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Full Length Research Paper

Growth rhythms in sunflower (*Helianthus annuus* L.) in response to environmental disparity

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Sunflower hybrids maintain high level of stability in a variety of environments. Environmental variations affect and modify plant attributes like growth, development and assimilation through physio-morphic functions, thus modifying plant phenology. Field experiments, one each in spring and autumn, were conducted at Pir Mehr Ali Shah, Arid Agriculture University, Rawalpindi, Pakistan for two years (2007 and 2008) to document the effect of environmental variations on growth rhythms of sunflower hybrids. Four Sunflower hybrids, Alisson-RM, Parasio-24, MG-2 and S-278 were planted in randomized complete block design with four replications. The data based on physiological attributes like leaf area (LA), specific leaf area (SLA), crop growth rate (CGR) and net assimilation rate (NAR) at 10 days interval after complete emergence to 60 days after emergence (DAE) were recorded. Overall higher values of LA, SLA, CGR and NAR were recorded during spring as compared to autumn for both years. LA, CGR and NAR of all the hybrids followed a sigmoid curve pattern during both seasons; however, at the start of the season lesser values were observed during spring as compared to autumn. SLA exhibited an opposite trend and continuously decreased till the end. Sigmoid curve pattern of LA, CGR and NAR may be related to environmental variables like temperature and sunshine hours. The decrease after a peak may be due to senescence of older leaves and shifting of crop from vegetative to reproductive phase.

Key words: Growth rhythms, environmental disparity, crop growth rate, net assimilation rate, leaf area.

INTRODUCTION

Sunflower crop plays a key role in supplementing domestic oil production due to its high biological yield potential, ability to resist drought and adjustment in the present cropping system (January, 2003). Sunflower is a temperate zone crop but it can perform well under various climatic and soil conditions. This adaptability makes it possible for the crop to be grown under a variety of environments (NODP, 2005). Among various non-conventional oilseed crops, sunflower has emerged as a promising crop. It adapts better to warmer temperatures and longer growing season (Johnston et al., 2002). Experimental trials have indicated that sunflower can be grown successfully in two seasons (spring and autumn) in Pakistan due to its wide range of adaptability; however, spring crop yields higher than autumn crop (Qader, 2006).

Crop characteristics are modified by environmental factors (as seasonal differences) in leaf area development and resource utilization during sowing in spring (Agele, 2003). Hassan et al. (1999) concluded that leaf area as well as crop growth increased gradually with the age of the crop, attained a peak at middle and declined therefore at advanced growth stages. Similarly, Jose et al. (2004) reported that leaf area and leaf area index increased during spring due to increased leaf area duration and intercepted solar radiation. Also, Heuvelink (1999) revealed that variation in SLA depends upon light intensity or seasons. Ritche and Ne Smith (1991) were, however, of the view that rate of plant development is mainly temperature driven.

CGR increases up to certain growth stage due to

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Abbreviations: CGR, Crop growth rate; **NAR,** net assimilation rate; **LA,** leaf area; **SLA,** specific leaf area; **DAE,** days after emergence.

maximum intercepted solar radiation beyond which mutual shading of leaves increases, thus affecting the light penetration to the base of the canopy and ultimately causing decline in CGR. Reduction of CGR at later growth stages might have been due to loss of active leaves and translocation of photosynthates to reproductive parts (Hassan et al., 1997). However, Caliskan et al. (2002) concluded that higher temperature during 0-45 DAS shortened the emergence period, head initiation, leaf area duration and crop growth duration which decreased the seed yield of monsoon sown crop; while maximum vigor, plant growth, crop growth rate, leaf area development and achene yield were recorded in the plots sown in spring. Similarly, Hendrickson et al. (2004) found increase in CGR with increase in temperature. Crop development was slower in spring season at the beginning; this is because after the emergence of temperature, it became lower as compared to higher crop development in autumn sowing (Feburreira and Abreu, 2001). Nayyar et al. (2007) observed higher values of crop growth rate, net assimilation rate, leaf area duration in warmer conditions as compared to lower values obtained in cold conditions.

Many physiological processes are usually sensitive to cold stress which is the main reason for the reduction of growth and yield of crops. Relatively, low temperature prevailing during autumn season creates an imbalance between source of energy and metabolic sink. Assimilate utilization is more depressed in lower temperature, imposing a greater restriction on biomass production than at optimum temperature (Paul et al., 1990). Similarly, Dennis et al. (2006) observed increase in NAR with the increase in temperature, but highest temperature caused a little decrease in assimilation and biomass which were maximum at intermediate temperature.

Temperature is the main driver of many plant developments as higher temperature speeds up plant development (Rawson et al., 1984). Both crops (spring and autumn) being grown in opposite environmental conditions, all growth, developmental and physiological processes are affected accordingly. Keeping in view two opposite sets of environments (spring and autumn) and potential of the crop in Pakistan, the present study was contemplated to record the growth rhythms of sunflower hybrids grown under two contrasting environments so that inputs addition may be synchronized with the demand of the plants.

MATERIALS AND METHODS

Field experiments were conducted at Pir Mehr Ali Shah, Arid Agriculture University, Rawalpindi, Pakistan which is located at 33° and 38° N and 73° and 04° E, during spring and autumn in 2007 and 2008. The soil of the experimental site was loamy in texture, having 43% sand, 46% silt and 11% clay; pH 7.4 and EC 0.66 mScm^{-1}. Prior to sowing, the particular site was fallowed 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_2O_5 per hectare was applied in the form of urea and DAP at the time of the last ploughing. Spring crop was sown on 18th March and autumn crop on 18th August during each year. Four sunflower hybrids, Alisson-RM, Parasio-24, MG-2 and S-278 were planted in randomized complete block design with four replications of 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, which involves putting two seeds per hill 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.

Five plants were removed from the second row of each plot (leaving outer row as border) at 10 days interval from complete emergence till 60 DAE for recording LA. Leaf area of five plants was recorded with the help of leaf area meter (CI-202 Area Meter, CID, INC, USA), from each plot by using destructive plant samples. The sampled plants were oven dried for 72 h in hot air ventilated oven for recording dry weight. SLA, CGR and NAR were calculated, using the formulas below:

SLA = Leaf area / Fresh Leaf Weight (Hunt, 1978).

CGR = I / SA x DW / DT (Radford, 1967),

Where SA = soil area occupied by the plant, and DW / DT = change in dry weight per unit time.

NAR = 1 / A x DW / DT (Radford, 1967)

Where A = LA, and DW / DT = change in dry weight per unit of time.

Weather data recorded during course of study are given in Table 1. Collected data were subjected to statistical analysis by applying MSTATC, separately for both seasons (Freed and Eisensmith, 1986). Analysis of variance techniques was employed to test the significance of data. Least significant difference test at 5% probability was used to compare the means (Montgomery, 2001).

RESULTS

The differences in leaf areas among the hybrids at 10 to 60 days after emergence (DAE) during both seasons (spring and autumn) were statistically significant (Table 2). The effect of differences in years among hybrids was also to be significant ($p < 0.05$) at 10 and 60 DAE during spring and at 10, 40 to 60 DAE during autumn. The effect of interactions (hybrids x years) among the hybrids was also statistically significantly different ($p < 0.05$) at 10 to 60 DAE during both seasons, except at 50 DAE during autumn.

The differences in specific leaf areas (SLA) among the hybrids at 10 DAE were also statistically significant during spring, but non significant in autumn (Table 3). However, the effect of the differences in years was not significant during spring but only in autumn. Differences in interactions (hybrids × years) were statistically significant during both seasons (spring and autumn). However, there was no significant difference in results observed among the hybrids, years and interaction for SLA at 20 DAE during both seasons (spring and autumn). At 30 DAE, differences in SLA were not statistically significant (p >

Table 1. Meteorological data of two years, spring 2007, 2008 and autumn 2007, 2008.

	Spring 2007					Spring 2008				
Month	Temperature (°C)		Rainfall (mm)	RH (%) (Mean)	Sunshine (Hours) (Mean)	Temperature (°C)		Rainfall (mm)	RH (%) (Mean)	Sunshine (Hours) (Mean)
	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

0.05) among the hybrids for both seasons (Table 3). However, differences observed in years and interactions (hybrids x years) during the seasons (spring and autumn) were statistically significant. At 40 DAE, SLA was statistically different among the hybrids and interaction during both seasons but the effect of differences in years was only statistically significant during spring, and also at particular values for autumn. Moreso, SLA statistically significantly varied among hybrids for spring season but the variations in SLA were not significant during autumn at 50 DAE. Variations in years among hybrids were statistically non-significant during both seasons (spring and autumn). Interactions (hybrids × years), however, statistically significantly differed during the spring, but not in autumn. Similarly, significant differences ($p < 0.05$) among hybrid, years and interaction were observed for SLA at 60 DAE during spring season, but the observed differences in SLA at 60 DAE during autumn were statistically non-significant.

Crop growth rate (CGR) was statistically different among the hybrids at 10 to 60 DAE during the seasons (spring and autumn) except at 10 DAE during autumn, in which differences in CGR were statistically non-significantly (Table 4). The effect of differences in years among the hybrids was statistically significant at 10, 30, 40 and 60 DAE during spring, while at 20 to 60 DAE during autumn. However, the effect was non-significant when observed at 20 and 50 DAE during spring and at 10 DAE during autumn. Similarly, interactions (hybrids x years) remained statistically different from 10 to 60 DAE during both seasons (except at 10 DAE during autumn).

The net assimilation rates (NAR) differences among hybrids were statistically significant ($p < 0.05$) at 10 and 30 DAE during spring and at 10, 40 to 60 DAE during autumn season (Table 5). However, at 20, 40 to 60 DAE during spring, and at 20, 30 DAE during autumn, the differences in NARs were statistically non- significant. The effect of differences in years among the hybrids was statistically non significant at 10, 20, 40 to 60 DAE during spring, and at 10, 30 and 40 DAE during autumn. However, significant differences were observed at 30 DAE during spring, and at 20, 50 to 60 DAE during autumn. The interactions (hybrids x years) appeared to differ significantly at 10, 30 and 50 DAE during spring, and at 10, 20, 40 to 60 DAE during autumn, whereas, at 20, 40 and 60 DAE during spring, and at 30 DAE during autumn season, the differences in interactions appeared to be statistically non- significant.

DISCUSSION

Leaf area and other growth parameters in most of the crop plants usually follow sigmoid pattern which is slow at the beginning, peak in the middle of the season and then declines slowly, giving minimum values near to maturity (Hassan et al., 1999). However, variations in temperature, relative humidity and sunshine hours may influence the

Table 2. Analysis of variance for leaf area.

Spring						Autumn		
Sampling Interval	**SOV**	**df**	**Mean Squares**	**F-Value**		**Mean Squares**	**F-Value**	
10 DAE	Year	1	7781.281	15.1994	**	8778.125	6.8844	*
	Error	6	511.948			1275.042		
	Hybrids	3	42884.115	40.2740	**	45311.208	72.0512	**
	Interaction	3	518.115	0.4866	**	337.708	0.5370	**
	Error	18	1064.809			628.875		
20 DAE	Year	1	15312.5	3.3539	NS	1696.53	0.6978	NS
	Error	6	4565.56			2431.15		
	Hybrids	3	28528.45	8.7437	**	29342.86	23.22	**
	Interaction	3	46.167	0.0141	**	1318.11	1.0434	*
	Error	18	3262.72			1263.32		
30 DAE	Year	1	1188.28	0.0523	NS	1937.53	0.8214	NS
	Error	6	22710.11			2358.9		
	Hybrids	3	250204.03	11.7388	**	195016.61	48.6715	**
	Interaction	3	3420.86	0.1605	**	1764.36	0.4403	**
	Error	18	21314.19			4006.79		
40 DAE	Year	1	51120.03	1.3693	NS	589155.12	341.0820	**
	Error	6	37332.03			1727.31		
	Hybrids	3	260060.53	9.7855	**	283562.91	37.0088	**
	Interaction	3	15015.86	0.5650	**	23183.7	3.0258	*
	Error	18	26576.22			7662.03		
50 DAE	Year	1	9214.03	0.1440	NS	1768140.12	57.6870	**
	Error	6	64007.24			30650.56		
	Hybrids	3	452102.69	54.4666	**	468577.66	42.7155	**
	Interaction	3	33078.94	3.9852	*	14147.45	1.2897	NS
	Error	18	8300.54			10969.72		
60 DAE	Year	1	3584503.12	48.9351	**	654082.03	62.55	**
	Error	6	73250.2			10456.24		
	Hybrids	3	1175022.87	34.8680	**	270359.11	43.89	**
	Interaction	3	30626.37	0.9088	**	10234.36	1.66	*
	Error	18	33699.15			6159.87		

** Highly significant at 1% probability level; * Significant at 5% probability level; NS = Non significant; df = degree of freedom.

expression at different stages (Baydar and Erbas, 2005). In present study, all the hybrids in spring season yielded higher leaf area than those during autumn season which declined after reaching a peak (Figures 1a and1b) in both seasons. Overall, lesser values during autumn season may be related to temperature prevailing in the season. Progressive increase in leaf area was noticed up to 50 DAE during two years of study. Decline in leaf area at later stages may be attributed to the senescence of the older leaves and mutual shading towards maturity. Hassan et al. (1999) observed a progressive increase in leaf area, which decreased after reaching a peak at later stages in linseed.

The specific leaf area (SLA) is computed from the values of leaf area (LA) and thus varies from those of LA. The spring sown crops having higher LA values also have higher SLA. In the present investigation, the overall higher SLA values were recorded, during spring season, at most of the growth stages than those during autumn season. This may be due to higher leaf area, leaf area duration and light interception in spring (Figures 2a and 2b). These results are in conformity with those of Heuvelink (1999) who reported that variation in SLA depends upon light intensity or seasons. Similarly, Jose et al. (2004) revealed that during spring SLA increase due to increased leaf area duration. Thus our findings are

Table 3. Analysis of variance for specific leaf area.

Spring						Autumn		
Sampling Interval	**SOV**	**df**	**Mean squares**	**F-Value**		**Mean squares**	**F-value**	
10 DAE	Year	1	31.82	0.5567	NS	903.65	12.1543	*
	Error	6	57.16			74.34		
	Hybrids	3	429.35	6.3936	**	174.06	2.2100	NS
	Interaction	3	164.38	2.4478	*	70.89	0.9000	**
	Error	18	67.15			78.76		
20 DAE	Year	1	21.2	2.8910	NS	41.9	0.6650	NS
	Error	6	7.33			63.01		
	Hybrids	3	13.62	0.5993	NS	19.17	0.4255	NS
	Interaction	3	12.15	0.5505	NS	35.04	0.7778	NS
	Error	18	22.73			45.05		
30 DAE	Year	1	143.69	7.1164	*	101.14	9.83	*
	Error	6	20.19			10.28		
	Hybrids	3	26.15	2.3270	NS	59.39	2.2648	NS
	Interaction	3	2.41	0.2153	**	222.02	8.4666	**
	Error	18	11.23			26.22		
40 DAE	Year	1	9.35	2.2236	*	161.86	14.5164	NS
	Error	6	4.2			11.15		
	Hybrids	3	85.42	36.8900	**	34.47	4.1661	*
	Interaction	3	0.4	0.1704	**	4.16	0.503	**
	Error	18	2.31			8.27		
50 DAE	Year	1	5.89	0.6510	NS	22.59	2.2674	NS
	Error	6	9.04			9.96		
	Hybrids	3	67.80	22.1274	**	28.38	1.2818	NS
	Interaction	3	1.93	0.6323	**	14.5	0.6550	NS
	Error	18	3.04			22.14		
60 DAE	Year	1	32.86	3.08	*	41.45	22.4699	NS
	Error	6	10.65			1.84		
	Hybrids	3	25.46	2.7137	*	20.89	5.3916	NS
	Interaction	3	27.5	2.9318	*	6.63	1.7114	NS
	Error	18	9.38			3.87		

** Highly significant at 1% probability level; * Significant at 5% probability level; NS = Non significant; df = degree of freedom.

consistent for spring. However, in this study, shorter leaf area duration of autumn crop gave lesser values of SLA.

Feburreira and Abreu (2001) reported that crop development was slower in spring season at start, as after emergence temperature was low as compared to high in autumn sowing. Almost similar results have been observed in the present study. The crop growth rate (CGR) values were lower in spring at 10 DAE as compared to autumn, whereas, at 20 to 50 DAE, spring crop growth rate attained higher values (Figure 3a). The accelerated CGR may be due to gradual increase in temperature and maximum intercepted solar radiation at these crop growth stages. However, slower crop growth rate was recorded in autumn at 20 to 50 DAE (Figure 3b), probably due to shorter crop growth period, gradual decrease in temperature with reduced intercepted solar radiation and reduced leaf area interactions. These results are in conformity with those of Hendrickson et al. (2004) who reported that CGR of warmer micro site increased with increase in temperature from 34 to 63% than that of cooler micro site. The decrease in CGR after 50 DAE for both the seasons may be due to age of the crop, causing senescence of mature leaves which ultimately influenced CGR.

In the present study, the net assimilation rate (NAR) progressively increased from 10 DAE and touched the

Table 5. Analysis of variance for net assimilation rate.

Spring						Autumn		
Sampling Interval	**SOV**	**df**	**Mean squares**	**F-value**		**Mean squares**	**F-value**	
10 DAE	Year	1	0.01	2.4645	NS	0.000	0.0016	NS
	Error	6	0.004			0.002		
	Hybrids	3	0.047	5.6293	**	0.014	4.9692	*
	Interaction	3	0.011	1.3695	*	0.005	1.6879	*
	Error	18	0.008			0.003		
20 DAE	Year	1	0.041	1.5876	NS	0.092	9.7939	*
	Error	6	0.026			0.009		
	Hybrids	3	0.055	2.1155	NS	0.038	1.8006	NS
	Interaction	3	0.013	0.4982	NS	0.005	0.2481	**
	Error	18	0.026			0.021		
30 DAE	Year	1	0.572	14.6189	**	0.530	2.4206	NS
	Error	6	0.039			0.219		
	Hybrids	3	1.27	60.7595	**	0.167	1.3938	NS
	Interaction	3	0.017	0.8125	**	0.152	1.2701	NS
	Error	18	0.021			0.119		
40 DAE	Year	1	0.001	0.007	NS	0.061	3.8644	NS
	Error	6	0.179			0.016		
	Hybrids	3	0.074	1.1808	NS	0.076	6.8307	**
	Interaction	3	0.003	0.0473	NS	0.004	0.3891	**
	Error	18	0.063			0.011		
50 DAE	Year	1	0.245	1.9575	NS	0.139	18.7404	*
	Error	6	0.125			0.007		
	Hybrids	3	0.267	4.6056	NS	0.043	6.9161	**
	Interaction	3	0.104	1.7960	**	0.003	0.4060	**
	Error	18	0.58			0.006		
60 DAE	Year	1	0.918	2.7487	NS	0.461	24.0836	**
	Error	6	0.334			0.019		
	Hybrids	3	0.07	0.5872	NS	0.025	4.3320	*
	Interaction	3	0.00	0.0034	NS	0.001	0.2548	**
	Error	18	0.12			0.006		

** Highly significant at 1% probability level; * Significant at 5% probability level; NS = Non significant; df = degree of freedom.

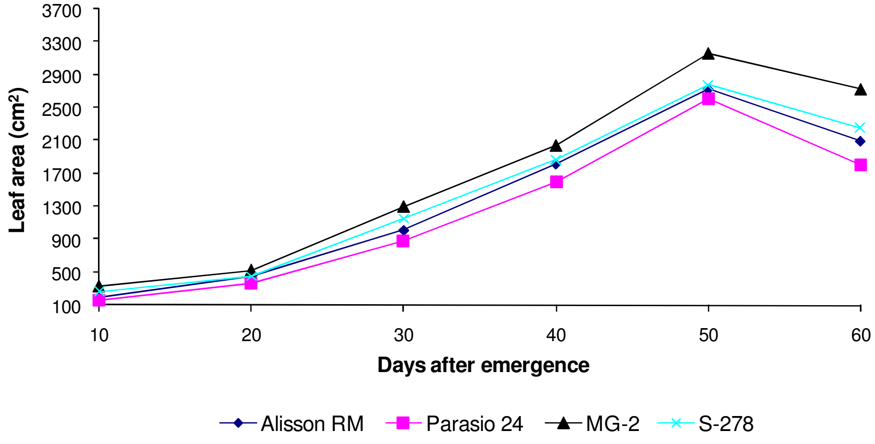

Figure 1a. Leaf area (cm^2) of sunflower hybrids during spring season (means of two years).

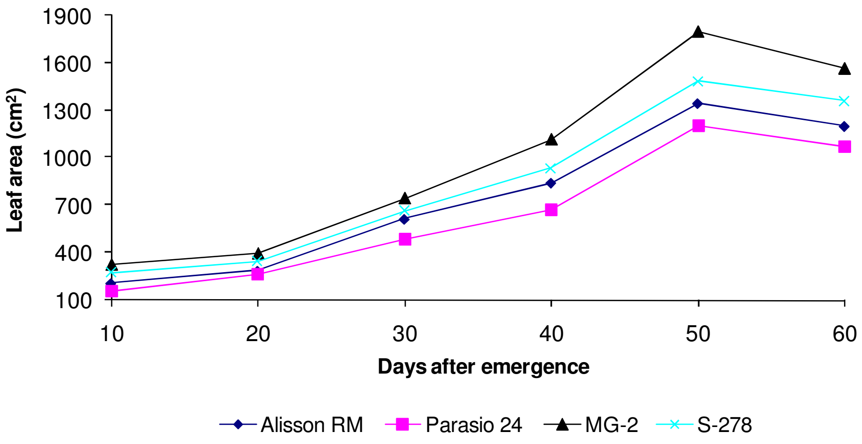

Figure 1b. Leaf area (cm^2) of sunflower hybrids during autumn season (means of two years).

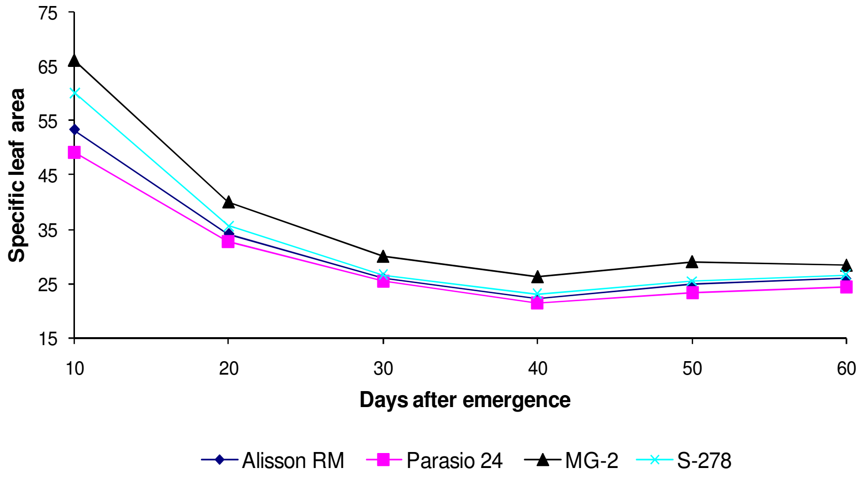

Figure 2a. Specific leaf area of sunflower hybrids during spring season (means of two years).

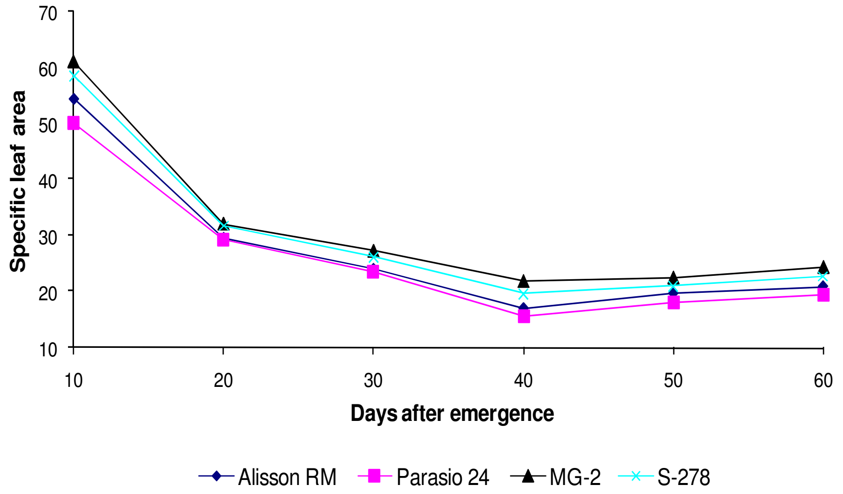

Figure 2b. Specific leaf area of sunflower hybrids during autumn season (means of two years).

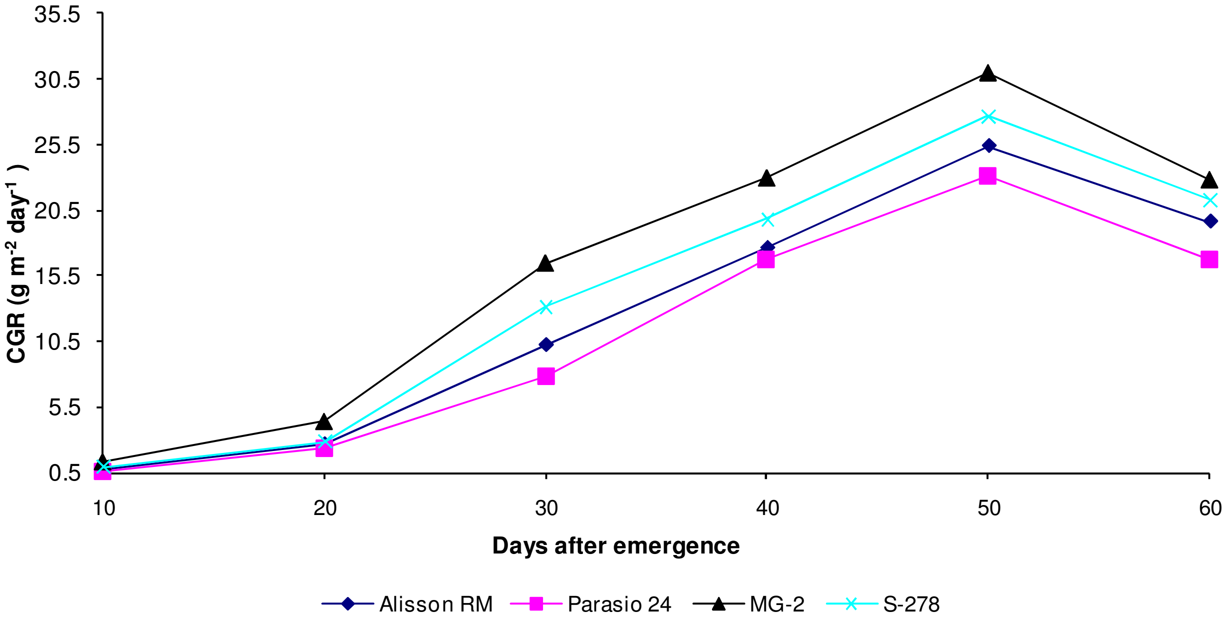

Figure 3a. Crop growth rate (g m^{-2} day^{-1}) of sunflower hybrids during spring season (means of two years).

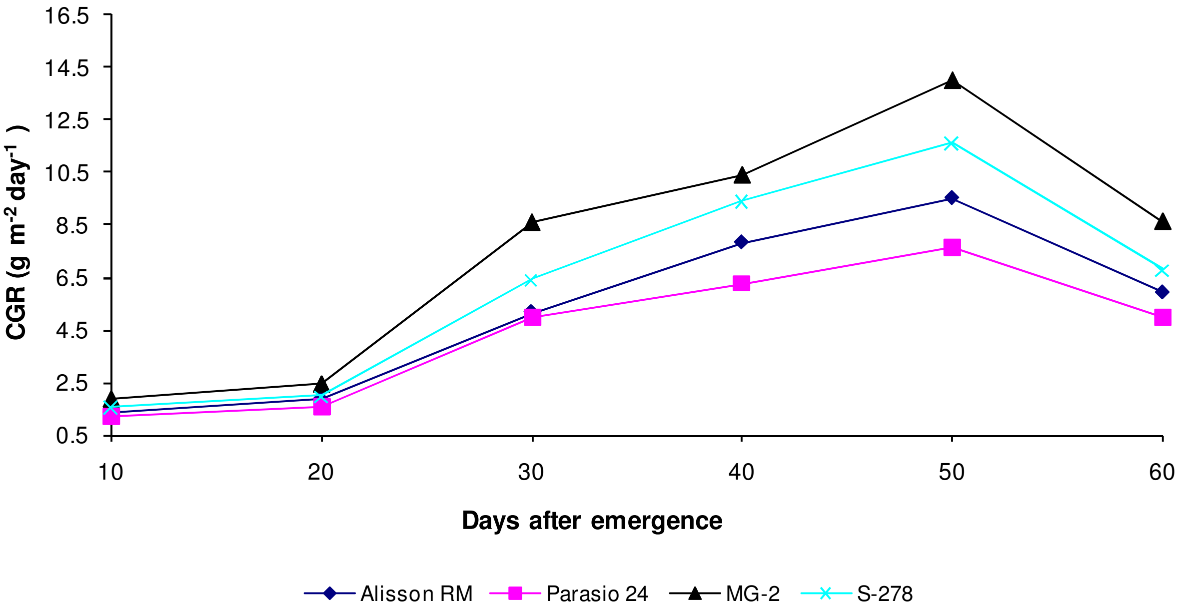

Figure 3b. Crop growth rate (g m^{-2} day^{-1}) of sunflower hybrids during autumn season (means of two years).

peak at 40 DAE during spring season (Figure 4a); thereafter, decreased up to physiological maturity. The decline in NAR at advanced growth stages during spring may be due to higher temperature prevailing at these crop growth stages which hampered the efficiency of the plants (Table 1). Our results are in accordance with those of Dennis et al. (2006) who revealed that NAR increases with increase in temperature, but very high temperature leads to a little decrease in assimilation and biomass (which is usually maximum at optimum temperature). During autumn season, NAR increased up to 20 DAE (Figure 4b); thereafter, continuously decreased with decrease in temperature. Decreased NAR values at later crop growth stages may be attributed to leaf age and a lower photosynthetic efficiency. Baydar and Erbas (2005) reported that low temperature is one of the limiting factors that adversely affect crop physiological processes.

It may be concluded that at peak physiological growth stages, the requirement of nutrients also touches the climax. Thus synchronizing addition of essential inputs is

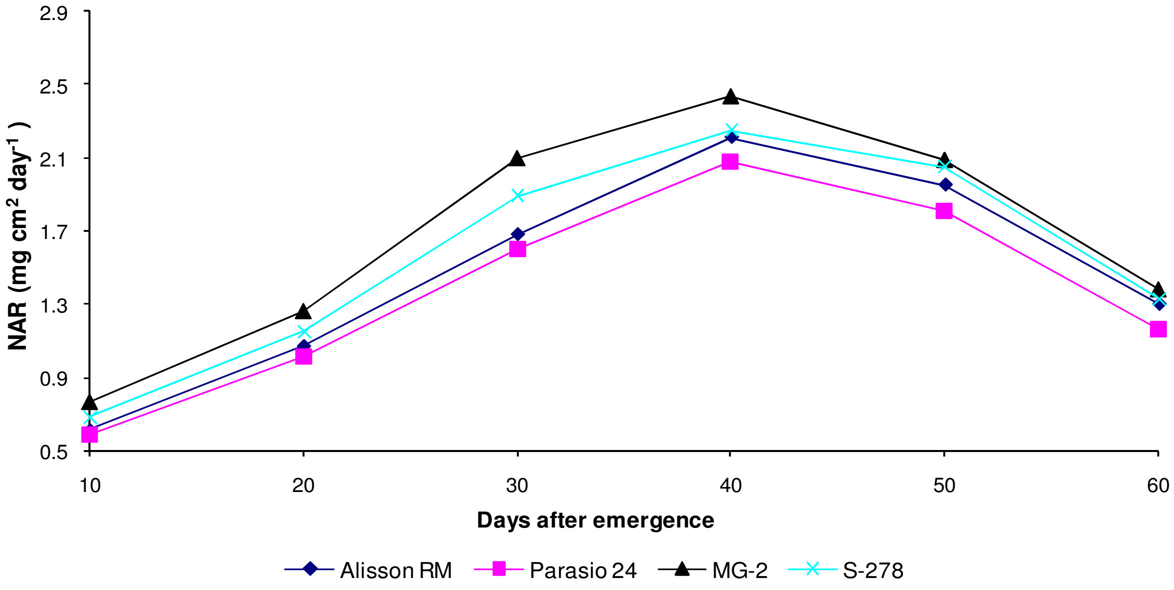

Figure 4a. Net Assimilation Rate (mg cm^2 day^{-1}) of sunflower hybrids during spring season (means of two years).

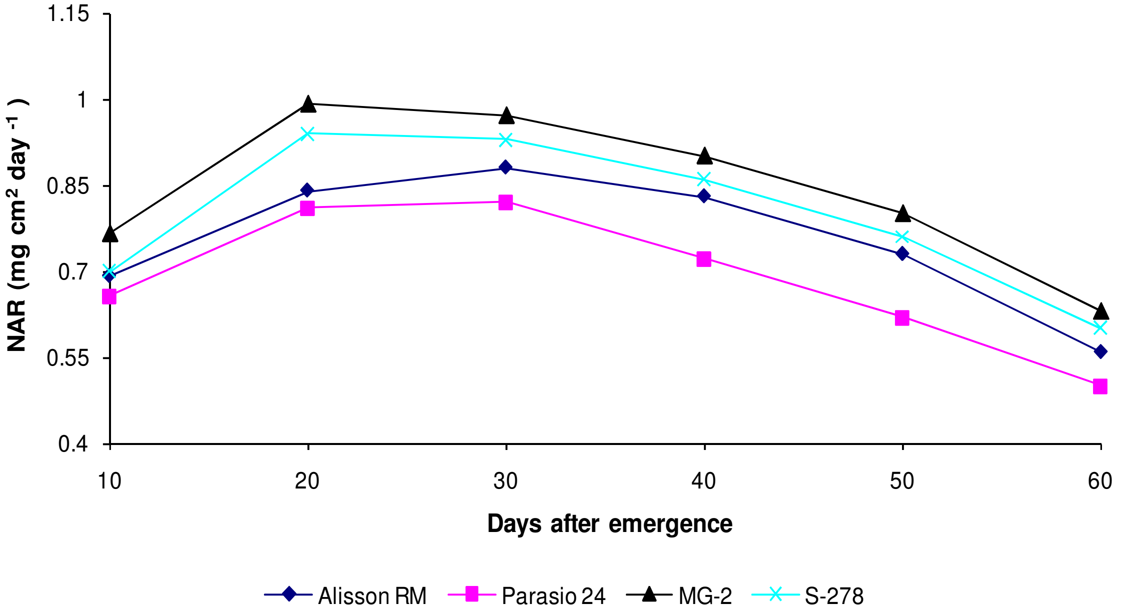

Figure 4b. Net Assimilation Rate (mg cm^2 day^{-1}) of sunflower hybrids during autumn season (means of two years).

necessary in order to avoid any stress, and to harvest the maximum yield and reduce the losses of inputs.

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