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Responses of hybrid and open pollinated sunflowers (*Helianthus annuus* L.) to defoliation

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Abstract

Leaf losses caused by different biotic and abiotic factors may considerably affect the yield and yield components of sunflower. A better understanding of the effects of defoliation on sunflower would improve the ability of farmers and crop insurance adjusters to evaluate the economic impact of leaf losses to sunflower. The objective of this study was to investigate the effects of defoliation applications on hybrid and open pollinated sunflower cultivars grown during the growing seasons of 2000 and 2001. The study assessed two sunflower cultivars (P64A52 and GK-70), three growth stages (R1, R3 and R5) and five defoliation levels (0, 25, 50, 75, and 100%). Significant differences among cultivars were observed for all characters except for days to maturity. Growth stages significantly affected days to maturity, seed filling percentage, the ratio of dehulled/hulled seed weight. When compared to cultivar and growth stages, the effect of defoliation applications was more pronounced. All agronomic characters were adversely influenced by increased levels of defoliation. Hundred percent defoliation reduced oil content by 26.3% and seed yield by 89% compared to the non-defoliated plots. Low levels of defoliation during the early reproductive growth stages (R1 and R3) did not result in a significant reduction in yield. The findings of the study showed that the extent of yield losses was related to the levels of defoliation.

Keywords: Sunflower, Defoliation, Leaf loss, Hail damage, Growth stage, Seed yield.
Abbreviations: R1- Reproductive stage 1; R3 - Reproductive stage 3; R5 - Reproductive stage 5 .

Introduction

The yield of crop plants is intimately associated with the photosynthetic rate of leaf and the active leaf area which plays an important role in carbon fixation. Consequently, formation of new leaves and stalks, and increased leaf area are of critical importance in determining the final performance of the plant (Gifford and Evans, 1981). Optimum leaf area should be produced to achieve maximum yield potential in crop yields. Yield reductions occur when leaf area is below optimum levels (Pereira, 1978). Leaf area may be adversely affected by a variety of factors including disease, pest, hailstorm, wind, herbicide, weed competition and high plant density. In such cases some cultivars cannot compensate for these losses and yield reductions occur, whereas other cultivars may be better able to tolerate the losses and may offset to some extent these negative effects. Defoliation affects the dry matter accumulation and seed yield, particularly by reducing the leaf area available for light interception and photosysnthesis. Previous study suggests that there is a strong association between light interception percentage and CO_2 fixation with the leaf area index (Boote *et al.,* 1985; Higley, 1992). The impact of leaf loss on the yield is closely related to development stages and defoliation levels. Previous studies conducted on sunflower confirmed this finding (De Beer, 1983; Schneiter *et al.,* 1987; Schneiter and Johnson, 1994). These studies showed that defoliation resulted in significant yield losses. Sunflower can compensate for defoliation damage at certain growth stages by increasing leaf area or delaying senescence. Effect on yield of defoliation in sunflower is dependent mainly on the time when defoliation occurs, but also on the amount of leaf defoliated. On the other hand, suitable cultivar selection also plays an important role in improving leaf area recovery after defoliation (Schneitner *et al.,* 1987; Moriondo *et al.,* 2003). Farmers are frequently faced by the risks caused by natural hazards, such as frost, floods, hail, insects, plant diseases, and drought, and constantly have to deal with such unfavorable conditions. In such cases, crop insurance can be an attractive option for managing these risks and also induces farmers to undertake riskier farming practices. Sunflower, the most important oil crop grown in Turkey, is easily affected by biotic and abiotic stress factors because it is broad-leaved; thus reductions in the yield due to particularly leaf losses occur. Estimates of the extent to which leaf losses may affect yield are of great importance in establishing a compromise between insurance companies and farmers. However, defoliation effects on sunflower have so far been studied only to a limited extent. The aim of this study is to examine the responses of hybrid and open-pollinated sunflower cultivars to the different levels of defoliation applied at the R1, R3, and R5 growth stages, and to determine the relationship between the leaf losses and yield reduction in these cultivars.

Material and methods

Plant and soil materials

The field research was conducted at experimental site of Ataturk University Agricultural Extension and Research Center at Erzurum (1850 m elevation), Turkey, during 2000 and 2001 on an a clay loam soil. The previous crop was barley (*Hordeum vulgare* L.) in 2000 and 2001. Air temperatures and precipitation values were collected from a meteorological station about 2 km north of the test site, and are presented in Figure 1. Preplant soil samples were taken from the 0- to 0.30-m and analyzed for residual nutrient levels. Soil propertie s in the depth were pH of 7.7 to 7.6,

Table 1. Influence of cultivar, growth stage, and defoliation levels on yield and some agronomic characters of sunflower cultivars grown in Erzurum in 2000 and 2001

	Treatments	*df*	Days to maturity (d)	Plant height (cm)	Head diameter (cm)	Seed filling percentage (%)	Ratio in dehulled/hulled seed weight (%)	1000 seed weight (g)	Seed yield (kg/ha^{-1})	Seed oil concentration (g kg$^{-1)}$
Year (Y)	2000		124.6	96.9 b	13.9 b	89.1	34.7 b	56.8	1489.9 b	433 a
	2001		124.4	131.1 a	16.7 a	90.6	35.7 a	55.7	1630.0 a	413 b
Cultivar (C)	P64A52		124.6	110.7 b	15.9 a	91.2 a	35.8 a	58.0 a	1639.2 a	413 b
	GK-70		124.3	117.2 a	14.7 b	88.5 b	34.6 b	54.4 b	1480.8 b	432 a
Growth stage (G)	R1		123.5 c	112.2	15.4	91.9 a	35.4 a	56.9	1563.3	423
	R3		124.1 b	114.2	15.1	87.4 b	34.4 b	55.3	1525.8	423
	R5		125.7 a	115.6	15.4	90.3 a	35.8 a	56.4	1590.7 a	421
Defoliation levels (D) (%)	0		131.1 a	122.3 a	17.7 a	97.6 a	41.5 a	65.2 a	2362.0 a	457 a
	25		126.1 b	117.0 b	16.7 b	96.0 a	37.3 b	62.4 a	1993.3 b	440 b
	50		123.9 c	116.2 b	16.1 c	95.7 a	35.5 c	61.2 b	1780.6 c	440 b
	75		121.6 d	112.7 b	14.6 d	92.2 b	32.6 d	55.4 c	1412.4 d	438 b
	100		119.5 e	101.8 c	11.3 e	67.9 c	29.1 e	36.9 d	251.5 e	337 c
CV (%)			0.75	8.31	7.83	6.84	7.00	10.90	10.83	4.36
Analysis of variance	Y	1	ns	**	**	ns	**	ns	**	**
	C	1	ns	**	**	**	**	**	**	**
	G	2	**	ns	ns	**	**	ns	ns	ns
	D	4	**	**	**	**	**	**	**	**
	Y x C	1	ns	ns	ns	ns	ns	ns	ns	**
	Y x G	2	**	ns	ns	ns	**	ns	*	**
	Y x D	4	**	**	**	ns	**	**	**	*
	C x G	2	ns	ns	ns	ns	ns	ns	**	ns
	C x D	4	**	*	ns	ns	**	ns	**	**
	G x D	8	**	ns	**	**	**	*	**	**
	C x G x D	8	**	ns	**	ns	ns	**	*	**
	Y x C x G	2	ns	*	*	ns	ns	ns	**	ns
	Y x C x D	4	**	*	ns	ns	*	ns	*	**
	Y x G x D	8	ns	*	*	*	**	*	**	*
	Y x C x G x D	8	ns	ns	*	ns	*	*	**	*

*, ** Significant at the 0.05 and 0.01 level, respectively. For each main effect, values within columns followed by the same letter are not significantly at P=0.05. CV, coefficient of variation; NS, nonsignificant.

organic matter of 0.60 to 0.83%, total Kjeldahl N of 0.30 to 0.42 g kg^{-1}, available P of 51.7 and 49.6 kg ha^{-1}, and available K of 1649 and 1594 kg ha^{-1}, respectively, for the growing season 2000 and 2001.

Treatments consisted of a factorial combination of two different sunflower genotypes (GK 70, open pollinated; P64A52, hybrid), and five defoliation levels (0, 25, 50, 75 and 100%) applied at three development stages (R1, R3, and R5). The growth stages are defined as follows (Schneiter and Miller, 1981); R1: the terminal bud forms a miniature floral head rather than a cluster of leaves. When viewed from directly above the immature bracts form a many-pointed star-like appearance. R3: the immature bud elongates more than 2.0 cm above the nearest leaf. R5: this stage is the beginning of flowering.

Experimental design and measurements

Plant defoliation was performed by removing with shears at defoliation time. For the 100% defoliations, all leaves were cut off and 0% defoliation was used as control treatment. Treatments for 25% defoliation were imposed by cutting off one out of every four leaves from bottom to top on sunflower plants; treatments for 50% defoliation by cutting off two out of every four leaves; treatments for 75% defoliation by cutting three out of every four leaves. The experimental design was a randomized complete block with a factorial arrangement of treatments replicated three times. The plots were 2.8 m wide and 6 m long and consisted of 4 rows spaced 0.7 m apart. Seeding was done on 11 May and 17 May during 2000 and 2001, respectively. Three seeds were sown in each hill, and the plots were hand-thinned to one plant per hill when the plants were at the 4 to 6-leaf stage. Before sowing, nitrogen fertilizer in the form of ammonium sulfate was broadcast and incorporated at a rate of 100 kg ha^{-1}. All plots received 80 kg P_2O_5 kg ha^{-1} as triple superphosphate before sowing (Ulgen and Yurtsever, 1995). Weeds between rows were controlled mechanically. Weeds in the rows were removed by hand. All plots were furrow irrigated regularly to avoid drought stress. A total of 4 irrigations each year were applied. The sunflower plants were hand-harvested at the stage of physiological maturation when the back of the head has turned from green to yellow and the bracts are turning brown. At harvest, ten plants from each plot were selected to determine days to maturity, plant height, head diameter, seed filling percentage, thousand-seed weight, and the ratio of dehulled/hulled seed weight. At maturity, head samples for yield were harvested from the two center rows of each plot, dried and threshed mechanically. Seed yield was adjusted to a 10.0% moisture basis. Seed oil concentration was determined by the Soxhlet apparatus.

Statistical Analysis

A combined year analysis of variance was conducted on all data using the SAS package (SAS Institute, 2001). For statistical analyses, cultivar, growth stage and defoliation level effects were considered fixed. When the *F*-test indicated statistical significance at the P = 0.05 level, the protected least significant difference (Protected *LSD*) was used to separate the means. To describe the impact of defoliation for seed yield, regression analysis for determination of linear, quadratic, and cubic relationships were done with PROC GLM. Linear, quadratic and cubic components of each regression equation were successively tested for significance and included in the equation if they significantly reduced the residual sum of squares ($P < 0.05$). Regression analyses were conducted on data points that were means of three replications.

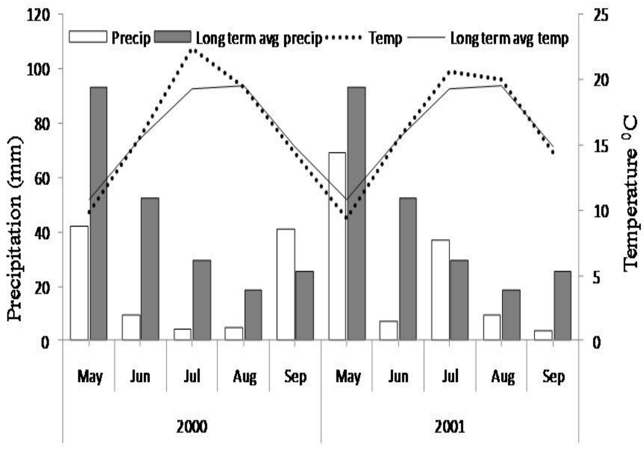

Fig 1. Monthly mean air temperature and precipitation during the growing season for each year of the study and 71-year average at Erzurum, Turkey.

Results and discussion

Average monthly air temperature and precipitation during the 2000 and 2001 growing seasons and for the 71-yr period are presented in (Fig 1). Growing-season precipitation in both study years (101.1 mm and 125.6 mm for 2000 and 2001, respectively) was considerably less than the long-term average (about 218.5 mm) (Fig 1). Average monthly temperatures (15.9 ^{0}C) during the 2001 and the 71-yr average were below the 2000 growing season (16.3 ^{0}C). The results clearly indicate that the total precipitation of growing seasons in both study years was unfavorable for sunflower growth.

Yield components

Year and cultivar did not have a significant effect on days to maturity, whereas the impact of growth stages and defoliation levels on this trait was significant (P< 0.01). On the other hand, effects of year x growth stage, year x defoliation level, cultivar x defoliation level, growth stage x defoliation level, cultivar x growth stage x defoliation level and year x cultivar x growth stage interactions on days to maturity were significant (Table 1). The responses of hybrid (P64A52) and open-pollinated (GK-70) genotypes to defoliation treatments were similar in days to maturity. Maturity of cultivars was more affected by treatments applied at the two later growth stages and the latest maturity was detected in R5 (125.7 days). The results suggest that the days to maturity varied according to defoliation levels; days to maturity were longer in non-defoliated plots. While plants in control plots reached maturity in 131.1 days, the fully defoliated plants matured in 119.5 days (Table 1). Taj *et al.,* (1998) determined that sunflower reached maturity quicker in response to increasing levels of defoliation. Similarly, the results of the present study also suggest that plants reached maturity earlier as a result of photosynthetic stress resulting from defoliation. The impact of year, cultivar and defoliation levels on plant height was significant (P< 0.01). Similarly, significant year x defoliation level, cultivar x defoliation level, year x cultivar x growth stage, year x cultivar x defoliation level, and year x growth stage x defoliation level interactions were also detected for plant height (Table 1). Plants were shorter in 2000 (96.6 cm) than in 2001 (131.1 cm). This variation in the plant heights in different years may be due to climatic differences. The tallest plant height was observed in the second year when the greatest rainfall was recorded during the growing season (Fig 1). Average plant heights measured for P64A52 and GK-70 were 110.7 and 117.2 cm, respectively. This difference between cultivars in plant height seems to be under genetic control. Although the plant height was less in R1 and R3 than in R5, the effect of growth stages on plant height was no significant. Plant height was significantly reduced as a result of increased levels of defoliation (Table 1), as was indicated previously (Schneiter *et al.,* 1987; Taj et *al.*, 1998). The results also showed that plant height was significantly reduced by 100% defoliation compared to the non-defoliated plants. Decreases in plant height with the defoliation may be due to reduction in plant growth and canopy and thereby reduced competition for light. All these changes result in the reduction in photosynthetic area of plant (Schneiter *et al.,* 1987). Head diameter of sunflower plants is one of the important yield components. For this reason, large head diameters may be desirable by producers. The growth stages, R1, R3, and R5, did not have a statistically significant effect on head diameter. In contrast, the effect of year, cultivar and defoliation levels were significant ($P< 0.01$). In addition, year x defoliation level, growth stage x defoliation level, cultivar x growth stage x defoliation level, year x cultivar x growth stage, year x growth stage x defoliation level and year x cultivar x growth stage x defoliation level were found to have significant impacts. Head diameter did not vary across growth stages and larger heads were obtained in the year 2001 (Table 1). These findings can be explained by the fact that total rainfall during July and August of the second growing season was higher than during the first year (Fig 1). In the second year (2001), plants experienced less water stress during the months when head growth and flowering occur. Head diameter is largely affected by environmental factors rather than genetic structure (Fick, 1978). Other researchers have also observed that head diameter showed differences in different years depending on climatic factors (Hashim and Schneiter, 1987; Ozer *et al.,* 2003). The head diameters of the cultivars used in the experiment were found to be 15.9 and 14.7 cm, respectively. This difference between cultivars for head diameter may be due to genetic differences. Increasing levels of defoliation resulted in a decrease in head diameter (Table 1). The largest head diameter, averaged across years and cultivars, was measured in non-defoliated plots. Previous studies also reported that increased defoliation levels significantly reduced the head diameter (Lal and Singh, 1997; Taj *et al.,* 1998; Shafiullah *et al*., 2001). As can be seen in Table 1, seed filling percentages in 2000 and 2001 were similar to each other, and the difference between them was statistically insignificant. Except for growth stage x defoliation level and year x growth stage x defoliation level, the seed filling percentage was significantly influenced by other variation sources. When averaged across the years, the seed filling percentage was 91.2 and 88.5% for P64A52 and GK-7, respectively. Analysis of variance showed that cultivar had a significant effect on seed filling percentage (Table 1) ($P< 0.01$). Source or sink dependence of seed filling may change with growth stages. (Alkio *et al.,* 2003).The responses of seed filling percentage to defoliation in the successive growth stages, R1, R3, and R5, (91.9, 87.4 and 90.3%, respectively) significantly differed ($P< 0.01$) (Table 1). The results of the present study were not consistent with the

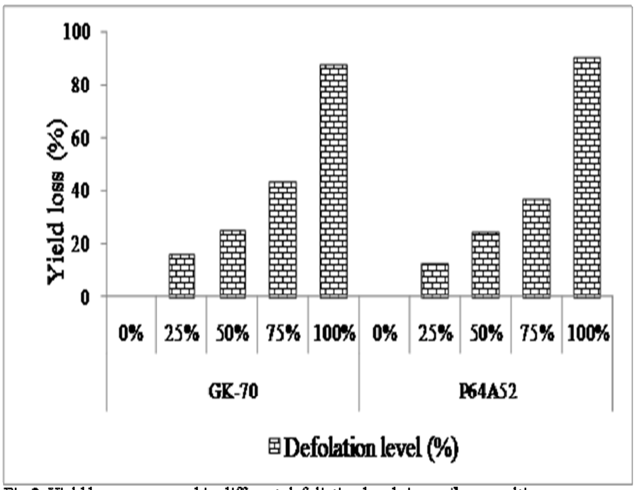

Fig 2. Yield losses measured in different defoliation levels in sunflower cultivars.

findings of Pereira (1978), who reported that defoliation in early growth stages reduced the seed filling percentage. The inconsistency in results may be due to different cultivars and defoliation practices. The seed filling percentage varied according to defoliation levels. The highest seed filling percentage was obtained in the control plots with an average of 97.6, while the lowest seed filling percentage value (67.9%) was observed when the plants was completely defoliated (100%). The defoliation level significantly affected seed filling percentage ($P< 0.01$). As the leaves on the middle section of the plant have broad surfaces and greater photosynthetic activity, effect of defoliation levels was highly significant (Abbaspour *et al.,* 2001; Valizadeh *et al.,* 2003). As can be seen from Table 1, there were significant differences in the ratio of dehulled/hulled seed weight for year, cultivar, growth stages and defoliation levels ($P< 0.01$). Other sources of variation except for year x cultivar, cultivar x growth stage, cultivar x growth stage x defoliation level, and year x cultivar x defoliation level x growth stage interactions also caused significant effects. Averaged across the genotype, growth stage and defoliation levels, the ratio of dehulled/hulled seed weight were 34.7% and 35.7% for 2000 and 2001, respectively. The higher ratio of dehulled/hulled seed weight in the second growing season appears to be due to more favorable climatic conditions, particularly rainfall amounts (Fig 1). The ratio of dehulled/hulled seed weight varied between cultivars. The ratio of dehulled/hulled seed weight of the hybrid cultivar P64A52 was higher than the open pollinated cultivar GK-70. These differences may be explained by genetic differences between cultivars. The growth stages least affected by defoliation practices were R1 and R5 (35.4% and 38.8% respectively) whereas the stage most affected was R3 (34.4%). Increased defoliation levels led to the reductions in the ratio of dehulled/hulled seed weight, probably due to a reduction in the photosynthetic area. The 100% defoliation reduced the ratio of dehulled/hulled seed weight by 29.87% relative to the control plots. Analysis of variance for 1000-seed weight is shown in Table 1. As can be seen from this table, there were no significant effects of year and growth stages on 1000-seed weight, whereas cultivars, defoliation levels, and the year x defoliation level, growth stage x defoliation level, year x growth stage x defoliation level, cultivar x growth stage x defoliation level, year x growth stage x defoliation level and year x cultivar x growth stage x defoliation level interactions had a significant influence on this trait. P64A52 had greater 1000-seed weight (58.0g) than GK-70 (54.4g). The 1000-seed weight, one of the most important yield components, is affected by the genotype and the cultivation practices applied (Dixon and Lutman, 1992; Esechie *et al.,* 1996;

Iqbal *et al.,* 2009; Karaaslan *et al.,* 2010). In our study, 1000-seed weight ranged from 65.2 g at the non-defoliated treatment to 36.9 g at the 100% defoliated treatment. This result points out a dramatically reduction in seed weight as a result of defoliation application. On the other hand, seed weight was not affected by the growth stages (R1, R3, and R5).

Seed yield

Effects of growth stages and defoliation treatments on seed yield varied significantly with years, and this caused significant year x growth stage and year x defoliation level interactions. In the first year of the study compared to the second year, lower seed yields were obtained (Table 1). For seed yield, cultivar x growth stage, cultivar x defoliation levels, growth stages x defoliation level interactions were statistically significant. These interactions may be explained by the differences in the response of sunflower genotypes to growth stages and defoliation levels. Significant differences occurred between the study years for seed yield. All factors and interactions for seed yield were statistically significant with the exception growth stage and year x cultivar interaction (Table 1). The higher rainfall during the second year of the study (Fig 1) enabled greater seed yield compared with the first year (1489.9 and 1630.0 kg ha^{-1} for 2000 and 2001, respectively). The seed yield responses of cultivars to the treatments were different, and the hybrid cultivar P64A52 produced more seed yield by 10.6% relative to the open-pollinated cultivar GK-70. This was not surprising as recent released cultivars, particularly hybrids, have more seed yield potential than the older ones. Defoliation treatment at different growth stages affected seed yield values but this difference was not statistically significant (Table 1). As can be seen in Table 1, the lowest seed yield among the growth stages occurred when defoliation was applied at the R1 and R3 stages. As sunflower can compensate for leaf losses during the earlier growth stages, leaf losses during the early stages of growth have less effect on the seed yield (Schneiter *et al.,* 1987). However, previous studies have shown that greater yield loss occurred with different growth stages, with the highest losses in the R3 and R4 (Dawson *et al.,* 1965), R2 (De Beer, 1983), R3 growth stages (Schneiter *et al.,* 1987; Muro *et al.,* 2001). This difference among the growth stages may be due to the fact that the studies were conducted using different cultivars, various locations as well as different levels of defoliation (De Beer, 1983; Muro *et al.,* 2001). Seed yields decreased declined sharply with increasing defoliation levels (Table 1), since plant leaves are major source of photosynthesis (Barimavandi *et al.,* 2010). The effect of defoliation levels on seed yield was statistically significant ($P< 0.01$) (Table 1). Losses in seed yield for the defoliation levels of 25, 50, 75, and 100% relative to non-defoliated plots were 15.6, 24.6, 40.2 and 89.4%, respectively, corresponding to a much greater reduction in seed yield compared to the study of Schneiter *et al.,* (1987) (Fig 2). Previous studies (Schneiter *et al.,* 1987; Muro *et al.,* 2001; Abbaspour *et al.,* 2001) confirmed that increased defoliation levels resulted in a decrease in seed yield of sunflower. Leaf loss leads to a reduction in photosynthetic area and consequently causes to reduce seed yield. Therefore, sunflower, the extent to which seed yield is affected by leaf losses depends on levels of defoliation. Maximum leaf area development is necessary for full interception and conversion of solar radiation to photosynthate and carbohydrate reserves in order to support maximum reproductive development and seed growth (Shanahan and Nielsen, 1987; Abdi *et al.,* 2007). Regression analysis was used on the combined data (both years) to relate values of the five defoliation rates to seed yield. A highly significant relationship existed between increasing rates of defoliation rates and seed yield (Fig 3). The shape of the relationships among defoliation levels and seed yield was characterized by significant quadratic trend (R^2= 0.963, Y= 2271.786 + 0.678X – 0.1989X^2). The relationships for the 2-yr data are illustrated in Fig 3.

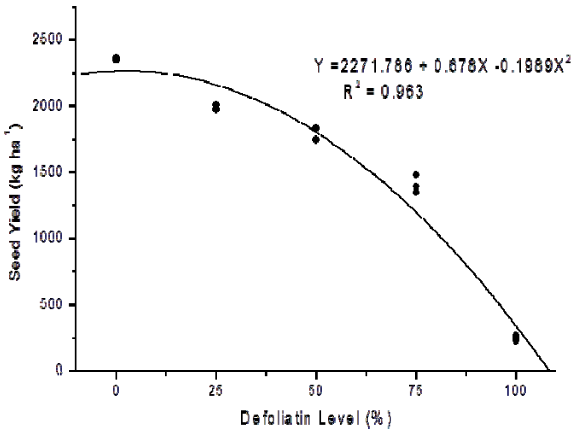

Fig 3. Relationship between seed yield and defoliation level in sunflower for the 2-yr data. Each point is the mean of three replications for treatment combinations.

Seed oil concentration

Results of analysis of variance showed significant differences ($P< 0.01$) between the study years, cultivars and defoliation levels for oil concentration (Table 1). Similarly, other interactions, except for cultivar x growth stage and year x cultivar x growth stage, had significant effects. Averaged over the cultivars, growth stages, and defoliation levels, oil concentration (433.0 g kg^{-1}) in the first year was higher than that in the second year (413.0 g kg^{-1}) (Table 1). Oil concentration of sunflower cultivars is significantly affected by environmental conditions during seed filling period. Low temperature and exposure to light during in this period result in reduced oil concentration (De la Vega and Hall, 2002). The cultivars examined in this study, P64A52 and GK-70, had a 413.0 and 432.0 g kg^{-1} oil concentration, respectively. Defoliation treatments at different growth stages did not show a significant difference. As the levels of defoliation changed, there have also been changes in the oil concentrations depending on the cultivars. The highest oil concentration (457.0 g kg^{-1}) was obtained in non-defoliated plots, whereas the lowest oil concentration (337.0 g kg^{-1}) was detected at the 100% defoliation level. No significant differences in oil concentration were observed among plants defoliated at the levels of 25, 50 and 75% (440.0, 440.0 and 438.0 g kg^{-1} oil concentration, respectively) (Table 1). The results indicate that a 100 % defoliation considerably affected oil concentration relative to the non-defoliated and other defoliated plots. As seen in Table 1, there were significant year x cultivar, year x growth stage and year x defoliation level interactions for oil concentration, probably because of the occurrence of the varying responses of cultivar, growth stage, and defoliation levels to years. On the other hand, the fact that the effect of defoliation levels on oil concentration differed with cultivars tested led to a statistically significant interaction between cultivar and defoliation level. The effect of growth stages on oil concentration differed depending on defoliation levels, and this caused significant growth stage x defoliation level interaction.

Conclusion

Significant yield losses may be encountered in sunflower plants, due to natural conditions such as hailstorms, frost, drought, disease or pest and these losses often result in a reduction in yield. Predictions of the extent to which leaf losses may affect yields are of great importance in establishing levels of compensation for producers, as this establishes a compromise between insurance companies and farmers. The results of this study showed that defoliation applications could considerably affect yield and other agronomic traits of sunflower depending on cultivar, growth stage and defoliation level. Using the equation identifying the relationship between yield and defoliation level, defoliation damage caused by hail and pest could be estimated. Results from this research provide producers and insurance adjusters a means to assess the damages caused by hail, pest etc. in sunflower.

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