Pak. J. Agri. Sci., Vol. 51(4), 835-846; 2014
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
http://www.pakjas.com.pk

INFLUENCE OF SEASONAL VARIATION ON RADIATION USE EFFICIENCY AND CROP GROWTH OF MAIZE PLANTED AT VARIOUS DENSITIES AND NITROGEN RATES

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Crop growth (CG) is a function of leaves exposed to solar radiations and ratio of the radiation intercepted by the canopy, which is termed as radiation use efficiency (RUE). Both CG and RUE of maize planted in spring and summer at three densities (43,000, 53,000 and 67,000 ha^{-1}) and three N-fertilizer rates (90, 120 and 150 kg ha^{-1}) were compared in a 3x3 split-plots, randomized complete-blocks design in three replications. The results revealed a significantly ($P<0.05$) longer (28.6%) pre- and shorter (5.0%) -post anthesis durations for spring than summer planted crop. The density and N-fertilizer rates did not show any significant changes in pre- or post anthesis duration. The CG and RUE were observed to be higher ($p<0.05$) in summer than in spring. Every increment in the density resulted in significantly ($P<0.05$) higher CG and RUE. Yield increased by increasing density from 43,000 to 53,000 but remained non-significant ($p<0.05$) thereafter at density 67,000 ha^{-1}. N-fertilizer rates 90 and 120 kg ha^{-1} did not show any significant ($p<0.05$) changes in CG, RUE and/or yield, but did increase significantly ($p<0.05$) the yield at 150 kg ha^{-1}. As compared to spring crop, interactive effect of treatments (density x N) were found significantly ($p<0.05$) higher for CG, RUE and yield in summer at N-fertilizer rate of 150 kg N ha^{-1} having density of 67,000 ha^{-1}. The study suggested that phases of crop growth and development were highly influenced by seasons, which affected CG and RUE, and hence the yield. Nevertheless, maintaining desired density of maize is more crucial than to increase N-fertilizer for maximum production in the season. Summer planted maize out-yielded spring crop due to relatively mild cooler weather at crop reproductive phases of the development.
Keywords: Crop growth, radiation use efficiency, plant density, nitrogen rate, spring and summer crops

INTRODUCTION

Demands of cereal grain consumption in Asia as compared to rest of the world will continue to increase as population expands in proportion to the rapid economic development underway in the region. Water shortage for crops is an issue of production in Asia (Bannayan *et al*., 2010). Increase in production due to population growth in countries like Pakistan will certainly demand more water and nutrients for crops for the sustainable use of the agricultural land (Asim, 2010; Katsura *et al*., 2010). Dry matter accumulation is result of higher fractional contribution from the environment and lowers from the soil, where solar energy plays its vital role in biomass productivity of a crop subject to its canopy volumes spread over the ground area (Hoffman and Severin, 2010). Maize is a leading summer crop of Pakistan. It is equally important in rest of the world to feed animals and human being. It is planted successfully as spring and as a summer crop in Pakistan. As compared to summer crop, spring crop has an advantage to stay long in the vegetative phase of development relatively in cooler days (Parent and Tardieu, 2012). The reproductive phase and subsequently the grain development starts in hot summer days which has relatively some effect on growth and yield due to mild to strong moisture stresses of the excessive soil moisture deficits on pollination, pollen viability and grain development (Prasad *et al*., 2011). It was observed that for spring crop the days expand faster while the crop is in the vegetative phase of development but thereafter remained more or less stable at anthesis and grain development. Contrary to that the summer crop remains in a stable photoperiod for the vegetative growth in relatively longer days in the early establishment phase of development. Additionally for summer crop, the daily mean temperature remains relatively low at anthesis, grain development and grain filling phases of the growth. The crop faced lower evapotranspiration by a continuous drop-out in the photoperiod when crop advanced in maturity. Seed growth and development of summer than spring crop generally faced mild shocks of soil moisture fluctuations in the field (Asim *et al*., 2013).

In semi-arid climates like Peshawar Pakistan, the solar radiation is abundantly available over the crop canopy round the year. However, its effective utilization depends on the production technology applied to the crop in cultivation. A linear relationship between dry matter and light interception is common for field crops including maize (Akmal and Janssens, 2004: Singer *et al*., 2011). Increased density per unit ground area has shown an increase in the use efficiency of light by the canopy (Giunta *et al*., 2009; Hoffman and Severin, 2010). Biomass accumulation per unit area over time is termed as crop growth (Li *et al*., 2010). Radiation interception by the canopy and net photosynthesis are therefore important parameters influenced biomass production and yield (Boedhram *et al*., 2001). Nitrogen (N) is highly volatile in the soil and is a key element limiting growth and productivity of crops in general and of cereals in particular (Van-Oosterom *et al*., 2010). Both higher N and optimum density have shown higher biomass productivity (Barbieri *et al*., 2008). Similarly, the optimum N-fertilizer application to maize crop has shown long persistence of plant leaf greenness in field with relatively better light interception, which may results higher grain yield (Zeidan *et al*., 2006). Both the required N and moisture results fairly stable growth in the linear phase of development if subjected to established production practices. This also ensures the canopy to utilize the resources (e.g. solar radiation) efficiently for production (Kiniry *et al*., 1999; Akmal *et al*., 2010; Ceotto *et al*., 2013). Use efficiency of light by the crop canopy is usually stable and works fairly well under the diversified climatic conditions to estimate the productivity (Boote *et al*., 1996). It might depend on some factors: e.g., inherent to species, climatic conditions of area and management practices applied for production (Curt *et al*., 1998; Tokatlidis and Koutroubas, 2004). It was therefore, intended to compare the crop growth rate and radiation use efficiency of maize planted as spring and summer season crop with various densities and N-fertilizer rates for grain yield.

MATERIALS AND METHODS

Experimental location: The study was conducted at the Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera, Pakistan. Location of the CCRI is 1540 km North of the Arabian Sea in District Nowshera, Khyber Pukhtunkhwa, Pakistan. Its latitude is 34° N, longitude is 72° E and altitude is about 288 m above the sea level. Climate of the area was continental but the regional climate was temperate. Soil of the experimental location was sandy loam, moderately calcareous having a pH of 7.7 and low in N contents (0.016%), organic matter (0.33%) and sulfur (8.3 mg kg^{-1}). Mean maximum temperatures were 29.64, 28.95°C (spring) and 34.95, 34.71°C (summer) in 1^{st} and 2^{nd} year of the study and mean minimum temperatures were 14.15, 13.82°C (spring) and 24.15, 23.92°C during vegetative phases of growth. Similarly, mean maximum temperatures were observed 38.14, 38.19°C (spring) and 32.14, 31.97°C (summer) in 1^{st} and 2^{nd} year of the study and mean minimum temperatures were 21.69, 21.80°C (spring) and 14.06, 16.04, 15.80°C during reproductive phases of the crop growth.

***Layout and treatments*:** Two experiments, one in spring and second in summer season, were conducted during 2006 and repeated in 2007 on different portions of the same field following wheat – maize cropping system for about more than a decay long time. Maize variety 'Jalal' was used in this study. Treatments (a) planting densities (D) and (b) N-fertilizer rates (N) were used for comparing crop growth (CG) and radiation use efficiency (RUE). The experiment was conducted in a split-plot arrangement, in a randomized complete block design using three replications. Plant densities (43000, 53000, and 67000 ha^{-1}) were used as main plot treatment and N-fertilizer rates (90, 120, and 150 kg ha^{-1}) as a subplot treatment. Each experimental unit measured 5.0 m in length and 6.0 m in width, accommodating eight rows in North-South direction. Each subplot was spaced with a blank row within main plots. Before sizing plots for treatments, land was prepared with a tractor at optimum field capacity by plowing three times followed by planking. During seedbed preparation, uniform application of P_2O_5 (Single Super Phosphate; SSP) and K (K_2SO_4) were applied broadcast at the rate of 110 and 80 kg ha^{-1}, respectively. A day before sowing, seeds were treated with an insecticide (Confidor – active ingredient Imidacloprid). Planting was done on ridges made with a tractor drawn-ridger equally spaced at 0.75 m and subsequently refined with a shaper. Spring planting was conducted on March 14, 2006 and March 03, 2007 while summer planting was completed on July 23, 2006 and July 28, 2007, manually using a relatively higher seed rate (38 kg ha^{-1}). The intended density was maintained in experimental units a week after emergence by manual thinning. N-fertilizer was applied as urea in subplots at the rate of 90, 120 and 150 kg N ha^{-1}. One half of the N-fertilizer was applied at sowing and other half about 32 days after sowing (DAS). All other agronomic practices e.g. weeding, hoeing, irrigation and granules application against borer's attack were kept constant for all treatments and experiments. Spring crop received four and summer crop five flood irrigations as per crop water demand. In additional to flood irrigations, spring season crop received 173.95 mm and 182.03 mm rainfall and summer season crop 156.20 mm and 176.60 mm during first and second year, respectively.

***Measurements and observations*:** Data regarding days to silking, tasseling and physiological maturity were recorded through regular field visits when 50% plants in an experimental unit reached to the respective growth stage. The pre anthesis duration of an experimental unit was estimated as difference between average value for days to tasseling and silking minus days to emergence. Likewise, post anthesis duration of an experimental unit was determined as difference between days to physiological maturity minus average readings of days to silking and

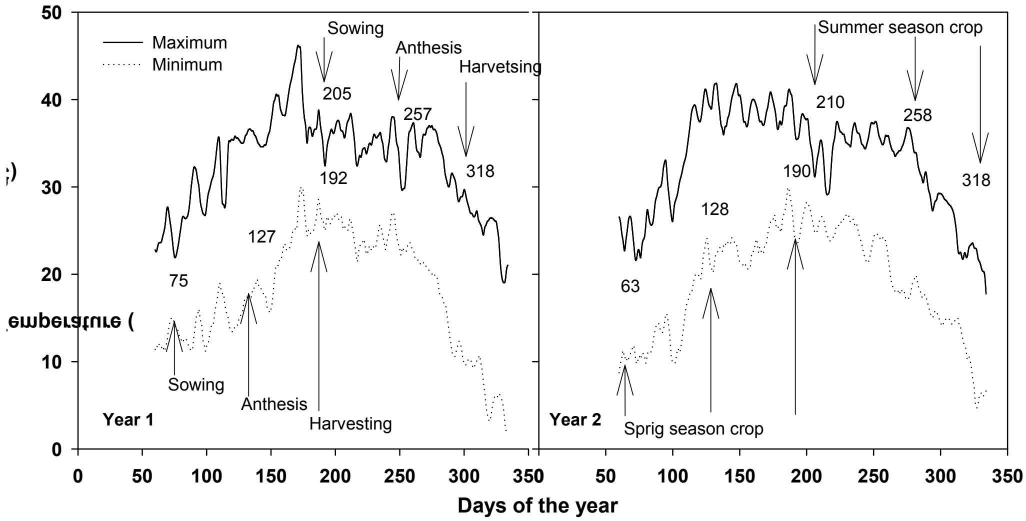

Figure 1. Temperatures maximum and minimum (5 days average) for growth and development phases in maize planted as spring and summer season crop.

tasseling. During crop growth and development, sequential data in all experimental units were periodically recorded for leaf area index, light interception by the canopy and dry matter production. Periodic light measurements were made at designated locations in an experimental unit between 10.00 to 13.00 h of the day using three sensors connected with a data logger. All sensors were calibrated by placing on ground in field for common readings for about an hour in field on the day of measurements. A quantum sensor (LI-190, LI-COR, USA) in combination with two line sensors (LI-191, LI-COR, USA) connected with a data logger (LI 1400, LI-COR, USA) was used for measurements (Akmal et al., 2010). Briefly on day of sampling, all sensors were placed in open field at sun to ensure a uniform reading. The quantum sensor was used for measuring irradiance above the canopy and pair of line sensors for measuring the reflectance and transmittance by the canopy, respectively. Eight readings each based on 5 minutes averages were recorded for irradiance, reflectance and transmittance by the canopy in an experimental unit and simultaneously stored in the LI-1400 (LI-COR, USA) data logger. The fraction of intercepted PAR by the canopy was calculated from averages of six readings excluding the first and last reading from each set of data.

Intercepted light =

Irradiance-Reflectance-Transmittance ÷ Irradiance (Eq.1)

The daily solar radiation data was obtained from a local weather station, located within 20 km distance from the experimental site. Fraction of photo-synthetically active radiation (PAR) was obtained from diurnal solar radiation by multiplying with factor 0.47 (Sinclair and Muchow, 1999). The PAR data were accumulated for the period from emergence to physiological maturity for 2006 and 2007. Fractions of periodic intercepted light measured in an experimental unit were subsequently multiplied with the corresponding commutative PAR readings for each experiment to obtain cumulative intercepted $PAR_{absorbed}$. On the day of light measurements, leaf area indices were also recorded using a non-destructive plant canopy analyzer LI-2000 (LI-COR, USA). After taking leaf area indices and the light measurements, a 0.5 m long row at two locations were harvested from an experimental unit for dry matter determination and the material was oven dried at 70^0C for not less than 36 h and/or until a constant weight arrived. Radiation use efficiency (RUE) was derived as slope of the regression between dry matter of the experimental unit and cumulative intercepted $PAR_{absorbed}$. Six readings for each experimental unit and experiment were used for regression. Crop growth rate (CG) was derived from slopes of the regression made between periodic biomass production and growing degree days (GDD ^{O}C) as independent parameter. Of the total periodic samples made for dry matter determinations, samples of 40^{th} and 90^{th}DAS were in linear fashion with highest correlations ($r^2 = 0.98$). Data of the five measurements made between 40^{th} to 90^{th} DAS were regressed against respective GDD and slopes of regressions (*b*) were taken as crop growth (CG). The GDD was calculated as mean of daily maximum and minimum temperatures less base temperature (10^OC). On the day of harvesting (Spring: Jul. 10, 2006 and Jul. 8, 2007; Summer: Nov. 13, 2006 and 2007), ten uniform representative plants were individually harvested for yield traits (cob height from ground, plant height, ear diameter, ear length, grains per ear etc.) from boarder rows of the experimental units in spring and summer seasons. Yield was estimated by harvesting all plants from two central rows. Maximum and minimum temperatures for the crop growth and development phases are shown in Fig. 1.

Statistical analysis: All data were statistically analyzed using SAS 9.3 software. Statistical analyses were made combined over the seasons for each year and two year's average data using appropriate analysis technique (Steel and Torrie, 1996). Means of treatments and their interaction were compared using Tukey (P<0.05) test. Based on the planting season, data for two years were averaged to determine correlation coefficients among the yield contributing traits (Kashiani and Saleh, 2010).

RESULTS

Pre- and post anthesis duration: Pre- and post anthesis durations of the two years did not coincide. First than 2nd year of the study showed a longer pre- and a shorter post anthesis duration (Table 1).

Table 1. Maize vegetative duration (days) pre-anthesis influenced by different densities (D) and nitrogen (N) as spring and summer planted crop.

Treatments	Year I	Year II	Mean
Season (S)			
Spring	67.94 a	67.59 a	67.77 a
Summer	55.16 b	50.24 b	52.70 b
Significance	NS	NS	**
Density (D ha^{-1})			
43,000	61.27 a	58.91 a	60.10 a
53,000	61.47 a	58.83 a	60.15 a
67,000	61.91 a	59.00 a	60.46 a
Significance	NS	NS	NS
Nitrogen (N kg ha^{-1})			
90	61.44 a	58.92 a	60.18 a
120	61.72 a	58.72 a	60.22 a
150	61.50 a	59.11 a	60.31 a
Significance	NS	NS	NS
Year (Y)	61.55 a	58.92 b	60.24
Interactions			
S x D	NS	NS	*
S x N	NS	NS	NS
D x N	NS	NS	NS
S x D x N	NS	NS	NS

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.
Means within a treatment that are followed by the same letters do not differ significantly (P<0.05, Tukey).

The pre anthesis duration (d) showed a significant (p<0.05) difference in the planting season (S). Spring crop took relatively longer duration to complete the vegetative phase than the summer crop. These arrangements were found common for both the years' average data as well as every single year of the study. Contrary to that none of the main treatment or its interaction showed any difference (p<0.05) for vegetative duration. The post anthesis duration (d) showed a significant difference for planting season (Table 2). Spring crop took relatively shorter duration to complete reproductive growth as compared to the summer crop. This pattern was found similar for two years average and every single year of study. Treatments planting density (D) and nitrogen rates (N) did not show any difference (p<0.05) for post anthesis duration. The only interaction of treatments density with season showed a significant (p<0.05) response during first year of experiment but not during second year. On the two years average data none of the interaction showed any statistical difference.

Table 2. Maize reproductive duration (days) post anthesis influenced by different densities (D) and nitrogen (N) as spring and summer planted crop.

Treatments	Year I	Year II	Mean
Season (S)			
Spring	47.49 b	52.40 b	50.18 b
Summer	50.61 a	54.98 a	52.80 a
Significance	NS	NS	NS
Density (D ha^{-1})			
43,000	49.44 a	53.19 a	51.38 a
53,000	49.36 a	53.66 a	51.52 a
67,000	49.02 a	54.11 a	51.57 a
Significance	NS	NS	NS
Nitrogen (N kg ha^{-1})			
90	49.00 a	53.19 a	51.10 a
120	49.11 a	54.11 a	51.61 a
150	49.72 a	53.78 a	51.75 a
Significance	NS	NS	NS
Year (Y)	49.28 b	53.69 a	51.49
Interactions	(Significance levels)		
S x D	*	NS	NS
S x N	NS	NS	NSS
D x N	NS	NS	NS
S x D x N	NS	NS	NS

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.
Means within a treatment that are followed by the same letters do not differ significantly (P<0.05, Tukey).

***Crop growth (CG)*:** Crop growth (CG) is rate of the biomass (g m^{-2}) production against growing degree days (GDD). ANOVA results indicated that CG differed significantly (p<0.05) among seasons, densities and nitrogen rates (Table 3). The spring crop showed lower CG (p<0.05) than the summer crop in each year of experiment and two year's average basis. The highest density (67,000 ha^{-1}) showed the maximum CG, which decreased significantly (p<0.05) by decreasing density per unit area. This decrease in CG by reducing density was common for each year of the experiment as well as two years average data. The treatments N rates also showed significant effect on maize CG. By increasing N application to the crop from N-fertilizer rates 90 to 120 kg ha^{-1}, a significant increase in CG was observed in every single years as well as two years average data. However, a further increase from N 120 to 150 kg ha^{-1} did not bring any change in the CG during first year of the study or in two years average. As compared to the year I, year II showed higher CG. Interactive effects of treatments (D x S, D x N, S x N, year x S x D, year x S x N and S x D x N) on CG were found significant ($p<0.05$).

Table 3. Maize crop growth (g m^{-2}) influenced by different densities (D) and nitrogen (N) as spring and summer planted crop.

Treatments	Year I	Year II	Mean
Season (S)			
Spring	1.61 b	1.52 b	1.56 b
Summer	1.93 a	2.25 a	2.09 a
Significance	**	**	**
Density (D ha^{-1})			
43,000	1.39 c	1.46 c	1.42 c
53,000	1.86 b	1.96 b	1.91 b
67,000	2.06 a	2.24 a	2.14 a
Significance	**	**	**
Nitrogen (N kg ha^{-1})			
90	1.71 b	1.80 c	1.75 b
120	1.80 a	1.92 b	1.86 a
150	1.80 a	1.94 a	1.87 a
Significance	**	**	**
Year (Y)	1.77 b	1.88 a	1.83
Interactions	(Significance levels)		
S x D	**	**	**
S x N	NS	**	**
D x N	**	**	**
S x D x N	**	**	**

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.
Means within a treatment that are followed by the same letters do not differ significantly ($p<0.05$, Tukey).

The CG went relatively faster at D 43,000 and D 53,000 ha^{-1} than D 53,000 and D 67,000 ha^{-1} both in spring and in summer crops (Fig. 2a). However, summer than spring season exhibited a relatively higher CG at all densities. A similar but stable increment in CG was observed for all N rates when plant density enhanced from D 43,000 to D 67,000 ha^{-1}. The CG was noted lower at N 90 kg ha^{-1} under all three densities. Increasing N to 120 kg ha^{-1} increased CG markedly at all three densities. A further increase in N to 150 kg ha^{-1} boosted CG at D 43,000 and D 53,000 ha^{-1} but not at D 67,000 ha^{-1}. Slight increases in CG were noticed when N application rose from N 90 to 150 kg ha^{-1} in spring and in summer. However, CG in summer was observed markedly higher than spring at all N rates. Spring and summer crop showed different CG trends in each year of the study under the changing plant densities (Fig. 2b). Crop growth was observed consistently positive in spring and summer with higher readings for summer than spring during both years. The CG rose marked to relatively stable at D 43,000 to D 53,000 and D 67,000 ha^{-1}, respectively for spring and summer during both years. However, the differences in CG between seasons at every next higher density declined during first year but not during second year. Interaction of treatments N with seasons and years revealed higher CG in summer than spring for both years (Fig. 2c). However, CG in summer during the 2nd years increased markedly as compared to 1st year. Interaction of treatment density with N during spring and summer showed different CG with greater values for year II than year I (Fig. 2d). Increased density and N enhanced CG in both spring and summer crops. The CG was observed markedly higher at D 53,000 ha^{-1} then D 43,000 ha^{-1} at all three N-fertilizer rates in spring and summer. Likewise, CG was observed higher at D 67,000 than D 53,000 ha^{-1} at all three N-fertilizer rates during spring and summer but with a non-significant ($p<0.05$) reading at N 150 kg ha^{-1} in spring.

***Radiation Use Efficiency (RUE)*:** Radiation use efficiency (RUE) is index of biomass production and absorbed PAR (DM g $MJ^{-1}PAR_{absorbed}$) during the crop growth and development. The RUE data showed higher ($p<0.05$) values for the summer than spring crop in each year of the study as well as for the two years average basis (Table 4).

Table 4. Maize radiation use efficiency (g DM MJ-1PARabsorbed) influenced by different densities (D) and nitrogen (N) as spring and summer planted crop.

Treatments	Year I	Year II	Mean
Season (S)			
Spring	1.11 b	1.64 b	1.37 b
Summer	2.09 a	2.81 a	2.45 a
Significance	**	**	**
Density (D ha^{-1})			
43,000	1.07 c	1.59 c	1.33 c
53,000	1.72 b	2.30 b	2.01 b
67,000	2.01 a	2.79 a	2.40 a
Significance	**	**	**
Nitrogen (N kg ha^{-1})			
90	1.53 c	2.08 c	1.80 b
120	1.60 b	2.33 a	1.96 a
150	1.67 a	2.27 b	1.97 a
Significance	**	**	**
Year (Y)	1.60 b	2.22 a	1.91
Interactions	(Significance levels)		
S x D	*	**	**
S x N	**	**	**
D x N	NS	**	NS
S x D x N	**	**	**

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.

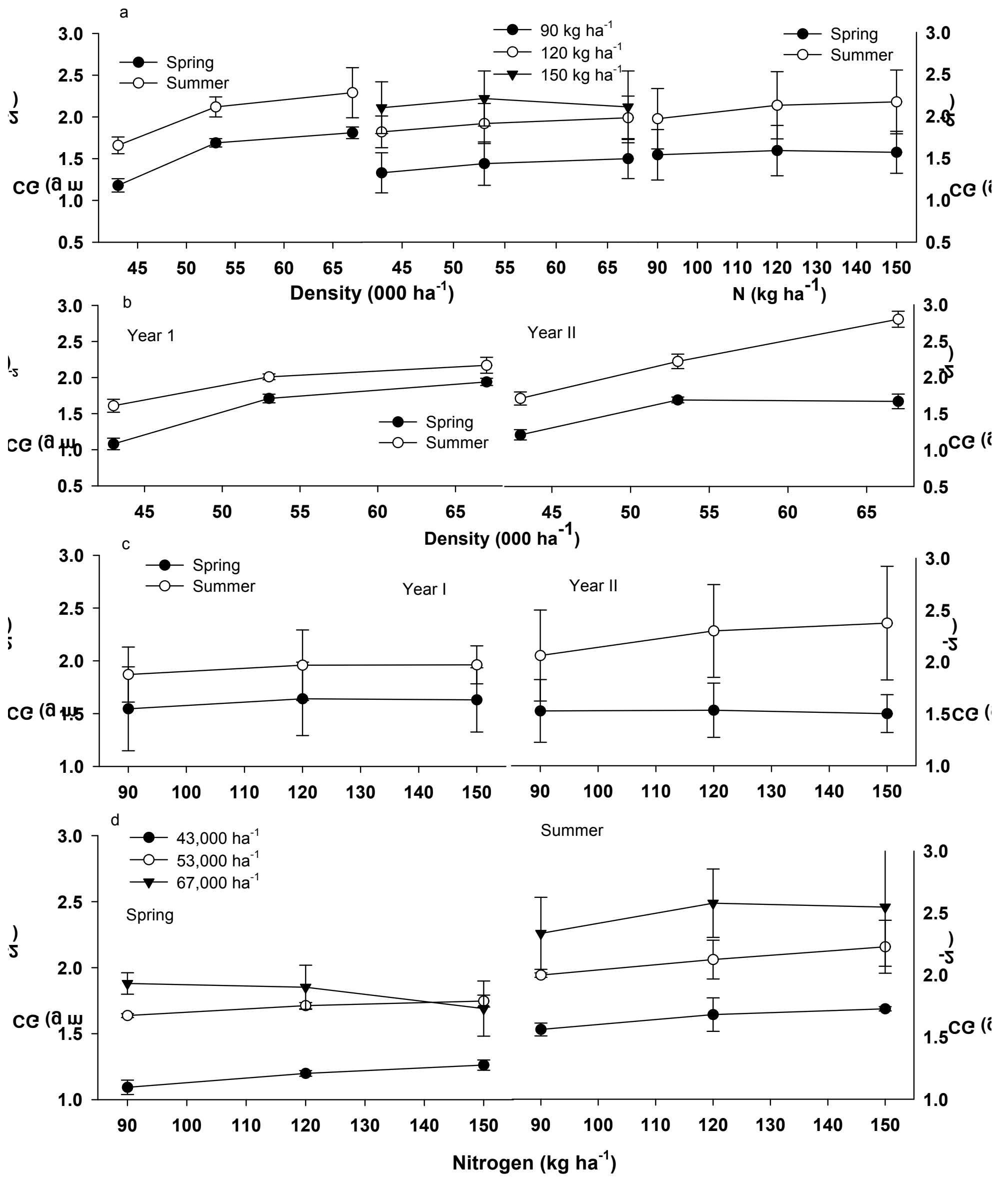

Figure 2. Interactive effects of treatments on crop growth (CG = g m^{-2}). Different windows of the figure show different interactions (a) density x seasons, density x N, season x N, (b) year x density x season, (c) year x season x N, and (d) season x density x N trends for the crop growth.

Means within a treatment that are followed by the same letters do not differ significantly (P<0.05, Tukey).

RUE was observed significantly greater ($p<0.05$) at a higher density (67,000 ha^{-1}), which decreased by reducing planting density per unit area. Higher N (150 kg ha^{-1}) also showed greater RUE in each year and two years average basis. Nonetheless, RUE did not show any change ($p<0.05$) between 120 and 150 kg N ha^{-1}application rates on two years average data. As compared to year I, the year II showed greater RUE. Interactive effect of treatments (density x S, density x N, S x N, year x S x density, year x S x N and S x density x N) on RUE was found significant ($p<0.05$). RUE was observed relatively greater when density increased from 43,000 to 53,000 ha^{-1} then 53,000 to 67,000 ha^{-1}in spring and summer (Fig. 3a). However, summer than spring exhibited higher RUE at all densities. A similar consistent increase in RUE was noted in all N rates when plant density enhanced from D 43,000 to D 67,000 ha^{-1}. RUE was observed much lower at 90 kg N ha^{-1} at all three densities. Increasing N to 120 kg ha^{-1} increased RUE markedly at all three densities. A further increase in N to 150 kg ha^{-1} augmented RUE but relatively at lower rates than that observed between 90 and

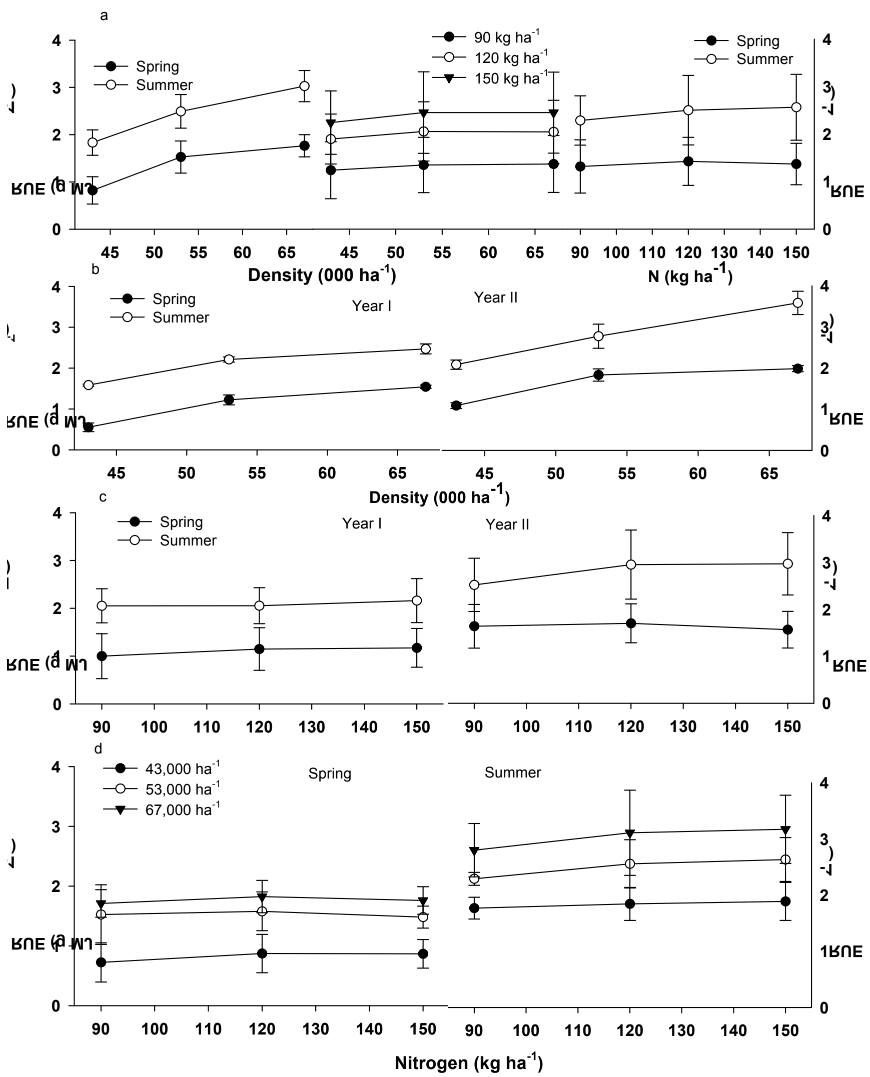

Figure 3. Interactive effects of the treatments on radiation use efficiency (RUE = g MJ-1). Different windows of the figure show different interactions (a) density x seasons, density x N, season x N, (b) year x density x season, (c) year x season x N, and (d) season x density x N trends for RUE.

120 kg ha^{-1}. RUE increased slightly when N rates increased from 90 to 150 kg ha^{-1} in spring and in summer. However, RUE of summer was observed markedly higher than spring at all N rates. Spring and summer season crop showed different RUE trends for every year of the study by changing density (Fig. 3b). RUE was observed with a stable increase in spring and summer with overriding values at summer than spring in both years. The RUE increased marked to moderate at D 43,000 to D 53,000 and D 67,000 ha^{-1}, respectively during spring and summer in year I and II. However, difference in RUE between seasons at every next higher density remained constant in the first year but slightly expands in the second years. Interaction of treatments N with S and years revealed higher RUE in summer than spring during both years (Fig. 3c). The RUE in summer during year II than year I increased markedly with higher differences at N 120 and 150 kg ha^{-1}. Interaction of density with N during spring and summer showed different RUE with relatively higher values for the 2nd year (Fig. 3d). Increased density and N slightly enhanced RUE during both seasons. However, RUE was observed relatively greater at D 53,000 ha^{-1} than D 43,000 ha^{-1} at all the N rates in spring and in summer. Similarly, RUE was observed higher at D 67,000 than D 53,000 ha^{-1} at all N rate for spring and summer but with marginal increases in spring at all N rates.

***Correlations Coefficient Matrix (CCM)*: Correlation** coefficient matrix (CCM) for growth and yield traits of the spring and summer crop is given in table 5. Values of the upper diagonal of the CCM show spring and lower diagonal summer crop. In the CCM table, each value after the decimal

Table 5. Correlation coefficients matrix (CCM) for yield and yield traits of spring and summer planted maize (regression squares).

Characters		GY	PH	EH	PAH	SY	HI	EL	ED	GPE	TGW
		Spring maize									
Grain yield (GY)			0.27 NS	0.55 **	0.37 *	0.67 **	0.57 **	0.49 **	0.61 **	0.50 **	0.35 NS
Plant height (PH)		0.80 **		0.07 NS	0.49 **	0.20 NS	0.18 NS	0.15 NS	0.20 NS	0.31 NS	0.20 NS
Ear height (EH)		0.77 **	0.61 **		-0.05 NS	0.58 **	0.05 NS	0.77 **	0.67 **	0.51 **	0.14 NS
Plant at harvest (PAH)		0.65 **	0.36 *	0.65 **	**	0.34 NS	0.14 NS	-0.03 NS	0.19 NS	-0.03 Ns	0.62 **
Stover yield (SY)	Summer maize	0.82 **	0.76 **	0.64 **	0.45 **		-0.23 NS	0.43 *	0.63 **	0.22 NS	0.36 NS
Harvest index (HI)		0.73 **	0.47 **	0.55 **	0.60 **	0.23 NS		0.17 NS	0.08 NS	0.39 *	0.03 NS
Ear length (EL)		0.67 **	0.68 **	0.40 *	0.27 NS	0.59 **	0.47 **		0.71 **	0.48 **	-0.07 NS
Ear diameter (ED)		0.61 **	0.43 *	0.65 **	0.30 NS	0.56 **	0.38 *	0.57 **		0.65 **	0.26 NS
Grain per ear (GPE)		0.77 **	0.80 **	0.73 **	0.39 *	0.56 **	0.64 **	0.54 **	0.64 **		0.10 NS
1000 grains weight (TGW)		0.76 **	0.49 **	0.65 **	0.40 *	0.79 **	0.34 NS	0.53 **	0.67 **	0.53 **	

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.

shows error correlation between traits with a significant and/or a non-significant level represented with star(s). In spring, positive significant ($p<10.05$) correlations were noted for grain yield with maximum traits. The data showed that maize grain yield was significant ($p<0.05$) with all the observed traits for summer for the spring with exceptions for plant height and thousand grains weight for spring crop (Table 5). No negative relationship was observed for any of the measured traits with yield for summer crop. The dry matter yield showed a negative response with harvest index of sprig crop and likewise did by the ear length with thousand grains weight only. Rest of the parameters found positively correlated with the other.

Grain yield (M g ha^{-1}): Grain yield (M g ha^{-1}) is reported in the Table 6. The summer crop out-yielded ($p<0.05$) the spring crop on two years average basis. However, the spring grain yield was higher ($p<0.05$) than the summer in year I but not in year II. Grain yield did not show any marked difference ($p<0.05$) at D 67,000 and D 53,000 ha^{-1} in each single year or two years average basis but found significantly ($p<0.05$) greater than D 43,000 ha^{-1}. Increased N application from 90 to 120 kg ha^{-1} showed a significant increase in grain yield in each year of the study as well as two years average basis. An increased from 120 to 150 kg N ha^{-1} did show a significant rise in grain yield during first year, but grain yield did not show any significant change at 120 and 150 kg N ha^{-1}in the 2nd year as well as for two years average data.

Table 6. Grain yield (M g ha^{-1}) in maize affected by plant populations and N-levels in spring and summer season crops

Treatments	Year I	Year II	Mean
Season (S)			
Spring	5.94 a	4.73 b	5.34 b
Summer	4.52 b	7.34 a	5.93 a
Significance	**	**	**
Density (D ha^{-1})			
43,000	4.93 b	5.36 b	5.15 b
53,000	5.35 a	6.50 a	5.92 a
67,000	5.40 a	6.27 a	5.83 a
Significance	NS	**	*
Nitrogen (kg ha^{-1})			
90	4.69 b	5.25 b	4.97 b
120	5.30 a	6.44 a	5.87 a
150	5.70 a	6.42 a	6.06 a
Significance	**	**	**
Year	5.23 b	6.04 a	5.64
Interactions	(Significance levels)		
S x D	NS	*	*
S x N	NS	**	*
D x N	NS	**	NS
S x D x N	*	**	*

* Significant at the 0.05 probability level; ** Significant at the 0.01 probability level; NS Not significant.

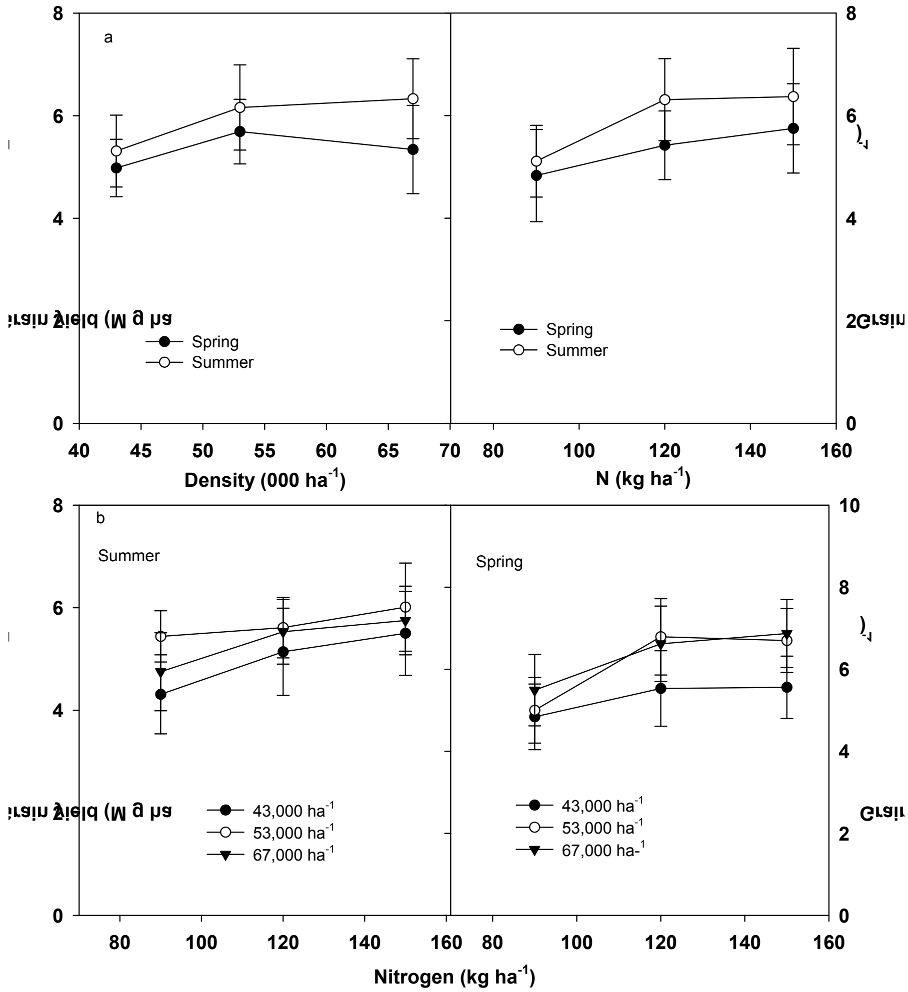

Figure 4. Interactive effects of treatments on grain yield (M g ha-1). Different windows of the figure show different interactions (a) density x seasons, density x N and (b) season x N x density trends for the grain yield.

Means within a treatment that are followed by the same letters do not differ significantly (P<0.05, Tukey).

Grain yield varied ($p<0.05$) for the treatment interaction (S x D, D x N, and S x D x N). Increased density from D 43,000 to D 53,000 enhanced ($p<0.05$) grain yield in spring as well as in summer but a further increase in density from D 53,000 to D 67,000 did not show any change ($p<0.05$) in grains yield (Fig. 4a). Grain yield of summer season remained higher than in the spring at all densities. Likewise, increased N application from 90 to 150 kg ha^{-1} showed a consistent increment for grain yield in spring as well as in summer. However, the grain yield did not differ at 120 and 150 kg ha^{-1} in summer. Summer crop showed relatively higher grain yield than spring. Density with N and S interaction revealed a higher ($p<0.05$) yield in summer than in the spring (Fig. 4b). Increased N showed an increase in grain yield at all densities. The D 53,000 ha^{-1} showed a higher yield during summer than any other densities. The density 43,000 ha^{-1} was lower in yield in spring and in summer. The treatment D 67,000 and D 53,000 ha^{-1} showed almost similar grain yield at 120 kg N ha^{-1} but with lower values at N 90 and 150 kg ha^{-1} for the summer crop. The yield of spring at D 43,000 and D 53,000 ha^{-1} was observed almost the same at 90 kg ha^{-1}. Likewise, grain yield for the treatments D 53,000 and D 67,000 ha^{-1} was observed almost the same at N 120 and 150 kg ha^{-1}.

DISCUSSION

Food security and climate change are, and will be, a challenge for massive growing world population. The challenge has to address reducing impact of ecosystem delivers foods for living beings. Under optimum growing conditions, biomass productivity of various species can be termed by the amount of solar radiations intercepted by green foliage and efficiency with which such intercepted radiation is converted to plant dry matter. Crop dry matter production is always linearly related to the amount of photo-synthetically active solar radiations (PAR) to the canopy green area index (Coetto *et al*., 2013). Quantifying radiation interception by canopies provide essential information about canopy physiological process, impacts microclimates and water dynamics which could be used in conjunction with crop growth and leaf area expansion to derive RUE (Hoffman and Severin, 2010). Radiation use efficiency is widely used in crop growth, climate and ecosystem production simulation modellings. Accurate estimation of RUE in crop canopy is difficult but possible and is based on how many radiation sensors deployed to field and its consistency (Singer *et al*., 2011). Crop growth is function of net assimilates production and partitioning in preferably above ground parts (Akmal *et al*., 2011). Between vegetative and reproductive phases of a plant life cycle, on two years averages the pre anthesis duration were estimated markedly longer and post anthesis moderately shorter for spring maize. The ratios in vegetative and reproductive phases were almost of similar fashion for each experimental year. Contrary to that in summer planted maize both pre- and post anthesis periods were of equal durations. It means that grain developments in the summer planted maize crop occurred in sufficient time span at a slower rate under relatively lower mean daily temperature. Moreover, plants were not subjected to drought shocks during the day time in post anthesis stage when planted in summer and might have resulted higher yield. Spring crop experienced two different climates: (a) increased photoperiod for the vegetative growth and development by increasing in the solar light availability and temperature durations, (b) relatively stable photoperiod and high temperatures with mild stress at day time for the pollination and grain development. Contrary to that summer planted maize thrived at a relatively stable weather conditions with a consistent decrease in the photoperiod, light intensity and mean daily temperature during the grain development stage (Iqbal *et al*., 2010). By comparing spring and summer season crops, in addition to relatively cooler weather of vegetative development phases, spring crops received 8% and 10% higher seasonal precipitation in year I and II, respectively.

Different parts of the plant exhibited variations in growth of leaf and stem due to changes in weather conditions (Fig. 1) e.g. characterization of special and temporal growth patterns within the plant parts (Hsiao et al., 1985), changes in the growth of cell length profiles of leaf and stem (Boote *et al*., 1996) and a partial drought stress in the growing media (Bannayan *et al*., 2010) that severely affected by disturbances in assimilates partitioning within the plants organs at different rates of availability and/or changing growth of leaf and stem with increased height by increased density. The denser treatment showed higher CG and RUE but may not necessarily be improved in production. It has been reported that higher density also ensured the maximum number of missing grains ear^{-1} and barrenness that affected crop yield adversely (Tokatlidis and Koutroubas, 2004). High density with sufficient N-fertilizer rate may utilize the resources (e.g. light and CO_2) optimum but may not necessarily return higher grains. However, it seemed obvious that high N-fertilizer may increase N accumulation in biomass and grains (Barbieri et al., 2008; Cox and Cherney, 2001). Plants remove nutrients from production system in the harvested products that has to be replaced on seasonal basis, however, in the present study, no significant ($p<0.05$) difference between 120 and 150 kg ha^{-1} was visible. It may be either due to uptake potential of the variety, limitation by other nutrients in soil, loss from soil as N is highly mobile etc. Lower RUE in spring than summer season could be due to relatively limited photoperiod of the crops and lower thermal hours at pre anthesis duration which may have resulted limited assimilates accumulation against higher respiration rates at cooler climate. It can be concluded that the growth conversion efficiency of assimilates of spring and summer seasons differed by relatively cooler days and nights of spring (Choudhury, 2001). Longer solar duration under sufficient water and N-fertilizer might have higher RUE that returned greater CG. It is obvious that PAR absorption by the crop canopy is closely associated with the amount of green foliage over the soil. Increasing density extends higher interception by denser canopy volume but may not be necessary to increase in return grain production (Zhang *et al*., 2008). Higher RUE at higher density is reported for consistent dry matter production but stem increment than total biomass (Smart *et al*., 2001). Leaf is major photosynthetic portion and increased in leaf area index and greenness (stay green longer) has improved RUE at a higher N-fertilizer (Giunta *et al*., 2008; Katsura *et al*., 2010) due to relatively maximum radiation interception by the crop canopy or higher average daily rate of net assimilation of dry matter (Vas *et al.,* 2004). Different RUE has been reported for maize in the literature (Singer *et al*., 2011) however, the mean value of RUE of the experiment falls within the lower range published in literature (Ceotto *et al*., 2013). On two years averages, the differences in RUE and CG were 78% and 34% of spring and summer season crops that corresponds to about 28% longer vegetative and 6% shorter reproductive phase of the crop growth. Here one could add the effect on production dynamics and senescence of the mature leaves within the crop canopy that influenced RUE and N-fertilizer economy of the vegetation. It is known that higher N-fertilizer to crop allows larger green leaf area to intercept maximum light, narrowing down transmittance fraction within gaps which might have resulted more assimilates for biomass than grain yield (Giunta *et al*., 2008;

Katsura *et al*., 2010). Higher yield in summer than spring might be due to around 6% increased in post anthesis duration of growth with a relatively mild cooler climate of grain development phase (Ali *et al*., 1994; Ulgar *et al*., 1997). No significant difference in yield at 53,000 and 67,000 ha^{-1} could be due to higher biomass production than it relative grain contribution. Higher yield at high N was natural (Tokatlidis and Koutroubas, 2004; Ammanullah *et al*., 2010) but has to be level off by limiting other soil nutrients. Yield with traits shows positive significant correlation (Yousaf and Salem, 2001; Kashiani and Saleh, 2010). However, negative correlation matrix of yield with traits in spring can be referred to "stress matrix" that yield might be in competition with natural or supplied resources e.g. growth rates contributed for plant height and harvest index. Negative correlation in spring may reflect to yield gap that could overcome with resources management or improved varieties.

***Conclusion*:** Spring planted maize benefits from relatively longer vegetative phase of the early development in a cool weather but unable to result efficient conversion of light into dry matter (radiation use efficiency). Contrary to the spring season, summer season crop exhibited 11% higher grains yield due to the cooler climate of grain development phases of the crop growth. There are evidence that CG of maize and thereby yield might be limited by sink capacity that could be enhanced through validation of existing production technology and appropriate varieties for spring and summer seasons.

Acknowledgement: The authors acknowledge with thanks financial cooperation of Higher Education Commission (HEC), Pakistan in the form of research grant to Universities. Special thanks are also extended to Prof. R.A. Khattak and Prof. Iftikhr H. Khalail for technical support in data analysis.

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