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Original Article

Influence of temperature and nitrogen on dry matter partitioning and plant development of two tropical cultivars of wheat (*Triticum aestivum* L.)

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Abstract

Wheat cultivars Mehran-89 and T.J.83 in controlled environment cabinet received two nitrate concentrations (6 and 0.6 mM) and two temperatures (20 °C and 15 °C). Both cultivars showed significant increase in growth and development parameters at high nitrate concentration. However, response of both cultivars varied to temperature as rate of development was enhanced by high temperature in Mehran-89 whereas same was accelerated by low temperature in T.J.83. Dry matter partitioning in shoots and roots increased by high nitrate concentration and low temperature in cultivar T.J.89, however, in cultivar Mehran-89, high nitrate concentration and temperature increased shoot dry matter whereas root dry matter was increased by low nitrate concentration at high temperature. The relationship of shoot dry weight to different parameters showed that high nitrate and temperature has significantly shortened the growth and developmental processes in cultivar Mehran-89 whereas similar results were obtained in cultivar T.J.83 at high nitrate and low temperature.

Keywords: *Triticum aestivum* L., wheat, temperature, nitrogen, dry matter partitioning

1. Introduction

Variability in plant development may be due to different management practices and different environmental conditions. Environmental requirements for the satisfactory growth and development for tropical crops have been less studied (Squire, 1990). Amongst environmental factors, temperature is considered a primary determinant of plant development. Temperature plays a central role in controlling crop emergence as well as leaf initiation and appearance rate (Miglietta *et al.,* 1995). For wheat, an air temperature of about 20-25°C is considered to be optimum for growth and development (Hossain *et al.,* 2011; Hakim *et al.,* 2012). Optimal crop growth requires a continuous supply of water, nutrients and radiation; as temperature rise, the demand for growth resources increases due to higher rates of metabolism, development and evapotranspiration (Martiniello and Teixeira da Silva, 2011). When growth resources are limited by high temperature, the size of plant organs such as leaves, tillers and spikes, is reduced. The sensitivity of metabolic processes to high temperature coupled with the reduced length of life cycle, results in low grain yield (Hossain *et al.,* 2012). Similarly, Slafer and Rawson (1994) suggested that since plant development is a progression of responses to the environment there must be historic as well as current effects of the environment on crop development. For example, Vincent and Gregory (1989) found more tillers at 12°C than at 25°C in winter wheat, Przywara and Stepniewski (1996) observed decrease in root and shoot weights at high temperature, and Asseng *et al.* (2011) noticed that high temperature increased leaf senescence and decreased grain filling.

The relationship between temperature and growth may also be predictable where other factors which affect growth, such as nutrient supply are strictly controlled

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(Gregory, 1986). Among plant nutrients nitrogen has been considered as a major growth and development element (Ericssion, 1995; Nikolic *et al.,* 2012). Optimum availability of N to wheat plant results in promising plant growth (Ahmad *et al.,* 2012) and higher yield (Mandal *et al.,* 2005; Iqbal *et al.,* 2010; Ali *et al.,* 2012) compared to improperly fertilized plants. Waraich *et al.* (2002) observed that increased N results in maximum leaf area index at tillering and booting stages, number of tillers, net assimilation rate, relative growth rate, grain weight and grain yield. Nitrogen is responsible for shoot and root growth (Comfort *et al.,* 1988) grain formation (Arduini *et al.,* 2006) and protein synthesis (Asseng and Milroy, 2006; Pathak *et al.,* 2008; Casagrande *et al.,* 2009; Acreche and Slafer, 2009). Nitrogen stress restricted growth of wheat plants (Semenov *et al.,* 2007) and their dry matter production (Wojcieska, 1994; Arduini *et al.,* 2006). High nitrogen treatment increased the number of tillers (Palta and Filley, 1995; Maqsood *et al.,* 2012) and shoot dry matter (Greef and Kullmann, 1992; Masoni *et al.,* 2007; Laghari *et al.,* 2010). There are conflicting reports in the literature about the effects of nitrogen supply on the rate of leaf emergence of cereals. Muchow (1988) found that the rate of leaf emergence was lower at low nitrogen in sorghum, and similar results have been found in barley (Dale and Wilson, 1978). However, Bauer *et al.* (1984) found no effects of nitrogen on the number of leaves in spring wheat. However, Latiri *et al.* (1998) reported that nitrogen stimulated dry matter production substantially due to increased leaf area index, which resulted in improved efficiencies of radiation and water use.

The main hypothesis of present study is that the growth and development of tropical cultivars of wheat respond to a change in temperature and nitrogen in the same way. This hypothesis is proposed because both tropical cultivars were selected under high nitrogen inputs and would therefore be expected to respond similarly to nitrogen status.

2. Materials and Methods

Seeds of two tropical cultivars (Mehran-89 and T.J.83) of wheat (*Triticum aestivum* L.) were obtained from Wheat Research Institute, Sakrand, Sindh, Pakistan. Seeds were soaked in aerated distilled water in a conical flask for 24 hrs at room temperature (18±1°C) and then were placed on moist tissue papers in a propagation tray in the light for 4 days at ambient CO_2 (350 ppm) in a controlled environment cabinet (Model 660, Sanyo Gallenkamp Ltd, Loughborough, Leics., UK). The control conditions were high N (6 mM nitrate) in half strength Long Ashton solution (Smith *et al,.* 1983), 20 C temperature, 70% relative humidity and 480 µmol $m^{-2} s^{-1}$ PAR for 16 hrs d^{-1} from HQI (halogen quartz lamp).

Plants were transferred to hydroponics 5 days after seed germination, in 3 L troughs, supported in modified Eppendorf tubes, with T-pieces and two pipette tips in each side for aeration at 0.8 L per minute. The growth solution was changed when the plants were 12 days old, and then twice weekly until 21 days old and thereafter every two days. The solution was KNO_3 (2 mM), Ca $(NO_3)_2.4H_2O$ (2 mM), $NaH_2PO_4.2H_2O$ (0.665 mM), $MgSO_4.7H_2O$ (0.75 mM), FeEDTA Na (0.05 mM), $MnSO_4.4H_2O$ (0.005 mM), $CuSO_4.5H_2O$ (0.0005 mM), $ZnSO_4.7H_2O$ (0.0005 mM), H_3BO_3 (0.025 mM), $Na_2MoO_4.2H_2O$ (0.0002 mM), NaCl (0.05 mM). When the nitrate concentration was reduced from 6 mM to 0.6 mM, the potassium and calcium concentrations were maintained using K_2SO_4 and $CaCl_2.6H_2O$.

Two experiments were carried out in growth cabinet (Fisons Gallenkamp, Model 600 H), with two concentrations of nitrate (6 and 0.6 mM) and two constant day/night temperatures (15 or 20°C), with a 16 hrs photoperiod. Relative humidity was measured as 65±10%, pH of growth solution was maintained between 6.5 to 7 and 160 µmol m^{-2} s^{-1} PAR light intensity was supplied at plant height (twelve 40 W ‘cool white’ fluorescent tubes and four 40 W tungsten bulbs). Three plants were harvested at random from each treatment. Number of fully expanded leaves on main stem, number of tillers and number of fully expanded leaves on tillers per plant were measured. Shoots are roots were dried for 48 hrs at 70°C and their dry weight was determined. Shoot, root and total dry weight were measured at 13, 23 and 33 days after sowing (DAS). Plants at low nitrogen were grown to 43 DAS to record final dry weight. Data taken from both experiments were statistically analyzed using Genstat, version 11 software (Lawes Agricultural Trust, Rothamsted Experimental Station, UK).

3. Results

3.1 Effects of nitrogen (6 and 0.6 mM) at high temperature (20°C day/night) on cvs. Mehran-89 and T.J.83

At 33 DAS plants of Mehran-89 produced significantly ($P<0.05$) higher shoot dry weight, total dry weight (Figure 1A), number of tillers and leaves on tillers (Figure 1B) when received high nitrogen at 20°C temperature. However, root dry weight (Figure 1C) was slightly higher when Mehran-89 plants were grown at same temperature but received low nitrogen at 33 DAS. Non-significant statistical difference between high (Figure 1B) and low (Figure 1D) nitrogen concentrations was observed regarding number of fully expanded leaves on main stem at 33DAS. Mehran-89 plants subjected to low nitrogen produced more or less same shoot dry weight, total dry weight (Figure 1C), number of tillers and leaves on tillers (Figure 1D) at 43 DAS which were produced by the same cultivar received high nitrogen at 33 DAS. More or less same trend was observed in cv. T.J.83 at 33 DAS. Plants produced significantly ($P<0.05$) maximum shoot dry weight, total dry weight (Figure 2A), number of tillers and leaves on tillers (Figure 2B) at 20°C temperature and received high nitrogen at 33 DAS. However, difference between high and low nitrogen concentrations regarding root dry weight (Figure 2A,C) and number of fully expanded leaves on main stem (Figure 2B,D) were non-significant statistically at 33 DAS. T.J.83 plants grown for 43 DAS under

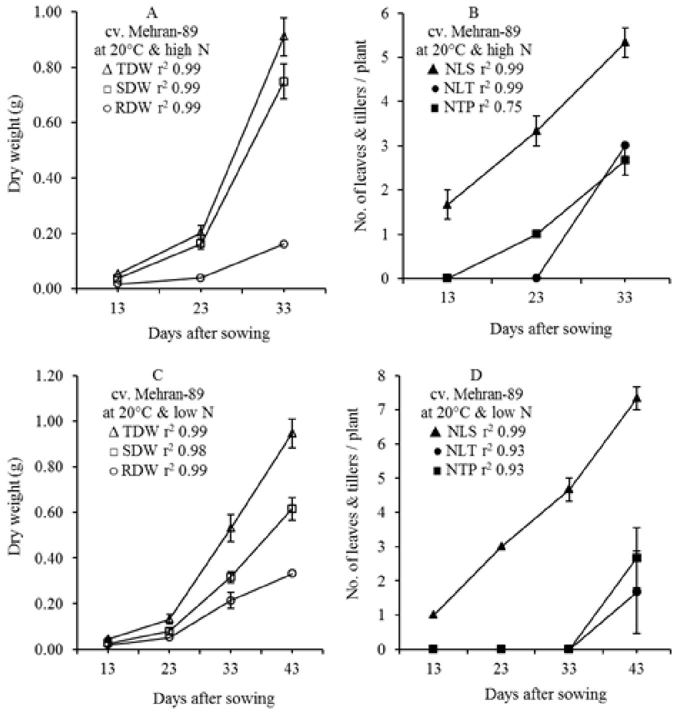

Figure 1. Temperature (20°C) and nitrate concentrations (6 and 0.6 mM) effects on dry weight, number of leaves and tillers of wheat cv. Mehran-89. Graph A and B show the effects of high nitrate concentration (6 mM) while graph C and D indicate the effects of low nitrate concentration (0.6 mM) on total dry weight (TDW), shoot dry weight (SDW), root dry weight (RDW), number of leaves on main stem (NLS), number of tillers per plant (NTP) and number of leaves per tiller (NLT). Vertical bars (where larger than the points) represent the standard error (s.e.) of variability.

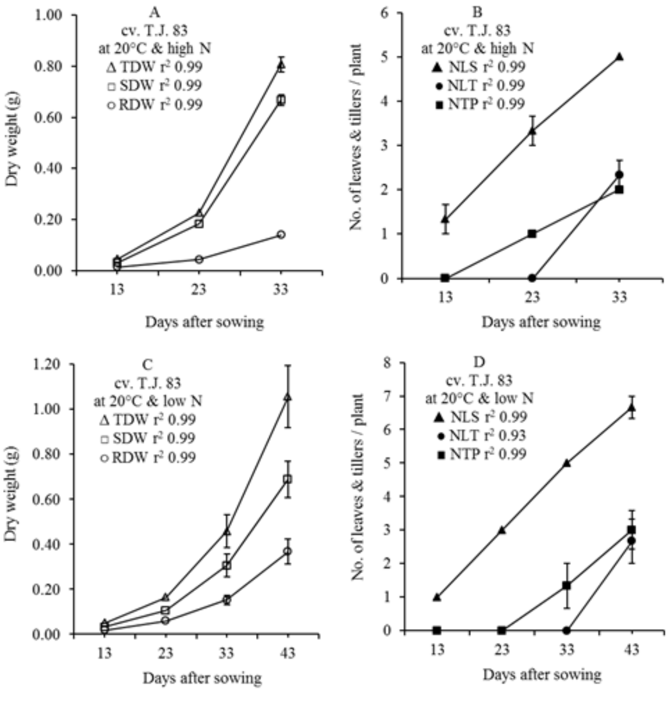

Figure 2. Temperature (20°C) and nitrate concentrations (6 and 0.6 mM) effects on dry weight, number of leaves and tillers of wheat cv. T.J.83. Graph A and B show the effects of high nitrate concentration (6 mM) while graph C and D indicate the effects of low nitrate concentration (0.6 mM) on total dry weight (TDW), shoot dry weight (SDW), root dry weight (RDW), number of leaves on main stem (NLS), number of tillers per plant (NTP) and number of leaves per tiller (NLT). Vertical bars (where larger than the points) represent the standard error (s.e.) of variability.

low nitrogen produced significantly higher total dry weight, root dry weight (Figure 2C), number of tillers and leaves on tillers (Figure 1D).

Relationships between root dry weight and shoot dry weight at 20°C temperature varied between Mehran-89 and T.J.83 cultivars (Figure 5A, 6A). Root dry weight increased linearly with increase in shoot dry weight. However, higher root dry weight was observed at low nitrogen for a given shoot dry weight (33% in Mehran-89 and 50% in T.J.83) even at 33 DAS in both cultivars. The relationship between shoot dry weight and number of fully expanded leaves on the main stem (Figure 5B, 6B), number of tillers (Figure 5C, 6C) and number of leaves on tillers (Figure 5D, 6D) at 20°C temperature was also varied between both cultivars. There were more main stem leaves and more tillers at low nitrogen in both cultivars at 43 DAS, but more leaves on tillers in Mehran-89 at high nitrogen (Figure 5D) for a given dry weight of shoot. There are more leaves on tillers in T.J.83 at low nitrogen (Figure 6D) for a given dry weight of shoot compared to Mehran-89 at 43 DAS.

3.2 Effects of nitrogen (6 and 0.6 mM) at low temperature (15°C day/night) on cvs. Mehran-89 and T.J.83

Maximum shoot dry weight, total dry weight (Figure 3A), number of fully expanded leaves on main stem, number of tillers and leaves on tillers (Figure 3B) were observed in cv. Mehran-89 at 15°C temperature and received high nitrogen at 33 DAS. Same cultivar produced higher root dry weight (Figure 3C) when grown at same temperature but received low nitrogen at 33 DAS. Plants of Mehran-89 treated to low nitrogen produced lower shoot dry weight, total dry weight (Figure 3C), number of fully expanded leaves on main stem, number of tillers and leaves on tillers (Figure 3D) at 43 DAS compared to plants received high nitrogen at 33 DAS. Wheat cultivar T.J.83 at 33 DAS produced maximum shoot dry weight, root dry weight, total dry weight (Figure 4A), number of fully expanded leaves on main stem, number of tillers and leaves on tillers (Figure 4B) when grown in high nitrogen concentration at 15°C temperature. Plants of same cultivar at 43 DAS under low nitrogen still showed lower shoot dry weight, root dry weight, total dry weight (Figure 4C), number of fully expanded leaves on main stem, number of tillers and leaves on tillers (Figure 4D).

Relationships between shoot dry weight and root dry weight (Figure 5A, 6A) and number of fully expanded leaves on the main stem (Figure 5B, 6B) at 15°C temperature varied between Mehran-89 and T.J.83 cultivars at 43 DAS. A linear increase in root dry weight and curvilinear increase in number of fully expanded leaves on the main stem with increase in shoot dry weight was observed at low nitrogen. However, a curvilinear relationship between shoot dry weight and number of tillers (Figure 5C, 6C) and number of leaves on tillers (Figure 5D, 6D) at 15°C temperature was found in both

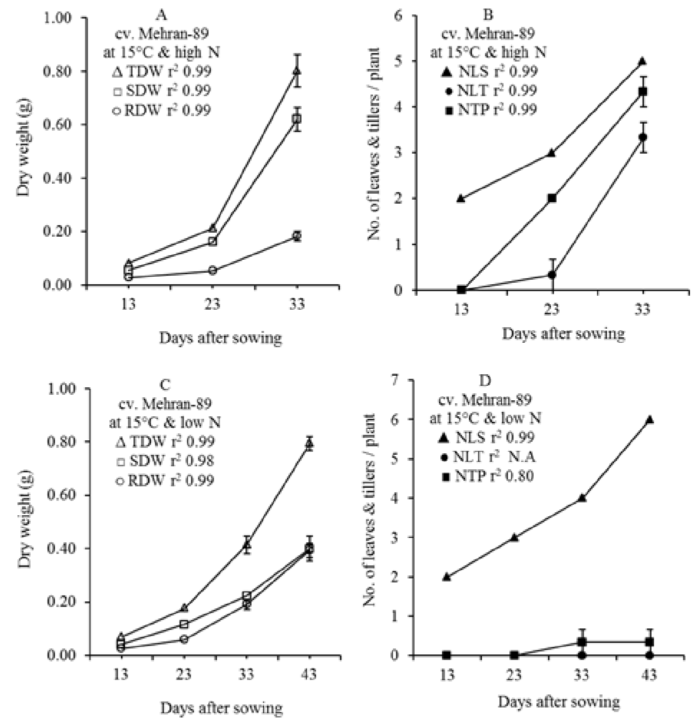

Figure 3. Temperature (15°C) and nitrate concentrations (6 and 0.6 mM) effects on dry weight, number of leaves and tillers of wheat cv. Mehmar-89. Graph A and B show the effects of high nitrate concentration (6 mM) while graph C and D indicate the effects of low nitrate concentration (0.6 mM) on total dry weight (TDW), shoot dry weight (SDW), root dry weight (RDW), number of leaves on main stem (NLS), number of tillers per plant (NTP) and number of leaves per tiller (NLT). Vertical bars (where larger than the points) represent the standard error (s.e.) of variability.

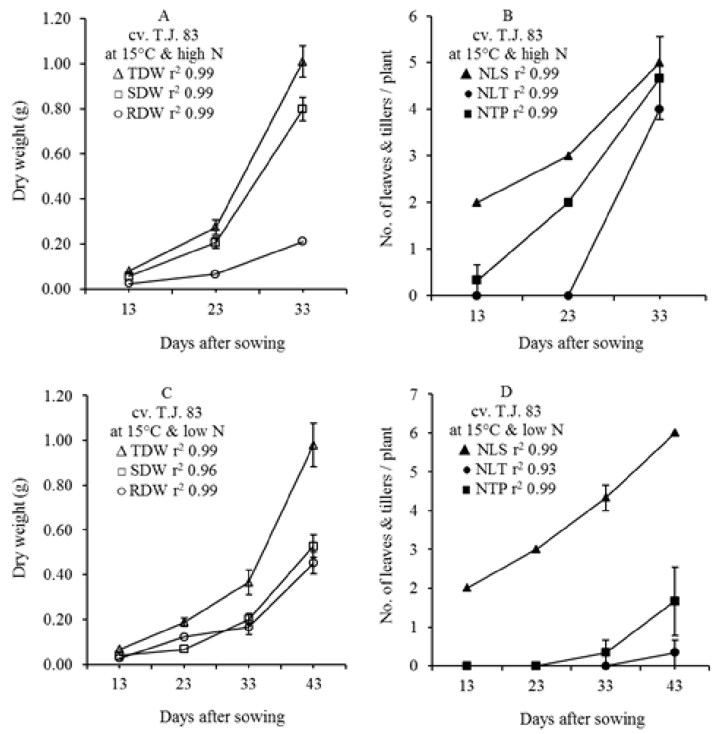

Figure 4. Temperature (15°C) and nitrate concentrations (6 and 0.6 mM) effects on dry weight, number of leaves and tillers of wheat cv. T.J.83. Graphs A and B show the effects of high nitrate concentration (6 mM) while graphs C and D indicate the effects of low nitrate concentration (0.6 mM) on total dry weight (TDW), shoot dry weight (SDW), root dry weight (RDW), number of leaves on main stem (NLS), number of tillers per plant (NTP) and number of leaves per tiller (NLT). Vertical bars (where larger than the points) represent the standard error (s.e.) of variability.

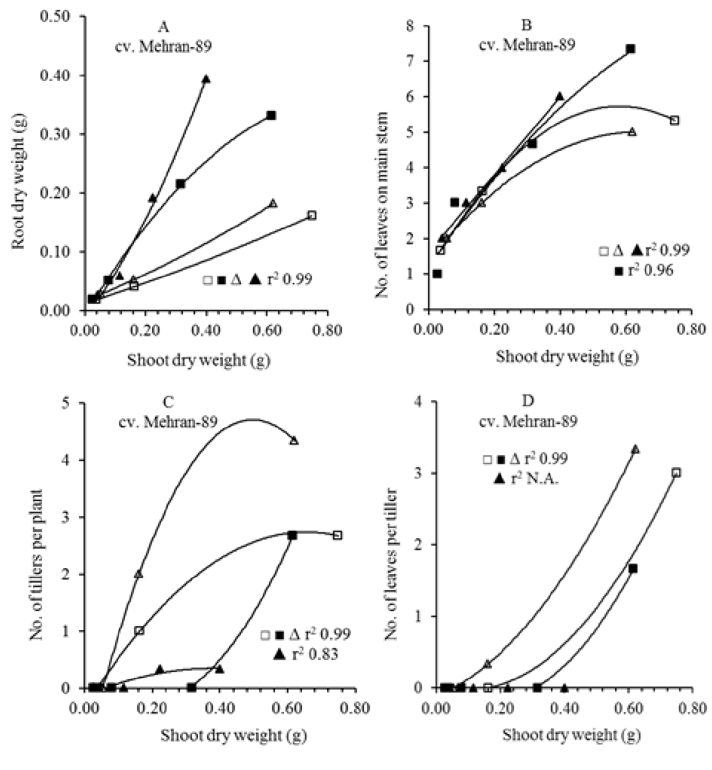

Figure 5. Relationship between shoot dry weight of wheat cv. Mehran-89 and A root dry weight, B number of leaves on main stem, C number of tillers and D number of leaves per tiller at 20°C high N (□) and low N (■) and at 15°C high N (Δ) and low N (▲).

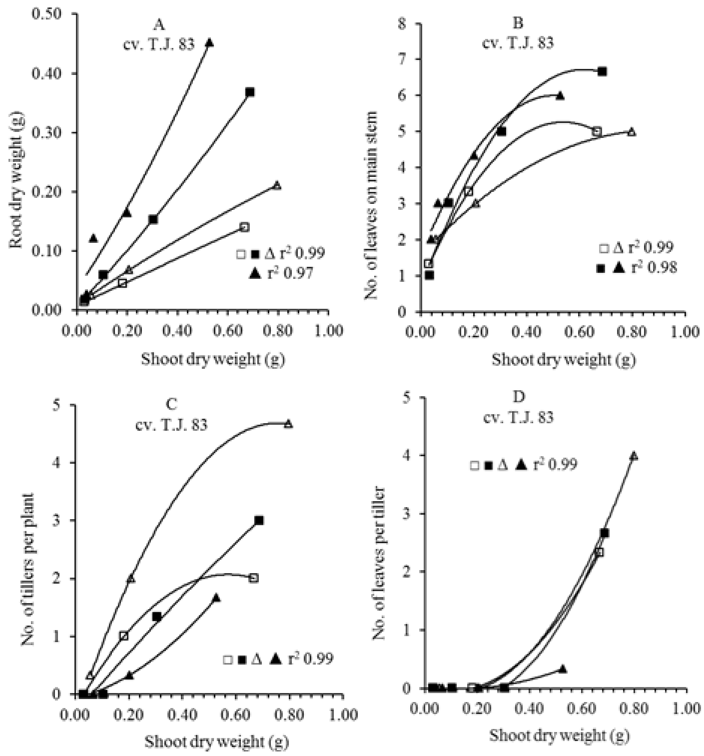

Figure 6. Relationship between shoot dry weight of wheat cv. T.J.83 and A root dry weight, B number of leaves on main stem, C number of tillers and D number of leaves per tiller at 20 °C high N (□) and low N (■) and at 15 °C high N (Δ) and low N (▲).

cultivars. There were more tillers and leaves on tillers at high nitrogen in both cultivars at 33 DAS for a given dry weight of shoot.

4. Discussion

Studies on plant integrated response to environmental factors in terms of shoot, root dry matter partitioning and other agronomic characteristics is still on-going research and has been focused on root and shoot interactions (Lioert *et al.,* 1999; Hebert *et al.,* 2001; Li *et al.,* 2001; Masoni *et al.,* 2007). In present studies, two major environmental factors (nitrogen and temperature) were chosen to establish their effects on dry matter partitioning of wheat cvs. Mehran-89 and T.J.83 and the relationship of shoot dry matter to other growth parameters. Present studies revealed that high nitrogen (6 mM) significantly increased total dry weight (42% at 20°C and 48% at 15°C), shoot dry weight (58% at 20°C and 64% at 15°C), number of leaves on main stem (13% at 20°C and 20% at 15°C), number of tiller per plant (100% at 20°C and 92% at 15°C) and number of leaves per tiller (100% at 20°C and 15°C) in cv. Mehrah-89 at 33 DAS. However, plants of same cultivar received low nitrogen (0.6 mM) significantly increased root dry weight (33% at 20°C and 5% at 15°C). Wheat cv. T.J.83 also showed similar trend and plant received high nitrogen (6 mM) significantly increased total dry weight (43% at 20°C and 64% at 15°C), shoot dry weight (54% at 20°C and 75% at 15°C), number of leaves on main stem (13% at 15°C), number of tiller per plant (33% at 20°C and 93% at 15°C) and number of leaves per tiller (100% at 20°C and 15°C) at 33 DAS. Root dry weight response of T.J.83 was higher (22%) in high nitrogen concentration (6 mM) at 15°C however at 20°C low nitrogen increased root dry weight by 9%. This indicated that plant growth and development depend on nitrogen supply and in general increasing the nutrient enhances plant growth and development (Bauer *et al.,* 1984; Nikolic *et al.,* 2012). The nutrient supply and demand of root and shoot are inter-dependent due to their different functions and local environment (Li *et al.,* 2001; Arduini *et al.,* 2006; Hakim *et al.,* 2012). Results of present study are therefore in agreement with previous findings as high nitrogen (6 mM) increased shoot, root and total dry matter.

In field conditions, metabolic activity in plants including the supply of assimilate is related to temperature, which affects both growth and development (Loomis and Connor, 1992; Martiniello and Teixeira da Silva, 2011). Under controlled environment of present studies, high temperature (20°C) and high nitrogen (6 mM) increased total dry weight and shoot dry weight up to 12 and 17% respectively in cv. Mehran-89 compared to low temperature (15°C) at 33 DAS whereas a significant increase in root dry weight (13%) and number of tillers (62%) was observed at low temperature (15°C). Similar temperature trend was observed when cv. Mehran-89 was grown in low nitrogen concentration (0.6 mM). On the other hand, low temperature (15°C) and high nitrogen (6 mM) significantly increased total dry weight (25%), shoot dry weight (20%), root dry weight (51%) and number of tillers (57%) in cv. T.J.83 at 33 DAS. However, number of leaves on main stem and leaves on tillers were not affected significantly by both temperatures (20°C and 15°C), agreeing with many reports (Miglietta, 1991; Yin and Kropff, 1996). Interaction of both factors indicated that plants of cvs. T.J.83 and Mehran-89 at both temperatures when received higher N produced maximum total number of leaves (main stem and tiller's leaves) 33 DAS however lower temperature accelerate the emergence of tillers when both cultivars received high N. Similar trend was observed when plants received low N regarding number of leaves on main stem 33 DAS. However, plants at both temperatures could not induce tillers when received low N 33 DAS. As mentioned earlier, the number of tillers per plant significantly increased at low temperature (15°C) in both cultivars which indicated that the rate of physiological processes does not change linearly with temperature but linear approximation can be established with development. The rate of organ initiation appears to be closely related to growth by the response of cell division to temperature (Farrar and Gunn, 1996).

At 15°C the relationships between the number of fully expanded leaves on the main stem and shoot dry weight were different at high (6 mM) and low (0.6 mM) nitrogen in both cultivars. There were more leaves at low nitrogen (0.6 mM) when the shoot dry weight was 0.20 g. This contrasts with Muchow (1988) who found fewer leaves in low nitrogen treatments in sorghum. The difference might be due to the difference in species. Relationships between the number of tillers and shoot dry weight were not the same at high (6 mM) and low (0.6 mM) nitrogen in both cultivars. There were more tillers at high nitrogen (6 mM) in both cultivars when compared at 0.20 g shoot dry weight however it appeared as temperature dependent (Altenbach *et al.,* 2003). Similarly, the relationship between the number of fully expanded leaves on tillers and shoot dry weight was different at high (6 mM) and low (0.6 mM) nitrogen in both cultivars. There were more leaves on tillers at low nitrogen in cv. Mehran-89 at 0.60 g shoot dry weight. The relationship between the number of tillers and shoot dry weight were different at high (6 mM) and low (0.6 mM) nitrogen in both cultivars i.e. more tillers at high nitrogen (6 mM) at 0.20 g shoot dry weight. Similarly, the relationship between the number of leaves on tillers and shoot dry weight showed more leaves of both cultivars at high nitrogen (6 mM), and fewer leaves at low nitrogen (0.6 mM) for a 0.20 g shoot dry weight. These results are in line with Dale and Wilson (1978) and Maqsood *et al,* (2012) who reported that high nitrogen increased leaf numbers in wheat.

Present findings revealed an interaction between temperature and N supply which ultimately regulated the induction of leaves and tillers. Generally, three ranges of temperature affect plant growth parameters. In the first range, growth and development rate increase with temperature, in the second optimal range, the process does not respond to temperature, and third range is supra-optimal, where the development rate decreases as temperature increases (Loomis and Connor, 1992; Martiniello and Teixeira da Silva, 2011). In present study, dry matter partitioning and organs development (leaves and tillers) response of both cultivars under two temperature regimes is different such as T.J.83 respond to low temperature while Mehran-89 to high temperature under high N concentration. It is reported that ranges of temperature differ for cultivars of wheat for individual phenophases but the form of response is generally applicable to all plants (Hossain *et al.,* 2011; White *et al.,* 2012). Present results therefore suggested that ideal optimal temperature for plant development varies from cultivar to cultivar. Similarly, plant organ development depends on nitrogen supply which is required for their induction (Nikolic *et al.,* 2012). It is a constituent of proteins, nucleic acids and chlorophyll. Its compounds comprise about 50 per cent of the dry matter content of plant cells. Availability of higher nitrogen stimulates greater nitrogen uptake which accelerates cell division, resulted in higher leaf and tiller numbers (Arduini *et al.,* 2006). However, there is often a stage of crop growth where wheat ceases taking up nitrogen when the maximum possible nitrogen content has been reached in the plant.

With regard to the hypotheses, the two tropical wheat cultivars were differed in response to temperature such as growth and development of T.J.83 was favored at low temperature (15°C) and high nitrogen (6 mM), thus its response is similar to temperate wheat cultivar Avalon (data not shown), whilst Mehran-89 was favored at high temperature (20°C) and high nitrogen (6 mM). The response of temperate wheat cultivar Avalon to low temperature may reflect the fact that winter wheat needs a cold period before phase change (data not shown). However, T.J.83 and Mehran-89 are spring wheat cultivars and do not need a cold period before switching to reproductive growth, but they differed in their response to temperature during their vegetative development. Thus the response to temperature is not due to differences between spring and winter wheat cultivars or differences between temperate and tropical cultivars. Both tropical wheat cultivars and temperate one (data not shown) were more responsive to high nitrogen, which supports the assumption made in the introduction that cultivars selected under high nitrogen would respond similarly to different nitrogen regimes.

5. Conclusions

It was observed that at high nitrogen (6 mM) and high temperature (20°C) tropical wheat cultivar Mehran-89 increased the number of leaves on main stem, number of tillers and leaves on tillers at 33 DAS. A similar trend was noticed in dry matter portioning. However, tropical wheat cultivar T.J.83 was more responsive to high nitrogen (6 mM) and low temperature (15°C). It is therefore, concluded that high nitrogen increased plant dry matter, number of tillers, leaf numbers on main stem and on tillers in both tropical cultivars, however the rate of development response of cultivars during vegetative phase varied with temperature.

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