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MORPHOLOGICAL AND PHYSIOLOGICAL CHARACTERISTICS OF WHEAT (TRITICUM AESTIVUM L.) UNDER DIFFERENT LIGHT CONDITION

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ABSTRACT

Light is the main environmental factor which regulates growth and development of crop plants. Decrease in light intensity due to shading adversely affects plant growth and development. The present study was conducted to analyze the effect of varying degree of shades on physiological characteristics and yield of wheat crop. Two shading treatments were applied i.e. 33 % shading (L1) and 66 % shading (L2) with full sunlight as control (L0). The experiment was conducted for 2 years during the winter seasons of 2010–2011 and 2011–2012 in a split-plot design with three replications with shading treatments in the main plot and five varieties of wheat in the sub plots. The findings of the study showed that the shade treatment had significant effect on the shoot height, tillering and internodal characteristics of the wheat varieties. Average dry matter accumulation in leaves, stem and spikes was reduction under varying degree of shades compare to full sunlight. The photosynthetic rate, stomatal conductance and transpiration rate at 10 days after anthesis (DAA) were significantly reduced while the intracellular CO2 concentration (Ci) increased with increase in shading during both the years. The total chlorophyll content increased whereas, chlorophyll a/b ratio decreased under shading. Grain yield of all the wheat varieties decreased with increase in shading during both the years. Varietal differences in grain yield under shading are discussed in relation to Pn rates and stomatal conductance.

Keywords: Photosynthetic rate (Pn), stomatal conductance (Gs), transpiration rate, grain yield, wheat.

INTRODUCTION

Light regulates plant growth and development through its effect on many plant processes like photosynthesis, chlorophyll synthesis and enzyme activation. Shading of plants generally decreases crop yields by reducing photosynthetic photon flux density and correspondingly, the crop photosynthesis. Changes in radiation influence both photosynthetic light and carbon use efficiency, and will ultimately affect total grain yield (Jiang et al. 2002). Shading during any developmental stage significantly impaired net photosynthesis in wheat leaves probably via changes in the functioning of chloroplasts and inhibition of the activity of photosystem II (PSII) (Mu et al. 2010). It is interesting that decrease in photosynthetic rate due to shading at the canopy level is less than at the single leaf level. This could be related to efficient acclimation- and adaptation capacities to different light regimes. For example, longer and thinner plants, increased area of leaf blades, and increased shoot to root ratios have been observed under shading (Pearcy, 2007**)**. The decrease of photosynthetic rate due to shading at the canopy level is less than at the single leaf level. This has been ascribed to efficient acclimatization and adaptation capacities of plants to different light regimes (Li et al. 2010). Agroforestry is stated to be a sustainable landmanagement system(King andChandler 1978). In any agroforestry system, tree crop interaction for solar radiation, moisture and mineral nutrients results in changed microclimates, which in turn affect the productivity of component crops. While moisture and nutrient availability could be agronomically managed, varietal selection ismore important for shade tolerance in such a system. Yield reductions in various grain crops have been reported due to such interactions. The objective of this study was to work out the physiological bases of yield reduction in wheat crop under varying degree of shades.

MATERIALS AND METHODS

The field experiments were conducted at the Norman Borlaug Crop Research Centre, G.B Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand during the winter seasons of 2010–2011 and 2011–2012. Pantnagar is located at 29oN latitude, 79.3oE longitude and an altitude of 243.8 m above mean sea level in the Tarai belt of Shiwalik range of the Himalayan foothills. It falls under the sub-humid and sub-tropical climatic zone. The experiment was laid out in a split plot design with three replications. The main plot treatments comprised of three different levels of sunlight viz. full sunlight as control, and 66 and 33 % of full sunlight as shade treatments while the sub-plot treatments consisted of five varieties of wheat. The gross plot size was 1.61 9 5.0 m while the net plot size was 1.15 9 4.0 m. A row spacing of 0.23 m, was maintained and the seed rate was 100 kg ha-1.

The height (cm) of five randomly selected shoots from marked one metre row length was measured and recorded from the ground level to the top of the longest leaf at 30 days interval after sowing till spike emergence and to the tip of the top most spikelets after spike emergence and the mean shoot height (cm) computed and the number of shoots were counted at two days interval in marked 1 m row length from 40th day after sowing and continued until the number of shoots became constant or started declining and the maximum number of shoots m^{-2} reported irrespective of time taken after sowing also all the internodes on five randomly selected and harvested shoots were measured with the help of scale and mean internode length (cm) for bottom upto top most one was computed at 90 and 128 days after sowing. Internodes were separated individually from top to bottom and kept in hot air over at 70 ± 2^{0}C and measured their dry weight at 90 and 128 days after sowing and average internode weight (mg) from one (top most) to last (bottom one) computed.

Dry matter accumulation studies were carried out at 20 days interval from sowing. Second, third, fourth, fifth and sixth rows from either side in each plot leaving border of 25 cm were utilized for plant sampling. For this, purpose, all the shoots from 25 cm row length were harvested from ground level i.e. the sampling area and separated into different plant components viz. stem/culm, leaves and spikes at various growth stages. Different plant components were then dried in plant drier at 70 ± 2^0 C temperature till constant weight and weighed to record the total dry matter accumulation in whole plants was calculated by summoning up the dry matter of stem, leaves and spikes/ sample area and then dry matters were converted to dry matter (g m^{-2}).

Data on photosynthetic rate, stomatal conductance andtranspiration rate were recorded at 10 days after anthesis between 12:00–14:00 h with the help of an Infra Red Gas Analyzer (Model: CI 310, CID Inc., USA). Data was recorded in the topmost fully expanded leaf (flag leaf). The temperature at the time of measurement was 28 ^{0}C at CO2 concentration between 320–370 ppm and at PAR levels between 1,200–1,350 lmol m-2 s-1. The observations were separately recorded on three leaves from each plot and mean value is presented. All these observations were made on intact leaves with a flow rate of 300 ml per minute.

Chlorophyll content of leaves was estimated by the following procedure described by Hiscox and Israelsam (1979). Five top most fully expanded leaves were randomly selected, cut at the base and taken to laboratory with their cut end dipped in water in test tubes to keep them fresh. The leaves were cleaned under running tap water and blot dried before chlorophyll estimation. Total chlorophyll content as well as chlorophyll a/b ratio was determined. Produce of net plot was threshed by using Pullman thresher. After winnowing, the grain yield was recorded.

RESULTS AND DISCUSSION

Yield reductions in various grain crops due to shading have been reported in agroforestry systems. Therefore, varietal differences in shade tolerance can be evaluated to find out suitable crop varieties for such systems. This requires understanding of photosynthetic behaviours of crop plants under shading that determines final grain yield. The objective of the present study was to work out the morphological and physiological bases of yield reduction in wheat crop under varying degree of shades.

The maximum and significantly taller shoots were observed under severe shade (i.e. 2/3 shading) 60, 90 and 120 DAS during both the years, respectively, whose height reduced significantly with each successive reduction in shade 30 DAS during 2010-11 and 60, 90 and 120 DAS both during 2010-11 and 2011-12 with no significant difference between severe and mild shades 60 DAS in 2011-12 (Table 1). The plant height is important for proper distribution and display of photosynthetic apparatus i.e. leaves. The data on shoot height (Table 1) showed that the stem elongation in early growth stage (upto 90 DAS) was rapid which increased with decreasing rate upto 120 DAS, thereafter declined subsequently at maturity in all the treatments, during both the years. Analysis of data indicated that under severe shade (i.e. 2/3 shading) increased shoot height as compared to control (i.e. full sunlight) at all the stages of crop growth. Kephart *et al*. (1992) reported that plants (perennial grasses) responded to reduced light by allocating a higher proportion of carbohydrates to maintain or increase leaf area and stem length. Similar findings were also reported by Varella *et al*. (2010) and Li *et al*. (2010). Among the wheat varieties, UP 2113 recorded higher shoot height than all other varieties at all the stages of crop growth. This was 5.9 and 11.1 per cent higher than PDW233 at 120 DAS during both the years, respectively. The result might be combined effect of genetic variations and their differential response to shade in increasing in their internode lengths.

The average internode length (cm) of I, II, III & IV internode from top downwards in wheat was significantly influenced by the varying degree of shades and wheat varieties at 90 DAS both during 2010-11 and 2011-12, except fifth internode length by varying degree of shades. The interaction between magnitude of shades and wheat varieties was influenced significantly for first and second internode only during both the years i.e. 2010-11 and 2011-12 (Table 2). The maximum and significantly longer mean internode length of first, second, third, fourth and fifth internodes from top was recorded under higher degree of shade at 128 DAS, respectively, which increased significantly with each successive reduction in shade 128 DAS during both the years, with no significant different between lower degree of shade (mild) and full sunlight for fifth internode (Table 3).

The average length (Table 2) of internode was increased from first to second from the top internode then decreased from third to fifth from top internode at 90 DAS under all the light availability condition i.e. full, 2/3 and 1/3 available light during both the years. Among the shade treatments, severe shade recorded higher internode length of 12.3 and 12.5 (first), 14.3 and 14.5 (second), 12.1 and 12.0 (third), 9.2 and 9.5 (fourth) and 6.1 and 6.3 cm (fifth) internodes from top at 90 DAS both during 2010-11 and 2011-12, respectively, than both under the mild shade and full sunlight conditions. At 128 DAS the internode length (Table 3) showed decreasing trend from first to fifth internode from top under all the light available condition both during 2010-11 and 2011-12. The increase in length of terminal internode i.e. peduncle was more obvious due to shading than the penultimate and lower internodes (Li *et al*., 2010). Among the wheat varieties UP 2565 registered higher length of all the internodes at 90 DAS, except fourth internode from top both during 2010-11 and 2011-12. Whereas, UP 2113 registered more length of all the internodes except second from the top at 128 DAS than the rest of the varieties both during 2010-11 and 2011-12. Cruz-Aguado *et al*. (2000) reported the significant increase in internode length of wheat varieties due to shading over the control.

The mean internode dry weight (mg) in first, second, third, fourth and fifth internode from top downwards in wheat was influenced significantly by varying degree of shades and wheat varieties 128 DAS during 2010-11 and 2011-12 (Table 4). However, the interaction between magnitude of shades and wheat varieties was influenced significantly only for first, second and fifth internodes from top during both the years.

The variety UP 2565 recorded higher mean internodal dry weight in first (1150 and 1164.0 mg), second (1060 and 1076.7 mg) and third (694.4 and 678.4 mg), while variety UP 2113 in fourth (693.3 and 697.2 mg) and fifth (633.3 and 623.3 mg) internodes during 2010-11 and 2011-12, respectively. Whereas, the varieties UP 2113 and UP 2565 did not differ significantly in third internode dry weight from top both during 2010-11 and 2011-12. The minimum and significantly lesser mean internode dry weight was recorded in UP 2113 for first internode; variety PDW 233 for second and third internodes; variety UP 2526 for fourth internode and UP 2684 for fifth internode from top at 128 the day during both the growing seasons i.e. 2010- 11 and 2011-12. The interaction between degree of shades and wheat varieties was found to be significant (Table 4).

The data revealed that (Table 3 and 4) average internode dry weight was increasing from first to fifth internode from the top. The internode dry weight was higher under full sunlight as compared to both the mild and severe shades at 90 and 128 DAS both during 2010-11 and 2011-12. Li *et al*., (2010) reported the significant reduction in dry weight of stems with increasing shade in wheat and the longer stems exhibited lower specific internode weight. Cruz-Aguado *et al*. (2000) envisaged that the difference in the net loss of dry matter between the upper and the lower internodes may be ascribed to the change in availability of photo-assimilate required meet the requirement of developing sinks.

Among the wheat varieties UP 2565 had higher dry weight of second and third internode from top and UP 2113 in fourth and fifth from top at 90 and 128 DAS respectively, both during 2010-11 and 2011-12. Whereas, first or peduncle node dry weight was higher from PDW 233, UP 2113 and UP 2684 at 90 DAS in 2010-11 and UP 2565 at 128 DAS in 2011-12. These might be due to genetic variability in photosynthate allocation amongst wheat varieties during different growth periods. However the wheat varieties internode dry weight was increased from first to fifth internode from the top at 90 and 128 DAS during both the years. Cruz-Aguado *et al*. (2000) reported that the loss of dry weight from the penultimate and from the lower internodes was larger than from the peduncle internodes. This indicated that shading promoted remobilization of the stored dry matter in the lower internodes as a plastic response to light (Li et al., 2010 and Valladares et al., 2002, 2003).

Total plant dry matter (g m^{-2}) accumulation in wheat was influenced significantly by degree of shades 40, 60, 80, 100 and 120 DAS during both the years and wheat varieties at all the stages (Table 5). The early development of a plant and its parts is prerequisite for expression of inherent potential and utilization of environmental and/or soil resources and to produce the economic sink by any crop variety. In general, growth has been studied as a function of time and it followed a sigmoidal pattern consisting of at least four distinct periods (a) an initial ‘lag’ phase during which growth rate is slow, as the internal changes occur that are preparatory to growth; (b) ‘log’ phase, since the logarithm of growth rate when plotted against time, yields a straight line during this period; (c) phase of decreasing growth rate and (d) a steady growth rate, a point at which the plant reaches maturity and growth ceases (Galston, 1969). In general, the duration of initial ‘lag’ phase remained up to 40 days, during which only 1.7 per cent of total dry matter was accumulation while ‘log’ phase, which ranged from 40 to 100 days after sowing and plants accumulated 66.6 per cent of total dry matter and the remaining 32.7 per cent total dry matter was accumulated during the third phase, which extent from 100 to 120 DAS (Table 5) and ultimately plants reached the maturity. The total plant dry matter accumulation ranged from 25.9 and 18.3 per cent under severe shade to 35.1 and 22.4 per cent under full sunlight condition at 40 days after sowing during both the years 2010-11 and 2011-12, respectively. After that, with successive growth, it increased continuously up to maturity of crop. However, under full sunlight the wheat varieties produced higher total plant dry matter as compared to under mild and severe shades, with consistent reduction with increased intensity of shade. Singh et al. (1996), Tomar et al. (1997) and Dhillon et al. (1998) have also observed varying degree of reduction in dry matter produced with increased magnitude of shade reacted by increased by increased tree densities of various species.

Among wheat varieties, PDW 233 accumulated maximum plant dry matter at maturity, while, all the varieties differed significantly from each other in their total dry matter at 20th and 120th day. Patil et al. (1994) observed significant differences in total dry matter accumulation per plant among wheat genotypes at all the growth stages of crop. The reduction in dry matter accumulation under mild and severe shade has been attributed to reduced rate of photosynthesis due to low light intensities (shading). Similarly, Nazir et al. (1993) have also found the duration of shading to be important and the increased duration of shading decreased the percentage of dry matter accumulation in plants.

The leaf biomass was increased 37.0 and 35.4 per cent of total under full sunlight as compare to severe shade at 40 DAS both during 2010-11 and 2011-12, respectively, but it was increased upto 100 DAS. This higher proportion of photosynthate allocation to leaves during these early stages of crop growth indicates that the priority sink for photosynthate allocation are the leaves. However, during advance growth stages upto 120th day, the proportion of leaf dry matter in total biomass decreased gradually during both the years. It indicates that priority sinks have been changing with age of crop plants from leaves to stem and/or reproductive parts. Similarly, in different wheat varieties, the photosynthate allocation to leaves decreased with age of crop with significant varietal differences in their leaf dry matter at 40, 60, 80, 100 and120 days. Varying magnitude of reduction in leaf biomass among wheat varieties was observed with increased intensity of shades which suggest the variation in their tolerance to shading by trees (Nandal et al., 1999).

The intercellular CO2 concentration (Ci), photosynthetic rate (Pn), stomatal conductance (Gs) and transpiration rate (E) of wheat varieties were significantly influenced by the degree of shading (Table 1). Diffusion of CO2 into the leaves is mainly driven through the stomatal aperture and linearly correlates with photosynthetic capacity. It plays an important role in the physiological process of plant modulated by environmental regime (Korner et al. 1979). The intercellular CO2 concentration (Ci) was significantly influenced by degree of shades at 10 days after anthesis (DAA) during both the years (Table 5). The CO2 concentration was higher under severe shade (L2, 66 % shading) as compared to mild shade(L1) and full sunlight (L0, control) during both the years. Maximum Ci was recorded under 66 % shading (L2) viz. 363.4 ppm during the first year and 370.8 ppm during the second year. The percent increase as compared to full sunlight was 10.9 and 12.5 % respectively, during 2010–2011 and 2011–2012. However, there were no significant differences among the wheat varieties. Even the interaction between wheat varieties and degree of shades were non-significant in terms of Ci. During both the years, the net photosynthetic rate was significantly higher (19.8 and 22.5 lmol CO2 m-2 s-1 during first and second year, respectively) under full sunlight (L1, control) which was reduced significantly with increase in the degree of shading. Among the varieties, PBW 233 exhibited significantly higher photosynthetic rate (16.7 lmol CO2 m-2 s-1) than other varieties during the first year while during 2011–2012, the varieties PBW 233, UP 2684 and UP 2526 recorded similar Pn rates that was highest among the varieties. Significantly lower photosynthetic rate was recorded in the variety UP 2113 during the second year. Mu et al. (2010) reported that small reduction in radiation showed marked reduction in Pn of wheat flag leaf. The response of net photosynthetic rate (Pn) to shading differed amongst the cultivars (Li et al. 2010). The decrease in Pn rate is usually explained by reduction in stomatal conductance, which reduces CO2 diffusion into the leaves (Condon et al. 2002). In the present study, reductions in Pn rates under shading despite higher intercellular CO2 concentrations indicate that Pn rate was limited by the availability of light. Stomatal conductance (Gs) is a measure of the maximum rate of passage of carbon dioxide into the leaf. In the present study, it was maximum and significantly higher under full sunlight. The values were 257.4 and 222.7 mmol CO2 m-2 s-1 during 2010–2011 and 2011–2012, respectively. It was reduced significantly with increase in the magnitude of shade (Table 5) during both the years. Among the varieties, PBW 233 recorded higher stomatal conductance (218.6 and 181.9 mmol CO2 m-2 s-1, respectively, during 2010–2011 and 2011–2012). While the varieties UP 2684 and UP 2113 recorded significantly lower stomatal conductance during 2010–2011, the variety UP 2113 only recorded the lowest value of Gs during second year of study. In the present study, as compared to full sunlight, reductions in Gs was 55.2 and 48.4 % during first and second year, respectively. These reductions in Gs explains the concomitant reductions in net photosynthetic rates under shade. Condon et al. (2002) reported that the decrease in Pn could be explained by reduction in stomatal conductance under shading. Camilo et al. (2002) reported that the stomatal conductance and assimilation rates werehigher in control plants, which indicated PAR limitation for photosynthesis in shaded plants. The relationship between Gs and Pn rate was also observed in the varieties. The transpiration rate (m mol H2O m-2 s-1) was also significantly higher under full sunlight during both the years. It was 1.94 in 2010–2011 and 1.72 in 2011–2012, respectively. There was a reduction of 65–67 % under severe shade as compared to full sunlight during both the years. This decrease in transpiration rates under shade could be due to the lower leaf and air temperatures that brought about a lower leaf-to-air vapour pressure gradient, and hence lower evaporative demand. Varietal differences in transpiration rates were non-significant during both the years. The interaction between degree of shading and varieties

were non-significant for these three parameters during both the years (Table 5). The total chlorophyll content of leaves as well as the chlorophyll a/b ratio is presented in Table 6. During both the years, the total chlorophyll content was higher under severe shade (2.27 and 2.42 mg g-1 FW, during first and second year, respectively) as compared to that in control (full sun light) or under mild shade (L1, 33 % shade).Varietal differences as well as interaction between shade levels and varieties were non-significant. On the other hand, the chlorophyll a/b ratio was significantly higher under full sunlight as compared to mild and severe shade in both the years. Even among the shading treatments, chlorophyll a/b ratio was significantly reduced with increase in shading from 33–66 %. Interaction effects of shading and wheat varieties on the chlorophyll a/b ratio are presented in Table 7. There were significant decreases in the ratio with increase in shading in all the varieties of wheat under study. Mishra et al. (2010) have reported that increase in total chlorophyll accumulation under shade was due to increase in chlorophyll b content, which indicates shade adaptation. In the present study also, higher total chlorophyll contents under shade were due to increase in chlorophyll b content as evident from the decreasing ratios of chlorophyll a/b under shading in all the varieties. However, it did not translate into higher photosynthetic rates as the latter decreased under shade. The maximum total grain yield, 42.9 q ha-1 during 2010–2011 and 43.6 q ha-1 during 2011–2012, was obtained under full sunlight which decreased significantly under mild and severe shades during both the years (Table 8). The reduction in grain yield under sever shading (66 % shade) was about 52 % during both the years as compared to that in full sunlight. A number of studies have shown reduced grain yield under shade or under trees (Verma et al. 2002; Kaushik et al. 2002). The interaction effect between shade levels and varieties show that all the five wheat varieties produced maximum grain under full sunlight which decreased with increased degree of shades during both the years. In the first year, the magnitude of reduction in grain yield under 33 % shading was lowest (15.3 %) in the variety UP 2113 while it ranged from 32–33.7 % in the rest four varieties. Under 66 % shading, all the varieties recorded about 50–53.4 % reduction in grain yield. In the second year, under 33 % shading, the variety PBW 233 recorded lowest reduction (29.7 %) in grain yield while the variety UP 2113 recorded the maximum reduction (41.1 %). Under severe shade, the reduction in grain yield was lowest in UP 2684(44.5 %) while in the rest four varieties, it ranged between 52.6–57.2 % as compared to that under full sunlight. This indicates that in both the years, the magnitude of reduction in grain yield was increased with increased shading and there were varietal differences in the magnitude of reduction.

However, magnitude of reduction in grain yield was less as compared to the magnitude of reduction in solar radiation (44.5–57.2 % reduction in grain yield as compared to 66 % reduction in solar radiation). Similar findings have been reported by Mu et al. (2010) that the wheat grain yield losses under shading were proportionately less than the reduction in solar radiation. An assessment of varietal performances under shade reveals that among the varieties, significantly lower grain yield was recorded in UP 2113 under full sunlight as well as at various degrees of shades during both the years. The variety PBW 233 out yielded other varieties except UP 2565 under any light condition in the first year. In second year also, PBW 233 recorded higher yields among the\ varieties under all light conditions. Closely following this variety was UP 2565 which recoded similar yields as that of PBW 233 under all light conditions in the first year and under full light only in the second year.

Conclusion

Higher grain yields of the variety PBW 233 can be ascribed to its higher net photosynthetic rate and stomatal conductance among the varieties. Moreover, these characters were unaffected by different levels of shades in the same variety (interaction were non-significant, Table 5). It is evident that the high yielding varieties PBW 233 and UP 2565 are expected to perform better under shade conditions due to maintenance of photosynthetic rates and stomatal conductance.

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Table 1. Shoot height (cm shoot^{-1}) in different wheat varieties and under varying degree of shades at different crop growth stages during both the growing seasons

Treatment	30 DAS		60 DAS		90 DAS		120 DAS	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades								
L0 – Full sun light	16.1	19.1	39.8	43.5	80.3	86.9	95.5	97.5
L1 – Mild shade	17.6	19.7	43.7	45.2	86.5	89.0	101.9	102.9
L2 – Severe shade	19.7	20.1	46.1	45.9	92.4	92.0	108.7	107.0
SEm±	0.7	0.3	0.2	0.2	0.4	0.2	0.4	0.3
CD at 5 %	0.2	NS	0.6	0.8	1.4	0.9	1.4	1.0
B. Wheat varieties								
UP 2684	17.6	19.3	42.5	44.9	85.1	89.3	100.9	99.6
UP 2526	18.1	20.7	43.8	46.0	86.9	89.3	101.9	102.7
UP 2565	17.8	19.0	43.4	45.4	85.9	91.2	100.8	101.2
UP 2113	18.5	22.1	44.5	46.8	89.9	93.2	106.5	110.9
PDW 233	17.1	17.1	41.9	41.1	83.9	83.4	100.2	98.6
SEm±	0.1	0.3	0.3	0.5	0.7	0.7	0.7	0.8
CD at 5 %	0.4	0.7	0.9	1.4	1.9	1.9	2.1	2.2
CV (%)	2.2	3.8	2.2	3.3	2.3	2.2	2.2	3.2
Interaction (A x B)	NS	NS	NS	NS	NS	NS	S	S

S - Significant NS - Non-significant DAS - Days after sowing

Table 2. Average internode length (cm) from top downwards in different wheat varieties and under varying degree of shades 90 DAS during both the growing seasons

Treatment	2010-11					2011-12				
	First	Second	Third	Fourth	Fifth	First	Second	Third	Fourth	Fifth
A. Degree of shades										
L0 – Full sun light	9.7	11.9	10.9	8.2	6.0	9.9	12.1	10.7	8.6	6.1
L1 – Mild shade	10.9	13.2	11.4	8.9	6.4	11.0	13.4	11.3	9.2	6.5
L2 – Severe shade	12.3	14.3	12.1	9.2	6.1	12.5	14.5	12.0	9.5	6.3
SEm±	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
CD at 5 %	0.3	0.2	0.3	0.4	NS	0.3	0.3	0.5	0.4	NS
B. Wheat varieties										
UP 2684	11.6	14.2	11.9	8.7	6.3	11.7	14.4	11.7	9.0	6.4
UP 2526	12.2	13.4	11.1	8.1	6.3	12.4	13.6	10.9	8.4	6.3
UP 2565	12.9	15.5	13.1	8.7	7.0	13.1	15.7	13.0	9.1	7.1
UP 2113	11.1	13.4	12.4	10.8	4.5	11.4	13.6	12.3	11.2	4.7
PDW 233	6.9	9.2	8.9	7.5	6.7	7.0	9.4	8.7	7.8	6.8
SEm±	0.1	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0.1	0.1
CD at 5 %	0.4	0.5	0.5	0.4	0.4	0.4	0.5	0.6	0.4	0.4
CV (%)	3.7	4.1	4.9	4.3	6.2	3.7	4.2	5.1	4.1	6.6
Interaction (A x B)	S	S	NS	NS	NS	S	S	NS	NS	NS

S - Significant NS - Non-significant DAS - Days after sowing

DAS = Days after sowing **L0** –Full sun light **L1** – Mild shade **L2** – Severe shade

Table 3. Average internode length (cm) from top downwards in different wheat varieties and under varying degree of shades on 128 DAS during both the growing seasons

Treatment	2010-11					2011-12				
	First	**Second**	**Third**	**Fourth**	**Fifth**	**First**	**Second**	**Third**	**Fourth**	**Fifth**
A. Degree of shades										
L0 – Full sun light	30.7	16.4	12.6	9.0	6.4	31.0	16.5	12.8	8.7	6.1
L1 – Mild shade	34.0	18.5	14.2	9.8	7.0	34.3	18.6	14.4	9.6	7.2
L2 – Severe shade	35.1	19.6	15.1	10.5	7.9	35.4	19.8	15.3	10.3	8.6
SEm±	0.2	0.1	0.1	0.1	0.2	0.3	0.1	0.2	0.2	0.3
CD at 5 %	0.7	0.5	0.2	0.3	0.6	1.0	0.5	0.6	0.6	1.1
B. Wheat varieties										
UP 2684	34.2	17.5	13.1	9.8	6.1	34.6	17.7	13.2	9.6	6.1
UP 2526	32.9	18.0	12.4	8.5	6.3	33.3	18.2	12.6	8.3	6.7
UP 2565	33.5	21.7	15.0	9.4	7.2	33.9	21.9	15.2	9.2	6.2
UP 2113	35.1	19.6	16.3	12.5	8.9	35.4	19.7	16.4	12.3	8.1
PDW 233	30.5	13.9	13.1	8.7	7.2	30.8	14.1	13.3	8.5	7.0
SEm±	0.5	0.4	0.3	0.2	0.2	0.5	0.4	0.3	0.3	0.3
CD at 5 %	1.4	1.2	0.9	0.6	0.6	1.6	1.2	0.9	0.8	0.9
CV (%)	4.3	6.8	6.3	5.8	8.9	4.8	6.9	6.4	8.1	13.3
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

S - Significant NS - Non-significant DAS - Days after sowing

Table 4. Total plant dry matter accumulation (g m^{-2}) of different wheat varieties and under varying degree of shades at various growth stages during both the growing seasons

Treatment	20 DAS		40 DAS		60 DAS		80 DAS		100 DAS		120 DAS	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades												
L0 – Full sun light	10.5	11.5	63.9	77.6	199.0	199.0	632.2	667.8	725.0	878.1	1070.6	1117.6
L1 – Mild shade	10.3	11.4	56.1	69.1	174.3	166.1	535.9	582.6	602.0	701.7	621.8	967.7
L2 – Severe shade	10.1	11.2	47.3	63.4	149.9	151.2	475.9	511.6	505.4	582.7	783.1	828.0
SEm±	0.1	0.4	0.4	0.2	0.5	1.5	4.7	3.7	3.6	3.4	2.4	2.9
CD at 5 %	0.3	NS	1.6	0.9	1.8	5.9	18.2	14.3	14.2	13.1	9.5	11.3
B. Wheat varieties												
UP 2684	10.5	12.1	54.7	71.5	158.3	160.8	492.4	525.1	579.3	678.9	876.3	924.3
UP 2526	10.1	11.4	55.0	67.4	174.9	166.9	543.3	582.6	605.6	717.6	907.2	953.5
UP 2565	9.9	10.3	56.9	69.0	177.1	162.0	538.1	570.7	579.0	697.0	935.7	980.5
UP 2113	10.4	11.6	53.4	67.5	176.8	186.9	590.5	631.2	653.0	749.4	645.4	990.7
PDW 233	10.8	11.4	58.9	74.7	185.1	183.9	575.7	627.0	638.2	761.4	961.2	1006.6
SEm±	0.1	0.3	0.7	1.0	1.3	2.7	5.7	5.8	6.9	6.7	6.8	8.7
CD at 5 %	0.3	0.9	2.0	2.9	3.8	7.9	16.7	16.9	20.3	19.4	19.9	25.4
CV (%)	3.2	8.3	3.7	4.3	2.2	4.7	3.1	3.0	3.4	2.8	2.2	2.7
Interaction (A x B)	S	NS	NS	S	S	NS	S	S	NS	S	NS	NS

Table 5. Intercellular CO_2 concentration (Ci), Photosynthetic rate (Pn), Stomatal conductance (Gs) and Transpiration rate at 10 days after anthesis in different wheat varieties and under varying degree of shades during both the growing season

Treatment	10 days after anthesis							
	Ci (ppm)		Pn (µmol CO_2 m^{-2} s^{-1})		Gs (mmol CO_2 m^{-2} s^{-1})		Transpiration rate (mmol H_2Om^{-2} s^{-1})	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades								
L0 – Full sun light	323.7	324.6	19.8	22.5	257.4	222.7	1.94	1.72
L1 – Mild shade	347.3	341.3	13.9	14.8	165.6	155.0	1.04	0.97
L2 – Severe shade	363.4	370.8	10.3	10.6	115.3	114.9	0.63	0.59
SEm±	2.2	2.3	0.3	0.5	3.1	3.5	0.05	0.02
CD at 5 %	8.7	9.1	1.3	1.9	12.1	13.8	0.20	0.06
B. Wheat varieties								
UP 2684	344.5	344.7	14.0	16.6	157.7	172.8	1.26	1.08
UP 2526	349.2	345.5	14.4	16.2	176.7	163.6	1.27	1.11
UP 2565	341.1	348.2	14.9	15.1	190.8	164.4	1.13	1.08
UP 2113	346.7	346.5	13.6	13.9	153.6	138.2	1.20	1.10
PDW 233	342.4	342.8	16.7	17.9	218.6	181.9	1.16	1.08
SEm±	4.0	2.9	0.6	0.6	4.7	3.3	0.10	0.04
CD at 5 %	NS	NS	1.6	1.7	13.8	9.7	NS	NS

S - Significant NS - Non-significant

Table 6. Chlorophyll a, Chlorophyll b and Total chlorophyll content (mg g^{-1} fresh weight) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Chl a (mg g^{-1} F. wt.)		Chl b (mg g^{-1} F. wt.)		Total chlorophyll content (mg g^{-1} F. wt.)	
	Anthesis		Anthesis		Anthesis	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades						
L0 – Full sun light	1.19	1.38	0.68	0.65	1.88	2.03
L1 – Mild shade	0.81	0.99	1.19	1.16	1.99	2.16
L2 – Severe shade	0.77	0.95	1.49	1.47	2.27	2.42
SEm±	0.02	0.04	0.03	0.01	0.07	0.05
CD at 5 %	0.09	0.16	0.14	0.04	0.27	0.19
B. Wheat varieties						
UP 2684	0.92	1.11	1.15	1.12	2.08	2.23
UP 2526	0.92	1.10	1.12	1.19	2.14	2.29
UP 2565	0.96	1.14	1.16	1.14	2.12	2.28
UP 2113	0.97	1.15	1.09	1.07	2.07	2.23
PDW 233	0.85	1.04	0.98	0.96	1.81	1.99
SEm±	0.03	0.03	0.04	0.05	0.09	0.07
CD at 5 %	NS	NS	0.13	0.14	NS	NS
Interaction	NS	NS	NS	NS	NS	NS

S - Significant NS - Non-significant

Table 7. Chlorophyll a/b ratio and their interaction in different wheat varieties and under varying degree of shades at anthesis during both the growing seasons

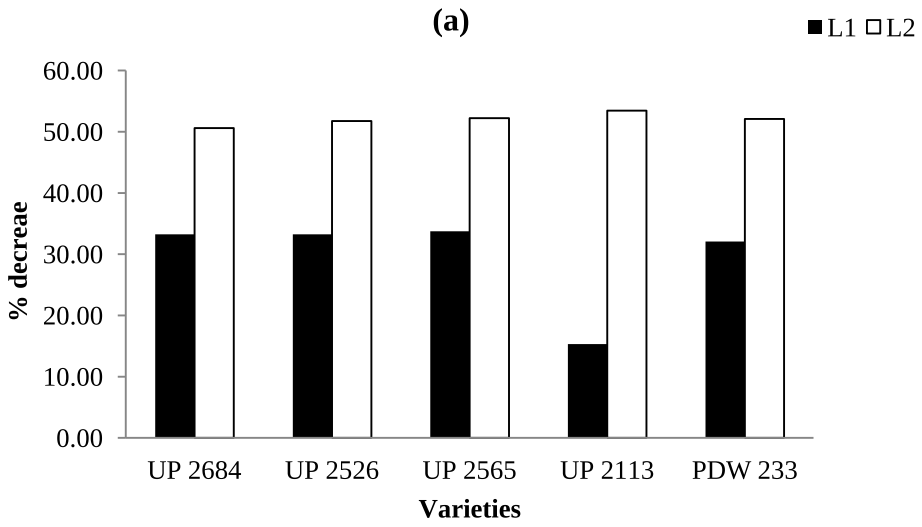
Treatment	Chlorophyll a/b ratio								
	2010-11	**2011-12**	**Interaction**	**2010-11**			**2011-12**		
A. Degree of shades			**Wheat varieties**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**
L0 - Full sun light	1.76	2.12	**UP 2684**	1.78	0.65	0.51	2.16	0.81	0.64
L1 - Mild shade	0.65	0.86	**UP 2526**	1.56	0.58	0.52	1.86	0.72	0.65
L2 - Severe shade	0.52	0.65	**UP 2565**	1.80	0.68	0.52	2.17	0.84	0.65
SEm±	0.02	0.02	**UP 2113**	1.83	0.80	0.52	2.19	0.99	0.65
CD at 5 %	0.07	0.09	**PDW 233**	1.82	0.55	0.52	2.19	0.95	0.66
B. Wheat varieties				SEm±	CD at 5%		SEm±	CD at 5%	
UP 2684	0.98	1.20							
UP 2526	0.88	1.07	To compare means of two B at the same 'A'	0.04	0.11		0.04	0.11	
UP 2565	1.00	1.22							
UP 2113	1.05	1.28							
PDW 233	0.96	1.27	To compare means of two 'A' at the same or different 'B'	0.03	0.12		0.04	0.14	
SEm±	0.02	0.02							
CD at 5 %	0.06	0.07							
Interaction	**S**	**S**							

S - Significant NS - Non-significant

Table 8. Grain yield (q ha^{-1}) and their interaction in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Grain yield (q ha^{-1})								
	2010-11	**2011-12**	**Interaction**	**2010-11**			**2011-12**		
A. Degree of shades			**Wheat varieties**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**
L0 - Full sun light	42.9	43.6	**UP 2684**	40.9	27.3	20.2	42.0	26.3	23.3
L1 - Mild shade	29.9	28.0	**UP 2526**	45.4	30.3	21.9	43.7	29.4	20.7
L2 - Severe shade	20.6	20.8	**UP 2565**	47.1	31.2	22.5	46.3	28.5	19.8
SEm±	**0.1**	**0.2**	**UP 2113**	33.3	28.2	15.5	39.1	23.0	18.3
CD at 5 %	**0.6**	**0.7**	**PDW 233**	48.0	32.6	23.0	46.7	32.8	22.0
B. Wheat varieties				SEm±	CD at 5%		SEm±	CD at 5%	
UP 2684	29.4	30.5							
UP 2526	32.5	31.2	To compare means of two B at the same 'A'	0.6	**1.8**		**0.8**	**2.4**	
UP 2565	33.6	31.5							
UP 2113	25.7	26.8							
PDW 233	34.3	33.8	To compare means of two 'A' at the same or different 'B'	**0.6**	**1.7**		**0.8**	**2.3**	
SEm±	0.4	0.5							
CD at 5 %	1.1	1.4							

S - Significant NS - Non-significant



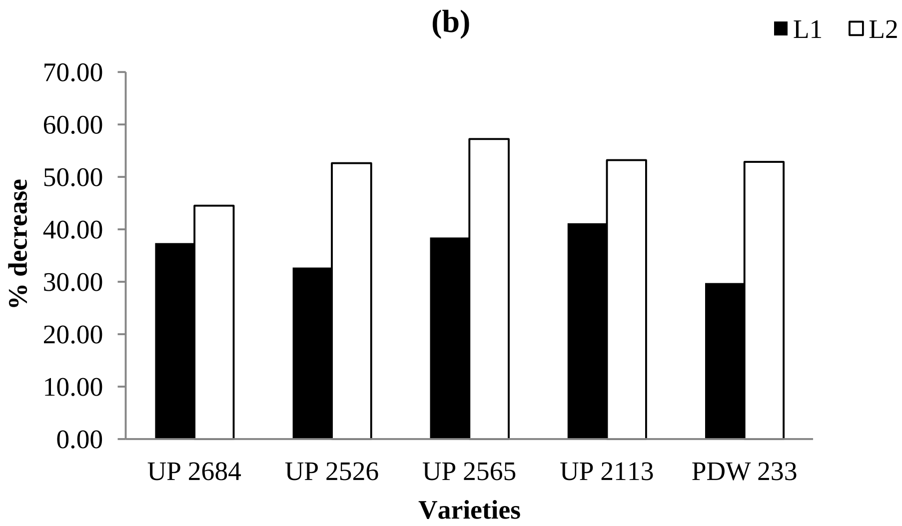


Fig 1. Per cent decrease in yield as compared to full sunlight (L0) in wheat varieties during 2010-11 (a) and 2011-12 (b)