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Full Length Research Paper

Influence of environmental variations on physiological attributes of sunflower

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High degree of adaptability, wide range of climatic conditions, high photosynthetic capacity, maximum stomatal conductance and efficient hydraulic mechanism allow sunflower crop to be productive in broad range of environments. Combined effects of environmental factors not only modify plant phenology but also cause many physiological changes. Field experiments, one each in spring and autumn were conducted at Pir Mehr Ali Shah, Arid Agriculture University Rawalpindi, Pakistan for 2 years (2007 and 2008) to document the effect of environmental variations on the physiological functions of sunflower hybrids. Four sunflower hybrids, Alisson-RM, Parasio-24, MG-2 and S-278 were planted in randomized complete block design with 4 replications. The data on physiological attributes like photosynthetic rate, stomatal conductance and transpiration rate at 10 days interval after complete emergence to 60 days after emergence (DAE) was recorded. Overall higher values of photosynthetic rate, stomatal conductance and transpiration rate were recorded during spring as compared to autumn for both the years. Photosynthates accumulation and utilization was depressed in cold imposing a restriction on biomass production than at warm temperature. Physiological performance of all the hybrids during spring at the start was slower as compared to autumn. Progressive increase in photosynthetic rate, stomatal conductance and transpiration was recorded with the gradual increase in temperature up to a certain level during spring but further increase in temperature caused decline in these attributes. However during autumn, values of all these 3 physiological attributes were higher at the start those declined with gradual decrease in temperature later in the season.

Key words: Photosynthetic rate, stomatal conductance, transpiration rate, temperature, varying environments.

INTRODUCTION

Sunflower is one of the major and most important non conventional oilseed crop in the world due to its excellent oil quality (Baydar and Erbas, 2005). It is a C_4 plant having higher photosynthetic rates but is sensitive to cold temperatures and as such is often referred to as warm season plant as compared to C_3 plants (Brouder and Volenec 2008).

Though a temperate zone crop yet can perform well under various climatic and soil conditions. It is better adapted to warmer temperatures and longer growing season (Johnston et al., 2002). Sunflower hybrids have an evolutionary advantage of being able to maintain high level of viability in a variety of environments (NODP, 2005). Experimental trials have indicated that sunflower can be grown successfully in 2 seasons (spring and autumn) in Pakistan due to its wide range of adaptability, however, spring crop yields higher than autumn crop (Qader, 2006). Summer season characterized by higher temperature and more light interception values is better with respect to plant growth, development, physiological processes and oil parameters over winter season that shows poor and slower plant growth, lower net assimilation rate, lesser net photosynthetic rate and dry matter partitioning, ultimately resulting in plants with shorter stature and low sink capacity (Rawson et al., 1984).

Environmental changes generate differences in transpiration and photosynthetic rates. The main functions of stomata is to allow CO_2 uptake by leaves to facilitate the stomatal conductance and diffusion of water vapors thus

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permitting the transpiration, responding to a number of environmental variables like temperature, photoperiod, vapor pressure deficit, CO_2 concentration and water stress (Sepulveda and Kliewer, 1986). Jarvis et al. (1999) concluded that reductions in stomatal conductance can cause reductions in transpiration rate and reduction in transpiration can cause partial de-saturation of the air adjacent to vegetation and the decreased evaporative cooling of leaves results in increased leaf temperature, thus both factors increase evaporative demand. Leaf stomata control plant CO_2 absorption through photosynthesis and water loss through transpiration and their aperture regulates water use efficiency of crops. Bunce (2007) concluded that increased stomatal conductance resulted in increased transpiration rate and low leaf water potential.

Many physiological processes are usually sensitive to cold stress which is main reason for the reduction of growth and yield of crops. The low temperature prevailed in most time of the autumn season and under such cold conditions, an imbalance appeared between source of energy and metabolic sink. The higher production in spring is attributed to the interaction of environmental factors, those partitioned the photosynthates in achenes. Variation in climatic factors affects photosynthesis and transpiration in different ways on crop plant (Abbate et al., 2004; Baydar and Erbas, 2005). In most plants, as a direct response to temperature, the photosynthetic rate is low at extreme low and high temperatures and has an optimum or maximum at intermediate temperature (Hikosaka et al., 2006). Similarly, Wang et al. (2008) concluded that gradual rise in temperature caused an increase in CO_2 concentration, chlorophyll content and photosynthetic rate up to maximum temperature (34.24°C), while further increase in temperature decreased all these 3 contents.

Temperature is the main driver of many plant developments as higher temperature speeds up plant development (Rawson et al., 1984). Both the crops (spring and autumn) being grown in opposite environmental conditions, all growth, developmental and physiological processes are affected accordingly. Keeping in view 2 opposite sets of environment (spring and autumn) and potential of the crop in Pakistan, the present study was contemplated to record the response of sunflower hybrids on physiological attributes once grown under 2 different environments.

MATERIAL AND METHODS

Field experiments were conducted at Pir Mehr Ali Shah, Arid Agriculture University Rawalpindi, Pakistan during spring and autumn 2007 and 2008. The soil of experimental site is loam type in texture having sand 43%, silt 46% and clay 11%, pH 7.4 and EC 0.66 m S cm^{-1}, which is located at 33° and 38° N and 73° and 04° E. Prior to sowing the particular site was fallow which was prepared for sowing by giving one soil inverting plough, thereafter, ploughed twice with tractor driven cultivator. Recommended dose of fertilizer of 80 kg nitrogen and 60 kg P_2 O_5 per hectare was applied in the form of urea and DAP at the time of last ploughing. Spring crop was sown on 18th March and autumn crop on 18th August during each year. 4 sunflower hybrids, Alisson-RM, Parasio-24, MG-2 and S-278 were planted in randomized complete block design with 4 replications keeping net plot size of 5 x 6 m^2 having 8 rows. Row to row distance was maintained at 75 cm and plant to plant distance at 25 cm. Planting was done with the help of dibbler putting 2 seeds per hill by using seeds at 5 kg ha^{-1}. After complete emergence one plant was maintained per hill by manual thinning. Weeds were kept under control manually throughout the crop life cycle. Weather data was recorded at nearby weather observatory.

Photosynthetic rates (µmol CO_2 m^{-2} s^{-1}), stomatal conductance (mol m^{-2} s^{-1}) and transpiration rates (m mol^{-1} m^{-2} s^{-1}) were recorded from 5 randomly selected plants from upper top most leaf (L_1) and next leaf (L2) of each plant at 10 days interval after complete crop emergence from 10 DAE (days after emergence) till physiological maturity (60 DAE) with the help of IRGA (Infra Red Gas Analyzer) (Leaf Chamber Analyzer, Type LCA-4, USA) as described by Long and Bernacchi, (2003). The collected data were subjected to statistical analysis (pooled over years) by applying MSTATC, separately for both the seasons (Freed and Eisensmith, 1986). Analysis of variance techniques were employed to test the significance of data. Least significant difference test at 5% probability was used to compare the means (Montgomery, 2001).

RESULTS

Data regarding photosynthetic rate at 10 DAE, presented in Table 1 exhibited differences among hybrids, years and interaction during spring season. However, statistically significant differences were observed among hybrids, years and interaction during autumn season. At 20 DAE, hybrids depicted statistical differences for photosynthetic rate during both spring and autumn seasons (Table 1). Comparison of the years depicted statistically significant differences during the spring season while statistically non significant differences during autumn. The interaction (hybrids x years) were statistically non significant for the spring while statistical differences were recorded for autumn. At 30 DAE statistical differences among hybrids for photosynthetic rate were observed during spring, but during autumn hybrids were statistically similar. Comparison of the years depicted statistically non significant differences during spring season while, autumn gave statistical differences. The interaction (hybrids x years) were also statistically significant for both the seasons.

Photosynthetic rate at 40 DAE (Table 1) exhibited statistical differences among hybrids during the spring while statistically non significant differences were observed among hybrids during autumn. Comparison of the years and interaction, depicted statistical differences during both (spring and autumn) seasons. Similarly, at 50 DAE photosynthetic rate exhibited statistical differences among hybrids during the both seasons. Comparison of the years showed statistically non significant differences

Table 1. Analysis of variance for photosynthetic rate.

Sampling Interval	Source of Variation	Degree of Freedom	Spring			Autumn		
			Mean Squares	F-Value		Mean Squares	F-Value	
10 DAE	Year	1	5.112	4.9471	NS	30.949	16.0961	**
	Error	6	1.033			1.923		
	Hybrids	3	1.533	3.5200	NS	21.238	8.6034	**
	Interaction	3	0.049	0.1133	NS	2.079	0.8423	**
	Error	18	0.435			2.469		
20 DAE	Year	1	22.311	13.6027	*	9.680	5.3280	NS
	Error	6	1.640			1.817		
	Hybrids	3	15.907	8.2479	**	7.227	5.5220	**
	Interaction	3	3.495	1.8123	NS	0.878	0.6707	**
	Error	18	1.929			1.309		
30 DAE	Year	1	1.848	1.2443	NS	15.680	19.9957	**
	Error	6	1.485			0.784		
	Hybrids	3	29.631	18.5670	**	1.857	2.9405	NS
	Interaction	3	0.122	0.0762	**	0.242	0.3834	**
	Error	18	1.596			0.632		
40 DAE	Year	1	0.057	0.0194	**	32.100	10.4292	*
	Error	6	2.937			3.078		
	Hybrids	3	30.336	15.5848	**	12.718	3.9475	NS
	Interaction	3	0.757	0.3889	**	0.861	0.2671	**
	Error	18	1.947			3.222		
50 DAE	Year	1	19.453	3.2944	NS	60.418	8.3956	*
	Error	6	5.905			7.196		
	Hybrids	3	12.018	6.2565	**	18.292	9.1124	**
	Interaction	3	0.877	0.4564	**	2.801	1.3955	*
	Error	18	1.921			2.007		
60 DAE	Year	1	2.112	0.7664	NS	55.546	107.3763	**
	Error	6	2.755			0.517		
	Hybrids	3	32.438	13.1227	**	21.156	70.1955	**
	Interaction	3	1.692	0.6844	**	0.842	2.7944	*
	Error	18	2.472			0..301		

during spring season, however, statistical differences were observed between years during autumn. The interaction (hybrids x years) were also statistically significant during both seasons. Photosynthetic rate at 60 DAE (Table 1) showed statistical differences among hybrids during both seasons. Comparison of the years showed statistically non significant differences during spring season. However, statistical differences were observed between years during autumn. The interaction (hybrids x years) were also statistically significant during both (spring and autumn seasons).

Stomatal conductance at 10 DAE (Table 2) exhibited statistical differences among the hybrids during spring, however, during autumn differences were statistically similar. Comparison of the years depicted statistically non significant differences during both spring and autumn seasons. Interaction (hybrids × years) were statistically significant during spring and statistically non-significant during autumn season. Similarly, statistically similar results among the hybrids for stomatal conductance at 20 DAE were recorded during spring season. However, autumn season exhibited statistically ($p < 0.05$) significant differences among hybrids for stomatal conductance. Comparison of the years as well as interaction (hybrids x years) were statistically significant during both the seasons. At 30 DAE, stomatal conductance exhibited statistical differences among the hybrids for spring season (Table 2) while, statistically similar results were observed during autumn season. Comparison of the years depicted statistically significant differences during spring season, however, statistically non significant results were observed during autumn season. Interaction (hybrids × years) were statistically different during spring while, statistically similar during autumn. At 40 DAE, stomatal conductance exhibited statistical differences among the hybrids, years and interaction during the seasons, spring and autumn (Table 2). At 50 DAE stomatal conductance showed statistical differences among the hybrids for spring season and showed statistically similar results during autumn. Comparison of the years depicted statistical differences during spring season as compared to similar results during autumn. Interaction (hybrids × years) were statistically significant during spring, while statistically similar during autumn. Similarly, Table 2 depicted statis-

Table 2. Analysis of variance for stomatal conductance.

Sampling Interval	Source of Variation	Degree of Freedom	Spring			Autumn		
			Mean Squares	F-Value		Mean Squares	F-Value	
10 DAE	Year	1	0.191	3.3235	NS	0.003	1.3287	NS
	Error	6	0.057			0.002		
	Hybrids	3	0.326	11.2704	**	0.011	3.7684	NS
	Interaction	3	0.041	1.4209	*	0.000	0.0000	NS
	Error	18	0.029			0.003		
20 DAE	Year	1	0.517	8.5068	*	0.029	14.6441	**
	Error	6	0.061			0.002		
	Hybrids	3	0.119	3.5299	NS	0.089	11.9821	**
	Interaction	3	0.028	0.8398	**	0.008	1.0762	*
	Error	18	0.034			0.007		
30 DAE	Year	1	0.106	18.3734	**	0.015	4.0268	NS
	Error	6	0.006			0.004		
	Hybrids	3	0.120	12.6331	**	0.005	1.8046	NS
	Interaction	3	0.068	7.1368	**	0.001	0.3826	**
	Error	18	0.009			0.003		
40 DAE	Year	1	0.353	7.3859	*	0.002	0.9584	**
	Error	6	0.048			0.002		
	Hybrids	3	0.172	5.2784	**	0.010	4.7335	*
	Interaction	3	0.009	0.2739	**	0.000	0.0591	**
	Error	18	0.033			0.002		
50 DAE	Year	1	0.138	19.4845	**	0.000	3.4498	NS
	Error	6	0.007			0.000		
	Hybrids	3	0.020	4.0844	*	0.002	8.2684	NS
	Interaction	3	0.010	2.1226	*	0.000	0.2071	NS
	Error	18	0.005			0.000		
60 DAE	Year	1	0.030	9.0239	*	0.009	11.4032	*
	Error	6	0.003			0.001		
	Hybrids	3	0.014	2.9993	NS	0.001	1.9261	*
	Interaction	3	0.001	0.2059	**	0.001	1.2681	*
	Error	18	0.005			0.000		

tically non significant differences among the hybrids for stomatal conductance at 60 DAE during spring season. However, autumn season exhibited statistically ($p < 0.05$) significant differences among hybrid. Comparison of the years and interaction depicted statistically significant differences during both, spring and autumn seasons.

Transpiration rate at 10 DAE, presented in Table 3 exhibited statistical differences among the hybrids for the both spring and autumn seasons. Comparison of the years depicted statistically non significant differences during both the seasons. Interaction (hybrids x years) were statistically non significant for the spring while statistical differences were observed for autumn. At 20 DAE, transpiration rate exhibited statistical differences among the hybrids for spring season (Table 3) while, statistically similar results were observed during autumn. Comparison of the years also depicted statistically non significant differences during spring while statistical differences were observed during autumn. Interaction (hybrids × years) were statistically significant during spring and statistically non-significant during autumn season. At 30 DAE, transpiration rate (Table 3) exhibited statistical differences among the hybrids for the both spring and autumn seasons. Comparison of the years exhibited statistically non-significant differences between the years during spring while during autumn statistical differences were observed between the years. The interaction (hybrids × years) depicted statistical differences during both the seasons. Transpiration rate at 40 DAE exhibited statistical differences among the hybrids for the both spring and autumn seasons (Table 3). Comparison of the years exhibited statistically non-significant differences between

Table 3. Analysis of variance for transpiration rate.

Sampling Interval	Source of Variation	Degree of Freedom	Spring			Autumn		
			Mean Squares	F-Value		Mean Squares	F-Value	
10 DAE	Year	1	4.478	3.3016	NS	2.117	1.0918	NS
	Error	6	1.356			1.939		
	Hybrids	3	2.550	3.1063	*	4.125	3.4042	*
	Interaction	3	1.329	1.6193	NS	0.475	0.3920	**
	Error	18	0.821			1.212		
20 DAE	Year	1	2.983	2.4368	NS	0.541	0.9575	**
	Error	6	1.224			0.565		
	Hybrids	3	4.936	6.8385	**	0.573	1.2163	NS
	Interaction	3	0.473	0.6555	**	0.076	0.1615	NS
	Error	18	0.722			0.471		
30 DAE	Year	1	0.875	1.5403	NS	0.004	0.0021	**
	Error	6	0.568			1.900		
	Hybrids	3	5.785	4.5492	*	3.947	7.4460	**
	Interaction	3	0.111	0.0871	**	0.322	0.6081	**
	Error	18	1.272			0.530		
40 DAE	Year	1	1.030	1.2299	NS	0.083	0.2231	**
	Error	6	0.837			0.372		
	Hybrids	3	4.179	5.1058	**	7.098	6.7882	**
	Interaction	3	0.078	0.0956	**	0.315	0.3008	**
	Error	18	0.818			1.046		
50 DAE	Year	1	4.985	4.7928	NS	0.080	0.1752	**
	Error	6	1.040			0.457		
	Hybrids	3	5.248	4.8974	*	0.220	1.1027	NS
	Interaction	3	0.354	0.3304	**	0.089	0.4451	NS
	Error	18	1.072			0.200		
60 DAE	Year	1	0.562	0.4624	**	1.509	3.6292	NS
	Error	6	1.215			0.416		
	Hybrids	3	11.003	20.4639	**	0.423	1.3361	NS
	Interaction	3	1.213	2.2553	*	0.093	0.2926	**
	Error	18	0.538			0.317		

the years during spring while during autumn statistical differences recorded. The interaction (hybrids × years) depicted statistical differences during both the seasons. Transpiration rate at 50 DAE showed statistical differences among the hybrids for spring season (Table 3) while, autumn season exhibited statistically ($p < 0.05$) similar results among hybrids. Comparison of the years exhibited statistically non-significant differences during spring while during autumn statistical differences were observed. Interaction (hybrids x years) were statistically different for the spring while statistically similar during autumn. At 60 DAE transpiration rate exhibited statistical differences among the hybrids during spring season (Table 3). However, autumn season exhibited statistically ($p < 0.05$) non significant differences. Comparison of the years exhibited statistically significant differences between the years during spring while statistically non-significant differences were observed during autumn season. Interaction (hybrids x years) were statistically different for both the seasons.

DISCUSSION

The gradual rise in temperature can cause an increase in CO_2 concentration and photosynthetic rate up to a maximum temperature level and beyond that CO_2 and photosynthetic rate both decreased (Wang et al., 2008). In the present investigations, minor differences among hybrids for photosynthetic rate were observed at 10 DAE during both the seasons at early crop establishment stage. With the increase in temperature in spring (Table 4) from 20

Table 4. Meteorological data of two years, spring 2007, 2008 and autumn 2007, 2008.

Month	Spring 2007					Spring 2008				
	Temperature (°C)		Rainfall (mm)	RH (%) (mean)	Sunshine (mean h)	Temperature (°C)		Rainfall (mm)	RH (%) (mean)	Sunshine (mean h)
	Max (mean)	Min. (mean)				Max. (mean)	Min. (mean)			
March	23.10	9.00	143.20	47.00	7.40	29.67	11.78	19.10	57.00	7.90
April	34.00	15.90	18.00	44.00	10.70	29.70	15.77	92.90	59.33	7.71
May	37.30	19.80	80.60	42.00	10.00	37.16	20.76	10.10	40.00	9.92
June	37.60	23.00	22.30	51.00	9.50	35.57	22.29	225.00	62.43	7.47
July	35.20	21.50	262.50	68.00	9.30	35.01	22.75	432.50	69.61	7.38
Autumn 2007						**Autumn 2008**				
August	34.20	21.80	485.00	72.00	8.30	33.32	22.97	221.00	66.61	7.46
September	32.90	19.40	201.00	68.00	7.80	32.28	19.67	66.00	51.83	8.14
October	31.50	12.60	0.00	54.00	9.60	31.03	15.37	24.00	43.83	7.88
November	26.00	8.20	10.00	71.00	7.00	25.24	8.13	18.00	50.46	8.53
December	-	-	-	-	-	20.77	5.49	71.70	55.88	6.44

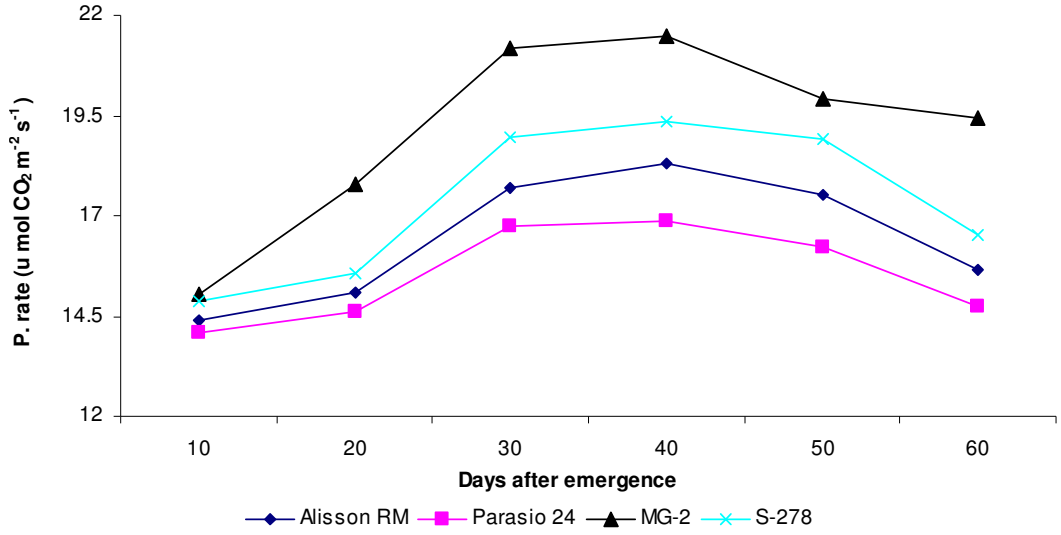

Figure 1a. Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of sunflower hybrids during spring season (means of 2 years)

DAE up to 40 DAE, photosynthetic rate continuously increased. Photosynthetic rate recorded from all the hybrids started decreasing from 50 DAE during spring season, although year 2007 depicted increase in photosynthetic rate at 50 DAE in spring (Figure 1a). Continuous decrease in photosynthetic rate was recorded during autumn season, from 10 DAE to physiological maturity (60 DAE) with gradual decrease of temperature (Figure 1b). These results are in conformity with those of Paul et al. (1990) who found that different temperatures affect photosynthetic rate differently, that is, photosynthetic rate increased with increase in temperature. Similarly, Baydar and Erbas (2005) concluded that low temperature is one of the limiting factors that adversely affect photosynthesis which is sensitive to cold stress.

Drew and Bazzaz (1982) concluded that with the increase of leaf temperature from 25 to 35°C, intercellular CO_2 increased from 200 to 600 µmol mol^{-1} which doubled the stomatal conductance. In present study, stomatal conductance progressively increased from 10 DAE to 40 DAE during spring season (Figure 2a) which could be due to the gradual increase of temperature (Table 4) during this period but from 50 DAE, stomatal conductance started decreasing, probably due to extreme temperature at this peak growth period. The decline in stomatal conductance from 50 DAE may also be attributed to leaf age which is supported by the findings of Grulke et al. (2004) who found that the magnitude of stomatal conductance

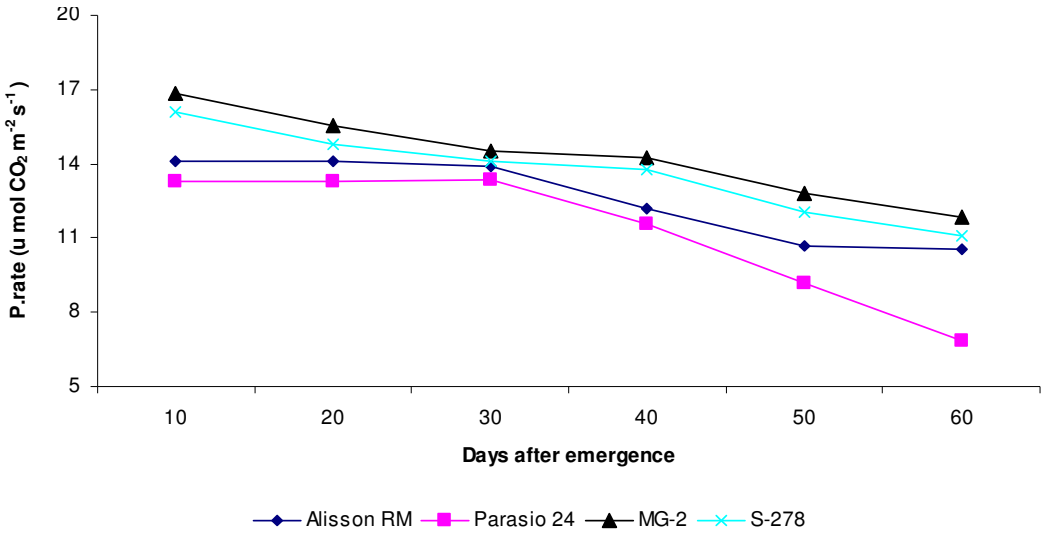

Figure 1b. Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) of sunflower hybrids during autumn season (means of 2 years).

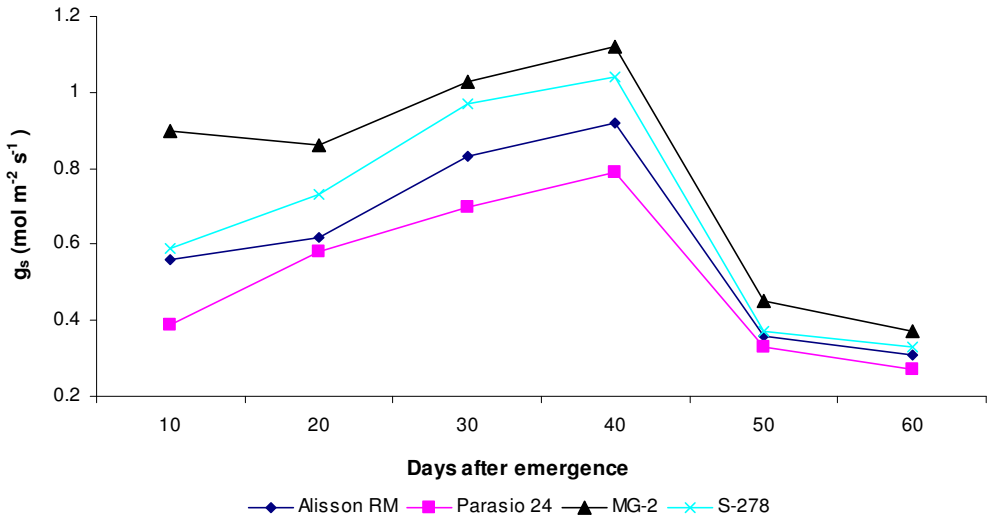

Figure 2a. Stomatal conductance (mol m^{-2} s^{-1}) of sunflower hybrids during spring season (means of 2 years).

vary temporally with leaves age, from pre-reproductive to reproductive stage leaf age caused a decline in stomatal conductance in sunflower. However during autumn season stomatal conductance gradually increased up to 20 DAE (Figure 2b) due to increased temperatures and higher rainfalls and thereafter, continuously decreased with the gradual decrease in temperature. Oja et al. (1988) concluded that stomatal conductance was maximum at higher temperatures in sunflower leaves and rapidly declined at lower temperatures. These results are also in accordance with those of Orta et al. (2002) who concluded that, as percent soil water decreased, crop water stress index increased causing decrease in stomatal conductance

The extreme weather conditions caused reductions in transpiration rate due to reductions in stomatal conductance (Jarvise et al., 1999). Similarly Moriana et al. (2002) found that plants reduced excessive water loss by closing their stomata at extreme growing conditions. In present investigation, transpiration rate progressively increased from 10 DAE to 40 DAE during spring season (Figure 3a) which may be attributed to the gradual increase of temperature during this period but from 50 DAE, transpiration rate started decreasing, probably due to extreme temperature (Table 4) and age of leaves. The decline in transpiration rate from 50 DAE may also be

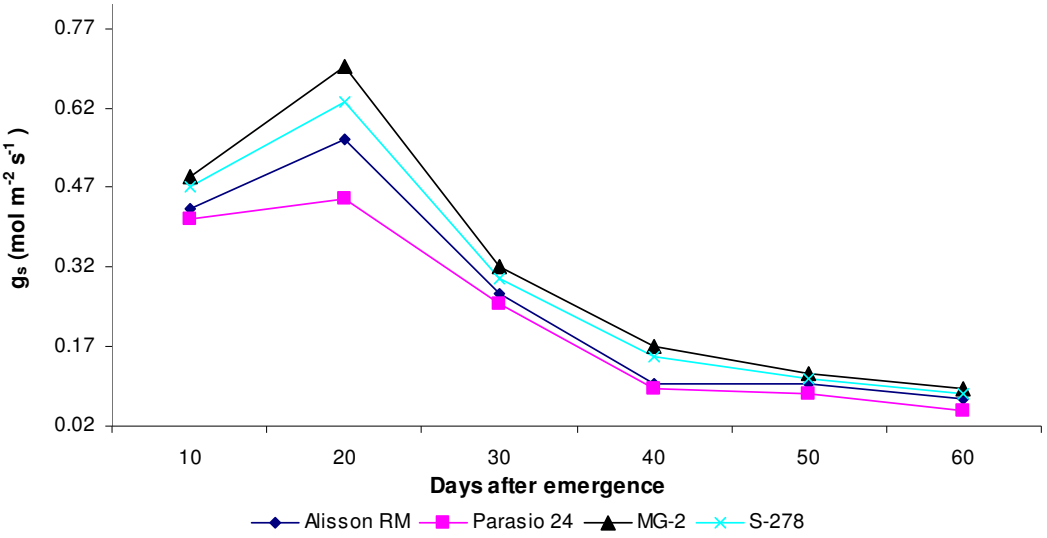

Figure 2b. Stomatal conductance (mol m^{-2} s^{-1}) of sunflower hybrids during autumn season (means of 2 years).

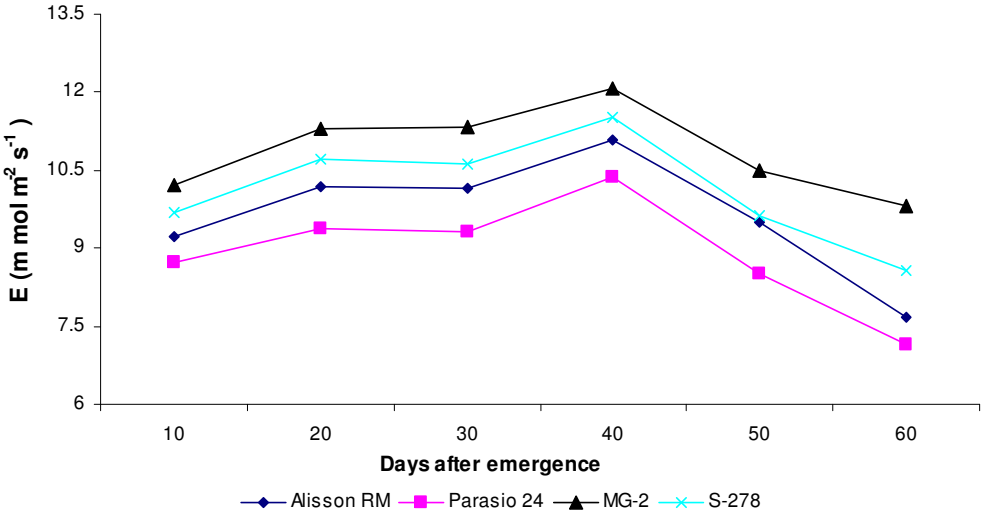

Figure 3a. Transpiration rate (m mol m^{-2} s^{-1}) of sunflower hybrids during spring season (means of 2 years).

attributed to leaf age which is supported by the findings of Grulke et al. (2004) they found that transpiration rate and stomatal conductance vary with leaves age from pre-reproductive to reproductive stage in sunflower. During autumn season transpiration rate gradually increased up to 20 DAE, (Figure 3b) probably due to increased temperatures and higher rainfalls and then continuously decreased as the temperature decreased. Baydar and Erbas (2005) concluded that low temperature is one of the limiting factors that adversely affect crop hydraulic and physiological processes. These results are in conformity with those of Bunce (2007) who concluded that hydraulic conductance in plants is affected by environmental factors.

It may be concluded from the present investigations that environmental changes affect physiological functions of sunflower those severely affected by extreme weather conditions. The maximum physiological processes leading to enhanced photosynthates accumulation and biological, seed and oil yield potential can be obtained at intermediate environmental conditions which were present in spring season. Spring season also provided longer crop duration and facility for the crop to enhance physiological performance of the hybrids by harvesting maximum intercepted solar radiation. The progressive decline of temperature and cold stress conditions accompanied with

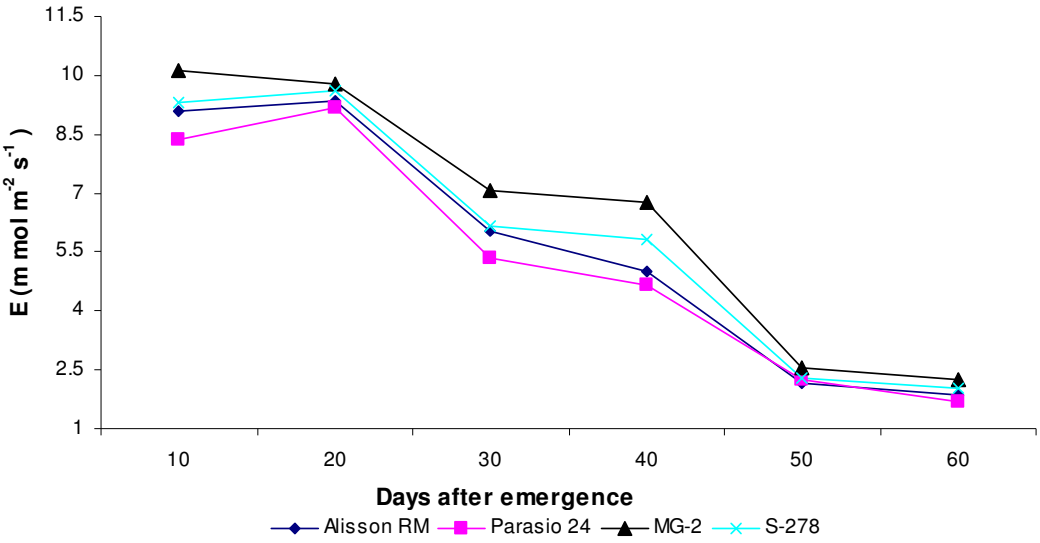

Figure 3b. Transpiration rate (m mol m^{-2} s^{-1}) of sunflower hybrids during autumn season (means of 2 years).

rainfalls during autumn season affected not only plant physiological functions but also decreased translocations and ultimately affected crop yield.

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