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Original article

Effects of temperature and day length on development rate of safflower cultivars

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Crop development is qualitative changes planned that makes the plant to ripening. Under irrigated conditions expected only climate elements able to change of plant growth and development and under these conditions, temperature and day length have more effective than the other elements. Data from planting dates trials conducted over the Kabootar-Abad Agricultural Research Station during 2003-2009 were used to develop models for estimating development rate of three varieties, Arak, Zendeh Rud and Goldasht. To calculate of developmental rate of every stage, duration of every stage was inversed. For determining model of development rate of every stage, development rate considered as dependent variable and day length, thermal variables and combination of these considered as independent variables in step wise regression. A step of regression was considered appropriate if the highest R2 was accompanied by the significant (p≤0.05) regression coefficient. Evaluation of model accuracy and sensitivity was performed, using the data of 2008-2009 that there was not any role in forming of models. No. of days from planting to emergence, emergence to heading, emergence to flowering, emergence to ripening and flowering to ripening were affected by planting dates. By increasing temperature, developmental stage periods decreased. Day length had the most effect on emergence to heading and emergence to flowering period and by increasing it, decreased. Tmean was the only variable that entered to model and explained about 76% of development rate of emergence period. About 83% of development rate of emergence to heading stage was determined by Tmax×DL. T2max×DL2 explained about 92% of development rate of emergence to flowering stage. T2max×DL2 with T4max explained about 81% variations of developmental rate of emergence to ripening stage. T3max was the only variable that entered the model of development rate of flowering to ripening stage and expressed about 47% variations of it. Contribution of thermal and day length parameters in determining of rate of different developmental stages is not constant. This may be related to different physiological nature of developmental stages and differences reactions of these stages to climatologic, edaphic and agronomic elements and interaction among them and with genotype of plant. Contribution of thermal and day length parameters in determining of rate of different developmental stages is not constant.

1. Introduction

Safflower is cultivation for various purposes. The petals is used in pharmacy and natural colors, the seeds for oil and cakes and the leaf and stem for feeding animals, in fresh or silage forms. Esfahan province is one of the most important producers of safflower in Iran (Froozan, 2005). Safflower due to high drought and salinity tolerance (Vollman, and Rajcan, 2010) is cultivated in marginal lands which facing salinity and suffer from water shortage and saline water application. Therefore the safflower plant is facing with various types of stresses during development periods. The knowledge and understanding of duration and timing of safflower development stages may be used to predict the more sensitive and effective yield formation stages to fulfill the plant requirement or to avoided stresses by adjusting the planting date and cultural practices to enhance yield. Therefore, understanding the plant vital activity and development stages including vegetative and reproductive stages in relation to time or phonology is an important phenomena issue.

In modern agriculture practices the timing of different growth and developmental stages during growing seasons is require. The ability to predict the growth and developmental stages is require for in time field operation, to achieve highest productivity, planning plant rotation, timing of pesticides and insecticide application, and tuning harvesting time with market requirement. The timing of each plant growth stage is mainly depending on genotype, daily temperature and day length.

At the first step, it is required to consider the developmental stages as a daily process. Since the daily development increments is not directly measurable, therefore it is required the average total development to be determined, based on short incremental times. In a short period the developmental process shows good homogeny. In this case, the rate of developmental stage is the inverse length of developmental stage (Robertson, 1983). This development portion is called increased fraction of daily development stage (Clarkson, and Russel, 1979). The simplest development model assumes the mean growth rate up to maturity stage or any other phonological stage is constant. Therefore equation 1 is obtained.

$$dM/dt=1/N=C \qquad (1)$$

Where, dM/dt, N and C are changes of development respect with time, length of stage and a constant value, respectively. Integration over length of phonological stage from stage 1 (S1) to stage 2 (S2) the equation 2 is obtained.

$$\int_{S1}^{S2} dM = \int_{t=0}^{N} dt / N = N / N = 1 \qquad (2)$$

Where, M is the maturity occurrence of each phenological stage. In other word summation of daily incremental development during each phonological stage when add up to 1, the development stage is completed.

In the early steps of plant growth and development modeling, the scientist used temperature due to higher contribution of temperature to plant development stages than any other factors. In the early age of plant development modeling all scientists believed that due to higher effect of temperature, calculation of an index based on temperature is able to decrease the crop growth model coefficient of variations (Robertson, 1983 ; Jame and Cutforth, 2004). The crop development model using constant growth rate (Clarkson, and Russel, 1979), the effective temperature index (Jame, and Cutforth, 2004) and none-linear heat index (Yin, et al., R. M. (1995) are among them. The meaningful effect of day length on growth, introduction of day length in addition to temperature was considered (Kajehpour and Seidi, 2001 ; Kajehpour and Dadashi 2003). The linear temperature-day length (Lown and Byth, 1973) temperature-night length (Robertson, 1998) second order temperature and day length (Majore, et al., 1975) and stepwise regression of temperature and day length (Kajehpour and Seidi, 2001 ; Kajehpour and Dadashi 2003) are among them.

The objective of present study is estimating spring-planted safflower development rate based on temperature and day length, and the effect of them on development stages for expansion into new similar area.

2. Material and methods

For estimation of developmental rates of 3 spring-planted safflower namely: Arak, Zendeh Rud and Goldasht, and evaluation of their development rate as effected by temperature and day length the data from planting dates experiment during 5 growth season in Kabotar-Abad Agricultural Experiment Station were used.

The three safflower cultivar in 2003 growing season were sown on six planting dates of first (6th May), second (31th May); third (6th June), forth (21th June), fifth (6th July) and sixth (21th July), and for 2003-2004, 2004-2005, 2005-2006, 2006-2007 and 2007-2008 growing season were sown on eight planting date of first (7th March), second (20th March); third (6th May), forth (21th March), fifth (6th July), sixth (21th June), seventh (6th July) and eighth (22th July). The 2003-2004 and 2004-2005 and the rest of experiment were replicated three and six times, respectively. The Kabotar-Abad agricultural station (32’ 30 N, and 51 49 East L, and 1541 masl) is located 30 Km south-east of Esfahan City and belong to Esfahan Agricultural and Natural Resources Research center. According to Koppen climate classification is located in a dry, very hot, with hot and dry summer. The long time mean annual precipitation of 212 mm and temperature of 16.1 Celsius degree.

Commercial cultural practices were employed during growing seasons. Each plot consisted of 4 rows and the first and forth rows and half a meter length from end of each row were elimination and the reaming plants were constituted the sampling population. For each plot the developmental stages according to following schemes were evaluated: a) the plant establishment, when the cotyledon emerge in 90 percent of planted row, b) heading, when on 90% of plant capitulars bud with 1 cm in diameter at the end of main stem become visible C) Flowering, the beginning of flower pollination in the main stem, in 10% of plant D) Maturity, when 90% of heading turn into brownish colure.

For calculation of growth rates the corresponding length of each period was inversed. The number of days from sowing (after first Irrigation) to establishment, establishment-emergence to heading, establishment-emergence to flowering and maturity were recorded. For each growth stage, the first day of growth stage was included and last day was excluded. For calculation of growth rate the inverse length of growth period was calculate. Daily maximum, minimum and mean temperature over research station and years under conditions were obtained from Kabootar Abaad Meteorological Station that located in the site of experiment. Duration between light intensity of 0.001 calcm-2min-1 (before sunrise and after sunset) of each day was calculated using the model provided by keisling (1982), and was considered as day length in hours with 4 significant digits. The mean of each temperature variables over the considered duration of development was calculated.

The correlation coefficient between metrological variable and length of each development period were calculated. For modeling the developmental stage, the inverse length of each development period (1/N) was considered as dependent variable and the temperatures and day length as independent variable using a step-wise regression.

The independent variable for sowing to emergence (establishment) were consisted of mean of minimum temperature (Tmin) mean of maximum temperature (Tmax), the average of daily temperature (Tmean), the difference between maximum and minimum temperature (Tmax-Tmin), and the square, cubic, and forth power of them. For the rest of development periods in addition to temperature variable, the day length mean, square, and cubic, and the multiplication of temperature variables with day length variable were included in the stepwise regression. A step of regression was considered appropriate if the highest R2 was accompanied by the significant (p≤0.05) regression coefficient.

3. Results and discussion

The duration of sowing to emergence of different cultivars was 4 to 20 days with average of 9.1 days. Overall, the duration of sowing to germination decreased by postponing sowing date due to increase air temperature (table 1). The negative and significant correlation between these two variables was in accordance with the results. The maximum days between sowing to germination in the first planting date (6th and 22th July) was 20 days for 2006 growing season, and the minimum value from fifth and sixth planting date (6th and 22th July) in 2004 growing season and eight planting date (21th June) in 2005 were obtained.

Table1

Correlation coefficients of cultivars development stages with meteorological variables .

Daily temperature	Maximum mean	Minimum mean	Mean average	Day length mean
Planting to Germination				
Minimum mean	0.979**			
Mean average	0.996**	**0.993		
Day length mean	0.916**	**0.942	0.935**	
Period mean	-0.888**	**-0.899	-0.901**	-0.952**
Germination to Heading				
Minimum mean	0.985**			
Mean average	0.994**	**0.996		
Day length mean	0.888**	**0.854	0.872**	
Period mean	-0.946**	**-0.906	-0.926**	-0.931**
Germination to Flowering				
Mean average	**0.985			
Day length mean	**0.996	**0.994		
Period mean	**0.808	**0.757	**0.796	
Minimum mean	**-0.977	**-0.954	**-0.973	-0.894**
Germination to Ripening				
Minimum mean	**0.956			
Mean average	**0.990	**0.987		
Day length mean	0.63	0.206	0.143	
Period mean	**-0.936	**-0.925	**-0.945	-0.368**
Flowering to Ripening				
Minimum mean	**0.964			
Mean average	**0.987	**0.994		
Day length mean	**0.973	**0.947	**0.954	
Period mean	**-0.788	**-0.858	**0.834	-0.788**

**: Significant at 1% probability.

The comparison of number of days from sowing to germination for different planting date during different growing years shows that the length of this period is not always consistent. Such inconsistency may be related to irrigation interval, variation of planting depth, and soil texture. Increasing temperature can be effective in acceleration of seed emergence when the other factors are favorable. For instance, if increasing temperature coincide with moisture stress or soil crust it may have a preventive effect on plant emergence.

The development rate form sowing to germination of 3 cultivars were from 0.05 to 0.25 with mean of 0.11. The stepwise regression for sowing to emergence (table 2) shows that the average day length temperature was the only variable which entered the model with the positive regression coefficient of and R2 of 75.75 (model no. 1).

$$1/N= =0.01057761 + 0.00648714\times Tmean \quad (1)$$

Since seed is germinated in soil, the selected variable is not able to fully explain seed germination. Even though soil temperature in 20 to 30 cm soil depth is in equilibrium with air temperature, but the relation between soil and air temperature are not simple and

Table 2

Summary of stepwise regression for estimating of development rate of different stages , planting to germination, germination to heading, germination to flowering, germination to ripening and flowering to ripening for cultivars under studied.

Variable1	Determination coefficient of model (R2)	Partial determining coefficient(P.R2)	Significant level of partial determination	Regression coefficient	Standard error of regression coefficient	Level of significant regression coefficient analysis
Planting to Germination						
Intercept	-	-	-	-0.01057761	0.00427969	0.0140
Tmean	0.7575	0.7575	0.0001	0.00648714	0.00021705	0.0001
Germination to heading						
Intercept	-	-	-	-0.000678158	0.00081328	0.0001
DL×Tmax	0.8324	0.8324	0.0001	0.00006701	0.00000178	0.0001
Germination to flowering						
Intercept	-	-	-	0.02122807	0.00457658	0.0001
DL2×T2max	0.9226	0.9226	0.0001	0.00000028	0.00000005	0.0001
Germination to Ripening						
Intercept	-	-	-	0.00000966	0.00043212	0.9822
DL2×T2max	0.7959	0.7959	0.0001	0.0000006	0.000000001	0.0001
T4max	0.8127	0.0168	0.0001	0.000000001	0.000000001	0.0001
Flowering to Ripening						
Intercept	-	-	-	0.018933315	0.00084711	0.0001
T3 min	0.4728	0.4728	0.0001	0.00000211	0.00000013	0.0001

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

unique and is influenced by soil colure, texture, moisture, mulches, soil aspect, cloud cover and fluctuation of air temperature (Jame and Cutforth, 2004). Therefore, other variable and relation are required to explained seed germination. Base on present study a more accurate prediction of sowing to emergence period require soil temperature and additional relevant variable, which require additional tool and which is not readily available. The following model was obtained for number of days require from sowing to emergence (Ayon, et. al., 2005).

$$1/N= 0.38 – 0.07Tmean + 0.0012T2mean \quad R2=90.68\%$$

Where N is number of days and other term are previously defined.

The period from emergence to heading for all cultivars was from 32 to 68 days with the average of 43.5 days. Generally with postponing in seeding the length of germination to heading decreased. The maximum and minimum days from germination to heading were observed in the first planting date (7th March) during 2005 growing season and sixth planting date (21th June) in 1386-87 growing season, respectively. The negative and significant correlation coefficient (table 1) between temperature and day length with the duration period shows that by increasing temperature and day length the length of emergence to heading (as the first visible sigh of flowering) decreases. Considering that safflower is a long day plant, in some planting date even with decreasing day length the number of days to heading not decreased. The occurrence of such phenomena might be due to compensatory effect of day length and temperature, which cause the plant does not display predicted responds.

$$1/N= - 0.00678158 + 0.00006701DL \times Tmax \quad (2)$$

The development rate from emergence to heading for all cultivars was 0.01 to 0.03 in different growing season with the average of 0.02. The mean day length and maximum temperature multiplication was the only variable which entered the model (table 1 and contribute to 83.24 percent of growth rate variations from emergence to heading.

The length of emergence to flowering for the all cultivars was ranging from 49 to 84 days with the average of 61 days. The cultivars in seventh planting date (6th June) during 2006 growing season and first planting date (7th March) during 2004 growing season had the minimum and maximum days from emergence to flowering. Similar to planting to emergence and emergence to heading with increasing temperature and day length, the length of this period decreased. The correlation coefficient between temperature and day length with the length of this period shows this phenomena (table 1).

The development rate from emergence to flowering for all cultivars was 0.011 to 0.020 in different growing season with the average of 0.016. The multiple of day length square with maximum temperature square was the only variable which entered the model (table 2) and contributes to 92.26 percent of growth rate variations from emergence to flowering

$1/N=0.02122807 + 0.00000028\times DL2 \times Tmax2$ (3)

The length of period from emergence to maturity for all cultivars was 79 to 115 days with the mean of 93 days. The minimum and maximum days of this period were from sixth planting date (21th June) of 2007 growing season and first planting date (7th March) of 2006 growing season. The trend of increasing temperature with delaying planting dates has an important role in decreasing the length of this period, and most of the decrease is due to acceleration in flowering. The negative and significant correlation coefficient (table 1) between temperature variable and the length of this period is in agreement with the result.

The development rate of emergence to crop maturity period of 3 cultivars was from 0.009 to 0.013 with the mean of 0.011. The result of stepwise regression analysis for the rate of emergence to maturity is given in table 2. The product of day length square by maximum temperature square was the first variable which entered the model and explained 79.59 percent of variation. The maximum temperature to the power of 4 was the second variable and described 1.68 percent of variation, in which with the first variable explained 81.27 percent of variation (Eq. 4).

4) $1/N=0.00000966 + 0.000000DL2 \times T2max – 0.00000000T4max$

The length of period from flowering to maturity of the tree cultivars for the studied year was from 16 to 47 days, with the mean of 31.4 day. The first planting date (7th March) 2005 growing season and the seventh planting date (6th June) of 2006 growing season had the longest and shortest period, respectively. Delay planting associated with gradual increasing of day length and temperature decrease the length of this period. The negative and significant correlation coefficient between heating parameters and day length with the length of this period (table 1)

Justified the results.

The developmental rate from flowering to crop maturity period of 3 cultivars were 0.021 to 0.063 with the mean of 0.032 per day. The cubic term of minimum temperature was the only variable which entered the model (Eq. 5) and described 42.98 percent of variation. The temperature variable, especially the minimum daily temperature plays an important role in length of this period and development rate of selected cultivars.

5)$1/N=0.01893315 + 0.00000211T3min$

4. Conclusion

The results of this study indicate that the contribution of temperature and daylength to various stages of development is not the same. Differences in physiological nature of development stages and difference in the response of development stages to climatic, edaphic and agronomic factors and the interactions of these factors with each other and with plant genotypes may be responsible for these reactions. Thus, a separate model may be needed for each cultivar and each development stages. Dividing the country to homogenous groups, in respect to temperature and daylength, may increase the accuracy of estimating models. This requires availability of sufficient phenological information from various climatic zones.

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