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Responses of Sunflower Yield and Grain Filling Period to Plant Density and Weed Interference

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Abstract: In order to study the effects of plant density and weed interference on sunflower yield and its attributes and also to determine the response of grain filling period in sunflower to plant density and weed interference, a factorial experiment was carried out using randomized complete block design with 3 replicates at research site of university of Mohaghegh Ardabili. Treatment were three levels of plant density (6, 8 and 10 plant m^{-2} as D_1, D_2 and D_3 respectively) and 2 levels of weed control (weedy and weed free). Results indicated that plant density had significant effects on sunflower growth characteristics. The highest grain yield obtained from D_2. The highest 1000-grain weight, grain per head, stem and head diameter, dry matter, yield per plant and harvest index recorded at D_1, while D_3 showed the highest values of plant height and percentage of hollow grains. The levels of weed control did not affected sunflower yield and yield attributes significantly (except number of grain per head) that probably due to soil salinity, weed genus, planting row space, density and high tolerance of sunflower to weeds. The highest rate and duration of grain filling recorded at D_1 in both levels of weed treatments. Furthermore, D_1 showed the highest mean of final grain weight, that probably due to effects of density on light interception by canopy.

Key words: Density, grain filling, sunflower, weed interference, yield

INTRODUCTION

Sunflower (*Helianthus annuus* L.) is one of the most important oil crops in the world, because it offers advantages in crop rotation systems, such as high adaptation capability, suitability to mechanization and low labor needs. Plant density is one of the most important cultural practices determining grain yield, as well as other important agronomic attributes of crop. Stand density affects plant architecture and alters growth and development pattern.

Density is one of the most important managment factors that indicates amount of radiation intercepted per plant. Therefore, the response of grain yield to density can be analyzed in term of the effect on the amount of intercepted radiation (Fernando *et al*., 2002). Degenhardt and Kondra (1981), Morrisson *et al*. (1990), Van Deynze *et al*. (1992), reported that low plant densities increased production of biomass and grain per plant, because of reduced competition among individual plants with the associated benefit of improved canopy radiation interception. The factors responsible for increasing grain yield under low planting densities to positive responses of yield components, such as head diameter, grain number per head and grains weight. Under high population densities at least one, if not several key yield components may impair grain yield potential and therefore, result in lower yields.

Holt and Zentner (1985), indicated that reduction of harvest index in sunflower is one of the most common features associated with high density. Low harvest index is caused by either small or poorly filled grains or in combination of both. Other study with sunflower, referred to delay in flowering resulting from crowding (Gubbels and Dedio, 1988).

Higher fruiting unit/area, observable in high planting densities, provides increased grain yield as apposed to fewer fruiting unit/area in lower densities. Studies on the effect of plant density on yield give inconsistent results, suggesting that the optimum plant density for yield depends upon the cultivar and the environment (Prunty, 1981). For instance, Wade and Foreman (1988), found that the achene yield in sunflower increased to maximum with increasing plant density and remained constant at even higher plant density under favourable environmental conditions. Under less favourable conditions however, the achene yield started to decline at very high plant density.

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Significant yield loss in oil crops is mainly due to weed competition, allelopathic effects and contamination of harvested products. Weed competition is the greatest early in the season, because weeds have a tendency of out growing the crop if they are not controlled early in the growth period (Gesimba and Langat, 2005). By the weed infestation regulates the exploitation of radiation, it can be affected as well as the dry mass yield and quantity of nutrients gained from the unit area (Yelverton and Coble, 1991; Tollenaar, 1992; Stanojevia, 2000). Weed infestation is one of the main causes of low sunflower yield. Daugovish *et al.* (2003), found that full weed competition reduced the yield of sunflower by 58%.

Besides quantitative effects on yield, weeds deteriorate the quality of products through the physical presence of their seeds. Weed density, type of the weeds, their persistence and crop management practices determine the magnitude of yield loss (Riaz *et al.*, 2006).

The use of herbicides however, is too uneconomical in addition to resulting in serious ecological and environmental problems such as, increase in herbicide resistance in the weeds, ground water contamination and environmental pollution. In fact, none of the weed control methods is the best under all conditions (Riaz *et al.*, 2006). Plant densities can affect on weed population. Studies by Gesimba and Langat (2005), on variable plant population influence on competitive relation showed that, in bushy stand of soybean, yield is less and permit increase weed growth. So, there is a need to make a comparative study of different weed management techniques in sunflower and to develop an integrated weed management approach, which should be efficient, cost effective and environmentally safe.

The grain filling of annual plants such as sunflower is a fundamental process for the reproduction and total harvestable yield of the species. Both weed infestation and high plant density adversely affect this process. The primary value of fitness for plants is to procreate grain as the base of new generation. In optimal condition the redundant energy of plant is drained to the growth of achene. But optimal environmental conditions for plant production could hardly be achieved. The interaction between the environment like weed infestation and cultural practices such as density may have a forceful affect on the grain filling process (Csikasz *et al.*, 2002).

The objectives of this study were to determine the effects of different plant densities on yield and its attributes, weed interference effects on yield components and effects of weeds and density on grain filling duration in sunflower.

MATERIALS AND METHODS

Field experiment was conducted out in Ardabil (lat 38° 15′ N; long 48° 15′ E; Alt 1350 m), Iran, at research site of university of Mohaghegh Ardabili in 2007. Climatically, the area placed in the semi-arid temperate zone with cold winter and hot summer. Average rainfall is about 400 mm that most rainfall concentrated between winter and spring. The soil was silty loam with EC about 3.61 ds m^{-1}, pH about 8.20 and SP about 46%.

The type of design was based on randomized complete block in factorial arrangement with three replications. Treatments were three densities containing, 6 (D_1), 8 (D_2) and 10 plant m^{-2} (D_3) plus weedy check (no-weeding) and weed free (hand-weeding) as control. Row spacing was 50cm and distances between plants in the rows were 30, 25 and 20 for D_1, D_2 and D_3 sowing densities, respectively. In weed free treatment, the first manual hoeing was done 25 days after sowing while the rest of three manual hoeings were done at 30 days interval to keep the crop weed free for entire growth period.

Plot size was 7×3 m with four rows per plot. Plots were separated by 1.5 m and blocks by 2.5 m unplanted distances. The area was mold board-ploughed and disked before planting. Sunflower seeds were planted in the first week of June. Three seeds were sown per hill and later thinned to one plant per hill. Thinning was done at 3-4 leaves stage. The field was immediately irrigated after planting. All other agronomic operations except those under study were kept normal and uniform for all treatments.

The mainly growing weeds in the experimental area were *Salsola kali*, *Convolvulus arvensis* L., *Amaranthus spinosa*, *Cirsium arvensis*, *Lactuca scariola*, *Centura cyanus* and *Chenopodium album.*

Traits such as plant height, head diameter, stem diameter, 1000-seed weight, number of hallow grains and grains per head measured by randomly selecting 3 plants in each plot. Harvest sample was taken of 3.0 m long from the two middle rows for measuring total dry mater, grain yield and other yield attributes.

The grain filling duration determined after flowering by sampling of 3 head per plot that were taken from all plots at 3-4 days intervals. Then the dry matter of 100 grain was determined. Increase of grain weight in grain filling period was calculated by using below equation:

$$GW = \begin{cases} a + gfr(daa), \ldots\ldots if \ldots daa < p_m \\ a + gfr(p_m), \ldots\ldots\ldots if \ldots daa \geq p_m \end{cases}$$

where, GW is the grain weight, a is the GW-intercept, gfr is the slope of grain weight and days after anthesis (daa) relationship until physiological maturity that indicates grain filling rate, daa is the days after anthesis and p_m is the day that occurs physiological maturity. Analysis of variance and regression were performed using MSTAT-C and SAS computer software packages. The main effects and interactions were tested using the Duncan's multiple range test.

RESULTS AND DISCUSSION

Density: Density had significant effects on the growth characteristics of sunflower (Table 1). Thousand-grain weight (TGW) is an important yield parameter (Kaya *et al*., 2007). Both of 1000-grain weight and the number of grains per head decreased significantly with increasing plant density. The highest grain weight (140.9 g) was found at D_1 (6 plant m^{-2}), followed by D_2 (8 plant m^{-2}) and D_3 (10 plant m^{-2}) with 119.8 and 102.1 g, respectively (Table 2). Increasing 1000-grain weight was likely attributed to bold grains as a result of more nutrition at low densities. These results are in accordance with the work of Rizzardi and Kuffel (1993).

Maximum number of achenes (552.2) was observed at D_1, followed by D_2 (447.3) and D_3 (383.8), respectively (Table 2). Number of grains per head plays an important role to determining grain yield. More number of grains per head got an advantage of larger head size. Similar results were also reported by Rizzardi and Kuffel (1993).

Maximum plant height (227.5 cm) was achieved at D_3 (10 plant m^{-2}) and followed by D_2 (211.8 cm), while minimum plant height (187.5 cm) was recorded at D_1, (Table 2). Taller plants at higher densities may be due to inter plant competition for light and aerial resources as reported by Gubbels and Dedio (1988), in sunflower and Blumenthal *et al.* (1988), in soybean. It is probably related to hormonal changes in plant tissues.

As plant population increased, head and stem diameter decreased significantly. The lowest density had the widest head and stem diameter (Table 2). These results demonstrated that increasing plant density resulted in a decrease in head and stem diameter, probably caused by competition for available space, as has been observed in rapeseed (Morrisson *et al*., 1990). Head diameter is an important yield component in sunflower. The crop planted at the lowest density (D_1) had the largest head (21.07 cm) and stem diameter (28.88 mm), but at the highest density (D_3) produced the smallest head (14.00 cm) and stem (24.07 mm). D_2 and D_3 did not show statistically difference (Table 2).

Maximum percentage of hollow grains (31.67%) was observed at D_3. D_1 showed minimum percentage of hollow grain (16.5%). At D_2 percentage of hollow grains was 21.33%, but D_1 and D_2 showed no statistically difference (Table 2). High percent of hollow grains at D_3 may be related to high competition and less assimilates under this density.

The highest dry matter (239.3 g) was recorded at D_1 that followed by 232.6 g at D_2, which was statistically similar to D_1. The lowest dry matter (182.1 g) was obtained from D_3, (Table 2). Low densities promoted dry matter accumulation of plant which was attributed to more nutritional area and aerial resources.

Grain yield per plant at harvest decreased significantly with increasing plant density. This is primarily a result of declining number of grains per head that related to head diameter.

Maximum grain yield per plant (68.02 g) was observed at D_1, followed by D_2 (55.85 g), while D_3 (40.78 g) showed minimum grain yield per plant (Table 2). Degenhardt and Kondra (1981) and Blumenthal *et al.* (1988), reported the same results.

Table 1: Analysis of variance for the effects of crop density and weed interference on studied traits of sunflower

		MS									
S.O.V	DF	1000 grains weight	grain/head	Yield	Height	Stem diameter	Head diameter	Hollow grain	Dry matter	Yield/plant	HI
R	2	293.302*	406.722^{ns}	156.22^{ns}	236.056^{ns}	0.292^{ns}	2.207^{ns}	41.167^{ns}	188.654^{ns}	6.495^{ns}	4.039^{ns}
Density	2	2269.935**	43358.389**	3030.056*	2437.556**	37.332*	77.327**	360.167**	5853.420**	1116.687**	58.845**
Weed	1	211.494^{ns}	4867.556**	43.556^{ns}	220.500^{ns}	5.556^{ns}	1.869^{ns}	4.500^{ns}	1124.961^{ns}	0.201^{ns}	11.234^{ns}
Density×Weed	2	1.894^{ns}	115.056^{ns}	223.722^{ns}	4.667^{ns}	4.091^{ns}	0.036^{ns}	2.167^{ns}	134.441^{ns}	1.642^{ns}	0.857^{ns}
E	10	59.869	451.189	904.956	79.989	5.542	2.167	18.900	461.344	6.914	5.750
C.V. (%)		6.40	4.61	7.14	4.28	9.02	8.58	18.77	9.58	4.79	9.55

*,** and ^{ns} show significant differences at 0.05, 0.01 probability level and no significant, respectively

Table 2: Means for yield components of sunflower at different densities (D)

	1000 grains Weight (g)	grain/head	Yield ($g\ m^{-2}$)	Height (cm)	Stem diameter (mm)	Head diameter (cm)	Hollow grain (%)	Dry matter ($g\ plant^{-1}$)	Yield/plant ($g\ plant^{-1}$)	HI (%)
D_1	140.9^{a}	552.2^{a}	408.7^{b}	187.5^{b}	28.88^{a}	21.07^{a}	16.5^{b}	239.3^{a}	68.02^{a}	28.60^{a}
D_2	119.8^{b}	447.3^{b}	447.2^{a}	211.8^{a}	25.35^{b}	16.43^{b}	21.33^{b}	232.6^{a}	55.85^{b}	24.17^{b}
D_3	102.1^{c}	383.8^{c}	407.8^{b}	227.5^{a}	24.07^{b}	14.00^{b}	31.67^{a}	182.1^{b}	40.78^{c}	22.55^{b}

Values followed by the same letters are not significantly different at 5% level

D_2 produced significantly higher grain yield (447.2 g m^{-2}) in relation to D_1 (408.7 g m^{-2}) and D_3 (407.8 g m^{-2}), respectively (Table 2). However, the yield difference in absolute terms was small, such as reported by Villalobos *et al.* (1994), Barros *et al.* (2004). This maybe related to the total number of grains m^{-2} (Barros *et al.*, 2004).

Low plant densities produced plants with large heads, those ultimately encouraged the maximum number of grains, but assimilates were not supplied in an enough quantities to fully nourish large number of grain. Ultimately grains remained under nourished. This effect related to the balanced plant structure and number of grains produced per head. This relationship between grain number and assimilates can affect total yield of sunflower. Studies on the effect of plant density on achene yield provided inconsistent results (Prunty, 1981).This suggests that the optimum plant density depends upon environmental conditions and the cultivars used.

The physiological efficiency and ability of a crop for converting the total dry matter into economic yield is known as Harvest Index (HI). Densities showed significant difference for HI. Crop sown at lowest density (D_1) had maximum HI (28.60%), followed by D_2 (24.17%), which was similar to D_3 (22.55%), (Table 2). Significant relationship between densities and HI confirms earlier findings.

Individual plant yield at the lowest density was significantly greater (66.79%) than the rest (Table 2). The equation $\ln(\Delta Y) = \ln(\Delta HI \times \Delta DM)$ was used (modified equation from Tollenaar *et al.*, 1994) to separate the contribution of increased DM and HI to higher yield (Y).The natural log of the percentage increase in the yield component (HI or DM) over the natural log of the percentage increase in yield was calculated as the contribution of the yield component (e.g, contribution due to HI = ln ΔHI/ ln Δtotal DM accounted 64.39% for weed free treatment and 63.57% for weedy treatment and apparent harvest index accounted 35.61% for weed free treatment and for weedy treatment 36.43% of the difference in yield between the highest and the lowest density.

Weed: The analysis of variance for sunflower grain yield and other traits at different levels of weed control indicated that this factor could not affected sunflower yield and yield attributes significantly, except number of grains per head (Table 1). The highest number of grains per head was 477.58 that recorded in weed free treatment, while the number of grains per head in weedy treatment was 444.68 (Fig. 1).

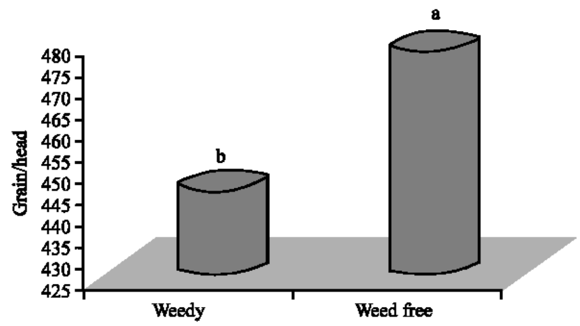

Fig. 1: Comparison of means for grain number per head of sunflower at different levels of weed treatments

Weed free treatment increased 1000-grain weight, head diameter, dry matter and yield per plant, but decreased plant height, stem diameter and hollow grains. However, these fluctuations were not statistically significant, in comparison with weedy treatment.

These results are inconsistence with Stanojevia (2000), Fuksa *et al.* (2004) in corn and Daugovish *et al.* (2003) in rapeseed and probably due to soil salinity, weed genus, density and high tolerance of sunflower to weeds. Furthermore, at this saline soil, weeds were suppressed by stress condition and were not more competitive to crop.

In the saline soil weed species had low growth rate, total size and LAI, rather than normal soils weeds. Primary tillage operations which bury as great a proportion of weeds in the soil as possible can reduce the total weed population which will germinate. This caused that sunflower could compete effectively with weeds in early growth stages. In the other hand, relative size of weeds and crop is one of the main factors that determine crop yield loss resulting from weed infestation. In the saline soil some crops such as sunflower, have larger relative size and erect stature than weeds. In early season, this point reduces weed competition with sunflower. Additional, row spacing plays an important role on weed density and their control by crop (Yelverton and Coble, 1991; Diepenbrok *et al.*, 2001, Riaz *et al.*, 2006). Row spacing for sunflower were commonly chosen about 75cm. In our study, row spacing was 50 cm. Narrow rows, gives the crop a competitive advantage over the weeds (Riaz *et al.*, 2006). Therefore, narrow row planting may help the sunflower crop to compete better with weeds and give a more uniform stand which matures earlier, like occurred in this study. Other factors such as cultivar, management practices like sowing date and planting density, can determine the magnitude of yield loss of weeds. A significant interaction was not found between sunflower density and weed control.

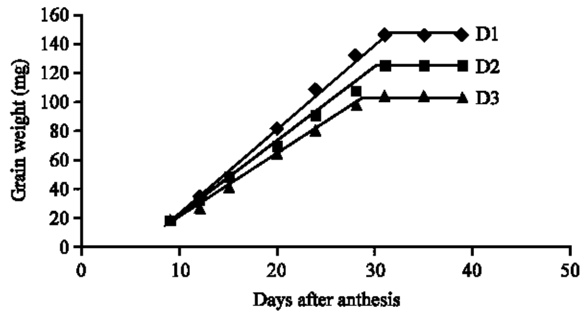

Fig. 2: Grain filling rate and duration in sunflower as affected by different densities in weed free plots (D1 = 6, D2 = 8 and D3 = 10 plant m^{-2})

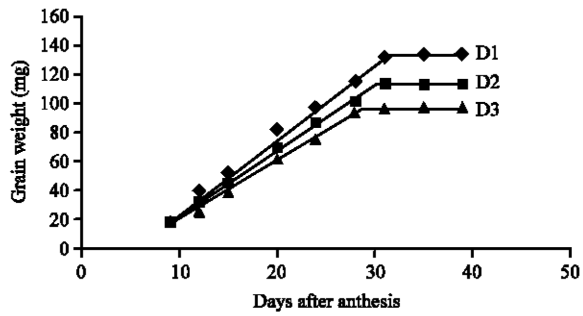

Fig. 3: Grain filling rate and duration in sunflower as affected by different densities in weedy plots (D1 = 6, D2 = 8 and D3 = 10 plant m^{-2})

Grain filling period: Figure 2, 3 and Table 3 demonstrate very well variations of the grain filling period determined by density and weed effects.

The average rates of grain filling were 4.97 and 4.48 mg day^{-1} for weed free and weedy treatments, respectively. The average duration of grain filling period for weed free treatment was 30.06 days and for weedy treatment was 29.66 days (Table 3). The highest rate of grain filling recorded at D_1 in both of weed free and weedy treatments, while D_2 and D_3 showed no significant differences in the rate of grain filling (Table 3). The average rate of grain filling at D_1 indicated about 40% increase in compare of D_3 that this increase was about 47% in weed free treatment and about 33% in weedy treatment. These results indicated that control of weed and density could influence the rate of grain filling, while duration of grain filling period did not affect by density and weed control as well as rate of grain filling. Although the highest duration of grain growth period recorded at D_1 in weed free treatment.

In the literature, there are no evidence on the effects of plant density on grain filling period, but few studies was done to demonstrate the effects of light interception

Table 3: Dynamics of grain growth (average rate and timing of the growth period) and mean of final grain weight in sunflower as affected by density and weed

Treatment	Rate (mg day^{-1})	End of grain growth period (daa)	Mean of final grain weight (mg)
Weed free			
D_1	6.02^a	31.2^a	147.1^a
D_2	4.82^b	30.1^{ab}	126.1^b
D_3	4.07^b	28.9^b	104.8^c
Weedy			
D_1	5.25^a	30.9^a	133.9^a
D_2	4.34^b	29.7^{ab}	113.4^b
D_3	3.85^b	28.4^b	96.8^c

Values followed by the same letters are not significantly different at 5% level

on grain weight. Studies by Ruiz and Maddonni (2006), on sunflower showed that, increasing of light interception increases the grain weight. Density is one of the most important management factors that indicate amount of radiation intercepted per plant (Fernando *et al*., 2002). Therefore, the highest grain weight obtains from the lowest density that provides maximum light interception per plant.

CONCLUSION

In this experiment, density showed significant effects on sunflower yield and its attributes. The highest total yield recorded from D2, indicated that the highest yield obtained from optimum plant density. Therefore, determining the optimum planting density for crops, such as sunflower is very important. Weeds could not affect the sunflower yield significantly, which maybe related to the soil texture of experimental field. This indicated that, the control of weeds in each area should be performance with attention to that area conditions such as soil and weather conditions. The highest rate and duration of grain filling recorded at D_1 and weed free treatment. It is demonstrated that optimal conditions to plant growth could be affected the grain filling period which is important factor to determine the total yield. Consequently, low densities increase the rate and duration of grain filling but, in order to gain the maximum grain yield of sunflower, it is necessary using higher densities.

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