INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY
ISSN Print: 1560–8530; ISSN Online: 1814–9596
09–323/MFA/2010/12–1–9–16
http://www.fspublishers.org

Full Length Article

Changes in Growth and Yield of Maize Grown in the Glasshouse

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ABSTRACT

Upcoming increase in global warming is potential threat to crop production, which necessitates determining responses of crops to cope with this ever-increasing adversary. This study focused on the responses of two differentially heat tolerant maize (*Zea mays* L.) varieties Sadaf (heat tolerant) and Agatti-2002 (heat sensitive) to glasshouse condition at three growth stages across spring and autumn seasons (by keeping the plants inside the glass canopies). Results revealed that growth and yield responses of maize varieties were quite differential across the seasons and treatments, which was evident from the interactions of varieties and treatment present in one season and disappeared in the other. Among the growth attributes, silking and grain filling stages during spring season were more sensitive to glasshouse effect as most the interactions of varieties and treatments were evident for various growth attributes. Although glasshouse condition diminished all the studies growth and yield characteristics, most explicit changes were noted in shoot dry mass and leaf area per plant at all growth stages. Among the cob and seed yield characteristics, glasshouse condition was more damaging to grain yield per cob and plant especially during spring season. To conclude, increased temperature inside the canopy during later stages of spring sown crop was the main reason for reduced growth and yield of maize. © 2010 Friends Science Publishers

Key Words: Global warming; Maize; Grain yield; Growth season

INTRODUCTION

High temperature is a major environmental factor that determines the crop growth and yield in some regions of the world (Al-Khatib & Paulsen, 1999; Ulukan, 2009). Plants grown under high temperature have lower biomass than those grown at low temperature (Blum, 1988). High temperature influenced the leaf expansion, internode elongation, motivate the flower bud abortion in *Brassica napus* (Young *et al.,* 2004), which may be due to limited supply of water and nutrients (Hall, 1992). High temperature causes photosynthetic acclimation and alters physiological processes directly and changes the pattern of development indirectly (Wahid *et al*., 2007). It increased the rate of development and shortened the growth period in annual species by virtue of rapid carbon fixation and biomass accumulation before seed set (Morison, 1996). Heat stress decreased the growth and accumulation of starch in tubers greater than shoot but did not affect the glucose in potato tubers (Lafta & Lorenzen, 1995).

Heat shock affects the cell division in meristems and reduces the growth of various parts, mainly the leaves (Salah & Tardieu, 1996). Maize leaf growth increased from 0 to 35°C, but declined at 35 to 40°C. Above 40°C, there was a steep decline in photosynthesis and alteration in protein metabolism such as protein denaturation, aggregation, enzyme inactivation, inhibited protein synthesis and its degradation (Dubey, 2005; Kim *et al*., 2007; Ristic *et al*., 2009).

High temperature affects the reproductive growth by increasing flower abortion and decreasing seed size (Talwar *et al*., 1999). Pollination an important stage in reproductive development, is especially sensitive to heat stress; the mature pollens, being more sensitive, failed to fertilize (Dupuis & Dumas, 1990). Heat stress causes premature development of anther and arrests its cell proliferation (Oshino *et al.,* 2007) and causes male sterility in certain plant species (Sato *et al*., 2006; Abiko *et al*., 2005). It reduced kernel density and reproductive growth in maize, wheat and *Suneca* during kernel development and its filling (Maestri *et al.,* 2002). Kernel dry weight reduced from 79 to 95% in field conditions in an inbred line of maize under heat stress (Commuri & Jones, 2001). High temperature affected the endosperm development in maize and reduced grain yield during endosperm cell division, which were due to interruption of cell division, aberrant sugar metabolism and starch biosynthesis (Monjardino *et al.,* 2005).

In view of the changing environmental conditions, mainly related to global warming, the plant growing patterns are subject to rapid and continuous changes (Porter, 2005; Wahid *et al*., 2007). Although maize is a C4 plant and can withstand relatively higher temperatures (Ashraf & Hafeez,

To cite this paper: Hussain, I., A. Wahid, M. Ashraf and S.M.A. Basra, 2010. Changes in growth and yield of maize grown in the glasshouse. *Int. J. Agric. Biol.*, 12: 9–12

2004), growth and yield response of this important cereal crop to glasshouse conditions have not been comprehensively studies. Maize is a short duration crop and is grown in spring and autumn seasons in Pakistan. It shows differential growth and productivity in these seasons, which might be attributed to prevailing season (Anonymous, 2008). Keeping in view the importance of global warming as a threat to crop production, studies were initiated to determine the seasonal variations in the responses of maize to glasshouse condition at three growth stages.

MATERIALS AND METHODS

Source of maize seed, treatment and plant growth conditions: For screening purpose, seeds of two maize (*Zea mays* L.) varieties Sadaf and Agatti-2002 were obtained from Maize and Millets Research Institute (MMRI), Yousafwala, Sahiwal, Pakistan. The experiments were conducted in the wire-house of the Department of Botany, University of Agriculture Faisalabad, Pakistan. Seeds (12 in number) of both the varieties were grown in plastic pots (dimensions 30 cm high, circumference of 82 cm at top & 70 cm at bottom). A hole was made in the bottom for leaching during replacement of the soil solution. Each pot contained 13 kg of dry sand, which was thoroughly washed with tap water followed by distilled water before filling. All the pots were applied with 2 L of half strength Hoagland's nutrient solution (Hoagland & Arnon, 1950), which was replaced after every four days. After germination five uniform and healthy seedlings were retained for making determinations at seedling, silking and grain filling stages. Glasshouse condition was created by shifting the pots containing growing plants in the canopy (light transmission index of was 75-80%) at respective growth stages, while the control set was kept outside the canopies. The harvesting was done 20 days after treatment application. For these pots, the roof of net house was covered with polythene sheet to produce the shading effect like canopy. The temperatures and RH inside and outside the canopies was recorded regularly during various times of the day/night throughout the experimental period (Fig. 1).

Leaf area was taken of intact plants as maximum leaf length×maximum leaf width×0.68 (correction factor computed for all leaves). Shoot length was taken of the pot grown plants, while root length was taken after carefully removing the roots from the sand. The fresh weights of both shoot and root were taken immediately after harvesting. For dry weights, the shoot and roots were put in the paper bags and kept in an oven at 70^{o}C for a week. For cob characteristics and grain yield, the cobs were removed at maturity. The number of rows per cob and number of grains per row were counted. The grains were extracted from the cobs and their yield was assessed after weighing to express on per plant basis. The harvest index (HI) was calculated as:

$$\text{HI (\%)} = (\text{grain yield per plant}) \times 100/(\text{straw yield per plant})$$

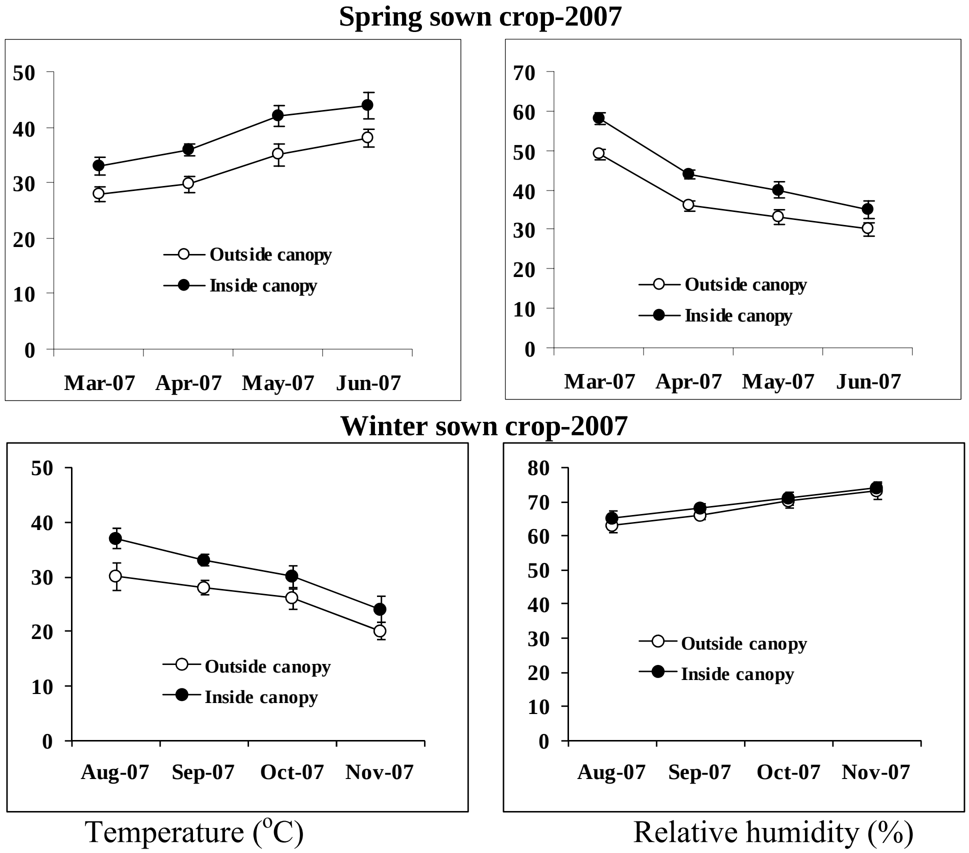
All the determinations were made in quadruplicate from this completely randomized experiment. The presence or absence of significant differences among different factors was ascertained with analysis of variance (ANOVA). Computer software COSTAT (CoHort software, 2003, Monterey, California) was used for all statistical analysis and MS-Excel was used to graphically present the data.

RESULTS

Growth characteristics: At seedling stage, there were significant differences in the treatments during spring ($P<0.01$) and autumn ($P<0.05$) seasons, for shoot length. With no varietal difference ($P>0.05$) under control condition in spring season, shoot length in Sadaf was higher than Agatti-2002 in the glasshouse. Likewise in autumn season, more shoot length was recorded from Sadaf than Agatti-2002 in both the conditions. However plants of both the varieties were shorter during spring season (Fig. 2). At silking stage, there was significant ($P<0.01$) difference in the varieties with a significant interaction of varieties and treatments in spring season grown plants. While in autumn season significant ($P<0.01$) difference was noted in the varieties and treatments, Sadaf showed greater shoot length than Agatti-2002 under both the conditions during spring season. However, in autumn season under glasshouse, Sadaf and Agatti-2002 showed greater shoot length than in control condition (Fig. 2). At grain filling stage, treatments showed significant ($P<0.01$) difference in the treatments in both the seasons. In both seasons, Sadaf showed greater shoot length than Agatti-2002 both under control and glasshouse conditions, although spring season grown plants had higher shoot length than autumn season ones (Fig. 2).

For root length in spring season, treatments, not the varieties, indicated significant ($P<0.05$) differences. However, in autumn season varieties, not the treatments, indicated significant ($P<0.05$) difference. During spring season, both the varieties indicated a similar pattern of changes in root length, although root length was lesser in glasshouse grown plants. In autumn season, although root length was higher in Sadaf, both the varieties showed relatively increased root length than the corresponding controls (Fig. 2). At silking stage, data revealed significant ($P<0.01$) differences in varieties, treatment, with an interaction ($P<0.05$) of these factors in spring season, while in autumn only treatments indicated significant ($P<0.01$) difference. In spring season, Sadaf exhibited longer roots than Agatti-2002 under control condition, but reverse behavior was noted in Agatti-2002 under glasshouse condition. Although much shorter than the spring season grown plants, glasshouse grown plants of both the varieties in autumn season indicated longer roots as compared to respective controls (Fig. 2). At grain filling stage, treatments indicated significant difference in treatments during both the seasons. In spring season, there was no difference in root length of control and glasshouse grown plants, which

Fig. 1: Variation in the temperature and relative humidity inside and outside the plexiglass fitted canopy during experiment in spring and autumn seasons in 2007

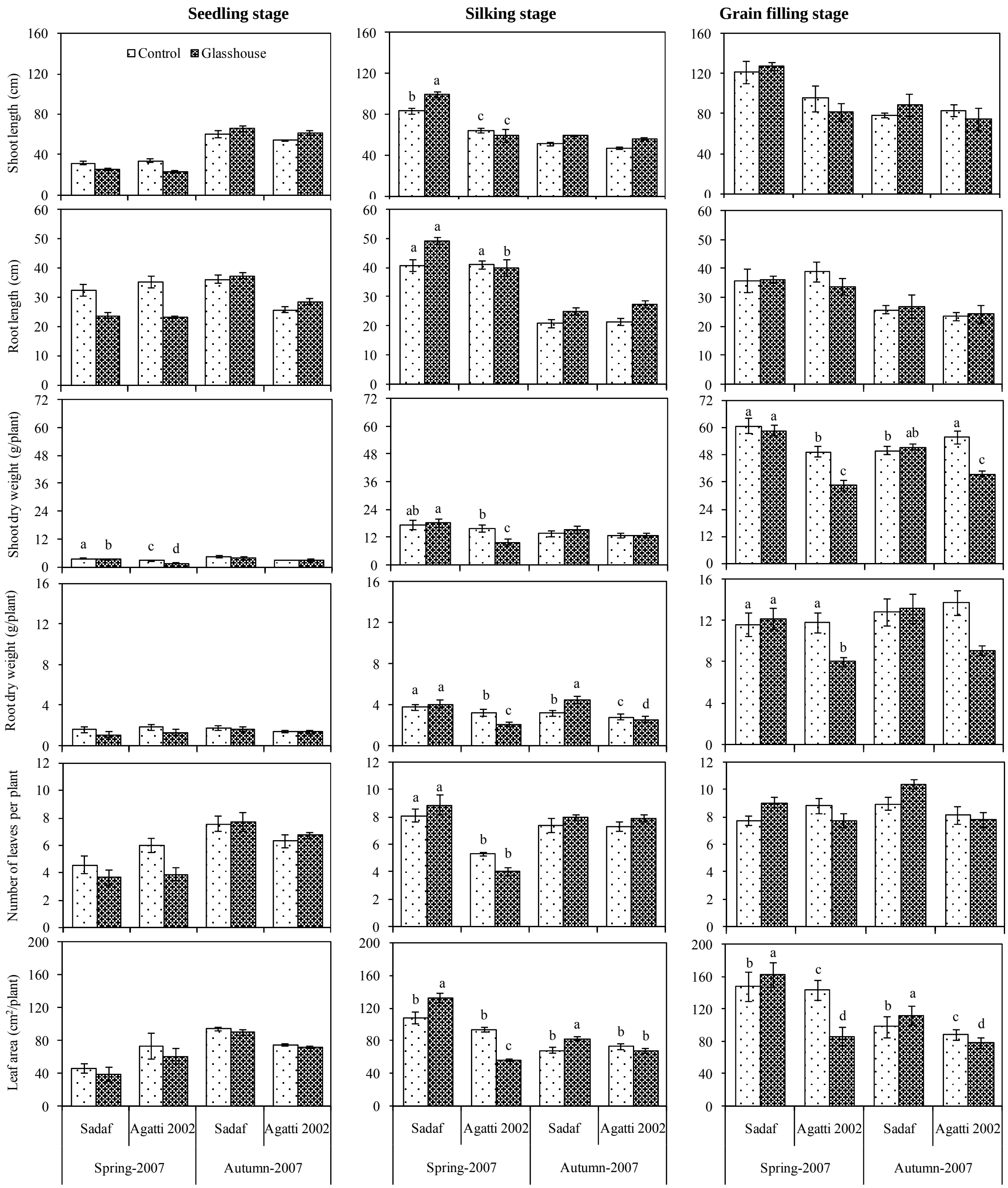


decreased in latter condition in Agatti-2002. Although much shorter than the spring season plants, control and glasshouse grown plants of both the varieties in autumn season indicated no difference (P>0.05) in the root length (Fig. 2).

For shoot dry weight, at seedling stage, in spring season, data showed significant (P<0.01) difference in the varieties and treatments with a significant interaction of both factors, while in autumn season there was significant (P<0.01) difference in the varieties and treatments. In spring season although shoot dry weight was low, glasshouse condition further reduced it in both the varieties, while this attribute was not affected much in glasshouse condition in autumn season. Sadaf indicated a higher shoot dry weight than Agatti-2002 in the glasshouse (Fig. 2). At silking stage, in spring season, data revealed significant difference in the varieties (P<0.01), treatments (P<0.05) and a significant (P<0.05) interaction of these factors. Contrarily, in autumn season the varieties only differed significantly (P<0.05). In spring season, varieties showing similar shoot dry weight under control, Agatti-2002 manifested significantly reduced shoot dry weight than Sadaf under glasshouse condition. While in autumn season, although lesser than spring season, both the varieties had similar shoot dry weight under control, however under glasshouse condition it was greater in Sadaf than in Agatti-2002 (Fig. 2). At grain filling stage, spring season grown plants revealed significant (P<0.05) difference in the varieties, while in autumn season, the treatments indicated significant (P<0.01) difference with a significant (P<0.01) interaction of varieties and treatments. In spring season, under either condition, Sadaf indicated greater shoot dry weight under either condition than Agatti-2002. In autumn season, however under control condition Sadaf showed relatively lesser shoot dry weight than Agatti-2002, while glasshouse condition did not influence this variable in Sadaf but decreased remarkably in Agatti-2002 (Fig. 2).

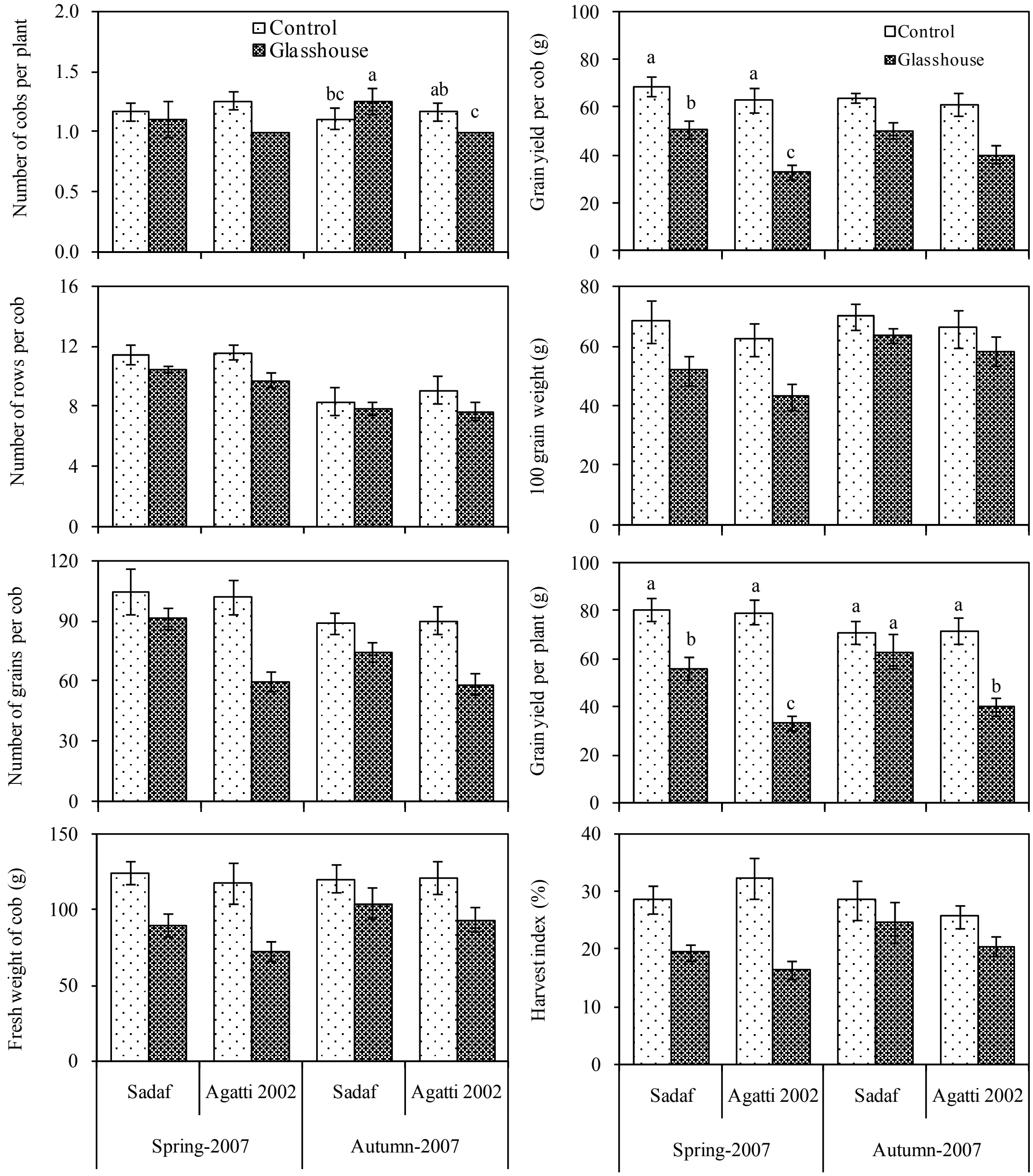
For root dry weight, at seedling stage, spring season grown plants data revealed significant (P<0.01) difference in the treatments, while autumn season grown plants showed significant (P<0.01) difference in the varieties. In spring season, both the varieties indicated similar root dry weight under control but a reduced one under glasshouse condition. In autumn season, on the other hand both the varieties showed similar response both under control and glasshouse condition for this parameter (Fig. 2). At silking stage, in both the seasons, there was significant (P<0.01) difference in the varieties and treatments with a significant (P<0.01) interaction of both the factors for root dry weight. In spring season, root dry weight was greater in Sadaf, which increased further under glasshouse condition, while

Fig. 2: Changes in some growth attributes of control and glasshouse grown plants of maize varieties during spring and autumn seasons at three growth stages. The comparisons have been made of the varieties separately for spring and autumn seasons, the data bars carrying same alphabet in a season differ non-significantly (P>0.05)



in Agatti-2002 glasshouse condition reduced it. In autumn season, the root dry weight increased in Sadaf under glasshouse condition over control, but in Agatti-2002 this parameter was similar under both the conditions (Fig. 2). At grain filling stage in spring season, there was no significant (P>0.05) difference in the varieties and treatments but there was significant (P<0.05) interaction of both factors. However in autumn season, varieties, not the treatments, showed significant (P<0.01) difference. In both the seasons, root dry weight was greater in Sadaf, which increased

Fig. 3: Changes in some cob and grain yield characteristics of control and glasshouse grown maize varieties during spring and autumn seasons at maturity, the data bars carrying same alphabet in a season differ non-significantly (P>0.05)



further under glasshouse condition, while in Agatti-2002 it was reduced mush under glasshouse condition (Fig. 2).

At seedling stage in spring season, the number of leaves per plant revealed significant ($P<0.05$) difference in the varieties and treatments, while in autumn season crop, only the varieties indicated significant ($P<0.05$) difference. In spring season crop, number of leaves per plant was relatively lesser in Sadaf than Agattti-2002 under control, while in glasshouse both varieties showed similar number of leaves. In autumn season, this number was greater than that observed in spring season, but glasshouse condition did not influence this attribute in both the varieties (Fig. 2). At silking stage in spring season, data revealed significant difference in the varieties, with a significant interaction of both the factors. However in autumn season, there were no significant ($P>0.05$) in the varieties and treatments. In spring season number of leaves was greater in Sadaf than Agatti-2002, which increased in the former and decreased in the latter variety under glasshouse condition. In autumn season, both varieties under either condition showed no big difference for leaf number under either condition (Fig. 2). At grain filling stage in spring and autumn seasons, only treatments revealed significant difference. In spring season, Sadaf displayed lower number of leaves per plant than Agatti-2002 under control condition, while a reverse trend was noted under glasshouse condition. In autumn season on the other hand, this number was greater in Sadaf than Agatti-2002 under control condition. Under glasshouse condition, Sadaf showed an increased, while Agatti-2002 a decreased number of leaves per plant (Fig. 2).

Leaf area per plant at seedling stage in spring season revealed a significant difference in the varieties and treatments. However, in autumn season, the varieties, but not the treatments, indicated significant difference. In spring season, leaf area per plant was lower in Sadaf than Agatti-2002 under control condition, which decreased in plants of both the varieties in the glasshouse condition. In autumn season, although Sadaf had greater leaf area per plant, glasshouse effect had no great effect on this attribute much in both varieties. At silking stage, data showed significant ($P<0.01$) difference in the varieties with a significant interaction of both the in spring season. In autumn season, although varieties and treatments indicated no significant ($P<0.01$) differences, while there was a significant ($P<0.01$) interaction of these factors. In spring season, Sadaf with greater leaf area than Agatti-2002 under control indicated a further increase in this under glasshouse condition. In autumn season, leaf area per plant was similar in both the varieties under control condition, while glasshouse condition increased it in Sadaf but decreased in Agatti-2002 (Fig. 2). At grain filling stage in both the seasons, data indicated significant ($P<0.01$) differences in the varieties and treatments with a significant ($P<0.01$) interaction of these factors. In spring season, both the varieties had similar leaf area under control condition, which increased in Sadaf but decreased in Agatti-2002 under glasshouse condition. In autumn season, although both the varieties displayed lesser leaf area, the trend of changes was similar to the spring season crop (Fig. 2).

Cob characteristics: Number of cobs per plant indicated no significant ($P>0.05$) difference in the varieties but a significant ($P<0.01$) one in treatments. However in autumn season, the varieties indicated significant ($P<0.05$) difference. Agatti-2002 had relatively greater number of cobs per plant than Sadaf under control condition in both seasons. However under glasshouse condition in spring season, both the varieties indicated a reduction, while in autumn season Sadaf showed an increase but Agatti-2002 a decrease in this parameter (Fig. 3). For number of rows per cob, data revealed a significant ($P<0.01$) difference in the treatments in spring season, while no difference in various factors was noted in autumn season for this attribute. In spring season, the varieties indicated a greater number of rows per cob than autumn season under control condition. However under glasshouse condition, this number was much reduced in spring than in autumn season (Fig. 3). Number of grains per cob indicated significant ($P<0.01$) difference in the varieties and treatments with a significant ($P<0.05$) interaction of these factors in spring season, while in autumn season, there was significant difference in varieties ($P<0.05$) and treatments ($P<0.01$). In spring season under control, the varieties indicated a similar number of grains per cob, which reduced substantially in Agatti-2002 under glasshouse condition. In autumn season, although the trend of changes was similar to the spring season, the reduction was lesser than in the latter season (Fig. 3). The cob weight indicated significant differences in the varieties ($P<0.05$) and treatments ($P<0.01$), while in autumn season only treatments indicated significant ($P<0.05$) difference. The glasshouse conditions reduced this attribute in both the seasons, albeit a greater reduction was noted in spring season (Fig. 3).

Grain yield and harvest index: Grain yield per cob indicated significant ($P<0.01$) differences in the varieties and treatments in both the seasons, but there was a significant ($P<0.05$) interaction of these factors in spring season only. Although similar in both the seasons and varieties under control, grain yield per cob decreased in both the varieties; Agatti-2002 indicated a greater reduction, particularly in the spring season (Fig. 3). For 100 grain weight, data revealed that varieties and treatments in spring season, while treatments in autumn season showed significant ($P<0.01$) differences. In both the seasons, although 100 grain weight was greater in Sadaf than Agatti-2002, glasshouse condition produced a greater reduction in the latter variety (Fig. 3). As regards grain yield per plant, there was significant ($P<0.01$) difference in the varieties and treatments with a significant ($P<0.01$) interaction of both these factors in both the seasons. Under control, grain yield per plant was greater in spring than autumn season. Under glasshouse condition, although grain yield per plant reduced in both the varieties, Agatti-2002 indicated a greater reduction than Sadaf and glasshouse condition was more adverse to this attribute in spring than autumn season (Fig. 3). For harvest index data showed that in spring season, only treatments, while in autumn varieties and treatments indicated significant differences. In spring, although harvest index was higher in Agatti-2002 than Sadaf under control condition, glasshouse condition greatly affected it in the former variety. In autumn season, Sadaf had greater harvest index than Agatti-2002 under control condition, while glasshouse condition was almost equally detrimental to this attribute (Fig. 3).

DISCUSSION

Most importantly, some interactions of the varieties and treatments for various traits present in one season disappeared in the other season at various growth stages (Figs. 2 & 3). This indicated that prevailing glasshouse condition modulated the maize growth and economic yield, although the effects were relatively lesser on the heat tolerant variety (Sadaf) than the sensitive one (Agatti-2002).

Determination of growth responses at various critical phenological stages indicates the specific responses of plants under study (Zaidi *et al*., 2003). This is because during transition from one growth phase to the other, there is reprogramming of gene expression and sensitivity to environmental conditions might be variable (Qin *et al*., 2004; Wahid & Close, 2007). These alterations in gene activities result in the developmental changes, as reflected from changes in plant growth patterns (Srivastava, 2002; Taiz & Zeiger, 2006). In this study, the determination made at three phenological stages (seedling, silking & grain filling) revealed that both the varieties behaved differently at all these growth stages under glasshouse conditions (Fig. 2). In addition, the influence of seasons was also well marked, as quite a few interactions appearing in spring season grown plants disappeared in autumn season grown plants. Among the growth stages, silking stage was the most critical for final plant productivity, because at this particular stage, number of changes including success of fertilization, seed set and grain filling follow the reception of pollen by the silk (Wahid *et al*., 2007; Rehman *et al*., 2009).

Determinations made for cob and grain yield and related characteristics indicated that spring season produced more conspicuous changes than autumn season (Fig. 3). Moreover the effect of glasshouse was also a major factor in producing changes in these attributes. Data revealed that, for cob most important differences observed across the seasons were evident in number of grain rows per cob and number of grains per cob, while for grain and grain yield components, grain yield per cob, grain yield per plant and harvest index were more important (Fig. 3). This revealed that glasshouse condition has definitive influence on the growth and economic yield attributes of maize.

If the differences in the ambient temperature inside and outside the canopy are taken together, it becomes clear that a rise in the temperature (in the months of May & June) of the spring season sown crop plays a crucial role in the occurrence of changes and producing interaction of varieties and treatments. Under glasshouse condition in spring season grown crop, where the temperature rises further by 5−7°C and relative humidity declines (Fig. 1). On the contrary, in autumn season at silking and grain filling stages there is a continuous decline in temperature and a rise in relative humidity. These changing climatic conditions appeared to play a role in narrowing down the differences in the varieties (Fig. 3), thus leading to the disappearance of interactions. In this context, it is pointed out that a single degree change in ambient temperature is likely to produce a set of changes in the plants (IPCC, 2007; Wahid *et al*., 2007).

In crux, glasshouse condition produces a lot of changes in growth and yield of maize, across spring and autumn seasons. Maize is greatly responsive to glasshouse conditions and thus presents excellent system for the selection of suitable germplasm for successfully growing during upcoming changes in climatic conditions.

Acknowledgement: The financial support of Higher Education Commission (HEC), Islamabad, Pakistan under Indigenous Ph.D. Fellowship Program (5000 Fellowships) Batch-II to first author is highly acclaimed.

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(Received 18 September 2009; Accepted 17 November 2009)