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Article

Crop Growth and Yield Losses in Wheat Due to Little Seed Canary Grass Infestation Differ with Weed Densities and Changes in Environment

O Crescimento das Culturas e as Perdas de Rendimento no Trigo Decorrentes da Pouca Infestação de Sementes de Alpiste Diferem com as Densidades de Plantas Daninhas e Alterações no Ambiente

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ABSTRACT - Understanding the weed interference with different sowing times of crop is inevitable for forecasting yield losses by weed infestation and designing sustainable weed management systems. A field experiment was carried out to evaluate the effects of sowing dates (20th November, 10th December) and various little seed canary grass (LCG) infestation levels (10, 20, 30 and 40 plant m^{-2}) on growth and yield of wheat under semiarid conditions. Plots with two natural infestations of weeds including LCG (Unweeded control; UWC) and excluding LCG (UWC-LCG) were maintained for comparing its interference in pure stands with designated densities. A season-long weed-free (WFC) treatment was also run. All the weeds/LCG infestation levels starting from 10 LCG plants m^{-2} considerably reduced the wheat growth (leaf area index, crop growth rate, total dry matter accumulation) and hampered the yield contributing factors in both sowing dates. Presence of LCG was more detrimental for growth of late-sown wheat (10th Dec), therefore, 40 LCG plants m^{-2} recorded more reductions in growth indices of wheat even than UWC. In late sown wheat crop, the grain yield losses by 40 LCG plants m^{-2} and UWC were comparable, however, these losses were much greater than UWC LCG. In crux, delay in sowing of wheat not only reduced the crop growth and yield but also enhanced the LCG/weed interference. Furthermore, greater competitive ability of LCG particularly for late-sown wheat suggests that it should be controlled in order to provide healthy environment for crop plants.

Keywords: interference, little seed canary grass, sowing time, weeds, wheat yield losses.

RESUMO - Entender a interferência de plantas daninhas com diferentes tempos de semeadura da cultura é inevitável para prever as perdas de rendimento decorrentes da sua infestação e projetar sistemas por meio do manejo sustentável delas. Um experimento de campo foi realizado com o objetivo de avaliar os efeitos de datas de semeadura (20 de novembro e 10 de dezembro) e diferentes níveis de infestação de sementes de alpiste (10, 20, 30 e 40 plantas m^{-2}) sobre o crescimento e rendimento de trigo em condições semiáridas. Lotes com duas infestações naturais de plantas daninhas, incluindo LCG (semente de alpiste, na abreviação em inglês) [controle não capinado (UWC, na abreviação em inglês)] e excluindo LCG (UWC-LCG), foram mantidos para comparar sua interferência em estandes puros com determinadas densidades. Um tratamento sem plantas daninhas (WFC, na abreviação em inglês) também foi realizado durante toda a estação. Todos os níveis de infestação de plantas daninhas/LCG a partir de 10 plantas LCG m^{-2}

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reduziram consideravelmente o crescimento de trigo (índice de área foliar, taxa de crescimento da cultura e acúmulo de matéria seca total) e prejudicaram os fatores que contribuem para o rendimento nas duas datas de semeadura. A presença de LCG foi mais prejudicial para o crescimento do trigo semeado tardiamente (10 de dezembro). Portanto, 40 plantas LCG m^{-2} *registraram mais reduções nos índices de crescimento de trigo até mesmo do que UWC. Na safra de semeadura tardia de trigo, as perdas de rendimento de grãos por 40 plantas LCG m*$^{-2}$ *e UWC foram comparáveis. No entanto, essas perdas foram muito maiores do que em UWC-LCG. No ponto crucial, o atraso na semeadura de trigo não apenas reduziu o crescimento e o rendimento da cultura, como também aumentou a interferência de LCG/plantas daninhas. Além disso, uma maior capacidade competitiva da LCG, particularmente para o trigo semeado tardiamente, sugere que ela deve ser controlada de modo a proporcionar um ambiente saudável para as plantas cultivadas.*

Palavras-chave: interferência, pouca semente de alpiste, tempo de semeadura, plantas daninhas, perdas de rendimento de trigo.

INTRODUCTION

Weed infestation remains the major detriment and ever-present threat to higher wheat productivity in Pakistan (Khaliq et al., 2013a,b). Weeds can incur a grain yield loss of 48% in wheat (Khan and Haq, 2002). However, the magnitude of weed-related losses depends on the type and density of a particular weed species, its time of emergence, and the duration of the interference (Estorninos et al., 2005; Hussain et al., 2015; Fahad et al., 2015). Crop yield usually declines with increased weed density and interference duration and yield losses are more severe when resources are limited and weeds and crops emerge simultaneously (Zimdahl, 2007). Knowledge of weed interference has a vital role in forecasting yield losses by weed infestation and designing sustainable weed management systems (Fahad et al., 2014).

Up to 45 weeds species have been reported in wheat fields of different growing regions of Pakistan (Qureshi and Bhatti, 2001). Among various major weeds, little seed canary grass (LCG; *Phalaris minor* Retz.) has been identified as the most pernicious and problematic grassy weed in wheat by virtue of its strong competitive behavior. It is a native weed of Mediterranean origin and has widely spread in more than 60 countries of the world (Singh et al., 1999). In recent decades, it has become a major threat to productivity and sustainability of wheat-based cropping systems (Chhokar et al., 2008). It is an annual grass and is difficult to eradicate because the seeds shatter before crop maturity and many of the seeds are ploughed into the soil, remain dormant and germinate when conditions become favorable. Its roots are small, numerous and fibrous, penetrating into the soil to a depth of several feet. It severely competes for growth resources and significantly reduces the grain yield as its time of emergence coincides with germinating wheat crops (Malik and Singh, 1995; Afentouli and Eleftherohorinos, 1996). The most likely reasons for its wide occurrence are its resemblance with wheat at the seedling stage, similar growth period, the earlier seed dispersal, dormancy of seeds for a long period of time and, until recently, the lack of efficient and appropriate herbicides for its effective control in wheat. The ability of dormant seeds to survive during rice period is a major fact for its prevalence in wheat-rice cropping system (Malik et al., 1998). Oad et al. (2007) have reported that LCG infestation can reduce wheat yield by 35% and its heavy infestation might incur a complete crop failure (Chhokar and Malik, 2002).

Planting time is of prime importance for crops as well as associated weed species. Sowing cereal crops at an appropriate time is one way of realizing higher economic yields as it allows crops to express their full yield potential. Delayed planting of wheat has been identified as a major bottleneck for high productivity, particularly in rice-wheat and cotton-wheat cropping systems of Indo-gangetic plains. Late planting not only affects germination but also leaf area development, crop growth behavior, number of productive tillers, number of grains per spike, 1,000 grain weight, and eventually the grain yield (Coventry et al., 2011; Anwar et al., 2011; Sattar et al., 2015). Kobayashi and Oyanagi (2006) have stated that optimum planting time minimizes the requirements of crop protection measures and can be manipulated to regulate weed composition under field conditions. Sowing of wheat at an appropriate time leads to a healthy crop stand that can suppress weed growth due to a more competitive ability. Interaction of weed species with crops is dependent on timing of weed emergence relative to crop. The timing of seed disturbance will determine conditions of seed germination and will have a great influence on germination and subsequent growth (Berzsenyi, 2000). Contrary to the cultivated crops species, weeds can emerge and grow with greater diversity in composition and density under a wide range of environmental temperatures (Matloob et al., 2015). Planting time of a crop is directly related to land preparation and soil disturbance during a critical period in growing season shall determine which weed seeds, at what stage of dormancy or viability, are available for germination. A study by Rasmussen (2004) has revealed that plots sown at optimum time have shown more weed biomass as compared with delayed planting. Weed related yield loss in corn and soybean was significantly less when planting was delayed beyond optimum time, presumably due to depleted weed seed banks (Buhler and Gunsolus, 1996; Gower et al., 2002).

Wheat and LCG have similar growth habits and adaptations to winter cropping regimes and any mismanagement in input usage can shift the advantage in favor of weeds (Hussain et al., 2015). In the context of global climate changes, LCG is supposed to inflict more interference on wheat due to its higher resource use efficiency and vigorous growth in response to elevated CO_2 level. Although plenty of data are available on effect of planting time on wheat performance and weed-crop competition, nevertheless, little is known on interaction of planting time and different densities of LCG under semiarid conditions. A conceptual and comprehensive understanding of both these factors may be useful in designing cautious, opportunistic and appropriate weed management strategies. We have hypothesized that different environmental condition under different sowing times may vary the interference of LCG in wheat. Therefore, the present study was carried out to appraise crop growth and yield losses in wheat by LCG interference under different sowing times in semiarid climate conditions of Pakistan.

MATERIALS AND METHODS

Experimental site

The present study was conducted at Agronomic Research Area, University of Agriculture, Faisalabad (31.25^o N, 73.09^o E, and 184 m above sea level). Due to high evapotranspiration, Faisalabad features a semiarid climate with mean annual rainfall of about 200 mm. The soil of the experimental site was sandy clay-loam with 51.45% sand, 21.35% silt, and 27.20% clay. Soil pH and EC were 7.5 and 0.95 dS m^{-1}, respectively. Organic matter, total nitrogen, available phosphorus and potassium were 0.71%, 0.062%, 14.4 mg kg^{-1}, and 187 mg kg^{-1}, respectively. Bulk density and cation exchange capacity were 1.42 g CC^{-1}, and 4.4 $cmol_c$ kg^{-1}. Meteorological data during the course of the study is presented in Figure 1.

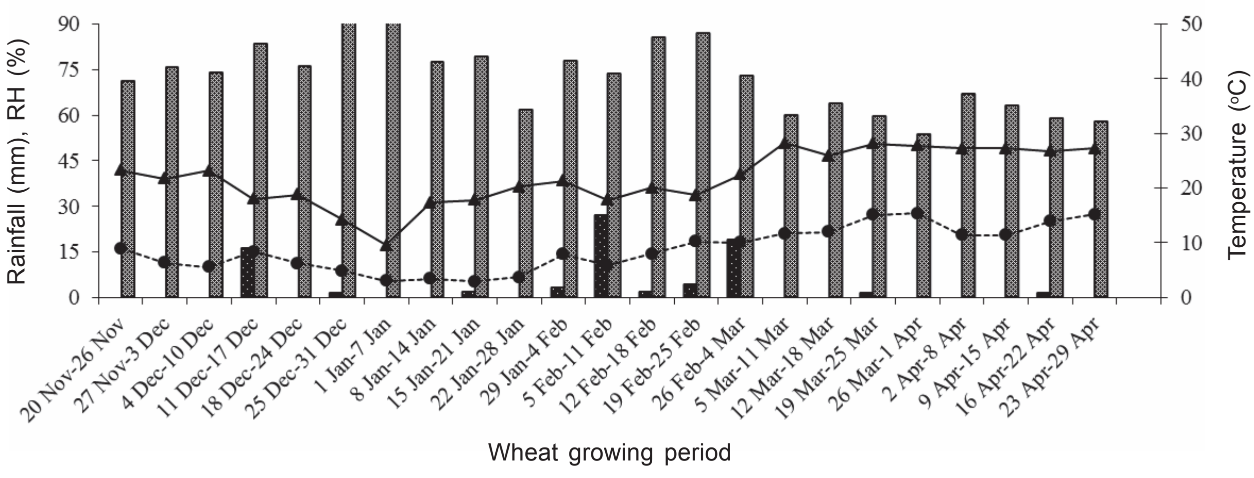


Figure 1 **-** Metrological data during the course of the present study. RH: relative humidity, straight line: maximum temperature, dotted line: minimum temperature.

Treatments

The experiment was comprised of two sowing dates (20th November, SD_1 and 10th December, SD_2) and four LCG densities viz., 10 (LCG 10), 20 (LCG 20), 30 (LCG 30), and 40 plants m^{-2} (LCG 40). Two natural infestations of weeds (*Coronopus didymus*, *Anagallis arvensis*, *Chenopodium album*, *Rumex obtusifolius*, *Meliolotus indica*, *Avena fatua*, *Convolvulus arvensis*, and *Fumaria indica*) including (UWC; Unweeded control) and excluding LCG (UWC-LCG) were maintained for comparing the interference of LCG in pure stands with them. The relative proportion of weeds (density basis) in these two treatments is presented in Figure 2. The UWC treatment had a natural infestation of weeds throughout the growing season and LCG with 30% (SD_1) and 27.6% (SD_2) of the total weed population were the most important among the monocot and dicot weeds in this treatment. Swine cress, constituting 24.4% of the total weeds population in SD_1, and common goose foot (19.7%) in SD_2 were the next important weeds in UWC (Figure 2). In the UWC-LCG treatment, all the LCG plants were manually removed after their emergence, but other weeds were allowed to grow with wheat throughout the crop cycle. Swine cress constituting 33.9% and 28.1% of the total weed population in SD_1 and SD_2, respectively, was the most dominant weed in UWC-LCG. Common goosefoot was the second major weed on density basis in both sowing dates. Weed population in SD_2 surpassed as compared with that in SD_1 (Figure 2). A season long weed free treatment (WFC) was also run. In WFC treatment, the plots were kept free from all the weeds including LCG. Seeds of LCG were manually sown in excess of the desired density in all plots except WFC at the time of wheat sowing. In the LCG density treatments, the required densities were maintained right from 15 days after sowing (DAS) wheat by pulling out all the weeds, except LCG and then thinning out the excess LCG plants.

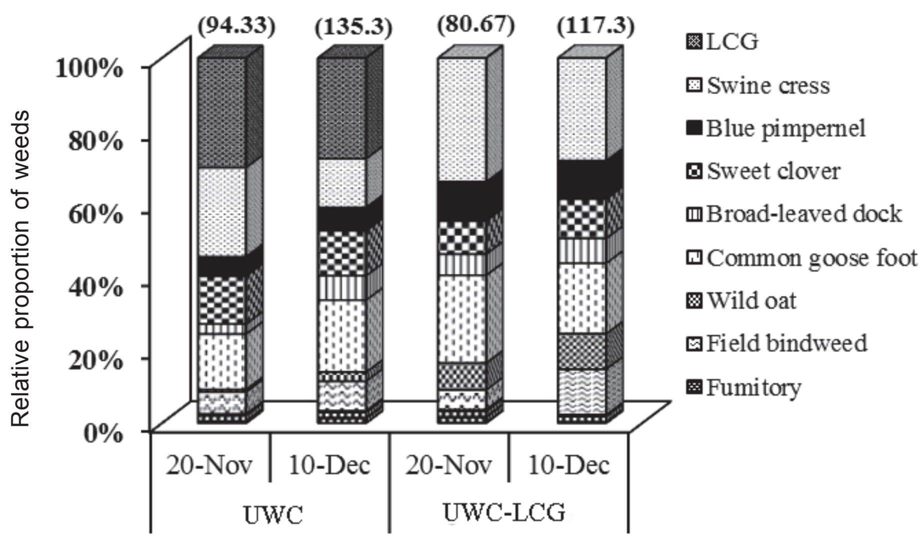


Figure 2 - Relative proportion of weeds (on density basis) in UWC (all weeds including LCG) and UWC-LCG (all weeds excluding LCG) treatments under two different sowing times of wheat.

Experimentation

For all the treatments, seedbed was prepared by cultivating the soil with a disc plow and then cultivating twice with a tractor mounted cultivator followed by planking. Seed of a commonly cultivated wheat cultivar "Millat-2011" was sown in 22.5 cm apart rows by single row hand drill at the rate of 125 kg ha^{-1}. A standard fertilizer dose of 120:60 kg N:P ha^{-1} was applied in the form of urea and diammonium phosphate. Whole of the phosphorus and 1/3rd of the N was applied as a starter basal dose while residual N was equally splitted at tillering and booting. The first irrigation was applied 15 days after crop emergence and subsequent irrigations were applied at tillering, jointing, booting, anthesis and grain filling. No serious incidence of insect or disease was observed and no pesticide or fungicide was applied to the crop. The crop was manually harvested at physiological maturity on 25th of April.

Data recorded

For crop growth analysis, wheat plants were sampled from a randomly chosen 50 cm length of the rows next to the border rows in each subplot at 15 days interval up to 120 DAS. Harvested plant material was separated into respective fractions (stem, leaves and spikes). Fresh and dry weight of each plant fraction were measured and used in subsequent calculations. Leaf area index (LAI) and crop growth rate (CGR) of wheat crop were computed using the formulae of Watson (1947) and Hunt (1978), respectively. Plant samples were kept in an electric oven at 70 °C for 48 hours for estimating total dry matter accumulation (TDM). Leaf area indices were used to calculate leaf area duration (LAD) of wheat crop (Hunt, 1978). Furthermore, net assimilation rate (NAR; g m^{-2} d^{-1}) was also computed at different growth stages of crop as the ratio of TDM and LAD (Hunt, 1978).

Number of productive tillers (m^{-2}) was counted from two randomly selected sites of each plot at physiological maturity and averaged. Data on spikelets per spike, number of grains per spike were recorded from 15 randomly selected plants taken from each plot and averaged thereof. Two random samples of wheat grains were drawn from the produce of each plot to record 1,000 grain weight after counting and weighing on a digital balance. At maturity, the crop was harvested leaving appropriate border rows, tied into bundles and sun dried for a week in respective plots. Total wheat dry biomass was recorded for each treatment and crop was threshed thereafter. Grain yield and biological yield per plot were then converted to tons per hectare (t ha^{-1}). Straw yield was computed as the difference between biological yield and grain yield. Whereas harvest index was calculated as the ratio of grain yield to total (above ground) biological yield and was expressed as percentage.

Experimental design and statistical analysis

The experiment was triplicated in randomized split-plot design with sowing dates as the main plots and LCG densities as the sub-plots. Analyses of variance were performed with all data to confirm variability of data and validity of results by employing Fisher's analysis of variance technique. The differences amongst treatments were separated using least significance difference (LSD) at 0.05 probability level.

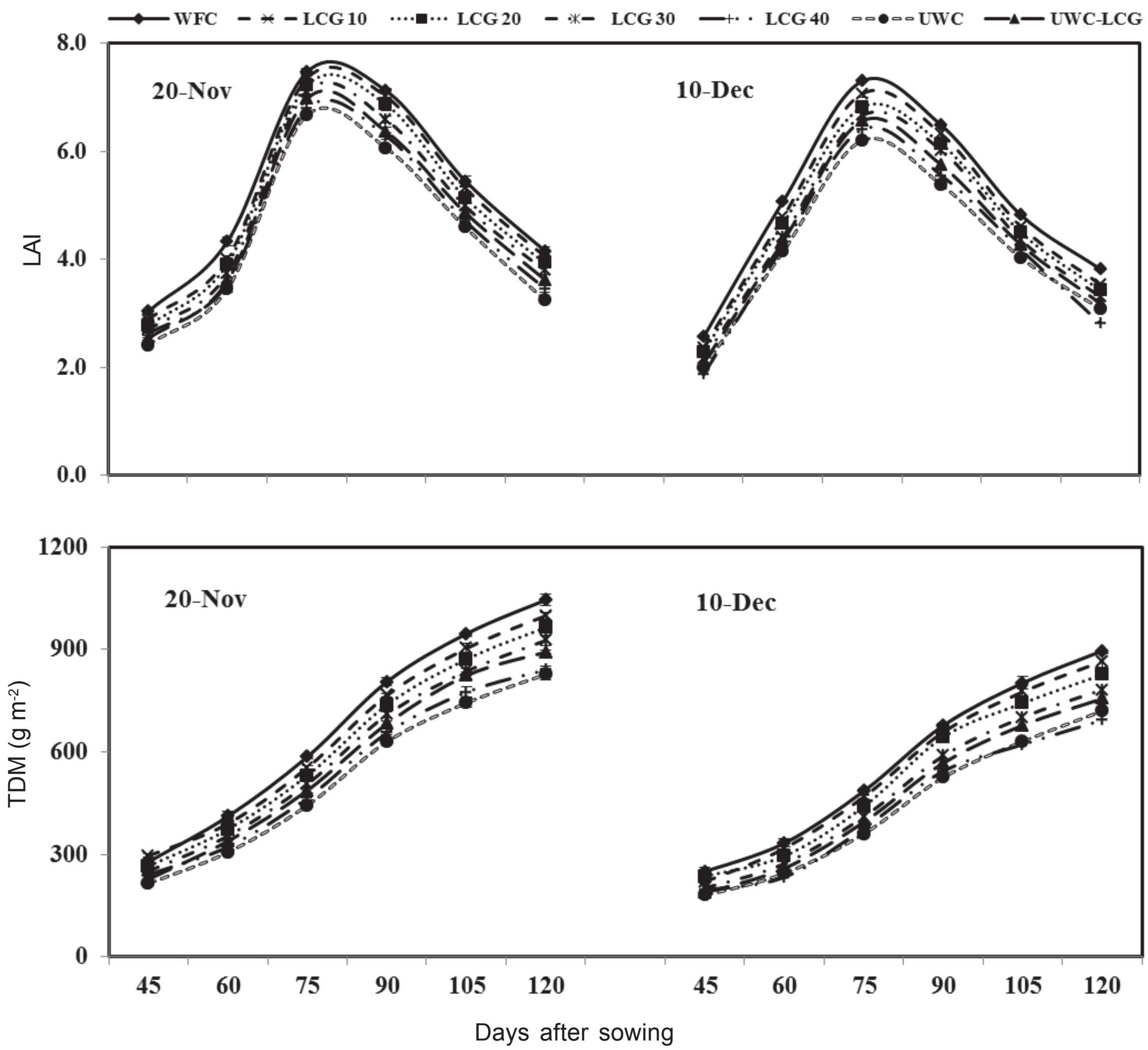
RESULTS

Wheat growth

All the weeds/LCG infestation levels starting from LCG 10 considerably reduced the growth of wheat in both sowing dates, particularly in SD_2 (Figures 3 and 4). The LAI, CGR, LAD, and TDM were higher in WFC for both sowing dates at all growth stages of the crop. The maximum values of LAI and CGR were achieved at 75 DAS, and 75-90 DAS, respectively which substantially declined with the passage of time. Whereas the highest values of TDM and LAD were recorded at 120 DAS and 105-120 DAS, respectively (Figures 3 and 4).

Averaged across various LCG/weed densities, LCG 40, UWC and UWC-LCG resulted in more suppression of wheat growth than the rest of treatments in both sowing dates. Treatments UWC-LCG, LCG 10, LCG 20 and LCG 30 recorded moderate reduction in growth attributes as compared with WFC, but these reductions were lower with respect to either UWC or LCG 40. Presence of LCG seemed more devastating for wheat growth in SD_2 than SD_1. Therefore, LCG 40 plots showed more reductions in LAI, CGR and TDM in SD_2 even than UWC (Figures 3 and 4).

Data regarding NAR at different growth stages of wheat depicted pronounced differences due to different LCG/weed infestation treatments as well as sowing dates (Figure 5). Higher NAR was recorded at the pre-anthesis stage for all treatments than that recorded at post-anthesis and grain filling stage. Presence of various LCG/weed densities resulted in lower NAR at all



Error bars are ±S.E. (n=3).

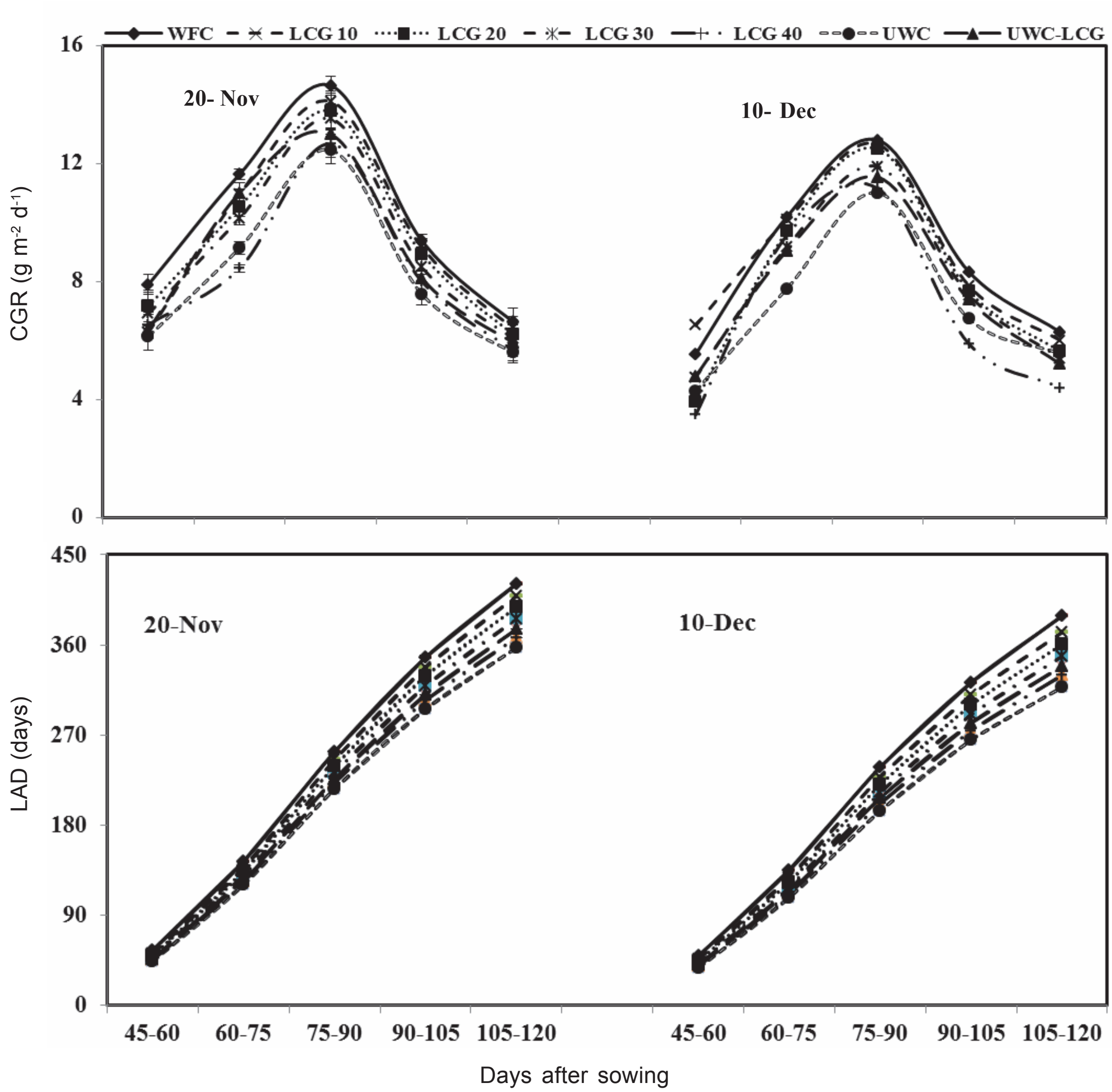
Figure 3 - Influence of various LCG/weeds densities and sowing time on leaf area index (LAI) and total dry matter (TDM) accumulation in wheat.

growth stages of wheat. Likewise, delay in sowing wheat inflicted a negative impact on NAR. Therefore, less NAR was observed in SD_2 as compared with SD_1.

Wheat yield and related attributes

Significant variations in wheat yield and its related attributes were observed under the influence of different LCG/weed infestation levels as well as sowing times of wheat (Figures 6-8). Nevertheless, an interactive influence of these two factors was only significant for the number of productive tillers and grain yield of wheat (Figure 6).

Maximum grain yield (4.95 t ha^{-1}) and number of productive tillers (415.17 m^{-2}) were recorded in WFC when wheat was sown early in season (SD_1). Infestation of 10 LCG plants m^{-2} had little impact on these attributes in SD_1, and both grain yield (4.70 ton ha^{-1}) and number of productive tillers (404.83 m^{-2}) in LCG 10 were statistically similar with WFC for SD_1. Presence of LCG/weeds was more devastating for late-sown wheat. Therefore, more yield losses in SD_2 were observed compared with SD_1. In SD_1, infestation of LCG 20, LCG 30, LCG 40, UWC, and UWC-LCG reduced the grain yield by 9%, 18%, 28%, 33%, and 25%, respectively. The respective reductions in grain yield for SD_2 were 19%, 27%, 34%, 38%, and 29%. Interference of LCG/weeds also reduced the



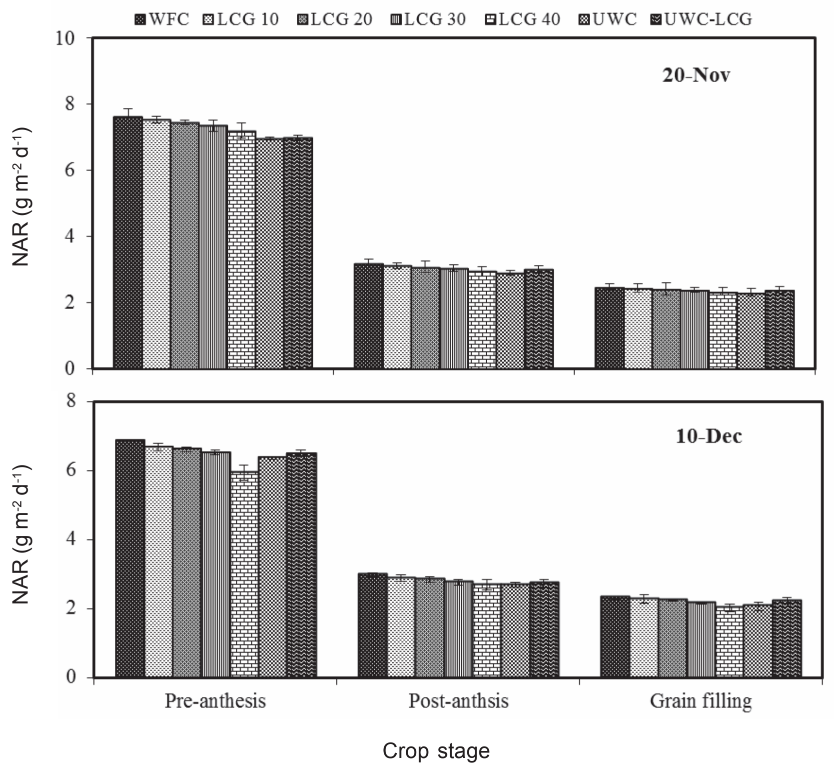
Error bars are ±S.E. (n=3).

Figure 4 **-** Influence of various LCG/weeds densities and sowing time on crop growth rate (CGR) and leaf area duration (LAD) of wheat.

number of productive tillers in the range of 3-32% and 9-40% for SD_1 and SD_2, respectively. In SD_2, LCG 40 was statistically similar with UWC for grain yield and number of productive tillers (Figure 6).

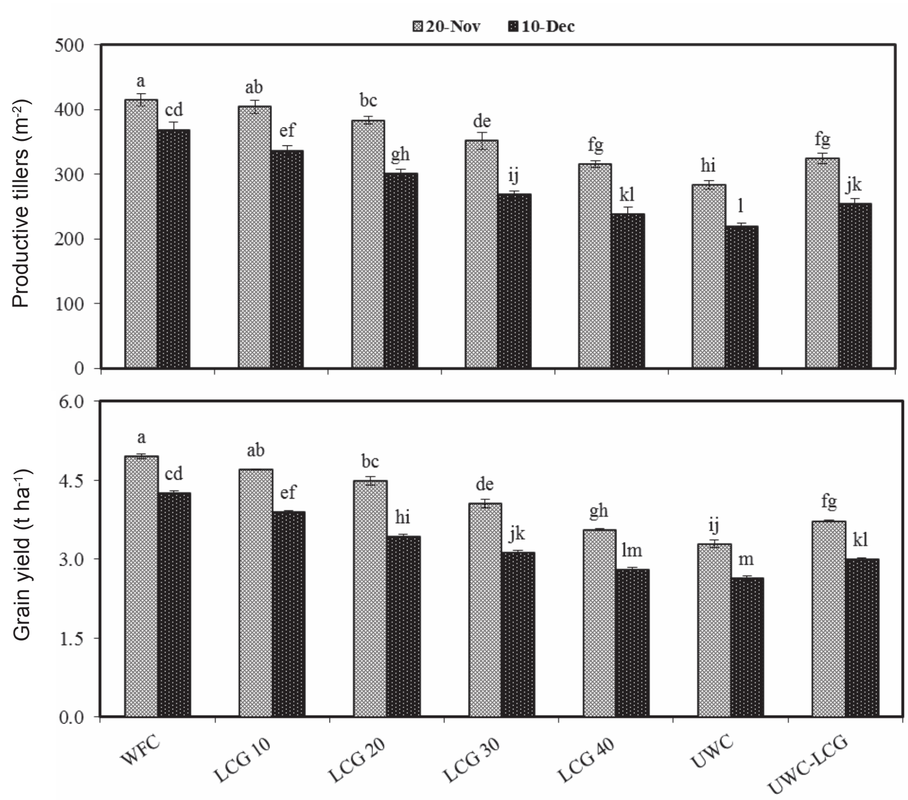
The presence of LCG/weeds in wheat provoked marked reductions in spike length (3-15%), spikelets per spike (4-17%), grains per spike (3-14%), and 1,000 grain weight (2-9%) compared with WFC, averaged across two sowing times (Figure 7). LCG 10 was statistically similar to WFC for spike length, grains per spike, and 1,000 grain weight. Maximum reductions in these attributes were recorded in UWC. However, this treatment was equally competitive to wheat as LCG 40. Compared with WFC, the 1,000 grain weight was reduced only by LCG 40, UWC, and UWC-LCG, and these three treatments were statistically similar with each other (Figure 7). Delay in sowing wheat had a negative impact on spike length, spikelets per spike, grains per spike, and 1000-grain weight. Compared with SD_1, spike length, spikelets per spike, grains per spike, and 1,000 grain weight of wheat in SD_2 were reduced by 12%, 11%, 8%, and 6%, respectively.

All the LCG/weeds infestation levels except LCG 10 significantly reduced the biological yield and harvest index of wheat compared with WFC. However, straw yield was reduced only by LCG 40,



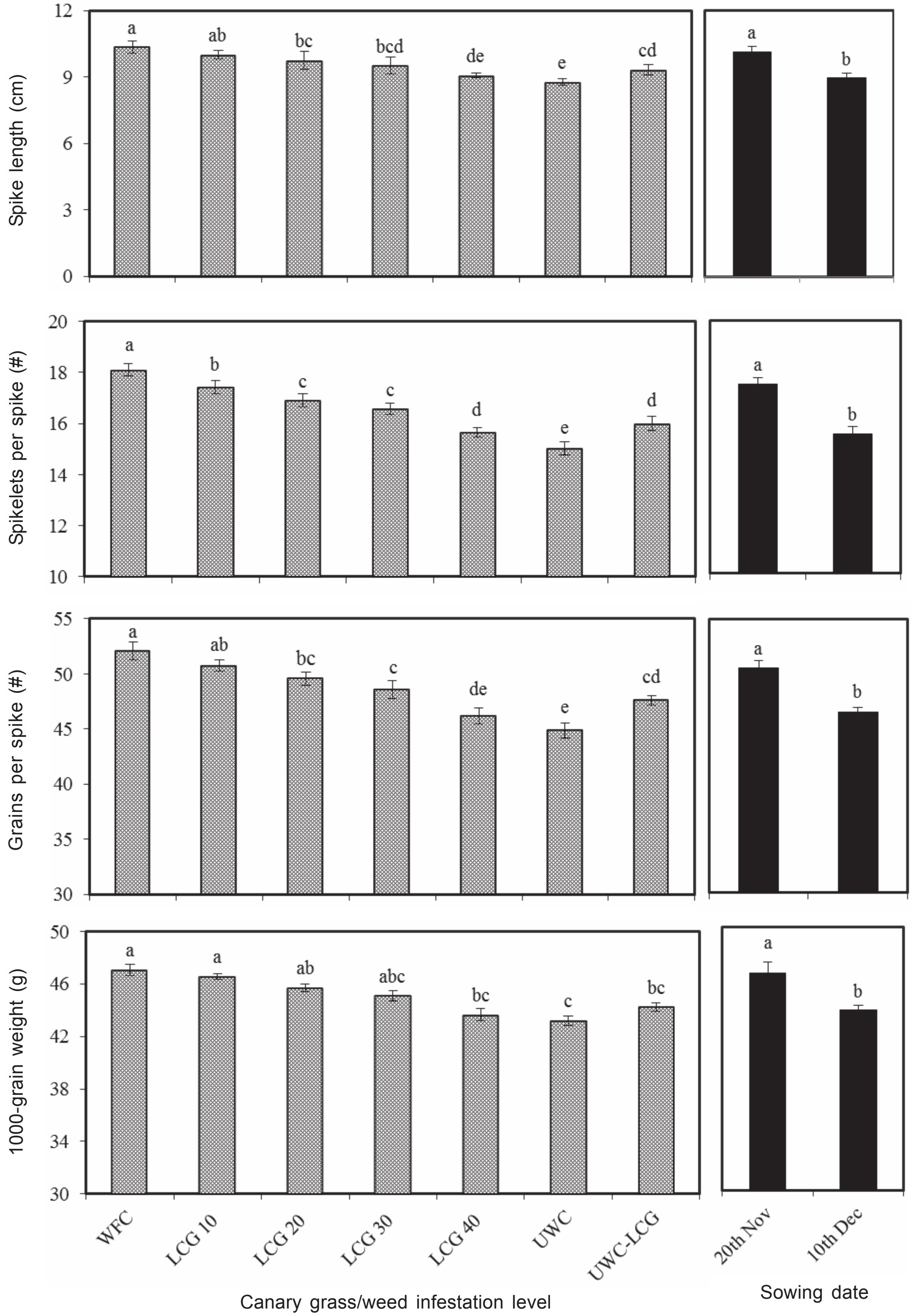
Error bars are ±S.E. (n=3).

Figure 5 **-** Influence of various LCG/weeds densities and sowing time on net assimilation rate (NAR) of wheat.



Error bars are ±S.E. (n=3).

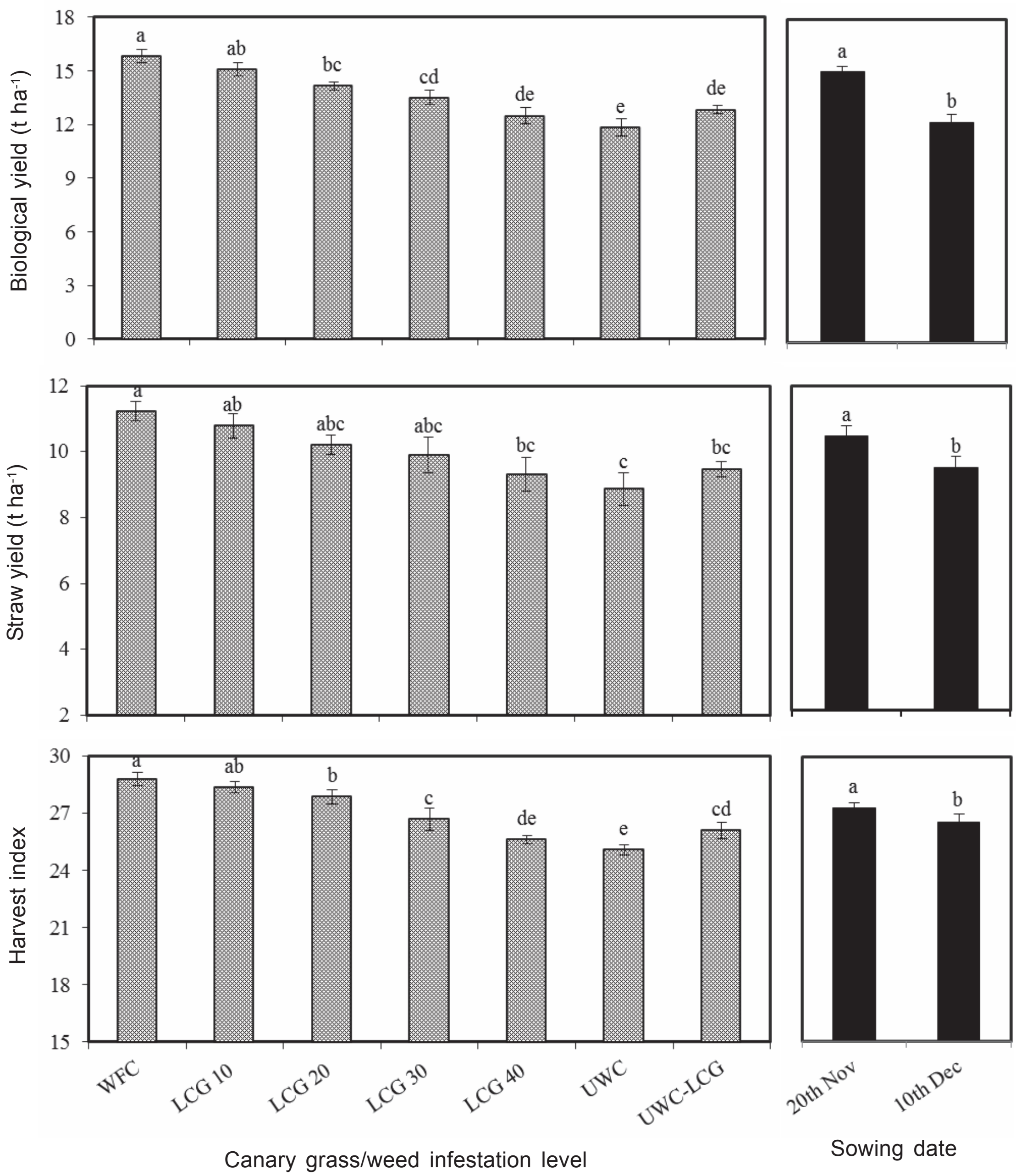
Figure 6 **-** Influence of various LCG/weeds densities and sowing time on number of productive tillers and grain yield of wheat.



Error bars are ±S.E. (n=3).

Figure 7 **-** Influence of various LCG/weeds densities and sowing time on spike length, spikelets per spike, grains per spike, and 1000-grain weight of wheat.

UWC, and UWC-LCG (Figure 8). Compared with WFC, maximum reductions in biological yield (25%), straw yield (21%) and harvest index (13%) were observed in UWC. This treatment was statistically similar to LCG 40 and UWC-LCG for biological yield and straw yield. The effect of sowing date on these attributes was also prominent and significantly lower biological yield (19%), straw yield (18%), and harvest index (3%) were recorded in SD_1 as compared with SD_2 (Figure 8).



Error bars are ±S.E. (n=3).

Figure 8 **-** Influence of various LCG/weeds densities and sowing time on biological yield, straw yield and harvest index of wheat.

DISCUSSION

The results are very clear to portray the strong relation between weed-crop interference and sowing time. Understanding the interactive effects of sowing time and LCG interference on wheat growth and yield is a key feature of this study. Wheat growth suppression and yield reduction in late sowing (SD_2) and under increased density of LCG may be attributed to the negative impact on germination and early stand establishment and enhanced competition for resources (Derakhshan et al., 2014). Overall higher growth suppression and yield reduction in SD_2 under different weed/LCG densities may be due to the poor early crop growth and aggravated competition (Duary and Yaduraju, 2005; Khaliq et al., 2013a). The negative impact of late sowing or high LCG density on wheat growth and yield just follows the general crop production and weed-crop competition principles (Hari et al., 2013; Farooq and Cheema, 2014). However, an interesting aspect of this study was the higher growth reduction under higher LCG density even when compared with UWC in late sowing. This trend might be due to the fact that LCG offers worse competition to less vigorous late-sown wheat (SD_2) as compared with the mixed weed flora under same conditions (Hussain et al., 2015).

Higher LAI of wheat in SD_1 as compared with SD_2 might be due to better leaf elongation and expansion and increased vegetative growth period (Sattar et al., 2010). Higher resources availability in weed free plots definitely improved LAI as compared with the weedy plots where crop plants were in direct competition for nutrients, air, light, and space (Khaliq et al., 2013a). However, the competition effect especially in case of LCG was more intense during later growth period. It can be speculated that in later stages crop growth is fast and requires rapid supply of resources to enter the maturity phase and the presence of weeds at that time proves more damaging (Derakhshan et al., 2014). LAI and CGR reached the maximum after a certain period of time and then started to decline, which might be due to the transition from vegetative to reproductive phases (Farooq et al., 2011). A similar trend for these growth attributes at different sowing times and weed densities has been reported in earlier studies (Das and Yaduraju, 1999; Khaliq et al., 2013a,b). Singh et al. (1999) have reported that LCG remained more dominant and competitive when wheat was sown late in the season. Delay in sowing wheat resulted in less TDM, which might be due to sub-optimal growing conditions during the vegetative growth phase (Farooq and Cheema, 2014). Leaf development and dry matter accumulation greatly depend on the prevailing temperature and unfavorable temperature (which is common in late sowing) negatively influences vegetative growth (Warrington and Kanemasu, 1983).

The negative effects of various LCG infestation levels were prominent in later stages of the crop. They may be attributed to an acute competition of weed/s for growth resources in later stages as compared to early stages of the crop (Khaliq et al., 2013a,b). Better leaf growth in SD_1 and WFC as compared with SD_2 and plots having different densities of LCG, UWC, or UWC-LCG lead to higher CGR, LAD, and TDM. Later these improved growth attributes also reflected in the form of better yield attributes and yield (Hussain et al., 2015). The NAR of a crop represents the net photosynthetic rate per unit LAD. If we follow the crop response in terms of NAR, it was decreased in later stages of crop and this may be due to a periodic increase in LAD, which resulted in less assimilation per unit time. Higher NAR in SD1 may be attributed to higher dry matter accumulation as compared with SD_2. Infestation of weed/s in wheat also resulted in less total dry biomass ultimately lower NAR as compared to WFC plots. More reduction in NAR at higher weed/s densities might be due to severe competition of weeds with wheat crop for growth resources (Shah et al., 2006).

Better crop growth definitely ensures good yield. The number of tillers represents the extent of plant population and the productive tillers directly depict the grain yield. The significant interactive effect of sowing time and weed infestation on number of productive tillers and grain yield shows the direct relation between two parameters. The reduction in number of productive tillers in case of late sowing (SD_2) is very obvious and has also been reported in several studies earlier (Shah et al., 2006; Tahir et al., 2009; Sattar et al., 2010; Baloch et al., 2012; Akhtar et al., 2012). The plots under heavy infestation of LCG significantly reduced the number of productive tillers due to competitive and suppressive effects (Cheema and Akhtar, 2006; Hassan and Khan, 2007; Shahzad et al., 2012). The situation becomes worse in SD_2 because negative influence of competition goes further intensely due to poor establishment (Zimdahl, 2007). Negative effects of LCG are directly associated with density and its dominance increased under late-sown crop (Singh et al., 1999). Such negative impact on productive tillers affects grain yield because there is a strong correlation between two parameters. This might be the reason due to which interactive effects of sowing date and weed density were significant only for these two traits (productive tillers and grain yield). Delay in sowing affected all the yield contributing traits like spike length, spikelets per spike, grains per spike, and 1000-grain weight leading to reduction in grain yield.

Late sowing reduced the crop growth as well as development duration, which lead to the poor spike growth and elongation (Baloch et al., 2012). Furthermore, the terminal heat stress at spike initiation and grain filling stages of wheat significantly affect grain attributes and reduce grain yield ultimately (Farooq et al., 2011).

Higher LCG densities negatively affected yield contributing traits and consequently final grain yield. The main reason might be the severe recourse competition inflicted by weed during the reproductive phase of the crop (Khaliq et al., 2015). Riaz et al. (2006) and Khan et al. (2007) have also observed less spike length when weeds were interfering with wheat crop. Similarly, less numbers of grains per spike in late-sown wheat crop may be attributed to less production of photosynthates due to the shorter growing period. High temperature induces changes in plants that may be either in physiological processes or developmental pattern (Farooq et al., 2011). Guilioni et al. (2003) have argued that high temperature stretches the grain filling period, resulting in less development of grain ultimately reducing the grain number in wheat crops. The findings of the present study depicted that increasing the density of LCG substantially decreased the number of grains per spike in wheat. This is attributed to the severe competition of weeds with wheat for growth resources. This competition prominently reduced the nutrients mobility towards the grains which ultimately affected the grain development potential of the plant. Shahzad et al. (2012) and Razzaq et al. (2012) also observed less numbers of grains per spike in weed infested plots.

Grain size is one of the important yield contributing factors. 1,000 grain weight expresses the grain size and wheat crop with bold grains generally results in higher yields. Singh and Dhaliwal (2000) have pointed out that in late-sown crop high temperature coupled with desiccating winds during the months of March-April bring forced maturity and lead to reduced grain weight. There was an inverse relationship between 1000-grain weight and LCG infestation levels. Under the lesser densities, the wheat was able to make better use of available resources and partition higher photosynthates to the grains, resulting in bolder grains. This was not in the case of higher weed densities, where there was an acute competition for soil and environmental resources.

The final grain yield is a function of cumulative effects of various yield components developed under the particular set of environmental conditions. Ali et al. (2004) have stated that a cultivar cannot attain its production potential unless it is planted on optimum time. In late planted wheat, early stages of the crops receive too low temperature, which results in impaired germination, poor tillering and slow growth of crop. The negative influence of various weeds/ LCG infestation levels on wheat yield might be due to weed competition with crop plants for important factors such as nutrients, water, light and space for their growth and reproduction. According to Chhokar et al. (2008), LCG is highly competitive and the season-long weed and its competition reduced the wheat yield by 45%. Singh et al. (1999) have also concluded that canary grass remains more dominant and competitive in late-sown wheat crop. Although late-sowing of wheat is common in several Asian countries, including Pakistan, the present study however depicted that it not only decreased the growth and yield of wheat but also enhanced the weed interference. Infestation of even 10 LCG plants per m^2 caused considerable reductions in wheat performance, particularly when the crop was sown late in the season. These results will be of worth for wheat growers in Pakistan because sowing of wheat at optimum time will not only increase grain yield but also reduce weed control requirements. Infestation of 40 LCG plants per m^2 was equally competitive with UWC for most of the characteristics studied. More competitive ability of LCG for wheat suggests that it should be controlled in order to provide better conditions for crop plants. Moreover, preventing the build-up of the weed seed bank in fields is particularly important, as allowing LCG to produce even a few seeds may cause them to be an increasing problem in subsequent seasons.

Delay in sowing wheat favored the competitiveness of weeds against timely sown wheat. However, the degree of interference was mainly dependent on the weed species. Infestation of LCG even at 10 plants m^{-2} considerably reduced the growth and yield of wheat, particularly when the crop was sown late in the season (SD_2). In SD_2, the grain yield losses by LCG 40 and UWC were comparable. However, these losses were much greater than UWC-LCG, which indicated that LCG is the most malicious weed and a great threat to wheat productivity. Further studies should be carried out to understand the mechanism of canary grass interference and to determine whether the negative effects of LCG can be mitigated with improved resource management.

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