African Journal of Environmental and Waste Management ISSN 2375-1266 Vol. 10 (6), pp. 001-009, June, 2023.
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Full Length Research Paper

Investigating the Photosynthetic Process of Spring Wheat (*Triticum aestivum*) in Rainfed Environments of Pakistan

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Accepted 10 March, 2023

The effect of planting window (PW) acting as changing temperature scenarios and water availability at critical stages of wheat (Zadok's scale) on photosynthesis (A), stomatal conductance (g_s) and transpiration rate (E) as well as their relationship with yield of spring wheat genotypes viz: Chakwal-50, Wafaq-2001 and GA-2002 was studied. The research was conducted at three locations of varying climatic conditions (National Agricultural Research Centre Islamabad (NARC), Barani Agriculture Research Institute Chakwal (BARI) and farmer's field at Talagang, District Chakwal) in year 2008-09 and 2009-10. The results showed that photosynthesis, stomatal conductance and transpiration rate were significantly affected under three locations due to change in temperature and water availability. Photosynthesis (27.03, 24.64 and 22.66 µ mole/m^2/second), stomatal conductance (0.78, 0.31 and 0.09 mole/m^2/second) were recorded and transpiration rate (8.66, 8.17 and 2.07 mole/m^2/s) were recorded at NARC, Chakwal and Talagang, respectively. The values of these attributes were highest in growing year 2008-09 due to optimum temperature and water availability. The results clearly indicated that CO_2 reduction rate, transmission of stomata and water loss rate were dependent on optimum temperature and moisture availability. Reduction in moisture availability and increase in temperature lead to reduction in photosynthesis which ultimately reduces the biomass produced and accordingly, limit the yield. Grain yield was observed to be 3540, 2352 and 1938 kg ha^{-1} for NARC, Chakwal and Talagang, respectively, which showed a regular reduction under three different observed environments. These physiological results of wheat genotypes can be used to find adaptive and potential genotypes for changing environment.

Keywords: Wheat, photosynthesis, stomatal conductance, transpiration, environment.

INTRODUCTION

Wheat ranked first in production all over the world after corn and have significant amount of dietary protein. Wheat crop is cultivated on a wide range of climatic conditions of the world. Its contribution towards agriculture and GDP is 13.1 and 2.8%, respectively (Economic Survey of Pakistan, 2008-09). Intergovernmental Penal on Climate Change accounted that world mean temperature rises about 0.3°C per ten years. This can be compared with experimental values of about 0.2°C per ten years. Crop production is to increase faintly at middle to high for average temperature increase of 1 - 3°C depending on crop, and then decrease after that in some areas. Future change in climate is likely to influence agriculture, hunger risk and shortage of water resources with increased climate unpredictability and

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Abbreviations: NARC, National Agricultural Research Centre Islamabad; **BARI,** Barani Agriculture Research Institute Chakwal; **A,** photosynthetic rate; **g_S,** stomatal conductance; **E,** transpiration rate; **IPCC,** Intergovernmental Panel on Climate Change; **PW's,** planting windows; **IRGA,** infrared gas analyzer; **CV,** coefficient of variation; **LSD,** least significant difference; **HEC,** Higher Education Commission, Islamabad, Pakistan; **VPD,** high vapour pressure deficit; **DAP,** diammonium phosphate.

quick glaciers melting. About 2.5 - 10% decrease in the yield of crop in the 2020s of Asia and 5 - 30% decrease in yield in the 2050s as compared with 1990 levels devoid of CO_2 effects, is proposed (IPCC, 2001). The environmental changes including soil conditions (mainly changes of soil moisture) and air conditions could greatly affect the physiological processes such as photosynthesis, respiration and partitioning of photoassimilate production in crops. Schneider (2007) concluded that an increase of 3°C world average temperature (by 2100, compared to the 1990-2000 mean level), may increase production at high latitude and decrease for some cereals in low latitude.

Crop phenology is above all, associated with temperature. Growth will be boosted when there is an increase in temperature. For one season crop, the time between sowing and harvesting will be short. The limitation of this type of cycle has an unfavourable effect on production and senescence would have occurred earlier. Current studies have revealed that there is conjugation between yield and higher rate of CO_2 fixation (Fischer et al., 1998). There is a complex relationship between photosynthesis and yield (Reynolds et al., 2000). About 30% of the assimilates is contributed through flag leaf photosynthesis for grain filling in wheat (Sylvester-Bradley et al., 1990) and grain filling initiation occurs with the start of senescence, therefore the most significant basis of grain yield is photosynthesis through flag leaf in wheat.

It has been generally realize that the photosynthetic performance of agricultural crops needs to be improved in order to increase the rate of biomass production and the yield potential. Under changing climatic patterns, to enhance biomass production rate and the yield potential, it has been recognized that the photosynthetic activity of agricultural crops requests were increased (Horton, 2000). Soil water deficit and high vapour pressure deficit (VPD) are often associated with high temperature (Larcher, 2002). Transpiration and photosynthesis are dependent on each other and cannot be separated as they take place in the leaf (Yu et al., 2001). Closing of stomata is greatly affected by external environmental factor which ultimately minimize the conductance of stomata (Medlyn et al., 2001) and it has also been reported by many authors that prominent change in climatic factors causes decline in conductance of stomata and loss of water in many crops. Stomatal conductance is reduce by 33 to 50% and rate of transpiration by 20 to 27% with change in the microclimate of crop (Kimball et al., 2002).

The purpose of the current research is to observe the photosynthetic and transpiration rate as well as the stomatal conductance in spring wheat at flag leaf by changing their exposure to temperature and moisture availability through change in planting windows (PW's), and their ultimate impact on yield under high, medium and low rainfall area of Pothwar.

MATERIALS AND METHODS

The present study elaborates the physiological aspects of spring wheat yield over diverse PW's and locations. Experiment was conducted 2008-09 through 2009-10 at the National Agricultural Research Centre (NARC), Islamabad, Barani Agriculture Research Institute (BARI) Chakwal and farmer field Talagang. In both years, five PW's viz. PW1, (sowing between 10 - 20 October for the year 2008-09 and 2009-10), PW2 (sowing between 21 - 31 October for the year 2008-09 and 2009-10), PW3 (sowing between 1 - 10 November for the year 2008-09 and 2009-10), PW4 (sowing between 11 – 20 November for the year 2008-09 and 2009-10) and PW5 (sowing between 01 - 10 December for the year 2008-09 and 2009-10) and three genotypes: Chakwal-50, Wafaq-2001 and GA-2002, were used. N and P as urea and diammonium phosphate (DAP) was applied (100 kg/ha of N and P). Weed control was done manually. Each year, the experiments was laid out using Randomized Complete Blocked Design (RCBD) and the crop was planted in four 4.5 x 10 m plots per planting window for each genotype with row spacing of 25 cm. Data was recorded regarding physiological aspects like photosynthetic rate, stomatal conductance and transpiration rate by infrared gas analyzer (IRGA) at flag leaf stage (Long and Bernacchi, 2003). At maturity, all genotypes from three locations were harvested for grain yield from an area of 1 m^2 and converted to kg ha^{-1}. Data regarding weather that prevailed during the study period was collected from the weather station located at NARC and BARI. For Talagang, the weather data was collected by forming local met observatory. The data included was maximum and minimum daily air temperature (°C), precipitation (mm) and sunshine duration (hours) as presented in Tables 5, 6 and 7.

Statistical analysis

The data were statistically analyzed using computer statistical programme MSTST C (Freed and Eisensmith, 1986). Analysis of variance techniques were employed to test overall significance of the data. Least significance differences test at 5% probability level was used to compare the means (Steel and Torrie, 1980).

RESULTS

Photosynthesis rate (A)

Planting windows and genotypes choice influenced yield of wheat in rainfed ecology where crop production is constrained by low rainfall. Because of the large seasonal variability in rainfed environments, results were used to investigate optimal sowing date and genotypes choice. Results revealed that with the change in PW's and locations, photosynthesis is affected. Photosynthesis and yield have shown significant correlation with changing PW's and locations in our study. High photosynthesis was recorded in growing year 2008-09 in Islamabad than Chakwal (Table 1), while decline in photosynthetic rate was recorded for Talagang. Photosynthesis variable response among locations has resulted in high grain yield for Islamabad but low for Chakwal and Talagang (Table 4). Among genotypes, decline in photosynthetic rate was observed from PW1 to PW5 at Islamabad, while it was low for PW1 and PW2 at Chakwal, then it increases for

Table I. Photosynthesis rate (A) of spring wheat genotypes at flag leaf under different planting windows and environments of Pothwar (2008-09 and 2009-10).

Location	Genotype	2008-09 (Environment 1)						2009-10 (Environment 2)					
		Management						Management					
		PW 1	PW 2	PW 3	PW 4	PW 5	Mean	PW 1	PW 2	PW 3	PW 4	PW 5	Mean
Islamabad	Chakwal-50	27.44	28.20	28.82	25.94	28.19	27.72	24.20	23.85	25.20	22.87	26.30	24.48
	Wafaq-2001	27.95	26.50	27.29	25.26	26.40	26.68	22.03	21.97	24.40	22.83	24.31	23.11
	GA-2002	27.42	27.17	25.95	24.84	28.06	26.69	20.82	21.86	21.90	22.40	21.42	21.68
	PW's mean	27.60	27.29	27.35	25.34	27.55		22.35	22.56	23.83	22.70	24.01	
	Islamabad mean	27.03						23.09					
Chakwal	Chakwal-50	24.94	25.88	25.84	25.50	25.64	25.56	21.15	23.07	23.07	22.81	22.55	22.53
	Wafaq-2001	22.11	25.17	25.09	26.21	25.87	24.89	22.95	23.38	21.91	20.96	23.42	22.53
	GA-2002	23.63	22.43	24.73	22.89	23.67	23.47	21.31	20.10	20.59	18.42	20.93	20.27
	PW's mean	23.56	24.49	25.22	24.86	25.06		21.80	22.18	21.86	20.73	22.30	
	Chakwal mean	24.64						21.77					
Talagang	Chakwal-50	24.13	22.64	23.03	24.37	23.11	23.46	19.92	20.23	18.99	19.46	18.69	19.46
	Wafaq-2001	23.98	22.58	23.08	23.79	20.81	22.85	19.93	19.03	17.94	18.39	19.01	18.86
	GA-2002	22.43	21.44	22.46	20.73	21.37	21.68	18.24	19.45	16.39	17.25	17.40	17.75
	PW's mean	23.51	22.22	22.85	22.96	21.76		19.36	19.57	17.78	18.37	18.36	
	Talagang Mean	22.66						18.69					
PW's mean among locations		24.89	24.67	25.14	24.39	24.79		21.17	21.44	21.15	20.60	21.56	
Year mean		24.77						21.18					
CV %		8.97											
LSD		2.869											

PW3 and PW4 and drops again for PW5. Genotype Chakwal-50 bears maximum photosynthetic activity in Islamabad in 2008-09. In the second year, overall drop in photosynthetic rate was observed for planting windows and locations. Highest photosynthesis was recorded for PW3 at Islamabad, while at Chakwal, PW2 showed high rate of carbon dioxide assimilation but decrease in photosynthesis was recorded for all PW's at Talagang.

Stomatal conductance (g_s)

PW's among three locations have shown reduced leaf stomatal conductance (Table 2). The mean change in stomatal conductance (averaged for the five PW's, that is, 0.77, 0.75, 0.83, 0.73 and 0.20 mol m^{-2} s^{-1} for Islamabad, averaged for the five PW's, that is, 0.26, 0.25, 0.21, 0.53 and 0.30 mol m^{-2} s^{-1} for Chakwal and averaged for the five PW's, that is, 0.06, 0.12, 0.08, 0.12 and 0.07 mol m^{-2} s^{-1} for Talagang) with changing PW's were 19, 16 and 13% for PW1 at Islamabad, Chakwal and Talagang, respectively. While for PW2, it was 19, 15 and 26%, for PW3, it was 21, 13 and 18 %, PW4, 18, 34 and 26%, and PW5, 20, 19 and 14% among three locations in the first growing years. Stomatal conductance in the second year was significantly affected due to PW's and locations; greatest stomatal conductance was recorded in PW5 at Islamabad, while at Chakwal and

Table 2. Stomatal conductance (g_S) of spring wheat genotypes at flag leaf under different planting windows and environments of Pothwar (2008-09 and 2009-10).

Location	Genotype	2008-09 (Environment 1)						2009-10 (Environment 2)					
		Management						Management					
		PW 1	PW 2	PW 3	PW 4	PW 5	Mean	PW 1	PW 2	PW 3	PW 4	PW 5	Mean
Islamabad	Chakwal-50	0.84	0.82	0.90	0.80	0.88	0.85	0.72	0.68	0.67	0.77	0.70	0.71
	Wafaq-2001	0.79	0.77	0.85	0.75	0.83	0.80	0.62	0.57	0.66	0.49	0.60	0.59
	GA-2002	0.68	0.66	0.74	0.64	0.72	0.69	0.58	0.56	0.60	0.54	0.58	0.57
	PW's mean	0.77	0.75	0.83	0.73	0.81		0.64	0.60	0.64	0.60	0.63	
	Islamabad mean	0.78						0.62					
Chakwal	Chakwal-50	0.17	0.27	0.23	0.70	0.46	0.36	0.16	0.27	0.11	0.11	0.05	0.14
	Wafaq-2001	0.12	0.29	0.22	0.47	0.20	0.26	0.07	0.42	0.13	0.08	0.17	0.17
	GA-2002	0.48	0.19	0.19	0.42	0.25	0.31	0.12	0.23	0.12	0.10	0.20	0.15
	PW's mean	0.26	0.25	0.21	0.53	0.30		0.12	0.31	0.12	0.10	0.14	
	Chakwal mean	0.31						0.15					
Talagang	Chakwal-50	0.05	0.28	0.04	0.06	0.07	0.10	0.04	0.27	0.03	0.05	0.07	0.09
	Wafaq-2001	0.06	0.04	0.17	0.17	0.08	0.10	0.05	0.03	0.14	0.16	0.07	0.09
	GA-2002	0.07	0.04	0.05	0.14	0.05	0.07	0.08	0.04	0.04	0.13	0.07	0.07
	PW's mean	0.06	0.12	0.08	0.12	0.07		0.06	0.11	0.07	0.11	0.07	
	Talagang mean	0.09						0.08					
PW's Mean among locations		0.36	0.37	0.37	0.46	0.39		0.27	0.34	0.28	0.27	0.28	
Year mean		0.39						0.28					
CV %		25.35											
LSD		0.1165											

Talagang, it was low. Wheat genotypes showed maximum stomatal conductance in both growing years (Table 3) at Islamabad with high grain yield (Table 4). Genotypes Chakwal-50 bear maximum conductance in the second growing year (2009-10). The results showed that the stomatal conductance decreased more in the drought environments (Chakwal and Talagang) than in the well-watered location (Islamabad), and more with PW3, PW4 and PW5.

Transpiration (E)

During the first year, there were markedly significant effects of PW's and locations on the transpiration of spring wheat ($P < 0.001$) (Table 3). The mean changes in transpiration in five PW's treatments (8.77, 8.24, 8.59, 9.24 and 8.49) were 20, 19, 19, 21 and 19%, respectively, at Islamabad, while for Chakwal, it was 17, 18, 16, 27 and 19% and 14, 16, 16, 25 and 26% for Talagang PW's, respectively, for the year 2008-9. In the second year, 2009-10 being drought year, the mean change in transpiration in five PW's (2.27, 2.52, 2.58, 1.98 and 2.71) were 18, 20, 21, 16 and 22%, respectively, at Islamabad, while for Chakwal, five PW's transpiration (6.77, 9.09, 6.65, 7.19 and 5.12) were 19, 26, 19, 20 and14%, respectively, and at Talagang, mean transpiration change among five PW's (1.34, 0.84, 1.54, 1.80 and 1.48) were 19, 12, 21, 25 and 21%, respectively. The results indicated that transpiration reduction was greater in droughted locations among five PW's treatments than in Islamabad PW's.

Mean transpiration among wheat genotypes have shown variable trend with highest transpiration in high rainfall year (2008-09) and less in the drought year (2009-10). Greater transpiration rate was recorded for GA-2002 at Islamabad and Chakwal for all PW's and lowest at Talagang. Similarly, Wafaq-2001 and Chakwal-50 had less

Table 3. Transpiration rate (E) of spring wheat genotypes at Flag leaf under different planting windows and environments of Pothwar (2008-09 and 2009-10).

Location	Genotype	2008-09 (Environment 1)						2009-10 (Environment 2)					
		Managements						Managements					
		PW 1	PW 2	PW 3	PW 4	PW 5	Mean	PW 1	PW 2	PW 3	PW 4	PW 5	Mean
Islamabad	Chakwal-50	8.49	7.96	8.31	8.96	8.22	8.39	2.76	3.48	3.14	2.34	3.38	3.02
	Wafaq-2001	8.47	7.94	8.29	8.94	8.20	8.37	2.34	1.53	2.09	1.95	2.91	2.16
	GA-2002	9.34	8.81	9.16	9.81	9.07	9.24	1.71	2.55	2.50	1.64	1.84	2.05
	PW's mean	8.77	8.24	8.59	9.24	8.50		2.27	2.52	2.58	1.98	2.71	
	Islamabad mean	8.66						2.41					
Chakwal	Chakwal-50	5.60	7.77	7.44	11.13	10.33	8.45	6.42	10.38	5.83	7.95	1.77	6.47
	Wafaq-2001	5.47	8.14	7.63	10.49	6.06	7.56	6.34	7.72	8.18	6.45	8.00	7.34
	GA-2002	10.81	6.76	5.62	12.15	7.21	8.51	7.55	9.16	5.94	7.16	5.60	7.08
	PW's mean	7.29	7.56	6.90	11.26	7.87		6.77	9.09	6.65	7.19	5.12	
	Chakwal mean	8.17						6.96					
Talagang	Chakwal-50	1.32	1.93	1.61	2.35	3.27	2.09	1.15	1.06	1.44	1.48	2.01	1.43
	Wafaq-2001	1.67	1.77	1.95	3.31	2.75	2.29	1.50	0.90	1.78	2.44	1.49	1.62
	GA-2002	1.54	1.44	1.56	2.34	2.19	1.81	1.37	0.57	1.39	1.47	0.93	1.14
	PW's mean	1.51	1.71	1.71	2.67	2.74		1.34	0.84	1.54	1.80	1.48	
	Talagang mean	2.07						1.40					
PW's mean among locations		5.85	5.83	5.73	7.72	6.37		3.46	4.15	3.59	3.65	3.10	
Year mean		6.30						3.59					
CV %		14.52											
LSD		1.00											

transpiration at Talagang but good at Islamabad and Chakwal for the year 2008-09.There was a significant effect of PW's and loca-tion on genotypes transpiration for the year 2009-10 (P < 0.001). Mean transpiration rate among genotypes at Chakwal was increased in the second year, while it was low at Islamabad and Talagang. Genotypes sown in Islamabad in growing season (2008-09) showed maximum transpiration rate (Table 3) along with high grain yield (Table 4) in all PW's than second growing year (2009-10). The variable trend of transpiration rate among treat-ments was greatly influenced by availability of moisture in the root zone.

DISCUSSION

Proper PW's and locations can increase photo-synthesis, suggesting that wheat growth is closely related to availability of moisture at flag leaf stage. At this stage, crop produces maximum photo-synthate by hunting all available moisture. How-ever, this can only be achieved by crop if it is sown at a proper time because gradual rise in temperature and drop in moisture can cause an increase in photosynthetic rate up to a maximum temperature level and beyond that, photosynthetic rate decreases (Wang et al., 2008). As the mean daily temperatures rises above approximately 15°C, the productivity of wheat decreases, partly because accelerated crop development rate reduces crop duration (Midmore et al., 1982). Photosynthesis is the primary source of dry matter production and grain yield in crop plants. The improvements of leaf photosynthesis have occu-rred in our research with the change in PW's and selection of suitable genotypes according to their adaptability in specific locations and by breeding high-yielding cultivars (Jiang et al., 2002). Changes in PW's leads to change in temperature and photosynthesis are one of the most res-ponsive physiological processes to high tempe-rature (Berry and Bjorkman, 1980). Comparison of

Table 4. Grain yield (Kg ha^{-1}) of spring wheat genotypes under different planting windows and environments of Pothwar (2008-09 and 2009-10).

Location	Genotype	2008-09 (Environment 1)						2009-10 (Environment 2)					
		Management						Management					
		PW 1	PW 2	PW 3	PW 4	PW 5	Mean	PW 1	PW 2	PW 3	PW 4	PW 5	Mean
Islamabad	Chakwal-50	4605	4500	3625	2550	2725	3601	3368	2677	1714	2758	1763	2456
	Wafaq-2001	2850	5750	3250	3450	2775	3615	3406	2644	2444	3011	2408	2782
	GA-2002	3000	3750	4000	3000	3275	3405	2982	2720	2843	2437	1955	2587
	PW's mean	3485	4667	3625	3000	2925		3252	2680	2334	2735	2042	
	Islamabad mean	3540						2609					
Chakwal	Chakwal-50	2872	2997	2622	1914	2038	2488	2125	1746	1220	587	753	1286
	Wafaq-2001	1758	3087	2165	2050	1899	2192	2444	1454	601	887	286	1134
	GA-2002	2129	2990	2611	2066	2083	2376	2151	2145	922	711	531	1292
	PW's mean	2253	3025	2466	2010	2006		2240	1781	914	728	523	
	Chakwal mean	2352						1237					
Talagang	Chakwal-50	2756	2529	1934	1564	1469	2051	1488	1222	854	411	527	900
	Wafaq-2001	1182	2616	1728	1692	1474	1739	1710	1018	420	621	200	794
	GA-2002	1905	2614	2123	1693	1788	2025	1506	1501	646	498	372	904
	PW's mean	1947	2587	1928	1650	1577		1568	1247	640	510	366	
	Talagang mean	1938						866					
PW's mean among locations		2562	3426	2673	2220	2170		2353	1903	1296	1324	977	
Year mean		2610						1571					
CV %		24.62											
LSD		716.5											

Table 5. Weather data for of high rainfall area of Pothwar (Islamabad).

Month	2008-09					2009-10				
	Mean temperature (°C)					Mean temperature (°C)				
	Maximum	Minimum	Mean	Rain (mm)	Solar radiation	Maximum	Minimum	Mean	Rain (mm)	Solar radiation
October	31	15	23	24.0	13.01	32	13	22	9	13.02
November	25	8	17	18.0	10.28	26	7	16	15.0	10.29
December	20	6	13	71.5	9.07	21	3	12	1	9.08
January	18	2	10	56.1	9.82	20	2	11	11.1	9.86
February	19	5	12	73.5	12.23	19	7	15	88.49	12.31
March	24	10	17	89.8	15.34	27	13	20	4.4	15.42
April	30	15	23	61.8	18.32	33	16	25	45.25	18.38
May	35	20	28	39.2	20.24	35	20	27.5	0	19.00
June	38	24	31	62.2	20.95	39	25	32	0	21.95

Table 6. Weather data for medium rainfall area of Pothwar (Chakwal).

Month	2008-09 Mean temperature (^oC)					2009-10 Mean temperature (^oC)				
	Maximum	Minimum	Mean	Rain (mm)	Solar radiation	Maximum	Minimum	Mean	Rain (mm)	Solar radiation
October	32	15	24	6.3	13.02	31	12	21	4	13.02
November	26	6	16	2.0	10.29	24	7	15	7	10.29
December	20	2	11	68.5	9.07	20	3	11	68.5	9.06
January	23	3	13	28.2	9.83	24	4	14	0	9.91
February	18	2	10	47.3	12.23	26	11	18	38.24	12.64
March	19	3	11	28.6	15.34	29	15	22	1.2	15.36
April	22	5	14	24.5	18.32	34	18	26	15.65	18.37
May	25	9	17	115.8	16.71	37	21	29	0	21.20
June	32	13	23	10.2	18.94	41	26	33.5	0	22.12

Table 7. Weather data for of low rainfall area of Pothwar (Talgang).

Month	2008-09 Mean temperature (°C)					2009-10 Mean temperature (°C)				
	Maximum	Minimu m	Mean	Rain (mm)	Solar radiation	Maximum	Minimum	Mean	Rain (mm)	Solar radiation
October	35	14	24	6.3	13.04	36	15	25	4	13.02
November	29	9	19	2.0	10.29	30	10	20	0	10.29
December	23	3	13	30.0	9.07	25	5	15	0	9.07
January	18	4	11	14.7	9.83	15	5	17	0	9.96
February	20	4	12	25.1	12.23	19	6	21	0.45	12.45
March	26	8	17	20.8	15.4	29	13	25	0	15.46
April	32	14	23	46.9	18.32	34	21	28	0	18.43
May	37	17	27	26.4	20.24	38	24	31	0	21.34
June	43	28	35	71.7	20.95	44	26	35	0	23.55

the photosynthetic activity at flag leaf with PW's and locations considered as environment have clearly indicated that the photosynthetic rate can be modified by exposing crop genotypes to variable environments. Table 1 shows significant differences in the photosynthetic rate of the three genotypes. Similar findings have been reported by Richards (2000). Photosynthesis is a key limiting factor in improving yield. All genotypes have showed maximum photosynthetic rate in Islamabad in growing year 2008-09 with high grain yield (Table 4), while in the growing year (2009-10), same genotypes showed low photosynthetic rate due to high temperature and low moisture available to crop. It is assumed that high temperature can limit the ability of plants to use light energy and improve the effect of photoinhibition (Stefanov et al., 1996). At Chakwal, temperature was more than that of Islamabad and moisture was low in both growing years, so photosynthetic efficiency was low and grain yield recorded was less; while at Talagang, all genotypes showed least photosynthesis rate due to high temperature. Our results depicted that photosynthetic rate in genotypes was comparable to environment which can be modified by changes in PW's.

Stomatal conductance is the speed at which water evaporates from pores in a plant. The significance of this factor reflects the importance of stomatal behaviour and response of wheat in water stressed conditions. Stomatal aperture is an important index of water use efficiency and photosynthesis as CO_2 is absorbed through stomata.

The current study has clearly indicated that the stomatal conductance was reduced by increase in temperature and decrease in moisture. Significant findings had been reported in this research which showed that stomatal efficiency can be modified by changing PW's which changes overall microclimate of crop. Similar findings have been reported by Medlyn et al. (2001). As stomatal conductance is a key factor for photosynthesis, so with reduced conductance, photosynthesis was reduced which limited the yield (Table 4). At Chakwal, temperature was higher than that of Islamabad and moisture was low in both growing seasons, therefore low stomatal conductance was observed. While at Talagang, temperature was higher than that of Chakwal, due to which, least stomatal conductance and reduced grain yield was recorded. The results depicted that reduced water availability clearly decreased stomatal conductance and this can only be managed by change in the PW's since stomatal conductance maintains photosynthesis and hydrological status of the plant (Gutierrez-Rodrigues et al., 2000).

Transpiration rate depends mainly on environmental factors like radiation, temperature, water vapour pressure deficit, wind speed and the water status of the plants. Significant findings had been reported in current research and it is in close agreement with that of Jolliet and Bailey (1992). A change in PW's changes temperature and rainfall available to crop which ultimately affected the stomatal conductance, transpiration and yield at three locations. Similar findings had been reported by many authors who concluded that modification in the environment causes partial stomatal closure and ultimately reduced stomatal conductance (Medlyn et al., 2001). Stomatal conductance usually decreases under changing climatic conditions (Drake and Gonzalez-Meler, 1997) and reduces stomatal conductance which leads to a decrease in transpiration rate on a leaf area basis (Kimball et al., 2002). This is in agreement with our result.

Conclusion

With reference to stated objectives of this study, that is, to develop an understanding of whether A, g_S and E of wheat are linked to yield and are affected by changes in PW's. Study has clearly shown that high correlations were observed between A, g_S, E and yield, and they were greatly affected by modified temperature and water availability. With increase in temperature and reduction in moisture, A, g_S, E were reduced and yield was reduced consequently. These results suggest that with the change in temperature and rainfall distribution, re-designing of crop sowing times considered as PW's in this research according to available resources must be done to get full potential of a crop. Based on these considerations, it is recommended to the farmers that sowing of crops must be changed to new patterns with the change in the climatic factors.

ACKNOWLEDGEMENT

The authors wish to express special thanks to HEC (Higher Education Commission, Islamabad, Pakistan) for the financial support to complete this research work.

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