IMPACT OF NITROGEN RATES ON GROWTH, YIELD, AND RADIATION USE EFFICIENCY OF MAIZE UNDER VARYING ENVIRONMENTS

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Growth, yield and radiation use efficiency (RUE) of hybrid maize, in response to different nitrogen rates (150, 200, 250, 300, 350 kg ha^{-1}) were analyzed for three different locations (Faisalabad, Sargodha and Sahiwal) in Punjab, Pakistan during 2004 and 2005. The results depicted a large yearly variations mainly attributed to more rainfall and incidence of solar radiation in 2005. Maize hybrids respond differently for all variable under study, at all sites except IPAR and radiation use efficiency for total dry matter RUE_{TDM} at Faisalabad. Hybrid Bemasal-202 gave more grain yield (23-35 %) than Monsanto-919 at different locations. Similar types of differences were noted in CGR and Final TDM. Increasing nitrogen rates had significant effects on CGR, final TDM and grain yield and RUE. The intercepted PAR, RUE_{TDM} and RUE_{GY} were significantly affected by hybrid potential and nitrogen application rates. On an average RUE_{TDM} varied from 2.45 to 2.73 g MJ^{-1} at different locations, while RUE_{GY} was recorded 1.12, 1.14, and 1.03 for Faisalabad, Sargodha and Sahiwal, respectively. Total dry matter and grain yield of different treatments was linearly related to IPAR at all location and the common regression (R^2) accounted for 94, 68, and 80 % for TDM & 64, 34, and 95 % for grain yield at the Faisalabad, Sargodha, and Sahiwal, respectively. It was concluded that planting of hybrid Bemasal-202 with 300 kg N ha^{-1} is the best recommendation for semi-arid areas of Pakistan.

Keywords: Maize, hybrid, CGR, grain yield, TDM, RUE, nitrogen rates

INTRODUCTION

The growth and yield of a crop can be adversely affected by deficient or excessive supply of any one of the essential nutrients (Wang *et al*., 2003; Ting-Hui *et al*., 2006). However, in intensive agriculture, nitrogen is the major nutrient determining crop yield. Nitrogen plays a central role in plant growth as an essential constituent of cell components.

The first prerequisite for high yields is a high production of total dry matter (TDM) per unit area that can be attained through optimizing the assimilate area i.e. LAI to enhance the interception of photo-synthetically active radiation (IPAR) and improving the radiation use efficiency. TDM of a crop is proportional to the total amount of intercepted radiation, (Biscoe and Gallagher, 1978). Andrade *et al*. (1993) reported a linear relationship between growth and intercepted PAR in maize. Information on the influence of radiation interception and RUE in Pakistan is still insufficient. Overseas research has shown that RUE increased with higher rates of nitrogen application (Muchow & Davis, 1988; Loomis & Amthor, 1999).

Main constraints to enhance maize productivity in Pakistan are lack of site specific production technology, inadequate nutrition such as nitrogen, inadequate water supply, weed infestation and insect pest attacks. The selection of unsuitable cultivars under a given set of environments is major factor responsible for low yield. The existing recommended dose of nitrogen 200 kg ha^{-1} for hybrid maize production is low for Pakistani soils which are under high cropping intensity, very low in organic matter and deficient of nitrogen. This research was planned to evaluate the growth, RUE and production performance of maize hybrids planted at varying rates of nitrogen under diverse agro-ecological conditions of Punjab, Pakistan. This work might assist the farmers in improving crop yield and sustaining profitability and crop growth modelers to improve models as well.

MATERIALS AND METHODS

Plains of Punjab fall in semiarid subtropical climatic zone and its soils are deficient in nitrogen. Measurements of maize growth, yield and radiation use efficiency (RUE) were made during 2004 and 2005 at Faisalabad, Sargodha and Sahiwal districts of Punjab province. Additional information regarding sites and soils are given in Table 1. The experiment was laid out in split plot design with four replications. The net plot size was 4.2 m x 10 m. Three maize hybrids i.e. Bemasal-202, Monsanto-919 and Pioneer 31-R-88 were planted in the main plots while five nitrogen levels 150, 200, 250, 300, 350 kg N ha^{-1} were randomized in sub plots. The crop was planted during the month of August on 70 cm spaced ridges and a plant spacing of 20 cm, using a seeding rate of 25 kg ha^{-1}. Phosphorus and potassium were applied at rate of 100 kg ha^{-1} in all plots at the time of planting as Triple Super Phosphate (TSP) and Sulphate of Potash (SOP), respectively. Fertilizers were broadcasted and incorporated at the time of seedbed preparation. Nitrogen fertilizer i.e. Urea was applied in three equal splits (Table 2). All other cultural practices such as Irrigation, thinning, hoeing, and plant protection measures were kept normal for the crop at all sites.

Crop growth rate

Crop growth rate (CGR) was calculated as proposed by Hunt (1978) at each sampling date. Mean CGR was calculated by averaging all CGRs determined at each destructive harvest.

Table 1. Summary of field attributes, soil and climatic characteristics of experimental locations

Location	Latitude Nº	Longitude Eº	Altitude (m)	Soil Series (USDA Classification)	Climatic zone
Faisalabad	31^o 26´	73^o 04´	184	Lyallpur (Fine-silty, mixed, hyperthermic Ustalfic Haplargids)	Dry Semi-Arid
Sargodha	32^o 04´	72^o 67´	188	Bhalwal (Fine-silty, mixed, hyperthermic typic calciargids)	Arid
Sahiwal	30^o 40´	73^o 06´	172	Jaranwala (Coarse-silty, Mixed, hyperthermic Typic Calciargids)	Wet Semi-Arid

Table 2. Crop husbandry operations for the experiments during growing season

Operations	Faisalabad		Sargodha		Sahiwal	
	2004	2005	2004	2005	2004	2005
Sowing dates	11.08.04	03.08.05	9.08.04	08.08.05	12.08.04	05.08.05
Cultivars	Bemasal-202, Monsanto-919, Pioneer-31-R-88					
Nitrogen (Urea)	Nitrogen was applied in three doses in all treatments					
1st Dose	11.08.04	03.08.05	09.08.04	08.08.05	12.08.04	05.08.05
2nd Dose	26.08.04	18.08.05	24.08.04	22.08.05	27.08.04	20.08.05
3rd Dose	30.09.04	24.09.05	28.09.04	27.09.05	02.10.04	27.09.05
Harvesting date	27.11.04	16.11.05	02.12.04	26.11.05	05.12.04	29.11.05

Sampling strategy

After 15 days of planting, destructive sampling was started. One meter long row from each plot was harvested at ground level after ten days interval leaving appropriate borders. Plants were separated into components and fresh weight for each fraction (leaf, stem, tassel and cob) was determined. A sub-sample (10 g) of each fraction was taken and oven dried to a constant weight. From these measurements total dry matter (TDM; g m^{-2}) was calculated at each harvest. At final harvest two central rows with a length of 10 m for each plot were harvested. All cobs were thrashed mechanically to estimate grain yield (GY) of entire plot and converted in to g m^{-2} to determine relationship between GY and RUE. To determine grain moisture, the sub sample of 250 g was weighted, dried and again weighted. Final yield was corrected to 0 % moisture.

Radiation interception

Fraction of intercepted Radiation (Fi) by the green surfaces of the crop canopy was calculated after ten days interval for each plot from Beer's law

Fi = 1- exp (-k x LAI) -- (2)

Where k is an extinction coefficient for total solar radiation equal to 0.7 for maize (Lindquist *et al., 2005*). The amount of intercepted PAR (Sa) was determined by multiplying values of Fi with daily incident PAR (Si), during the season.

Sa = Fi x Si -- (3)

The amount of total PAR intercepted by the crop was calculated by multiplying Fi with 50 % of incident radiation (Szeicz, 1974). Cumulative intercepted PAR (∑Sa) WAS calculated By adding all values of intercepted PAR (Sa) recoded at each ten days interval.

Radiation use efficiency

Radiation use efficiency for TDM (RUE_{TDM}) and grain yield (RUE_{GY}) was calculated as the ratio of total biomass and grain yield to cumulative intercepted PAR ($\sum Sa$).

RUE_{TDM} = TDM / $\sum$Sa----------------(4) and

RUE_{GY} = Grain Yield / $\sum$Sa-----------(5)

Alternatively, radiation use efficiency was estimated by regressing yield against accumulated intercepted radiation (Monteith, 1977).

Statistical analysis

Data collected on different parameters were analyzed statistically and significance of treatment means was tested using least significant difference test at 5% probability level. Pooled analysis was carried out within location across years/seasons (Gomes & Gomes, 1984).

RESULTS AND DISCUSSION

Summary of weather variables recoded during 2004 and 2005 for each location is presented in Fig.1. During both cropping seasons the Sahiwal site was relatively hotter than the Sargodha and Faisalabad sites. Mean temperatures were higher by approximately 1-2 ^{o}C at the Sahiwal where as Sargodha was also slightly warmer than Sahiwal by 0.5-1 ^{o}C. However, the pattern of average temperature was similar at all the three sites. Rainfall was experienced during monsoon (August to September) and was variable at all the three sites during growing seasons: Faisalabad had lower precipitation 134 mm than Sargodha (148 mm) and Sahiwal (182 mm) in 2004. Comparable rainfall values recorded in 2005 were 159 mm, 219 mm and 242 mm, respectively. In general, all sites have more rainfall during 2005 as compared to 2004. Radiation levels were also different at each site during both the seasons.

Crop growth rate

Seasonal effect was differentially significant at all location, mean CGR was higher 7 % (20.48 vs 19.21 g m^{-2} d^{-1}) and 14 % (19.74 vs 17.38 g m^{-2} d^{-1}) in 2005 at Sargodha and Sahiwal locations respectively. In contrast at the Faisalabad site, crop had 10 % higher CGR (21.47 vs 19.49 g m^{-2} d^{-1}) in 2004. Cultivar differences in mean CGR were non-significant at Faisalabad. However, cultivar differences were significant at Sargodha and Sahiwal sites. Averaged over the sites, mean CGR was 20.18 g m^{-2} d^{-1} in hybrid Bemasal-202 and 19.70 g m^{-2} d^{-1} in cv. Pioneer-31-R-88 (Table 3).

At all sites, N application significantly enhanced mean CGR over standard rate of N (200 kg N ha^{-1}).

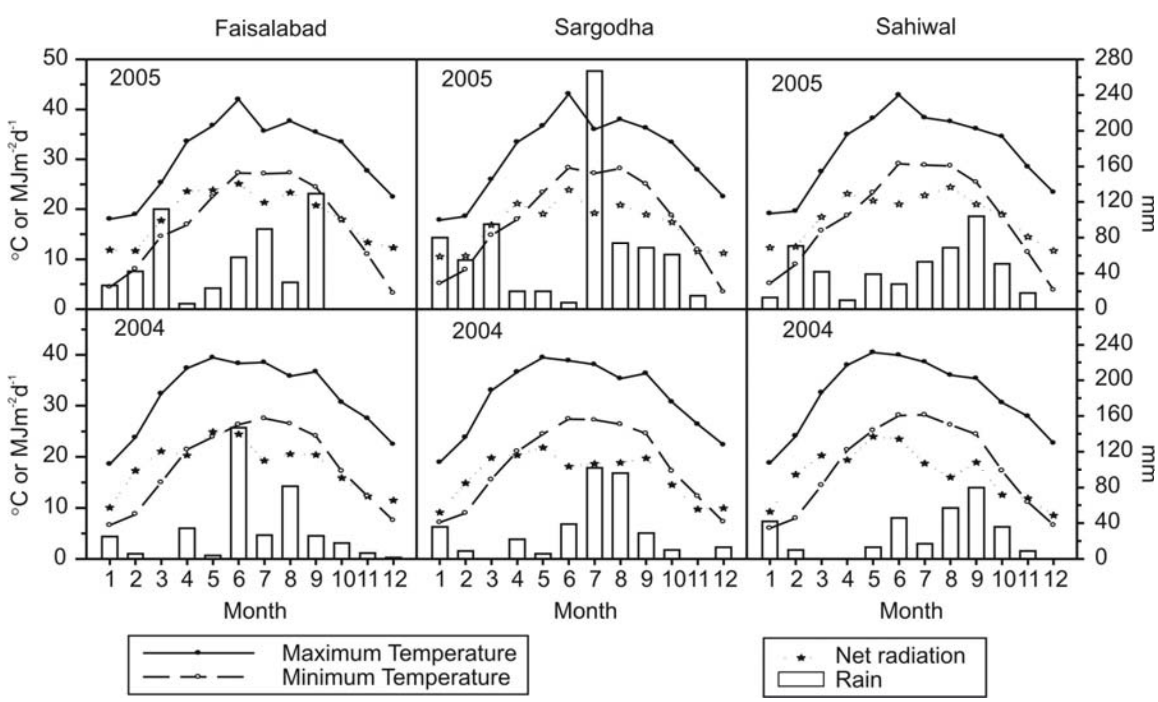

Fig. 1. Average monthly maximum and minimum air temperature, solar radiation and total monthly rainfall for the experimental sites

Maximum mean CGR (21.37 g m^{-2} d^{-1}) was recorded in plots fertilized with 300 kg N ha^{-1} that was statistically at par with 350 kg N ha^{-1} growing with mean CGR 21.0 g m^{-2} d^{-1}. The minimum CGR (16.99 g m^{-2} d^{-1}) was recorded in plots fertilized with 150 kg N ha^{-1}. To expound the factors determining grain yield in different treatments, the plant growth was examined throughout the season. Growth analysis showed that treatment differences in CGR were associated with those in final grain yield (Fig. 2). It was suggested that a higher CGR during flowering may be prerequisite to attain a higher grain yield. These differences in CGR among treatments during the period might have resulted from the variation in environmental conditions. In particular, radiation directly influences the plant biomass production (Monteith, 1977; Horie and Sakuratani, 1985). Interestingly, there was significant difference in the amount of intercepted radiation among treatments during the growth period. Thus, differences in CGR could be ascribed to variations in the amount of intercepted light as well as its efficiency of use. Generally, CGR is composed of RUE, Sa, K and LAI. Among these components a significant difference was clearly observed in RUE during growth (Table 4).

Total Dry Matter

Seasonal effect on total dry matter (TDM) was significant at Sargodha and Sahiwal, while at Faisalabad differences in TDM were non significant. Averaged over locations crop produced 7 % more TDM (1802 vs 1691 g m^{-2}) during 2005 as compared to 2004 (Table 3). Total dry matter production, at final harvest, was significantly affected by hybrids at all locations in similar trend. Averaged over location maximum TDM was accumulated by Bemasal-202 (1798 g m^{-2}). Minimum TDM accumulation was recorded in hybrid Monsanto-919. Quadratic response of nitrogen to TDM was observed at all three locations. On an average maximum TDM (1891 g m^{-2}) was produced by 300 kg N ha^{-1} which was statistically at par with treatment 350 kg N ha^{-1}. Minimum TDM (1524 g m^{-2}) was recorded in treatment 150 kg N ha^{-1}. This increase in TDM with higher level of nitrogen was due to better crop growth, which gave maximum plant height, LAI and ultimately produced more biological yield. Corn biomass increase with applied N in a quadratic manner was also reported by Shapiro *et al*. (2006). Total dry matter production in maize was also directly proportional to radiation interception as reported by Kiniry *et al*., (1999). These observations are fully supported by Khan *et al*. (1999) and Sharar *et al*. (2003). Total dry matter of different treatments was linearly related to (IPAR) at all location and the regression accounted for 94, 68, and 80 % at the Faisalabad, Sargodha, and Sahiwal, respectively (Fig.3).

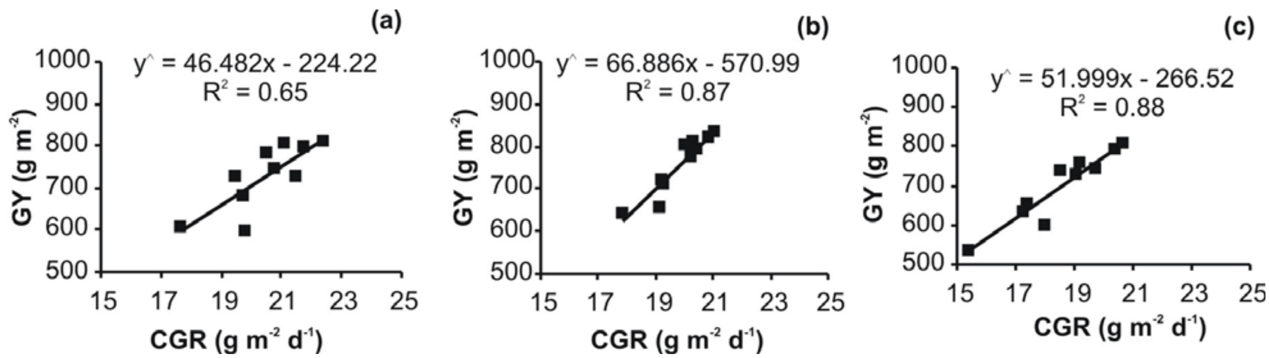

Fig. 2. Relationship between two years pooled grain yield and CGR at Faisalabad (b) Sargodha and (c) Sahiwal

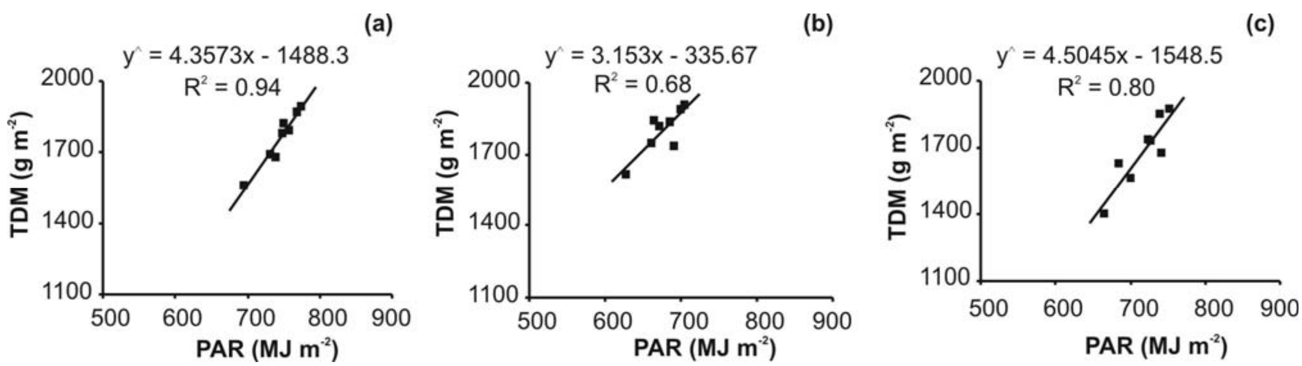

Fig. 3. Relationship between two years pooled final TDM and cumulative intercepted PAR at (a) Faisalabad (b) Sargodha and (c) Sahiwal

Grain Yield

Year effects on grain yield of maize were highly significant at Sargodha and Sahiwal sites, where as it was non significant at Faisalabad site (Table 3). Grain yield was recorded 10 % (720 vs 792 g m^{-2}) and 14 % (652 vs 745 g m^{-2}) more at Sargodha and Sahiwal sites respectively in 2005 as compared to 2004. It is mainly attributed to more number of grains during 2005 at these experimental sites. The yield differences between the years might be ascribed to different daily variation in maximum and minimum temperatures resulting in different daily leaf temperature across the year, different patterns of rainfall and relative humidity over the two years and other temporal variations in the environment. Such environmental variations across the year also resulted in better growth and development of maize in 2005 than 2004 which is evident from the results discussed earlier in this section. D'Andrea *et al.* (2008) also reported year difference (897 vs 711 g m^{-2}) in maize yield in 2000 and 2001. Hybrid differences in grain yield were significant at all location with similar trend. Maximum average grain yield (791 g m^{-2}) was recorded in case of Bemasal-202 followed by Pioneer-31-R-88 producing (775 g m^{-2}) that were statistically at par with each other. The minimum grain yield (698 g m^{-2}) was produced by Monsanto-919. Different nitrogen levels markedly increased grain yield over standard (200 kg N ha^{-1}) treatment. At all locations response of nitrogen was quadratic in nature. Averaged over locations plots fertilized with 150 kg N ha^{-1} (below standard treatment) produced significantly less grain yield (596 g m^{-2}) than plots fertilized at higher levels. Maximum grain yield (817 g m^{-2}) was recorded in plot fertilized with 300 kg N ha^{-1}which is statistically at par with yield recorded at 350 kg N ha^{-1}, while standard treatment (200 kg N ha^{-1}) produced considerably lower yield (596 g m^{-2}) as compares to higher rates of nitrogen. Nitrogen stress in plots fertilized at lesser levels of nitrogen might be the cause of lesser crop growth, which leads to lower radiation interception, RUE and therefore kernel number and grain yield (Sincalir and horie, 1989; Uhart and Andrade, 1995). Overall, mean grain yield was lower (727 g m^{-2}) at Faisalabad as compared to Sargodha (823 g m^{-2}) and Sahiwal (849 g m^{-2}).

Incident and Intercepted Radiation

The amount of intercepted photosynthetically active radiation (IPAR) during the growth cycle at all the sites was 76, 68 and 66 % at Faisalabad, Sargodha and Sahiwal sites, respectively.

Climatic conditions of a year significantly increased interception of PAR at Sargodha and Sahiwal, where as at Faisalabad site these differences were non significant. Averaged over the locations, climatic conditions of 2005 increased IPAR by 5 % (729.88 vs 696.13 MJ m^{-2}) as compared to 2004. Cultivar differences in intercepted PAR were non-significant at Faisalabad site and significant at Sargodha and Sahiwal sites. Averaged across all sites, mean intercepted PAR was 714, 705 and 721MJ m^{-2} in hybrid Bemasal-202, Monsanto-919 and Pioneer-31-R-88, respectively. Nitrogen levels significantly affected the amount of intercepted PAR at all locations. These responses were quadratic in nature at Faisalabad and Sahiwal sites and cubic at Sargodha; increasing rate of N significantly increased PAR interception up to 300 kg N ha^{-1} after that a slight decrease was observed at 350 kg N ha^{-1} that was not statistically different from 300 kg N ha^{-1}. The minimum interception of PAR (663.04 MJ m^{-2}) was recorded in plots fertilized with 150 kg N ha^{-1}.

Radiation Utilization Efficiency for TDM

Seasonal effect on RUE_{TDM} were non significant at Faisalabad and Sargodha sites where as year effect on RUE_{TDM} at Sahiwal site was significant where climatic conditions of 2005 enhanced 13 % RUE_{TDM} (2.59 vs 2.30 g MJ^{-1}) over 2004. Cultivar differences in RUE_{TDM} were significant at the Sargodha and Sahiwal locations and non significant at the Faisalabad site. Hybrid Bemasal-202 used radiation more efficiently (2.69 g MJ^{-1}) for TDM accumulation followed by Pioneer-31-R-88 (2.64 g MJ^{-1}), whereas hybrid Monsanto-919 was lowest efficient user of radiation (2.51g MJ^{-1}) for TDM accumulation as compared to formers (Table 4). Significant differences were found in RUE_{TDM} among N treatments at Faisalabad and Sahiwal, where increasing level of N increased RUE_{TDM} over standard treatment (200 kg N ha^{-1}). Three sites average, mean RUE was 2.73 g MJ^{-1}, 2.71 g MJ^{-1} and 2.63 g MJ^{-1} recorded with above standard N rate treatments 300, 350 and 250 kg N ha^{-1}, respectively. The minimum value of mean RUE_{TDM} was registered from plots fertilized with 150 kg N ha^{-1}. Overall, average RUE_{TDM} were 2.73, 2.66 and 2.45 g MJ^{-1} at Faisalabad, Sargodha and Sahiwal, respectively. The common regression analysis depicted values of RUE_{TDM} 4.35, 3.15 and 4.50 g MJ^{-1} for Faisalabad, Sargodha and Sahiwal, respectively (Fig 3).

Radiation Utilization Efficiency for grain yield

Seasonal effects on (RUE_{GY}) were significant at Sargodha and Sahiwal sites in similar trend. Crop used radiation more efficiently in 2005 than 2004. Differences in RUE_{GY} between year at the Faisalabad were non significant. The values of RUE_{GY} varied from

0.95 g to 1.22 g MJ^{-1} between different years. Effects of cultivars were significant at all three sites. Hybrid Bemasal-202 out performed in average RUE_{GY} (1.19 g MJ^{-1}). Nitrogen application affected RUE_{GY} in a cubical manner at all locations (Table 4). In general increasing level of N significantly increased RUE_{GY} up to 300 kg N ha^{-1} after that there was no significant increase in RUE_{GY}. Averaged at all locations, RUE_{GY} varied from 0.96 g MJ^{-1} to 1.20 g MJ^{-1} among various N application treatments. The mean RUE_{GY} at three sites were 1.12, 1.14 and 1.03 g MJ^{-1} at Faisalabad, Sargodha and Sahiwal. Previous studies have shown that N application increases RUE in various crops (Green, 1987, and Ahmad *et al*., 2008). The increase may be ascribed to a greater assimilate production or a decreased partitioning of current assimilates to root system (Whitfied and Smith, 1989).

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