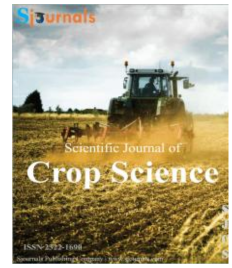

Original article

Estimating of development length stages of a soybean (*Glycine max* L.) variety by using meteorological elements

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A B S T R A C T

Awareness of the role of temperature and day length on plant growth and development can be used in agronomic management and plant breeding, and provide basic and essential information for prediction of development stages. To estimate the length of development stages of a soybean variety namely Wood Worth using the temperature, day length and planting dates of this variety in different regions of Isfahan during 1996-1999. To determine the model of each stage, the length of each stage as a dependent variable and thermal variables, day length, and the product of multiplication of thermal variables with day length variables were used as an independent variable in step wise regression. For all stages by delaying in planting, the length of the stage decreased. The coefficients of determination for planting to emergence, emergence to flowering, emergence to poding and emergence to maturity were 76.4%, 85.6%, 86.9% and 92.2%, respectively. The results of this study show that the contributions of thermal parameters play a major role in determining the estimation models of development stages of Wood Worth variety.

1. Introduction

Soybean is an annual, broad leaf oil seed crop of the family leguminous. Soybean is very valuable for protein and oil production, it has a great diversity in cultivars and a wide range of climatic and soil adaptation (Khjeapour, 1994). Soybean cultivation area in the country are about 62,000 hectares with an average yield of 2317 kg/ha (Ahmadi, 2016). The highest level of soybean cultivation is in the northern provinces of the country. Soybean is a thermophil crop and show more sensitivity to day length than any other crop. Day length sensitivity of soybean varieties is very different. Soybean varieties based on sensitivity to the day length are classified in 13 groups and the higher the maturity group, the greater the sensitivity to the day length (Khjeapour, 2004). The minimum soil temperature for germination of soybean is about 15°C and its optimal growth is achieved when the mean daily temperature is about 25°C (Singh, 1994).

The temperature and the length of the day are important climatic elements. The intensity of radiation and the length of sunshine hours, the amount of absorption, diffusion, and reflection of sunlight during the passage of the atmosphere, the differences between terrain and terrestrial waters in absorbing radiation, the characteristics of the earth's surface, the intensity and direction of energy transfer in hot and cold ocean flows and horizontal movements and air velocity are effective factors in the spatial and temporal dispersion of temperature (Ahrens, 2007). The length of the day in each place is the time it's spent in brightness. The divergence of the earth's axis in rotation around the sun causes the amount of radiation to earth's surface and the length of radiation in any latitude to change and seasonal variations occur. In the summer, with increasing latitude, the length of the day increases (Ahrens, 2007).

If development is passing from one stage to another stage of life, according to Fehr et al. (1994), the stages of soybean development include emergence(V_E), cotyledons(V_C), nod formation(V_1…Vn), flowering(R_1), full flowering ($R_{2)}$, beginning pod formation(R_3), full pod formation($R_{4)}$, beginning of seed formation($R_{5)}$, complete seeding(R_6), early ripening(R_7) and complete ripening(R_8). Factors such as the availability of water, nitrogen, and photosynthetic materials affect growth and development. When the plant is irrigated, it is expected that all factors, with the exception of climatic elements, are controlled. In this way, only the climatic elements are able to change the growth and development. The effect of temperature and day length will be more than other elements on plant development stages. In each location, the planting date determines how the development stages coincide with the temperatures and the length of different days during the growing season. The relationship between plant development and temperature has been known since ancient times and it has been shown that among climatic factors, temperature has the most effect on plant development. The length of the day is also a climatic element that has a significant effect on development. In this regard, the evolutionary reaction of plants to daily variations of periods of light and darkness is called photoperiodism (Jame et al., 1994).

In many studies, the effect of temperature on soybean development stages has been investigated (Mitchell and Russel, 1971; Mayers and Byth, 1991). Majer et al. (1975) stated that in early mature soybean varieties, the temperature is more effective than day length in development rate. They reported a high correlation between soybean development rate and growing degree days during flowering until full maturity, and showed that this correlation reached maximum during ripening. The effect of day length on the growth and development of plants is altered by other environmental factors and sometimes even stopped. Most plants do not react to the length of the day unless their heat requirements were provided (Alizadeah and Kocheki, 1989). Different studies (Hodges and Frech, 1985; Nissly et al., 1981) have emphasized the interaction between temperature and day length on soybean development stages and have shown that with increasing temperature and decreasing the length of day, plant development rate increasing. Sinclair et al. (1991), in their studies on 9 soybean cultivars, calculated a linear model(below model) with a coefficient of explanation between 74 and 89 percent.

$$1/f = a+bP+cT$$

In the model, 1/f is development rate or inverse of days between the planting to flowering, P is day length, T is temperature and a, b and c are the regression coefficients.

The aim of this study was to estimate the length of different development stages of Wood Worth soybean cultivar by using temperature and day length to determine the time of occurrence of these stages in order to provide agronomic requirements.

2. Materials and methods

In this study, estimation of the development length stages of a soybean variety namely Wood Worth was carried out in different planting dates. Also, the effect of temperature and day length variations on length of these stages was investigated. For this purpose, the planting date of this cultivar during different years in Khatun Abad (32°40'N; 51°48'E; 1555m), Kholeanjan (32°23'N; 51°34'W 1651m), Qahdearijan (32°34'N; 51°30'W; 1680m) and Kabutarabad (32°30'N; 51°49'E; 1541m) were used. This variety with indeterminate growth habit and belonging to the third maturity group in nine dates, the first (from May 8 to 10), the second (from May 18 to May 20), the third (from May 28 to May 30), the fourth (from May 8 to June 10), the fifth (from 18 to 20 June), the sixth (from 28 to 30 June), the seventh (from 6 to 8 July), the eighth (from 16 to 18 July) and the ninth (from 25 to 27 July) was cultivated. In 1994, in Kholeanjan, the third planting date in the Kabutarabad, the second planting date, in 1995, in the Khatun Abad, the second, third and sixth planting dates, in 1996, in Qahdearijan, the first to fourth planting dates in Kabutarabad, the 6th planting date in 1997, in Kabutarabad, the planting dates of the fifth, seventh, eighth and ninth in Qahdearijan, the planting date were recorded. Each region and year wsa considered as an independent experiment. Each experiment was based on two factor of agricultural design experiment, planting dates were considered as the main factor and cultivar was considered as sub factor.

Cultural practices were performed according to usual soybean experiments. During the experiment, the dates of the stages of R_E (emergence), R_1 (beginning of flowering), R_3 (beginning of pod formation) and R_8 (full maturity) were recorded according to the method of Fehr et al. (1971). The length of each development stage was calculated, using the difference between the date of the beginning of stage and its end date per day. The starting day of each stage counted and the end of that stage not counted.

The correlation coefficients between meteorological variables and development length stages were calculated. The length of each development stage (N) as a dependent variable and thermal parameters and day length were used as independent variables in the step wise regression of SAS. The equations of different stages of development were obtained. Equations were selected that had the maximum determination coefficient with its significant components.

3. Results and discussion

The length of sowing to emergence of this variety varied between 3 and 15 days, with average of 8.5 days. In general, delay in planting decreased length of this period due to increased temperature. The negative and significant correlation (-0.59^{**}) between these two variables is consistent with this conclusion. The maximum period from planting to emergence was at the first planting date (May 8) of 1996-1997, and the minimum was at the ninth planting date (July 27th) of the same year. Comparison of the number of days from planting to emergence in different planting dates during the years of experiment shows that with the same average temperatures, the length of planting to emergence is not the same in some cases. This variation may be related to agronomic characteristics. It should be noted that increasing the temperature when could accelerate the emergence that the other factors for germination and emergence provided. For example, if at the time of temperature increasing, moisture deficiency or soil crust is a limiting factor, it can act as a deterrent the rate of germination and emergence. The results of step wise regression for the duration of planting to emergence (Table 1) showed that the T_{max} is the first variable entered to the model and explained 61.6% of model variation. T^2_{max} was the second variable entered in the model and explained 14.8% of the variations of length of this period in the presence of the previous variable. These two variables together resulted in 76.4% (Model 1).

$$N = 28.831-- 0.48T_{max} - 0.010T^{2}_{max} \quad R^2 = 76.4\ \% \quad \text{(Model 1)}$$

It seems that this model can partly but not completely explain the relationship between seed emergence and soil temperature. It should be noted that some other factors affect the seed emergence such as air temperature, soil moisture and planting depth.

The period from R_E to R_1 was varying from 31 to 49 days with an average of 42.9 days. The maximum period was at the first planting date (May 8th) of 1994-95 and minimum period was at the seventh planting date (July 6th) of 1995-96. The highest average temperature (29.18°C) for this period was on the seventh planting date of 1997. The lowest average temperature (22.12°C) for this period was on the first planting date of 1997. Although the day length average has not much variation in different planting dates, the maximum and minimum values were 14.53 and 14.19 hour, for the fourth planting date of 1996 and the seventh planting date of 1997, respectively (Table 2).

Table 1
Equations for different developmental stages of Wood Worth soybean cultivar.

Variable	Model R^2	Partial R^2	Regression coefficient
			Planting to germination
Intercept	-	-	28.831
T_{max}	0.616 *	0.616	-0.480
T^2_{max}	0.764 *	00.148	0.010
			Germination to flowering
Intercept	-	-	83.252
T^2_{mean}	0.664	0.664	-00.012
T_{mean}	0.825	0.161	-1.302
$(T_{max}-T_{min})^2$	0.856	0.031	-0.108
			Germination to poding
Intercept	-	-	27850.856
T^3_{mean}	0.364	0.364	-0.068
T^2_{max}	0.547	0.183	-0.836
T_{mean}	0.695	0.148	-73.621
T^2_{max}	0.713	0.118	53.492
$(T_{max}-T_{min})^2$	0.769	0.056	0.016
			Germination to maturity
Intercept	-	-	-1670014.351
T^3_{max}	0.236	0236	-1.632
T^2_{mean}	0.423	0.187	-0.415
T^2_{min}	0.548	0.125	6.192
T_{mean}	0.656	0.108	184.069
$DL*T_{max}$	0748	00.092	89.378
$DL^2*T^2_{mean}$	0.838	0.090	0.719
DL	0.899	0.061	8687.332
DL^2	0.922	0.023	395.291

1. DL, Tmax, Tmin, Tmean are day length mean, maximum mean, minimum mean and mean average respectively.

The number of days from R_E to R_1 was reduced by delay in planting. In short-day plants, transformation from vegetative stage to reproductive stage, along with a shortage of day length, is accelerated, and long days lead to delays in flowering. In other words, if the length of the dark periods is less than the critical length or the length of days longer than the critical level, the plant flowering does not happen or its flowering is delayed and the short days will accelerate flowering in these plants. For each yteirav, it is possible to determine the approximate maximum length of the day, which days longer than it, delay the flowering intensely. Soybean is a short day plant and expected that delay in planting and increasing day length will increase the period from R_E to R_1. Such a reverse reaction in this experiment show temperature was the main factor for reducing the number of days from R_E to R_1. Negative significant correlation (-0.73^{**}) between the period and temperature and also the positive correlation between the period and day length (0.32) confirm this result. The relationship between this period and mean daily temperature show that when the temperature increase about 1°C, the period of this stage decrease about 1.5 days. The results of step wise regression for this period (Table 1) show that T^2_{mean} was the first variable that entered to the model and explained 66.4 percent of the variation. The second variable was T_{mean} with 16.1% partial R^2. $(T_{max}-T_{min})^2$ was the third variable and explained about 3.1% of the model variations. By these variables the model accuracy reached to 85.6% (Model 2). By considering that soybean is a short day plant, it seems that the mathematical relations used in the model different from physiological relationships that influenced by different climatic and agronomic factors.

$$N = 83.252 - 0.012\,T^2_{mean} - 1.310T_{mean} - 0.108\,(T_{max} - T_{min})^2 \quad R^2 = 85.6\% \quad \text{(Model 2)}$$

Table 2
Length period mean, temperature and day length for flowering stage of Wood Worth variety in different years and planting dates.

Planting date	Period length (day)	Temperature (°C)	Day length (hour)
		1994	
Second	49	22.83	14.40
Third	47	25.52	14.48
		1995	
Second	45	23.45	14.49
Third	43	25.90	14.50
Fifth	34	28.53	14.52
		1996	
First	50	23.20	14.32
Second	47	24.48	14.43
Third	45	25.68	14.51
Forth	40	25.44	14.53
Sixth	37	26.10	14.40
		1997	
First	48	22.12	14.40
Second	46	21.15	14.46
Third	42	22.93	14.50
Forth	40	23.79	14.49
Seventh	31	29.18	14.19

1. During the experiment, the first planting date was in the first ten days of May and the seventh planting date in the first ten days of July. The other planting dates were between these two dates.

The length of the period from R_I to R_3 varied from 52 to 74 days with an average of 62 days. The maximum was at the first planting date (8th of May) of 1994-95, and the minimum was at the seventh planting date (6th of July) of 1995-96. Such as planting to emergence and emergence to flowering by delay in planting the length of emergence to poding also decreased. Climb trend of mean temperature average with delay in planting date reduced the number of days from emergence to the formation of the pod. A negative significant correlation (-0.66**) between these two variables confirm this result. T^3_{mean}, T^3_{max}, $T_{mean,}$ T^2_{max} and $(T_{max} - T_{min})^2$ entered to the model of R_1 to R_3 (Table 1) and explained 36.4%, 18.3%, 14.8%, 11.8% and 5.6% of variations respectively. The total model's diagnostic coefficient was 86.9% (Model 3). It seems that thermal variables can justify all changes in this period.

$$N = 27850.856 - 0.068T^3_{mean} - 0.836T^3_{max} - 73.621T_{mean} + 53.492\, T^2_{max} + 0.016\, (T_{max} - T_{min})^2 \quad R^2 = 86.9\% \quad \text{(Model 3)}$$

The period from R_1 to R_8 varied from 103 to 143 days with average of 122.3. Such as other stages maximum and minimum length of this period were in the first planting date of 1994 and in the seventh planting date of 1995 respectively. It seems that with increasing temperature at later planting dates, flowering has accelerated and as a result, the length of the ripening decreased. Negative correlation between thermal variables and ripening length was consistent with this conclusion (-0.53**). The results of step wise regression (Table 1) show that four thermal variables including T^3_{mean}, T^2_{mean}, $T^2_{min\ and}$ T_{mean} entered in the model and explained 23.6%, 18.7%, 12.5% and 10.8% of variations respectively. Also, $DL*T_{max}$, $DL^2*T^2_{mean}$, DL and DL^2 entered in the model, and along with the four previous variables explained 92.2% of the variation of the germination to maturity period (Model 5).

$$N = -1670014.351 - 1.632\, T^3_{max} - 0.0415\, T^2_{max} + 6.192\, T^2_{min} + 184.069\, T_{mean} + 89.378\, DL*T_{max} + 0.719\, DL^2 * T^2_{mean} + 8687.332\, DL + 395.291DL^2 \quad R^2 = 92.2\% \quad \text{(Model 5)}$$

Generally, with the prolongation of the development period, the coefficient of detection increased. For example R^2 for the stages of planting to emergence (the shortest stage) and emergence to maturity (the longest stage) was 76.4% and 92.2% respectively. The reason for this is more accurate estimation of longer stages. Recognizing longer stages is more precise and less varied in different planting dates and replications than any other for example; the diagnosis of the physiological maturity stage in the field is much more accurate than detecting other stages such as emergence, poding and seeding.

Regarding the lack of arrival of day length variables in the model of flowering stage due to the sensitivity of the soybean plant to day length, it seems that the mathematical relationships used in developmental models are different from physiological relationships that are affected by climatic and agronomic factors. For determining the response of plants to environmental variables, requires adequate phenological studies and the varieties with different maturity groups in each climatic region.

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