Pak. J. Agri. Sci., Vol. 51(1), 49-58; 2014
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

EXOGENOUS APPLICATION OF ABSCISIC ACID MAY IMPROVE THE GROWTH AND YIELD OF SUNFLOWER HYBRIDS UNDER DROUGHT

Safdar Hussain[1,*] , Muhammad Farrukh Saleem[2], Javaid Iqbal[1], M. Ibrahim[1], S. Atta[1], T. Ahmed[1] and M.I. A.Rehmani[1]

[1]College of Agriculture, Dera Ghazi Khan-32200, Pakistan
[2]Department of Agronomy, University of Agriculture, Faisalabad, Pakistan
***Corresponding authors e-mail:safdarb1184@yahoo.com**

Sunflower genotypes perform differently under different water regimes. Drought stress at various growth stages drastically reduces the growth, development and yield of sunflower hybrids. However, exogenous application of abscisic acid helps in mitigating drought stress by improving growth, development and yield of sunflower. In the present study, three sunflower hybrids viz. DK-4040 (large stature), S-278 (medium stature) and SF-187 (short stature) were exposed to varied irrigation regimes and abscisic acid application schedule i.e. $T_{1:}$ four irrigations with schedule (25DAS, at bud, flower initiation and at achene formation) and with no ABA spray,T_2: three irrigations with schedule (25DAS, at flower initiation and at achene formation) and with no ABA spray, T_3: three irrigations with schedule (25DAS, at flower initiation and at achene formation) and with 8µMABA spray at bud initiation, T_4: three irrigations with schedule (25DAS, at bud initiation and at achene formation) and with no ABA spray, T_5: three irrigations with schedule (25DAS, at bud initiation and at achene formation) and with 8µM ABA spray at flower initiation. Experiment was laid out in Randomized Complete Design with factorial arrangement having three replications. ABA application at bud or at flower initiation under drought stress helped in mitigating the detrimental effects by improving growth and yield of sunflower hybrids. Enhancement in drought tolerance of sunflower genotypes was better when ABA was applied at bud initiation stage than that of at flower initiation stage under drought. Improvements in head diameter, achenes per head, 1000-achene weight, achene yield, oil yield, biological yield, harvest index, leaf area index and crop growth rate was recorded. Sunflower hybrid DK-4040 showed more improvement in drought tolerance byfoliar application of ABA under water deficit stress than that of the SF-187 and S-278. It is suggested that sunflower hybrid DK 4040 should be grown under drought stress by foliar application of ABA at bud initiation stage.
Keywords: Abscisic acid, growth and yield, drought stress, sunflower

INTRODUCTION

Among the environmental stress factors water is one of the most limiting factor for crop production. On global basis, water determines the distribution, responses and adaptation of plant species. Droughts occurred periodically which had extensive impacts on global food production and supply (Wisner and Chase, 1984). It has been estimated that in the tropics droughts cause an average annual yield loss of 17 percent (Edmeades *et al.*, 1999) and it might be severe and total crop failure can also occurred.

Drought tolerance has been observed in field crops species but it varies from crop to crop. Development of crop varieties that require lesser amounts of water and more tolerant to water shortage fulfilled the future nutritional requirements of the increasing population of the universe (Jaleel *et al*., 2007). Plants have different mechanisms to cope drought stress such as drought avoidance and tolerance. Morphological and physiological diversity have been observed in plants to tolerate the drought (Blum, 1997; Saensee *et al*., 2012). Sunflower cultivars have ability to deplete available soil moisture differently (Mahal *et al*., 1998). High achene yield of sunflower under drought can be achieved by increasing total water use and harvest index while reducing soil evaporation and ultimately placing the crop at low vapor pressure deficit. In dry region, water present in deep profile and deep proliferated rooted species and cultivars had maximum ability for utilization of water (Hoad *et al*., 2001). Full and normal irrigations are essential for good crop production, but when there is shortage of water, it becomes very necessary to differentiate the critical growth stages of the crop, where irrigation could be missed, without significantly reducing the grain yield. In sunflower, irrigation missing at flower initiation drastically reduces achene yield (Hussain *et al*., 2010; Hussain *et al*., 2012a) and biological yield (Petchu *et al*., 2003) as compare to achene yield (El-Tayeb, 2005) and biological yield (De-Guang *et al*., 2001) obtained after missing irrigation at vegetative stage (Shamim *et al*., 2009; Hussain *et al*., 2013). This is due to reduction in number of achenes head^{-1} (Kadayifei and Yildrim, 2000).

Abscisic acid has a pivotal role to tolerate the water deficit conditions in field crops. Resistant cultivars have higher levels of ABA when they are exposed to water stress, and sensitive cultivars can be converted to resistant types by exogenous application of ABA (Celliar *et al*., 1998). In response of water deficit, ABA markedly begins to increase in plant leaf tissues and to a lesser extent in other plant tissues including roots (Salisbury and Marinos, 1985). This leads to stomatal closure which finally reduced the rate of transpiration. It also inhibits shoot growth, and root growth appears to be promoted which increased the water supply. Exogenous application of ABA to intact plants has been observed to increase the drought tolerance (Wang *et al*., 2003; Hussain *et al*., 2010). Foliar spray of 5µM ABA to cotton under drought significantly increased seed number and lint mass per plant (Pandey *et al*., 2003). Drought stress in soybean reduces pod setting which was alleviated by exogenous application of 0.1 mM ABA (Liu *et al*., 2004).

So the current research work was designed with the objective to compare the performance of diverse sunflower hybrids under water deficit environments and to optimize the ABA level application at appropriate growth stage for achieving higher yields of sunflower hybrids under drought.

MATERIALS AND METHODS

In the current study, seed of sunflower hybrids DK-4040 (tall stature), S-278 (medium stature) and SF-187 (short stature) was obtained from the Regional Office of the Pakistan Oil Development Board, Faisalabad. The study was conducted for two consecutive years 2008 and 2009 at Agronomic Research Farm, University of Agriculture, Faisalabad, Pakistan. The data on average temperature, relative humidity and rainfall were collected from the Agro-meteorological cell, Department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan and presented in Fig. 1. Physiochemical characteristics of soil were analyzed before sowing of the crop and presented in Table 1. The experiment was laid out in randomized complete block design (RCBD) with factorial arrangement having three replications and net plot size was 3.0 m x 5.0 m.

Sunflower hybrids (DK-4040, S-278 and SF-187) were sown on ridges by dibbler with seed rate of 8 kg ha^{-1}. Ridge x ridge

Table 1. Pre-sowing analysis of the soil of research field

	Determination	Unit	Value 2008	Value 2009
A	Physical Analysis			
	Sand	%	66.6	64.5
	Silt	%	16.6	18.5
	Clay	%	16.8	17
	Textural class		Sandy clay loam	
B	Chemical Analysis			
	pH		8.1	7.98
	EC	dS m^{-1}	1.26	1.39
	Organic matter	%	0.79	0.73
	Total Nitrogen	%	0.045	0.049
	Available Phosphorus	mg kg^{-1}	6.63	6.78
	Available Potassium	mg kg^{-1}	169	165

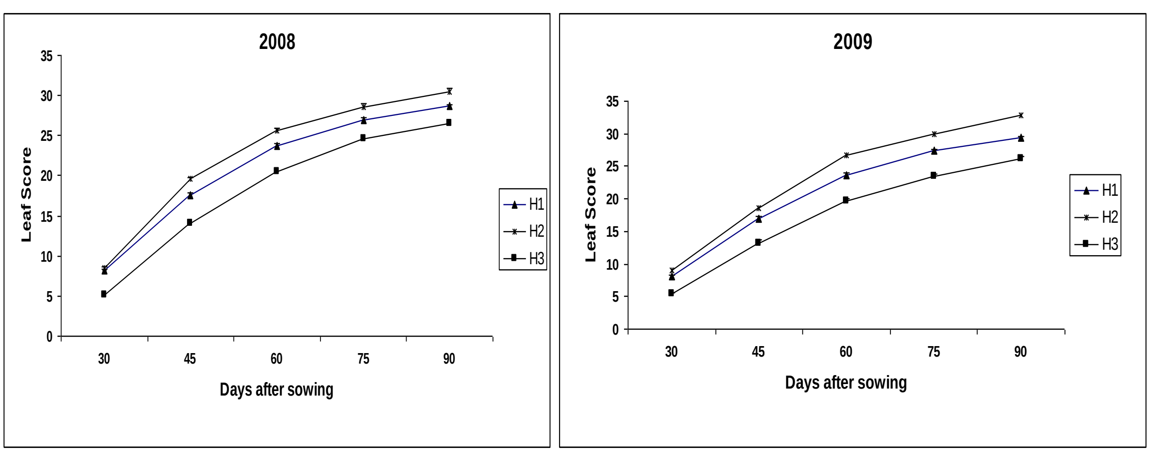

Figure 1. Leaf score of different sunflower hybrids during 2008 and 2009; H_1= DK-4040; H_2= S-278; H_3= SF-187

and plant x plant distance of 75 cm and 25 cm, respectively was maintained. Recommended dose of fertilizer N (150 kg ha^{-1}) and P (100 kg ha^{-1}) were applied by using urea and diammonium phosphate (DAP). Half dose of nitrogen and full dose of phosphorus were applied at sowing, while remaining nitrogen dose was used with 1^{st} irrigation. The first irrigation was applied at 4-6 leaf stage (25 DAS), the 2^{nd} irrigation at bud initiation stage (45 DAS) except the plots, which were subjected to water stress at this stage, the 3^{rd} irrigation at flower initiation stage (67 DAS) except the plots, which were subjected to water stress at this stage. The 4^{th} irrigation was applied to all plots at grain formation stage (90 DAS).Polo and Radomil Gold were sprayed for the control of white fly and head rot, respectively.

Abscisic acid powder of Sigma Aldrich, Japan was applied to the crop as foliar spray. The effect of application of two ABA levels (0 and 8µM) at two growth stages (bud initiation and flower initiation) under three irrigation regimes (no drought stress, drought stress at bud initiation and drought stress at flower initiation) was evaluated (Pandey *et al*., 2003, Hussain *et al*., 2010; Hussain *et al*., 2012a; Hussain *et al*., 2012b; Hussain *et al*., 2013).Weighted quantity of ABA (as per treatment) was added in a graduated cylinder and 1 L volume was made in volumetric flask by adding distilled water. Knapsack sprayer was calibrated (250 L ha^{-1}) and use to spray the solution. Distilled water was sprayed in the control plots.

Data pertaining to plant height, head diameter, achenes per head and 1000-achene weight were recorded from ten randomly selected plants in each plot and then averaged. The plants were harvested at maturity, heads were cut by sickle, dried in sun, threshed manually and achene yield per plot was recorded. Moisture contents of achene were determined after random selection from each plot. Achene yield was adjusted to 10% moisture content and converted into kg ha^{-1}. In order to determine the oil yield, the oil contents of random samples taking from each plot were determined by Soxhlet Fat Extraction method (AOAC, 1990). The achene yield was changed to oil yield by using the following conversion formula

$$\text{Oil yield (kg ha}^{-1}) = \frac{\text{achene yield (kg ha}^{-1}) \text{ X achene oil contents (\%)}}{100}$$

For biological yield, air-dried sunflower hybrid plants (excluding achenes) was weighted on plot basis and then converted into kg ha^{-1} and finally recorded weight was added to the already computed achene yield (kg ha^{-1}). Harvest index was calculated by the following relation (Gifford and Evans, 1981).

$$\text{Harvest index (\%)} = \frac{\text{achene yield}}{\text{biological yield}} \text{X } 100$$

Leaf area was measured by a leaf area meter (DT Area Meter, model MK2) at an interval of fifteen days. The sampling was started 30 days after sowing (DAS) and terminated 90 DAS. Five randomly selected plants from each plot were selected for measurement of leaf area and thereafter, leaf area index (LAI) was computed by using the formula given by Watson (1947).

$$\text{LAI} = \frac{\text{leaf area}}{\text{land area}}$$

Crop growth rate (CGR) was determined at fortnight intervals by randomly selecting five plants from each plot. Random sampling was started 30 days after sowing (DAS) and completed at 90 DAS. After harvest, samples were weighed to determine fresh weight. Each plant sample was then chaffed, thoroughly mixed and then sun dried. After that samples were placed in oven at $70 \pm 5^{o}C$ to dry the plant material up to constant dry weight. Then dry weight m^{-2} was computed and used to estimate the crop growth rate as mentioned by Hunt (1978).

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

W_2 and W_1 dry weight per unit land area (g m^{-2}) at second and at first harvest, respectively, while t_2 and $t_1$were time corresponding to second and first harvest (days), respectively.

The data were analyzed by using Fisher's analysis of variance technique at the probability level of 0.05 through program MSTAT-C. Least significant difference test employed to estimate the difference among mean of treatments (Steel *et al*., 1997). Meaningful orthogonal contrasts were studied to compare the differences between 4 irrigations and 3 irrigations and also between ABA and no ABA application (Little and Hills, 1978).

RESULTS AND DISCUSSION

***Yield components of sunflower hybrids*:** Varietals differences in plant height (Table 4) were observed during conduct of this experiment which categorized DK-4040 as tall, S-278 as medium and SF-187 as a short stature hybrid. Drought stress either at bud initiation or flower initiation significantly reduced plant height and more detrimental impact of water deficit were observed at bud initiation. Differential plant height of sunflower genotypes was also recorded by Schwarzbach *et al*. (2000). This reduction in plant height under drought was due to impaired mitosis, cell expansion and cell elongation (Hussain *et al*., 2008). Drought prior to reproductive stage decreased plant height (Hammadeh *et al*., 2005). Same trend was found in a study where sunflower plants irrigated at bud initiation were 19 cm taller than that of those irrigated at flower initiation stage (Unger, 1983). This increase in plant height was due to more stem dry matter production which might increase plant height. In present study exogenous application of 8µM ABA either at bud initiation or flower initiation to sunflower hybrids under drought significantly improved plant height. ABA helped in mitigating the adverse effects of drought by improving water availability to plants. Water availability

Table 2. Meteorological data

Month	Minimum Temperature (Ċ)		Maximum Temperature (Ċ)		Relative Humidity (%)		Rainfall (mm)	
	2008	2009	2008	2009	2008	2009	2008	2009
February	13.14	16.02	17.23	18.54	37.34	64.14	6.8	18.2
March	22.72	20.77	26.85	23.99	37.84	53.52	0	14
April	26.03	26.25	30.52	31.11	33.57	41.67	16	22.9
May	30.76	32.43	36.89	35.98	30.16	31.42	75.5	9.11
June	32.92	33.84	39.21	38.67	48	33.6	41.7	9.6

Table 3. Meaningful orthogonal contrasts

Parameters	4 I vs 3 I		ABA vs no ABA	
	2008	2009	2008	2009
Plant height	*	*	*	*
Head diameter	*	*	*	*
Number of achenes per head	*	*	*	*
1000-achene weight	*	*	*	*
Achene yield	*	*	*	*
Biological yield	*	*	*	*
Oil yield	*	*	*	*
Harvest index	*	*	*	*

4 I, four irrigations; 3 I, three irrigations; ABA, abscisic acid spray; vs, versus; *, significant; ns, non-significant

Table 4. Role of exogenous application of abscisic acid on yield and yield components of sunflower hybrids

Hybrids	Treatments	Plant height (cm)		Head diameter (cm)		Achenesper head		1000 -achene weight (g)	
		2008	2009	2008	2009	2008	2009	2008	2009
DK-4040	C	215.32a	225.92a	22.87a	23.41a	1172.98a	1201.87a	51.97a	53.61a
	SBNA	144.27e	151.34e	15.04d	15.40d	887.63c	909.53c	39.25c	40.48c
	SBA	170.56d	178.99d	19.61b	20.07b	1087.69ab	1114.50ab	47.58b	49.07b
	SFNA	176.64c	185.34c	13.75e	14.07e	676.02d	692.72d	34.02d	35.09d
	SFA	187.65b	196.93b	16.65c	17.04c	1061.90b	1087.91b	43.19c	44.55c
S-278	C	179.61a	188.44a	19.46a	19.92a	1065.28a	1091.27a	48.81a	50.35a
	SBNA	127.13e	133.44e	12.91d	13.21d	822.28b	842.51c	36.44b	37.59b
	SBA	135.68d	142.35d	16.09b	16.47b	958.66a	982.25ab	44.89a	46.31a
	SFNA	148.53c	155.90c	10.29e	10.53e	704.75c	722.06d	29.78c	30.73c
	SFA	161.19b	169.09b	14.63c	14.98c	879.76b	901.33b	38.45b	39.6b
SF-187	C	140.52a	147.46a	22.38a	22.91a	1032.46a	1057.66a	56.93a	58.71a
	SBNA	108.22e	113.61e	12.85d	13.15d	845.62b	866.27b	44.19b	45.59b
	SBA	115.82d	121.56d	18.55b	18.98b	936.90b	959.84b	53.22a	54.91a
	SFNA	119.55c	125.51c	10.44e	10.68e	760.84c	779.56c	35.93c	37.04c
	SFA	131.66b	138.21bs	15.99c	16.37c	855.06b	876.09b	46.45b	47.92b
LSD		2.51	2.46	0.70	0.72	108.18	110.71	4.38	4.51

C, control (no abscisic acid application); SBNA, stress at bud initiation and no abscisic acid application; SBA, stress at bud initiation and abscisic acid application; SFNA, stress at flower initiation and no abscisic acid application; SFA, stress at flower initiation and abscisic acid application; LSD, least significant differences; Mean values sharing the same letter in a column do not differ significantly at $P< 0.05$.

might be improved by conserving plant moisture due to partial closing of stomata, reduction in transpiration and increase in root penetration (Hoad *et al*., 2001).

Results of the current study indicated that under no drought stress sunflower hybrid DK-4040 had maximum head diameter than that of S-278 and SF-187 (Table 4). Head diameter of all studied sunflower hybrids was significantly reduced under drought. Reddy *et al*. (1998) also reported reduction in head diameter of different sunflower hybrids under drought. More decrease in head diameter was observed when water deficit occurred at flower initiation than at bud initiation (Hussain *et al*., 2012). This reduction was due to decrease in production of assimilates under water deficits (Wahid and Rasul, 2005) and their less allocation to the floral organs (Setter *et al*., 2001). Exogenous application of ABA under drought either at bud initiation or flower initiation significantly improved head diameter of studied sunflower hybrids (DK-4040, S-278 and SF-187). This improvement was attributed to the applied ABA which helped in water conservation in plants and improved plant growth by increasing water use efficiency (Turner *et al*., 2001) which might have enhanced the translocation of assimilates to head and finally increased head size.

Sunflower hybrids differed in achenes per head under drought and well watered conditions (Table 4). Sunflower hybrid DK-4040 produced a more achenes per head than SF-187 and S-278 while later two produced statistically similar achenes per head. This variation in production of achenes per head was due to genetic potential of sunflower hybrids (Bakht *et al*., 2006). Water deficits at bud initiation or flower initiation significantly reduced the achenes per head of sunflower hybrids and more drastic effect of water shortage was observed when stress was applied at flower initiation. This reduction in achenes per head under drought was due to less seed set and more seed abortion as was observed in soybean (Liu *et al*., 2004) and cotton (Pandey *et al*., 2003). Similarly exogenous application of ABA under drought significantly improved achenes per head. This improvement in achenes per head might be due to more seed set and less seed abortion. Exogenous application of ABA under drought significantly increased seed number in cotton (Liu *et al*., 2004) and pod set in soybean (Pandey *et al*., 2003).

Results in Table 4 depicted that sunflower hybrids showed significantly different 1000-achene weight under normal and limited irrigation conditions. Divergent 1000-achene weight of sunflower hybrids were also observed by Bakht *et al*. (2006). More decrease in 1000-achene weight was noted when drought stress was applied at flower initiation thanbud initiation. This kind of response was also observed in sunflower (Daneshian *et al*., 2005). Foliar applied ABA to sunflower hybrids under water deficit conditions increased 1000-achene weight because it increased availability of water and translocation of assimilates to sink (achene). ABA had the ability to compensate plant water loss through partial closure of stomata, reduction in leaf development (Davies and Zhang, 1991) and increase in root penetration (Alfredo and Setter, 2000).

Achene yield (Table 5) of sunflower hybrids was statistically different under drought and normal irrigated condition. Maximum achene yield was noted in DK-4040 compared to SF-187 and S-278. Bakht *et al*. (2006) also noted more achene yield of DK-4040 than SF-187. Water deficits applied to hybrids at flower initiation caused more reduction

Table 5. Role of exogenous application of abscisic acid on yield and yield components of sunflower hybrids

Hybrids	Treatments	Achene yield (kg ha^{-1})		Biological yield (kg ha^{-1})		Oil yield (kg ha^{-1})		Harvest index (%)	
		2008	2009	2008	2009	2008	2009	2008	2009
DK-4040	C	3326.74a	3552.27a	13112.18a	13826.99a	1262.90a	1379.09a	24.61b	24.97b
	SBNA	1924.44c	2054.18d	8096.55e	8538.82e	682.01d	744.71d	22.53c	22.88c
	SBA	2802.45b	2993.97b	10452.92d	11018.69d	1025.98b	1120.25b	25.85a	26.26a
	SFNA	1310.77d	1396.22e	11204.90c	11815.4c	432.99e	472.64e	10.80e	10.97e
	SFA	2554.75b	2728.69c	11457.24b	12081.16b	883.92c	965.16c	21.17d	21.76d
S-278	C	2828.98a	3022.65a	13033.27a	13745.24a	1013.35a	1106.49a	20.94a	21.26a
	SBNA	1685.97d	1797.79d	10910.03e	11503.38e	563.04d	614.65d	14.54b	14.76b
	SBA	2416.18b	2579.98b	11150.33d	11794.30d	828.93b	904.97b	20.77a	21.03a
	SFNA	1224.35e	1303.76e	11784.55c	12427.36c	383.59e	418.68e	9.54c	9.69c
	SFA	1914.29c	2042.93c	12220.24b	12884.12b	621.82c	679.08c	14.85b	15.08b
SF-187	C	3222.58a	3444.23a	12830.88a	13527.50a	1208.80a	1320.02a	24.34a	24.72a
	SBNA	2039.34d	2176.73d	11023.77d	11625.16e	720.82d	786.99d	17.59c	17.86c
	SBA	2845.42b	3023.86b	11617.38c	12249.10d	981.93b	1072.18b	23.63b	23.94b
	SFNA	1532.17e	1633.85e	11790.56c	12432.80c	496.72e	542.44le	12.15d	12.34d
	SFA	2489.99c	2624.76c	12195.33b	12929.67b	761.79c	831.70c	19.59c	19.45c
LSD		50.071	64.38	179.76	58.46	18.46	20.44	0.50	0.55

C, control (no abscisic acid application); SBNA, stress at bud initiation and no abscisic acid application; SBA, stress at bud initiation and abscisic acid application; SFNA, stress at flower initiation and no abscisic acid application; SFA, stress at flower initiation and abscisic acid application; LSD, least significant differences; Mean values sharing the same letter in a column do not differ significantly at $P < 0.05$.

in achene yield than at bud initiation. Drought timing is more crucial than its intensity (Hussain *et al*., 2010; Hussain *et al*., 2012a; Hussain *et al*., 2013). Limited water application to sunflower at heading, flower initiation and milking reduced achene yield and more reduction in sunflower yield occurred when drought was employed at flower initiation (Daneshian *et al*., 2005). This reduction in achene yield of sunflower hybrids under drought occurred due to decrease in head diameter (Nasri, 2005), number of achenes per head (Liu *et al*., 2004) and 1000-achene weight (Daneshian *et al*., 2005). Foliar application of ABA to sunflower hybrids under drought at bud initiation had better effect on achene yield than applied at flower initiation. This improvement in achene yield might be due to the ability of ABA to regulate loss of water in the plant through incomplete closing of stomata, increasing root penetration (Hoad *et al*., 2001) and water use efficiency which ultimately increased translocation of assimilates to achenes.

Biological yield of sunflower hybrids decreased under drought and more decrease was observed when irrigation was skipped at bud initiation than flower initiation (Table 5). This decrease in biological yield was due to decrease in plant height, total dry matter production, leaf area, shoot growth and achene yield (El-Tayeb, 2005). Results of present study further depicted that foliar application of ABA to sunflower hybrids under water stress at bud or flower initiation improved biological yield. Drought resistant cultivars have higher level of ABA and drought sensitive cultivars of crops would be converted to resistant cultivars by the application of ABA (Celliar *et al*., 1998) which increased crop productivity and might have improved biological yield. Contrary to our findings exogenous application of ABA under drought reduced biomass production in two contrasting population of *Populus davidiana* which was due to lower dry matter accumulation and its more allocation to roots than shoot (Chunyang *et al*., 2004).

Differential oil yield of sunflower genotypes was observed under water deficits and normal irrigation conditions. Drought significantly decreased oil yield of sunflower hybrids (Table 5) and similar results were also observed by Ardakani *et al*. (2005). More reduction in oil yield was observed when water shortage was faced by crop at flower initiation than bud initiation. Similar response was also recorded by Reddy *et al*. (1998). This reduction in oil yield under drought might be due to decrease in achene yield. Results of the current study also depicted that exogenous application of ABA under drought increased oil yield due to conservation of water in plants. This conservation of plant moisture took place due to partial closing of stomata (Blum, 1997).

Varietals difference in harvest index was noted and maximum harvest index was computed in DK-4040 than that of S-278 and SF-187 (Table 5). Drought significantly decreased harvest index and more decrease was observed when stress imposed at flower initiation than bud initiation. This reduction in harvest index was due to decrease in seed number with less variation in individual seed weight. Seed number decreased by reduction in head size and the area which had visible seeds (Fereres *et al*., 1986). Furthermore, reduction in harvest index under drought was also due to decrease in biological yield (Petchu *et al*., 2003) and achene yield (Daneshian *et al*., 2005) which finally decrease harvest index (Ardakani *et al*., 2005; Nasri, 2005). Our findings further indicated that foliar application of ABA to sunflower hybrids under drought either at bud initiation or at flower initiation significantly improved harvest index. This improvement in harvest index might be due to increase in achene and biological yield of sunflower hybrids.

***Allometry of sunflower hybrids*:** Varietal difference in leaf score was observed among sunflower hybrids (Fig. 1); however, ABA application had non-significant effect on leaf score throughout the life of sunflower (Fig. 2). It indicated that dose of ABA was not more enough to cause defoliation although leaf area of sunflower hybrids was reduced. Further, this might be inherent ability of the sunflower hybrids to retain their leaf numbers under periodic drought and re-watering conditions.

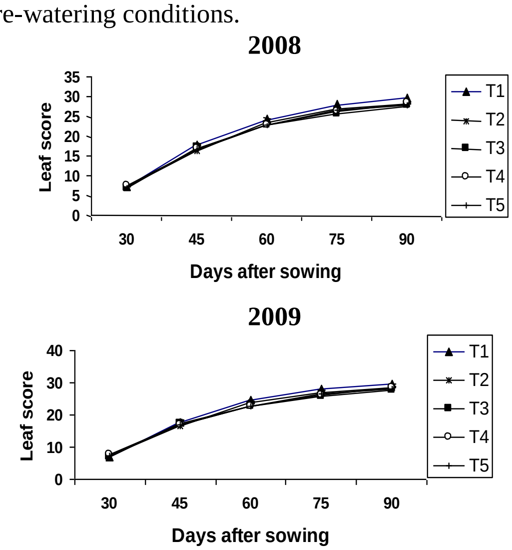

Figure 2. Effect of irrigation and abscisic acid schedules on leaf score during 2008 and 2009

T_1= 4 irrigations and no ABA; T_2= irrigation skip at bud initiation and no ABA; T_3= irrigation skip at bud initiation and ABA; T_4=irrigation skip at flower initiation and no ABA; T_5=irrigation skip at flower initiation and ABA

Genotypic variation in leaf area index was noted among sunflower hybrids (Fig. 3). Water deficit either at bud initiation or at flower initiation statistically decreased leaf area index of sunflower hybrids (Fig. 4). More reduction in leaf area index of hybrids was observed when drought stress employed at bud initiation than at flower initiation.

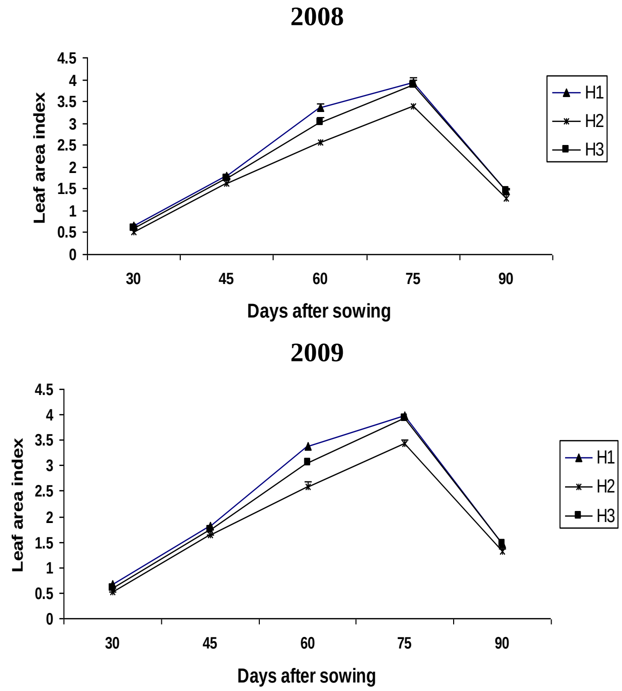

Figure 3. Leaf area index of different sunflower hybrids during 2008 and 2009; H_1= DK-4040; H_2= S-278; H_3= SF-187

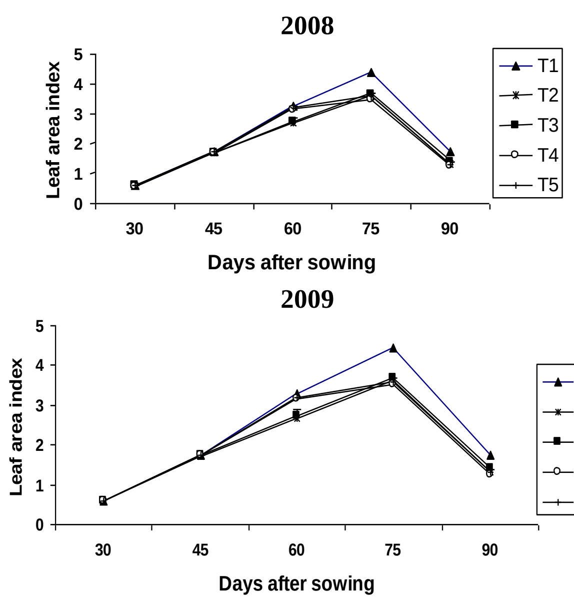

Figure 4. Effect of irrigation and abscisic acid schedules on leaf area index during 2008 and 2009

T_1= 4 irrigations and no ABA; T_2= irrigation skip at bud initiation and no ABA; T_3= irrigation skip at bud initiation and ABA; T_4=irrigation skip at flower initiation and no ABA; T_5=irrigation skip at flower initiation and ABA

Leaf growth was more sensitive to water deficit than shoot and root growth which ultimately caused low leaf area index (Ardakani *et al*., 2005; Nasri, 2005). This low leaf area index is beneficial to plants as less leaf area is exposed to radiation which ultimately reduced transpiration (Schuppler *et al*., 1998). Foliar application of ABA to sunflower hybrids at bud initiation or flower initiation under drought increased leaf area index. ABA played positive role in the regulation of water status of plant by modifying the growth and function of guard cells. Furthermore, ABA also helps in induction of genes that encode enzymes and other proteins which protect plants from cellular dehydration (Luan, 2002). This might have enhanced mitosis, cell expansion and cell enlargement in leaf which finally improved leaf area index of sunflower hybrids.

Genotypic variations in crop growth rate were observed in sunflower hybrids (Fig. 5). Drought stress at bud initiation or flower initiation statistically decreased crop growth rate (Fig. 6). More severe reduction in crop growth rate was observed in hybrids of sunflower when drought stress occurred at bud initiation. Water deficit stress at vegetative or at flower initiation stages of sunflower reduced total dry matter production which finally decreased crop growth rate (Ardakani *et al*., 2005).

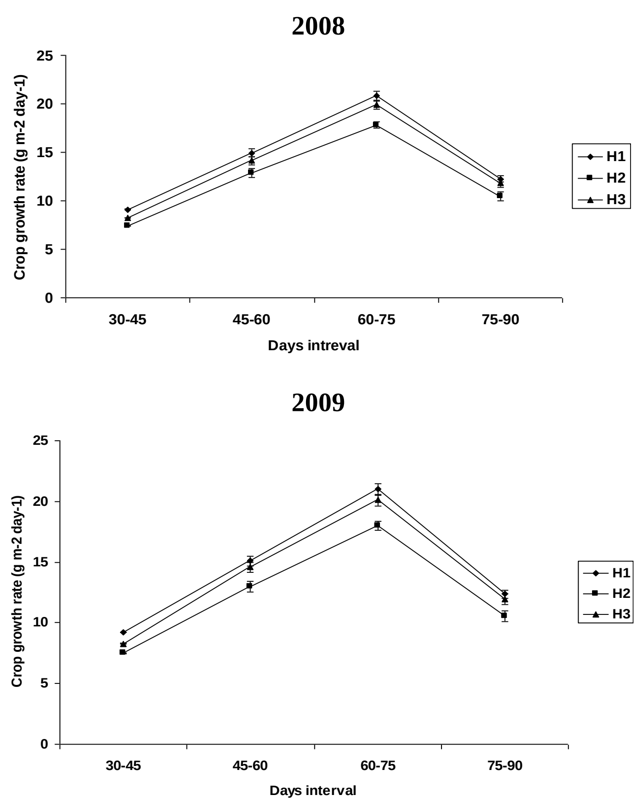

Figure 5. Crop growth rate of different sunflower hybrids during 2008 and 2009

H_1= DK-4040; H_2= S-278; H_3= SF-187

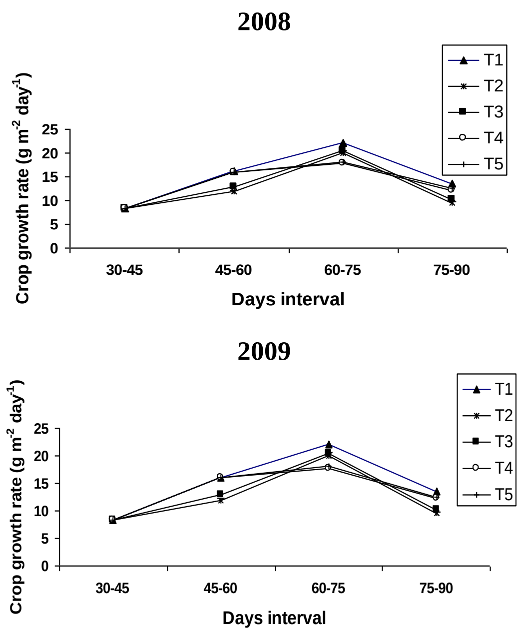

Figure 6. Effect of irrigation and abscisic acid schedules on crop growth rate during 2008 and 2009

T_1= 4 irrigations and no ABA; T_2= irrigation skip at bud initiation and no ABA; T_3= irrigation skip at bud initiation and ABA; T_4=irrigation skip at flower initiation and no ABA; T_5=irrigation skip at flower initiation and ABA

Irrigation at bud initiation favored dry matter production in leaf and stem while its application at flower initiation was important for head and seed development (Unger. 1983), which clarified that drought stress at bud initiation caused more reduction in crop growth rate. Contrary to our results non-significant effect on crop growth rate was observed by Hussain *et al*. (2000) under drought. Water stress decreased mitosis, cell expansion and elongation which finally caused decrease in plant height, leaf area and crop growth rate (Hussain *et al*., 2008; Hussain *et al*., 2012b). Exogenous application of ABA under drought caused increase in crop growth rate of sunflower hybrids. This improvement in crop growth rate was due to the conservation of plant moisture. This water conservation took place by partial closing of stomata, and increase in root penetration (Salisburry and Marinos, 1985). Exogenous application of ABA increased dry weight of sunflower leaves which ultimately increased crop growth rate (Unyayar *et al*., 2004).

Meaningful orthogonal contrasts study about yield and yield components of sunflower hybrids highlighted (Table 3) that contrasts of 4 irrigations vs 3 irrigations, ABA spray vs no ABA spray were significant for plant height, head diameter, number of achenes per head, 1000-achene weight, achene yield, oil yield, biological yield and harvest index.

Conclusion**:** Drought stress to different sunflower hybrids showed damage to crop productivity. Normal irrigation application to sunflower hybrids increased crop growth and yield while foliar application of ABA under normal decreased allometry and yield. ABA application to sunflower hybrids under water deficit conditions at bud or flower initiation helped in mitigating the adverse effects of drought; however, the response was better when ABA was applied under drought stress at bud initiation than that of flower initiation stage. Sunflower hybrid DK-4040 showed better response for drought tolerance through foliar application of ABA than SF-187 and S-278 because it showed improvement in allometry, yield and yield components.

Acknowledgement**:** Authors highly acknowledge the Higher Education Commission, Govt. of Pakistan, for providing financial support for conducting the current valuable research.

REFERENCES

Alfredo, A.C.A. and T.L. Setter. 2000. Response of cassava to water deficit: Leaf area growth and abscisic acid. Crop Sci. 40: 131-137.

AOAC. 1990. Official Methods of Analysis, 15th Ed. Association of Official Analytical Chemists, Inc. Virginia, USA. pp.770-771.

Ardakani, M.R., A.H.S. Shirani and D. Habibi. 2005. Drought stress effects on quantitative characters of commercial sunflower cultivars and hybrids. Interdrought-II, the second international conference on integrated approaches to sustain and improve plant production under drought stress; Rome, Italy, September, 24-28. pp-132.

Bakht, J., S. Ahmad, M. Tariq, H. Akhtar and M. Shafi. 2006. Performance of various hybrids of sunflower in Peshawar valley. Asian Res. Publishing Network 1(3): 25-29.

Blum, A. 1997. Crop responses to drought and the interpretation of adaptation. In: I. Belhassen (ed.), Drought Tolerance in Higher Plants: Genetical, Physiological, and Molecular Biological Analysis. Kluwer Academic Publish, Dordrecht. pp. 57–70.

Cellier, F., G. Conejero, J.C. Breitler and F. Casse. 1998. Molecular and physiological responses to water deficit in drought sensitive lines of sunflower. Plant Physiol. 116: 319-328.

Chunyang, L., Y. Chunying and L. Shirong. 2004. Different response of two contrasting *Populus davidiana* cultivars to exogenous abscisic acid application. Environ. Exp. Bot. 51: 237-246.

Daneshian J., R. Ardakani, D. Habibi and E. Gafaripour. 2005. Drought stress effects on yield, quantitative and qualitative characteristics of new sunflower hybrids. Interdrought-II, the second International Conference on

Integrated Approaches to Sustain and Improve Plant Production under Drought Stress; Rome, Italy, September 24-28. p-175.

Davies, W.J. and J. Zhang. 1991. Root signals and the regulation of growth and development of plants in drying soil. Annu. Rev. Plant Physiol. Plant Mol. Biol. 42: 55–76.

Edmeadas, G.O., J.O. Balanos, S.C. Chapman, H.R. Lafitte and M. Banziger. 1999. Selection improves drought tolerance in tropical maize population. I. Grains in biomass, grain yield and harvest index. Crop Sci. 39:1306-1315.

El- Tayeb, M.A. 2005. Response of barley grains to the interactive effect of salinity and salicylic acid. Plant Growth Regul. 45: 215-224.

Fereres, E., C.G. Gimenez and J.M. Fernandez. 1986. Genetic variability in sunflower cultivars under drought .I. yields relationships. Aust. J. Agric. Res. 37(6):573-582.

Gifford, R.M. and L.T. Evans. 1981. Photosynthesis, carbon partitioning and yield. Ann. Rev. Plant Physiol. 32: 485-509.

Hammadeh, I., P. Maury, P. Debaeke, J. Lecoeur, L. Nouri, S.P. Kiani and P. Grieu. 2005. Canopy nitrogen distribution and photosynthesis during grain filling in irrigated and water stressed sunflower genotypes. Interdrought-II, the second International Conference on integrated approaches to sustain and improve plant production under drought stress; Rome, Italy. September, 24-28. p.94.

Hoad, S.P., G. Russell, M.E. Lucas and I.J. Bingham. 2001. The management of wheat, barley and oats root systems. Adv. Agron. 74:193-246.

Hunt, R. 1978. Plant growth analysis. Studies in Biology No. 96. Edward Arnold, London: pp.26-38.

Hussain, M.K., E. Rasul and S.K. Ali. 2000. Growth analysis of sunflower (*Helianthus annuus* L.) under drought conditions. Int. J. Agric. Biol. 2(1-2):136-140.

Hussain, M., M.A. Malik, M. Farooq, M.Y. Ashraf and M.A. Cheema. 2008. Improving drought tolerance by exogenous application of glycinebetaine and salicyclic acid in sunflower. J. Agron. Crop Sci. 194: 193-199.

Hussain, S., M.F. Saleem, M.Y. Ashraf, M. A. Cheema and M. A. Haq. 2010.Abscisic acid, a stress hormone helps in improving water relations and yield of sunflower (*Helianthus annuus* L.) hybrids under drought. Pak. J. Bot. 42(3):2177-2189.

Hussain, S., B. L. Ma, M.F. Saleem, S.A. Anjum, A. Saeed and J. Iqbal. 2012a. Abscisic acid spray on sunflower acts differently under drought and irrigation conditions. Agron. J. 104(3):561-568.

Hussain, S., A. Ali, M. Ibrahim, M.F. Saleem and M. Ahmad alias Haji A. Bukhsh. 2012b. Exogenous application of Abscisic acid for drought tolerance in sunflower: A review. J. Ani. Plant Sci. 22(3):806-826.

Hussain, S., M. Ahmad, S. Ahmad, J. Iqbal, M.N. Subhani, S.M. Nadeem, S. Atta and M. Ibrahim. 2013. Improvement of drought tolerance in sunflower by foliar application of abscisic acid and potassium chloride. Pak. J. Nut. 12(4):345-352.

Jaleel, C.A., P. Manivannan, G.M.A. Lakshmanan, M. Gomathinayagam and R. Panneerselvam. 2007. Alterations in morphological parameters and photosynthetic pigment responses of *Catharanthus roseus* under soil water deficits. Colloids Surf. B. Biointerfaces doi:10.1016/j.colsurfb.2007.09.008.

Kadayifei, A. and O. Yildrim. 2000. Response of sunflower seed yield to water. Turkish J. Agri. Forest. 24(2): 137-145.

Little, T.M. and F.J. Hills. 1978. Agricultural Experimentation. John Willey and Sons, New York, USA. pp.66-67.

Liu, F., C.R. Jensen and M.N. Andersen. 2004. Pod set related to photosynthetic rate and endogenous ABA in soybean subjected to different water regimes and exogenous ABA and BA at early reproductive stage. Ann. Bot. 94: 405-411.

Luan, S. 2002. Signalling drought in guard cells. Plant Cell Environ. 25: 229–237.

Mahal, S.S., H.S. Uppal and B.S. Mankotia. 1998. Performance of spring sunflower under different levels of soil moisture regimes and nitrogen. Environ. Eco. 16(3): 599-602.

Nasri, M. 2005. Interaction of nutrient elements and drought stress in cultivars of *Brassica napus*. The second international conference on integrated approaches to sustain and improve plant production under drought stress.Rome, Italy. September 24-28, p.109.

Pandey, D.M., C.L. Goswami and B. Kumar. 2003. Physiological effects of plant hormones in cotton under drought. Biol. Plant. 47 (4): 535-540.

Petchu, E., A. Arsintescu and D. Stanciu. 2003. Studies regarding the hydric stress effect on sunflower plants. Analele Institutuli de Cereale si Plante Technice, Fundulea 70:347-356.

Reddy, G.C., V. Maruthi, M. Vanaja and D.G. Rao. 1998. Effect of moisture stress and management practices on productivity of rainfed sunflower. Ind. J. Agron. 43:149-153.

Saensee, K., T. Machikowa and N. Muangsan, 2012. Comparative performance of sunflower synthetic varieties under drought stress. Int. J. Agric. Biol. 14:929-934

Salisbury, B.F. and N.G. Marinos. 1985. The ecological role of plant growth substances. In: R.P. Pharis and D.M. Reid (eds.), Encyclopedia of plant physiol. Vol. 11. Springer-verlag, Berlin, Heidelberg, New York.

Schuppler, U., P.H. He, P.C.L. John and R. Munnus. 1998. Effects of water stress on cell division cycle-2-like cell-cycle kinase activity in wheat leaves. Plant Physiol. 117:667-678.

Schwarzbach, A.E., L.A. Donovan and L.H. Rieseberg. 2000. Transgressive character expression in a hybrid sunflower species. Ameri. J. Bot. 88: 270-277.

Setter, T.L., B.A. Flannigan and J. Melkonian. 2001. Loss of kernel set due to water deficit and shade in maize; carbohydrate supplies, abscisic acid and cytokinins. Crop Sci. 41: 1530-1540.

Shamim, A., R. Ahmad, R.Y. Ashraf, M. Ashraf and E.A. Wariach. 2009. Sunflower (*Helianthus annuus* L.) response to drought stress at germination and seedling growth stages. Pak. J. Bot.41(2): 647-654.

Steel, R.G.D., J.H. Torrie and D.A. Dicky. 1997. Priciples and procedures of Statistics: A biometrical approach, 3rd Ed. McGraw Hill Book Co. Inc. New York. pp.400-428.

Turner, N.C., G.C. Wright and K.H.M. Siddique. 2001. Adaptation of grain legumes (pulses) to water limited environments. Adv. Agron. 71:123-231.

Unger, P.W. 1983. Irrigation effects on sunflower growth, development and water use. Field Crops Res. 3:181-194.

Unyayar, S., Y. Keles and E. Unal. 2004. Proline and ABA levels in two sunflower genotypes subjected to water stress. Bulg. J. Plant Physiol. 30(3-4): 34-47.

Wahid, A. and E. Rasul. 2005. Photosynthesis in leaf, stem, flower and fruit In: M. Pessarakli (ed.). Handbook of Photosynthesis, 2nd Ed. CRC Press, Florida. pp.479-497.

Wang, Z.L., B.R. Huang and Q.Z. Xu. 2003. Effects of abscisic acid on drought responses of Kentucky bluegrass. J. Am. Soc. Hort. Sci. 128(1): 36–41.

Watson, D.J. 1947. Comparative physiological studies on the growth of field crops. I. Variation in net assimilation rate and leaf area between species and varieties and within and between years. Annal. Bot. 11:41-76.

Wisner, T.N. and C.A. Chase. 1984. World Food Trade and US Agriculture. pp.1960-1983.