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Changing of Vegetative to Reproductive Ratio as a Response to Different Sowing Dates in Sunflower

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Abstract: Sunflower is an important source for edible oils and biodiesel production. Its productivity is limited by many agronomical practices one of which is the sowing date. In this study, the effects of different sowing dates from early April to late June on phenology and yield of sunflower cultivars were investigated. The results showed that sunflower has a relatively long period of possible sowing dates, stretching from early April to late June in North West of Iran. However, delayed sowing dates significantly decreased the number of days needed for phenophases. For every day of delay, the model predicted ($R^2 = 0.97$) a losing rate in achene yield by 22.2 kg h^{-1} from the first sowing date. For relationships between growing degree days (GDD) and yield, almost the same results were obtained. About 22 kg h^{-1} reduction ($R^2 = 0.79$) in yield per day was estimated by GDD index when the average GDDs per day was 14.2. However, helio-thermal units (HTU) did not predict this reduction accurately. A suggested comprehensive model, that used the percent of yield losses and changes in vegetative to reproductive ratio, found a significant and positive relationship between the indices and yield losses. For all indices, an increase in vegetative to reproductive ratio resulted in increased grain yield losses.

Keyworks: flowering, GDD, *Helianthus annuus*, yield

Introduction

Identifying the yield restricting factors of crops is useful in breeding and agronomic programs. Among the agronomical practices, sowing date/ or planting date is one of the most important factor which affects the yield and growth parameters of the sunflower. The best time for sowing is usually adjusted by soil temperature when raises up to Tb (Tb- base temperature is the lowest temperature which germination

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can occur) (Bazin *et al*., 2010). Also, decreases of air temperature below growth requirements after seedling emergence slow down growth and negative temperatures increases the chilling and freezing injuries in sunflower plants (Clay *et al*., 2014). Besides the mentioned aspects, flowering and seed filling stages in sunflower are very sensitive to environmental stresses (García-López *et al*., 2016); therefore, the sowing date should be carefully chosen to avoid from any threat at these stages. Another important issue connected to sowing date is the harvesting time. If sowing date delayed, it is possible that the harvesting meets with high air humidity or raining at late summer. Thus, it increases harvesting risks, because, achene moisture contents must be reached below 15 % in order to ready to harvest by combine machines (Touch *et al*., 2015). Studies have been shown that at the normal condition, early sowing dates of crops generally results better yield than late sowing dates because appropriate temperature and adequate soil water contents are available for flowering and seed filling stages (Chen and Wiatrak, 2010; Schillinger *et al*., 2012; Salmerón *et al*., 2016; Teetor *et al*., 2011; Wang *et al*., 2016). Sunflower varieties also response differently to sowing dates (Balalić *et al*., 2012; Zheljazkov *et al*., 2011). The growth season of sunflower (window) is determined by soil temperature at sowing and freezing air temperature in the late of the season which for most of sunflower varieties is 8 °C and −2 °C, respectively. The longer growing season duration increases the sowing possibility of all sunflower types. Furthermore, it helps to sow crops at different dates. Nevertheless, setting the best time for each region must be determined by field experiments. Quantitative models which carefully predict and describe influences of sowing dates on sunflower phenology and its yield are rare/ or very complex. Thus, this study was aimed to investigate i) influence of different sowing date on phenology and yield of sunflower varieties and ii) introduce a simple model/or models which predict phenology and yield of sunflower based on agro-climatological indices.

Methods and Materials

To evaluate the impact of sowing dates on sunflower phenology and yield, a research trial was carried out at Agricultural Research Station in Khoy, Iran (38° 32′ N; 44° 59′ E). Experimental design was a randomized complete block with split plots replicated four times. The plot size was 3 × 6 m. The main plots were five sowing dates (10-Apr., 30-Apr., 20-May, 9-Jun. and 29-Jun.). The subplots were two cultivars: Golshid (a short season oil sunflower hybrid (Cms31 × R46) and a native nut sunflower variety (Galami). Golshid had a relative maturity of 90 days and Galami a relative maturity of 110 days. The soil texture was clay loam and plots prepared by with spring disking and harrowing. Sowing depth was 4 cm and plant density was arranged at 25 × 70 cm (57,142 plants.ha^{-1}). Synthetic fertilizers at the 1:1.5:1.5 (NPK) ratios were applied at a rate of 200 kg per hectare at sowing based on station soil analysis. Weeds were managed by hand when was needed and the farm was stayed weed free during experiment. During the season, bird netting (plastic net) was used to discourage birds from damaging achenes (seeds). To record phonological stages; time (days after sowing), the growing degree days (GDD) and helio-thermal units (HTU) were calculated for the following stages which have been described by Biologische Bundesantalt and Chemische (BBCH) scale;

1. Emergence: Cotyledons completely unfolded (BBCH 10)
2. Inflorescence emergence: inflorescence separating from youngest leaves, bracts distinguishable from foliage leaves (BBCH 53)
3. Beginning of flowering: ray florets extended, disc florets visible in outer third of inflorescence (BBCH 61)
4. Full flowering: disc florets in middle third of inflorescence in bloom (stamens and stigmata visible) (BBCH 65)
5. End of flowering: most disc florets have finished flowering, ray florets dry or fallen (BBCH 69)
6. Physiological ripeness/ or Physiological maturity: back of the anthocarp yellow. Bracts marbled brown. Seeds about 75–80 % dry matter (BBCH 87)

The meteorological data of minimum (Tmin), maximum (Tmax) temperature and sun shine hours were obtained from the synoptic station of Khoy (Table 1). To calculate GDD and HTU the following formulas were used, respectively.

$$GDD = \sum \left(\frac{Tmax - Tmin}{2} \right) - T_{base} \quad T_{base} = \ +8\,°C$$

$$HTU = \sum (GDD \times sun\ shine\ hours)$$

Table 1: Average monthly of agro-climatological data during sunflower growth season in Khoy, Iran (38° 32' N; 44° 59' E).

	Apr	May	Jun	Jul	Aug	Sep	Oct
Average Max Temperature °C	14	19	22	28	28	24	17
Average Min Temperature °C	2	7	10	14	14	10	5
Average Precipitation mm	54	50	21	4	7	14	48
Average Sunlight Hours/ Day	7h 24’	9h 05’	11h 18’	11h 36’	10h 05’	7h 48’	5h 42’
Average Daylight Hours/ Day	13h 10’	14h 14’	14h 47’	14h 32’	13h 37’	12h 23’	11h 06’
Percentage of Sunny (Cloudy) Daylight Hours	57 (43)	65 (35)	77 (23)	81 (19)	75 (25)	64 (36)	52 (48)

To calculate relationship between achene yield and oil yield of sunflower, the performance of 61 varieties/ or hybrids was used from different Global Agro-Ecoecosystems from 2010 to 2016. This model predicts indirectly the oil yield via the achene yield. Thus, any changes of achene yield under different sowing dates are reflected at oil yield production.

All data was analyzed using a GLM model analysis (SAS V. 9.1) where replicates were considered random effects. The Duncan procedure was used to separate means when the F-test was significant ($P \leq 0.05$).

Results and Discussion

Agro-climatological parameters

The results revealed that the effects of sowing dates on days to the plant phenophases was significant (Table 2) also the genotypes had a significant difference for the trait. When the crop sown at early April, the days were short and also minimum temperature was low (Table 1). Thus, the sum of the factors delayed the days to the plants emergence significantly in April sowing dates.

Table 2: Effects of sowing date on phenology of sunflower.

Treatments	Days					
	Emergence	Inflorescence emergence	Beginning of flowering	Full flowering	End of flowering	Physiological maturity
Sowing dates						
10-Apr.	11.5 a	72.1 a	94.8 a	102.9 a	107.3 a	140.5 a
30-Apr.	8.6 b	65.0 b	84.0 b	88.5 b	93.3 b	124.9 b
20-May	7.5 b	52.8 c	71.7 c	77.3 c	83.0 c	110.5 c
9-Jun.	5.8 c	46.2 d	67.0 d	70.1 d	74.2 d	104.3 d
29-Jun.	5.5 c	43.8 e	46.0 e	53.2 e	56.0 e	91.7 e
Varieties						
Golshid	7.2	48.8 b	64.6 b	69.1 b	73.3 b	97.4 b
Galami	8.2	63.1 a	81.1 a	87.5 a	91.8 a	130.6 a
ANOVA (only for treatments)						
Sowing date (S)	**	**	**	**	**	**
Varieties (V)	Ns	**	**	**	**	**
S × V	Ns	**	**	**	**	**

Same letter at column are not different at $p \leq 0.05$; **Significant at $p \leq 0.01$.

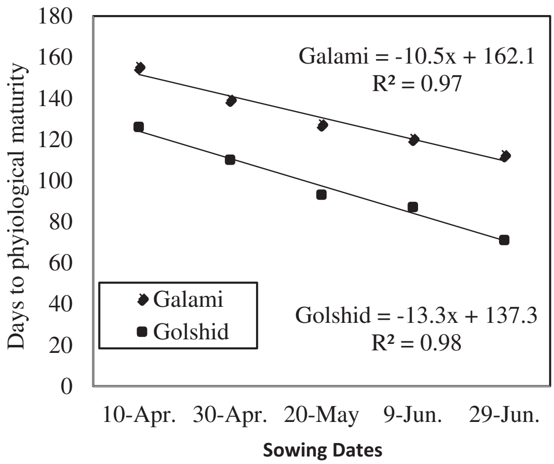

Figure 1: The response of physiological maturity in sunflower plants to sowing dates.

Rapid accomplishment of phenophases was noticeable during late sowing dates whereas it was delayed during early sowing dates (Table 2). Higher amounts of solar radiation and higher daily mean temperature recorded during summer season might be induced the early attainments of phenophases of sunflower. Variation of phenophases under different sowing date was reported by Zheljazkov *et al.* (2009) for sunflower. It was obvious that emergence time follow up soil temperature, therefore, at late sowing dates the value remarkably decreased from ~12 days to ~6 days. The similar results were also found for other phenophases, however, among sowing dates, results for 20 May and 9-Jun. were close to each other's. Galami spent more time to complete the phenophases than Golshid (Table 2). Except for emergence stage, the varieties had significant differences to complete the rest stages. As shown in Table 2, the interactions between sowing dates and varieties for inflorescence, flowering and physiological maturity were significant at $p < 0.01$ in terms of time to the phenophases. This result shows that the response of two sunflower varieties to sowing dates is different. An example scatterplot is shown in Figure 1 for physiological maturity against sowing dates. The plotted regression for sunflower varieties revealed a negative liner relationship between delaying in sowing dates and time to physiological maturity (Figure 1). Apart from the similarity in the shape of the regressions, the coefficients of the equations are different (Figure 1) which here the intercepts are indicators of relative maturity and the slops values represent the response of the varieties to sowing dates. In other words at first sowing date the maturity time is predicted only by intercepts for varieties (e. g. 162 days for Galami and 137 days Golshid). Therefore, shorter season variety (Golshid) with a high change in slop coefficient was more sensitive than full season variety (Galami) to the different sowing dates. The result revealed that the response of sunflower varieties to sowing date is a species specific phenomenon. Similar results have been reported for wheat, maize and sunflower genotypes (Hamam and Khaled, 2009; Hefny, 2010; Zheljazkov *et al*., 2011).

There was a significant difference ($p \leq 0.01$) between treatments in terms of phenophases for GDD in all of stages (Table 3). The lowest GDD to emergence was recorded for 30-April sowing date whereas the latest sowing date had the highest value. At North West of Iran spring rainfall occurs on early April, therefore, high amounts of water at soil medium delays germination process due to anoxia. As a result, all the accumulated GDD were not used at germination and emergence processes for 10- April sowing date compared to 30-April, which obviously was seen at days to the emergence (Table 2 and Figure 2). Based on the results, a positive trend and significant increases at GDD for emergence was observed after 30-April sowing date. It was because of raising the soil temperature at later sowing dates which hastened seedling emergence with regression trend of; $Y_{(\text{to emergence})} = -0.06(\text{GDD}) + 10.895$, $R^2 = 0.95$ (the model extracted from emergence data of Tables 2 and 3; time plotted against GDD). So, after elapse of raining days and at normal conditions with 16 units increase at GDD, the emergence time was accelerated up to 24 h. It seems all incoming temperatures

Table 3: Growth degree days (GDD) requirements for phenology of sunflower.

Treatments	Growth Degree Days					
	Emergence	Inflorescence emergence	Beginning of flowering	Full flowering	End of flowering	Physiological maturity
Sowing dates						
10-Apr.	49 d	603 c	914 c	1087 b	1156 c	1720 a
30-Apr.	37 e	720 b	1067 b	1066 b	1153 c	1718 a
20-May	61 c	761 a	1093 ab	1191 a	1283 a	1680 b
9-Jun.	77 b	753 a	1105 a	1170 a	1232 b	1596 c
29-Jun.	92 a	725 b	831 d	943 c	990 d	1370 d
Varieties						
Golshid	54	589	795	916	990	1407
Galami	71	835	1149	1262	1335	1826
ANOVA (only for treatments)						
Sowing date (S)	**	**	**	**	**	**
Varieties (V)	**	**	**	**	**	**
S × V	**	**	**	**	**	**

Same letter at column are not different at $p \leq 0.05$; **Significant at $p \leq 0.01$.

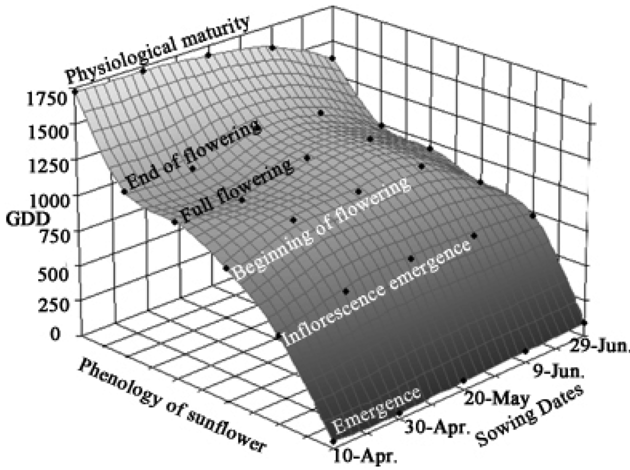

Figure 2: The response phenology of sunflower plant to growth degree days (GDD) at different sowing dates.

to system did not participate to complete emergence processes and parts of it contribute in hasten of the processes.

The result of GDD from inflorescence emergence to end of flowering revealed that the 20 May and 9 June sowing dates intercept significantly the high amount of GDD in comparison to the rest of sowing dates (Table 3 and Figure 2). The lowest GDD for flowering stages was belong to the 29 June sowing date. Although new breeding sunflower varieties classify as a day neutral plant, however, the finding emphases on relative sensitivity of the used varieties to photoperiod. Results imply that during shorter days the flowering of the sunflower is accelerated (Table 3). These observations support earlier findings of Aiken (2005) who reported that the sunflower plant had a short-day response to photoperiod at development to maturity stages. In all stages the Galami needed more GDDs to complete its growth and development periods compared to Golshid.

The early sown sunflowers attained maximum values to reach the physiological maturity stage (Tables 2 and 3). April sowing dates accumulate maximum values and at the rest of sowing dates the values were significantly decreased. Rethink about the relation between days and GDD for physiological maturity shows a positive trend (Tables 2 and 3) i. e. when a sowing date give more time to growth, the accumulated GDD increases. Whereas, this trend for inflorescence emergence and flowering is not true, and the trend is relatively negative. Thus, a more caution might be done at interpreting result of available days to get GDD for different stages.

The influences of sowing date, varieties and their interaction on the heliothermal unit were significant ($p \leq 0.01$). According to Table 4, this index predict same results for 30-Apr, 20 May and 9-Jun sowing dates for flowering and

Table 4: Helio-thermal unit (HTU) requirements for phenology of sunflower and yield affected by sowing dates.

Treatments	Helio-thermal unit					
	Inflorescence emergence	Beginning of flowering	Full flowering	End of flowering	Physiological maturity	Yield (kg. h^{-1})
Sowing dates						
10-Apr.	5024 d	8124 b	9869 b	10,577 c	14,979 b	2959 a
30-Apr.	6721 c	10,386 a	10,451 a	11,379 b	17,341 a	2726 a
20-May	7641 b	11,280 a	12,334 a	12,374 b	17,451 a	2730 a
9-Jun.	7903 a	11,780 a	12,480 a	13,151 a	16,835 a	2428 b
29-Jun.	7585 b	8720 b	9972 b	10,495 c	14,657 b	1895 c
Varieties						
Golshid	4478 b	6379 b	9389 b	10,655 b	14,423 b	2758 a
Galami	6514 a	11,128 a	13,098 a	14,056 a	17,080 a	2030 b
ANOVA (only for treatments)						
Sowing date (S)	**	**	**	**	**	**
Varieties (V)	**	**	**	**	**	**
S × V	**	**	**	**	**	**

Same letter at column are not different at $p \le 0.05$; **Significant at $p \le 0.01$.

physiological maturity stages. The lowest helio-thermal unit for inflorescence emergence was obtained by early sowing date. With delay in sowings, the value significantly increased up to 9-Jun. and afterwards decreased (Table 4). In terms of varieties, Galami needed more helio-thermal units to close its phenophases in compared to Golshid (Table 4).

Effects of sowing dates on the achene yield of sunflower were also significant ($p \le 0.01$) and with delaying in sowing dates the yield was remarkably decreased (Table 4). However, among the three first sowing dates the differences were not significant. While, the later dates caused a sharp decline in the achene yield of sunflower. This is supported by De La Vega and Hall (2002) study which reveal that sunflower (*Helianthus annuus* L.) yields are strongly reduced when normal sowing dates are delayed in Argentina. Similarly, Baghdadi *et al*. (2014) found that earlier sowing date give better seed yields than later sowing dates for native nut sunflower in North of Iran. Furthermore, Mirshekari *et al*. (2012) concluded that the high achene yield of oil sunflower is determined by an optimum temperature during flowering and early seed development. To reach to this purpose, they suggested April 20th sowing date in North West of Iran which is very close to recent study.

Relation between agro-climatological indices and the yield of sunflower at different sowing dates

To introduce a model/ or models which predicts the performance of sunflower at different sowing dates could be useful in the agronomic management practices and decision making. With respect to Figure 3, the fitted regression lines show relation between the grain yield of sunflower and the indices (Day, GDD and HTU). When the growth time to physiological maturity is reduced by sowing dates, the yield decreased (Figure 3a) and the losing rate was 22.2 kg h^{-1} per a day delay from the first sowing date. The high R^2 of the model illustrates that the model efficiently predicts the variables/ or the strength of the relationship between variables is very high (97 %). Almost the same results could be seen at relation between GDD and yield (Figure 3b). Considering about 14.2 average GDDs per day (the average GDD and time requirements at maturity stage are 1616 unit and 113 days, respectively. Thus, the average GDD returns per a day is about 14.2 units), the fitted model predicts ~22.4 kg reduction in yield per a day postponing at sowing dates (based on model Figure 3b; $22.4 = 1.58 \times 14.2$). However, the results for relation between yield and HTU did not show significant and strength relationship (Figure 3c).

Because of variation in the result of the produced models for GDD and HTU, the need for a comprehensive model which could uses for both indices seems to be necessary. Thus, the following model introduced to answer the questions. The sunflower development is completed by two distinct growth phases; vegetative and reproductive. Here, the study assumed that the first phase cover development from emergence through inflorescence emergence and the second from inflorescence emergence to physiological maturity. In other words, the inflorescence emergence was considered as a separation point. With delaying sowing dates both of the phases are negatively affected (Table 2), however; not by a same proportion. The reduced period (cycle) of the reproductive stages is more visible than of the vegetative stages. Thus, the balance between their ratios changes and the ratio of vegetative to reproductive stages increases. If the percent of yield loses (compared to first date) plots against the increased ratio of vegetative to reproductive stages for the indices, noteworthy results come out. Rearranged data lead us to a significant, positive and strength relationship between the changed ratios and indices (Figure 4). Increased vegetative to reproductive ratio which affected by sowing dates, increased grain yield losses. The trend for both indices is similar with an order 2 polynomial trendline.

The finding revealed importance of photosynthesis during reproductive stage. It indirectly implies that the post-anthesis assimilate production play a critical role in the seed filling and yield of sunflower. Thus, the reduction of accumulated GDD or

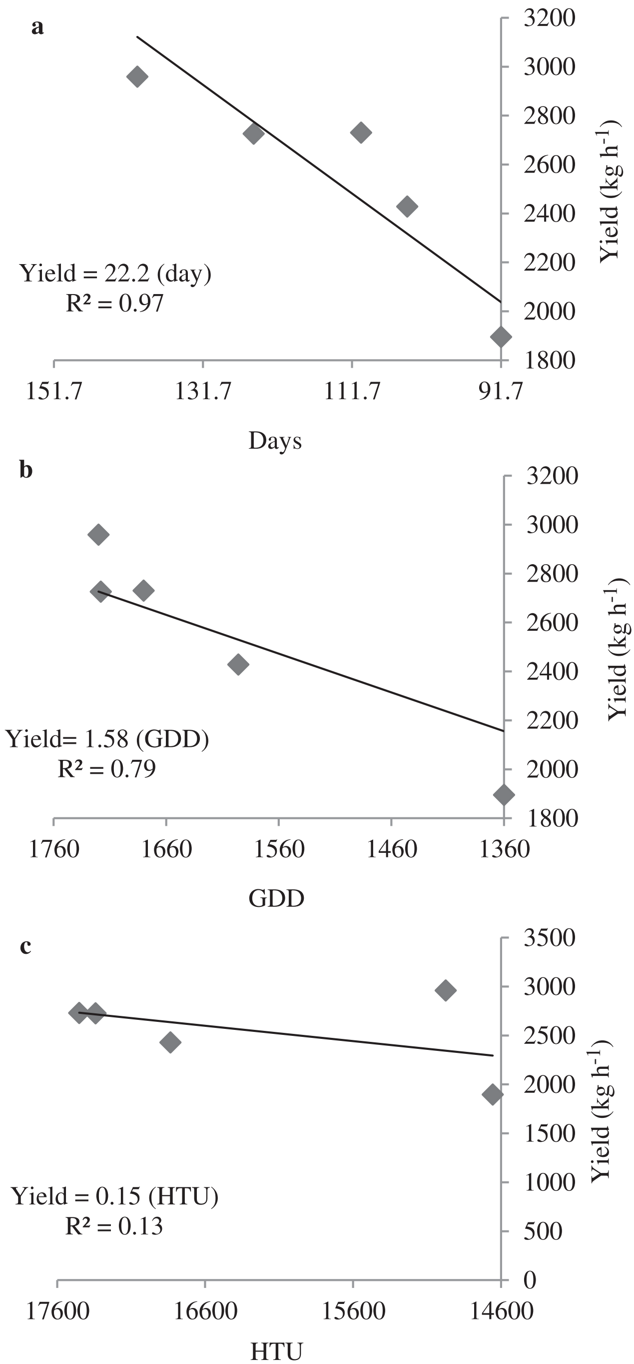

Figure 3: Relation between Agro-Climatological indices and the yield of sunflower at different sowing dates: a-relation between days and yield; b- relation between GDD and yield; c-relation between HTU and yield.

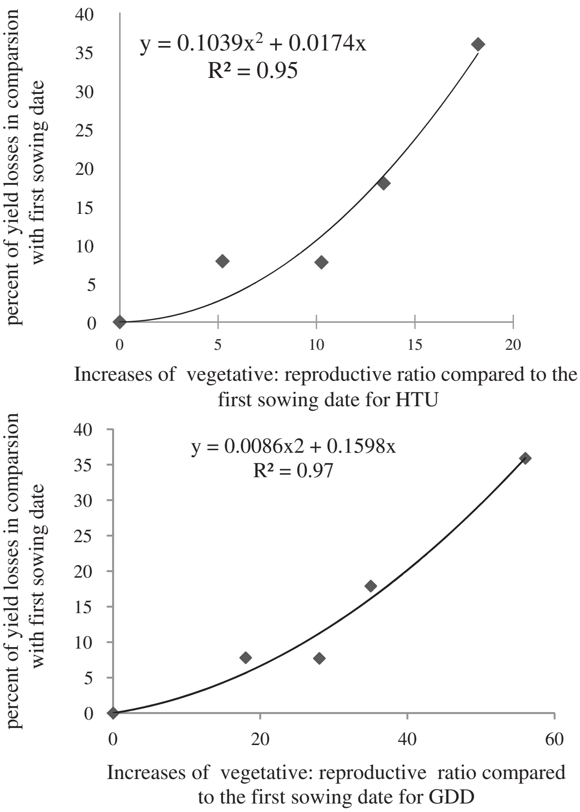

Figure 4: Relation between yield and changes in vegetative to reproductive growth ratio compared to first sowing date for growth degree days (GDD) and helio-thermal units (HTU).

HTU at reproductive stage as a result of delay in sowing dates consequently reduces the photosynthesis rate and its duration, considering that the photosynthesis is a function of temperature and light. Therefore, any reduction at photosynthesis rate will reduce the performance of the crop. It has been documented that extend of post-anthesis duration increases sunflower productivity (De La Vega *et al*., 2011; Ram and Davari, 2011). They suggested that due to completion of vegetative structures as active sources, the produced assimilates during reproductive stage are allocated to seeds as active sinks. Remobilization of reserves also is affected by sowing dates in crops. Based on Aynehband *et al*., (2011) studies, early sowing dates of wheat cultivars shows high value for mobilization reserves. It may be another reason of high productivity in early sowing dates. Generally, change in sink capacity, source capacity, leaf area duration and reserves remobilization causes a remarkably fluctuation of sunflower yield in different sowing dates. With respect to high relationship between achene yield and oil yield of sunflower varieties (Figure 5), the variation of oil yield is easily predictable based on the achene yields.

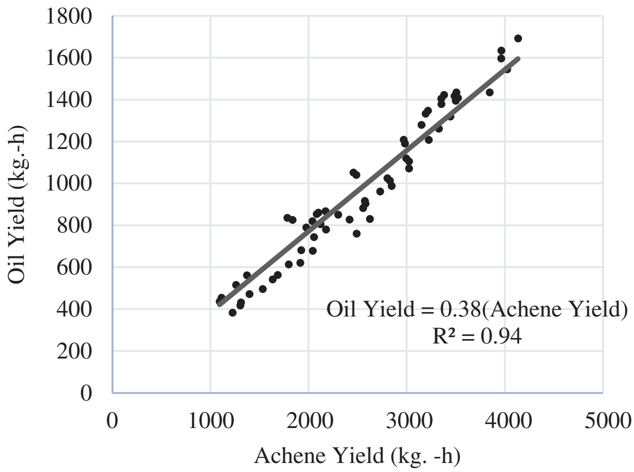

Figure 5: Relationship between achene yield and oil yield of sunflower (data derived from performance of 61 varieties/ or hybrids sowed in different Global Agro-Ecoecosystems since 2010).

Studies of Balalić *et al.* (2012) have been revealed that the oil content of sunflower achene is mostly influenced by the hybrid (69.6 %) followed by the year (10.3 %) and sowing date (6.8 %). Therefore, the low variations in oil content of seeds in different sowing dates allows us to use the main determinant of the oil yield i. e. achene yield to describe the effects of sowing dates on this trait by agro-climatological indices.

Conclusion

This finding illustrates the importance of sowing date in phenology and the yield of sunflower varieties. Modifying the sowing dates altered significantly the growth periods of sunflower varieties. Delayed sowing dates shortened the emergence, vegetative and reproductive stages. Because of low variation at the results of HTU, this index purposed to predict the phenophases especially the reproductive stages. The change in the vegetative to reproductive ratio could efficiently be used to predict the yield of sunflower at different sowing dates by both of GDD and HTU indices. The result also revealed that the short season variety was more susceptible than full season variety to sowing dates.

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