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GROWTH STUDIES OF YIELD VARIABILITY IN WHEAT (*TRITICUM AESITIVUM* L.) UNDER VARYING DEGREE OF SHADES

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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 growth 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 during the winter seasons of 2010–2011 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 mean crop growth rate, mean relative growth rate, net assimilation rate, leaf area ratio, leaf area index and specific leaf weight were significantly influenced by increasing shade. Grain yield of all the wheat varieties decreased with increase in shading during the year (i.e. 2010-11). Varietal differences in grain under shading are discussed in relation to leaf area index and crop growth rate.

KEYWORDS: Light intensity, Shading, Crop growth rate, Leaf area index and Specific leaf weight

INTRODUCTION

Light is the main environment factor which determines the rate of crop development possibly because all plants and their process of development are sensitive to it. Light plays an important role in many plant processes like chlorophyll synthesis, enzyme activation, photosynthesis governing growth and development of plants. As a consequence of increase in aerosols, air pollutants and population density, dimming or shading (decrease in global radiation, i.e. the sum of the direct solar radiation and the diffuse radiation scattered by the atmosphere) have become major challenges to crop production in many areas of the world (Mu *et al*., 2010). Dimming or shading not only reduce radiation but also increase the fraction of diffuse light and alter the spectral quality. Diffuse light is more efficiently utilized by plants and can offset small decrease in direct radiation and actually enhance the CO2 uptake, photosynthesis and plant growth. Mean while, with increasing intensity of shading, the fraction of blue light (400-500 nm) increases while of red light (600-700 nm) decreases, which might affect both physiological parameters as well as plant morphology (*e.g.* main culm development, tillers appearance and stomatal conductance) (Li *et al*., 2010). Agroforestry is very specially stated to be a sustainable land management system (King and Chandler, 1978). But more recently, the rational of developing agroforestry has been modified to include three alternatives: a higher total, a more diversified and/or a more sustainable production from available resources than is possible with other forms of land-use (Lundgren, 1982). 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 is more 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 growth characteristics of yield reduction in wheat crop under varying degree of shades.

MATERIALS & 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 season of 2010–2011. 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 x 5.0 m while the net plot size was 1.15 x 4.0 m. A row spacing of 0.23 m, was maintained and the seed rate was 100 kg ha^{-1}.

Leaf area measurement

All green leaves of sampled shoots for dry matter accumulation studies were used for leaf area measurements. The separated green leaves (excluding leaf sheaths) were categorized into small, medium and large sized groups and counted. Five leaves from each category were randomly selected and their leaf area was measured by automatic leaf area meter (Model: LI-COR, USA). Sum of the product between the number of leaves and the mean leaf area in each category was taken as the leaf area of the sample (*i.e.* 25 cm row length) and converted to leaf area m-2. The following growth indices were computed using following the formulae as suggested by Radford (1967).

Mean Crop Growth Rate

Mean crop growth rate (CGR) (g m^{-2} day^{-1}) was computed by using the following formula;

$$\text{Mean CGR} = \frac{W_2 - W_2}{t_2 - t_1}$$

Where, W_1, and W_2 were total plant dry matter (g m^{-2}) at time t_1 and t_2 of a growing period, respectively.

Mean Relative Growth Rate

The increase in dry weight per unit original dry weight of the plant per unit time called mean relative growth rate (mg g^{-1} day^{-1}). The mean relative growth rate (RGR) was calculated using the following formula;

$$\text{Mean RGR} = \frac{\text{Log e } W_2 - \text{log e } W_1}{t_2 - t_1}$$

Where,

W_1 = Total dry weight of plants (g m^{-2}) at start of the test period *i.e.* t_1

W_2 = Total plant dry weight (g m^{-2}) at the end of the test period i.e. t_2

Net Assimilation Rate

The net assimilation rate (NAR) (mg cm^{-2} day^{-1}) is the increase in weight of dry matter of a plant per unit leaf area per unit time. It was calculated with the following formula

$$\text{NAR} = \frac{W_2 - W_2}{A_2 - A_1} \times \frac{\text{log e } A_2 - \text{log e } A_1}{t_2 - t_1}$$

Where, W_1 and A_1 are the total dry matter and leaf area at time t_1 and W_2 and A_2 at time t_2, respectively.

Leaf area ratio

The leaf area ratio (LAR) (cm^2 g^{-1}) is defined as the ratio between leaf area (A) and total plant dry weight (W). It reflects the leaf area supporting each unit of plant dry weight. The mean LAR was computed as;

$$\text{LAR} = \frac{A_2 - A_1}{W_2 - W_1} \times \frac{\text{log e } W_2 - \text{log e } W_1}{\text{log e } A_2 - \text{log e } A_1}$$

Where, W_1, W_2, A_1 and A_2 were same as described earlier for other growth parameters.

Leaf area index

Leaf area index (LAI) was calculated as follows;

$$\text{Leaf area index} = \frac{\text{Leaf area}}{\text{Land area}}$$

Specific leaf weight

The specific leaf weight (mg cm^{-2}) is the ratio between leaf dry weight (WL) and leaf area (A). It is an indicator of thickness of the leaf or the leaf weight per unit leaf area, calculated as follows;

SLW = WL / A

Produce of net plot was threshed by using Pullman thresher. After winnowing, the grain yield was recorded.

RESULTS & 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 growth characters of crop plants under shading that determines final grain yield. The objective of the present study was to work out the growth characters of yield reduction in wheat crop under varying degree of shades.

Leaf Area Index (LAI)

The leaf area index in wheat was significantly influenced by varying degree of shade and wheat varieties 20, 40, 60, 80, 100 and 120 DAS during the growing season i.e. 2010-11. The maximum (0.45, 1.47, 3.78, 4.90, 5.04 and 0.99 in 2010-11) and significantly higher leaf area index was observed under severe shade (*i.e.* 2/3 shading) 20, 40, 60, 80, 100 and 120 DAS during 2010-11, which reduced significantly with each reduction in shade at all the stages during 2010-11. The interaction between varying degree of shade and wheat varieties was influenced significantly at all the stages, except at 20 DAS during 2010-11. The variety UP 2113 recorded maximum (0.42, 1.35, 3.27, 4.61, and 0.85 in 2010-11) and significantly higher leaf area index at 20, 40, 60, 100 and 120 DAS, being at par with UP 2526 at 80 DAS during 2010-11. The minimum and significantly lowest leaf area index was observed in UP 2565 at 20, 40, 100 and 120 DAS during the growing seasons i.e. 2010-11. Whereas, the UP 2565 recorded lowest leaf area index at 60 and 80 DAS in 2010-11 during both the years *i.e.* 2010-11. Leaf area plays a significant role in growth and development as it intercepts radiation and provides the photosynthetic surface in plants (Singh and Gupta, 1970). The leaf area development was slow up to 40 days followed by rapid development upto 100 days and thereafter, it declined (Table 1). The leaf area development was better in severe shade as compared to under full sunlight (i.e. control) and mild shade (1/3 shading). Similar pattern in leaf area development under Populus has been reported by Jain (1998). As far as wheat varieties are concerned, significant variations in their leaf area index were recorded, as has also observed by Singh (1988) and Kumar (1989). The leaf area development which is the function of leaf length and width, has increased by each successive increase in shade at all the growth stages as also reported in sunflower by Trapani *et al.* (1992) and of general vegetation by Cohen *et al.* (2002).

TABLE 1: Leaf area index (LAI) and Specific leaf weight (SLW) (mg cm^{-2}) of different wheat varieties and under varying degree of shades at various growth stages during the growing season

Treatment	2010-11											
	20 DAS		40 DAS		60 DAS		80 DAS		100 DAS		120 DAS	
	LAI	SLW	LAI	SLW	LAI	SLW	LAI	SLW	LAI	SLW	LAI	SLW
A. Degree of shades												
L0 – Full sun light	0.33	1.88	0.94	3.97	1.77	6.42	2.94	4.14	3.45	5.32	0.44	3.42
L1 – Mild shade	0.38	1.61	1.13	2.89	2.76	3.45	4.35	2.74	4.14	3.94	0.79	1.64
L2 – Severe shade	0.45	1.28	1.47	1.86	3.78	2.10	4.90	2.33	5.04	2.93	0.99	1.14
SEm±	0.01	0.01	0.01	0.04	0.04	0.02	0.02	0.02	0.03	0.06	0.01	0.05
CD at 5 %	0.01	0.03	0.04	0.15	0.14	0.08	0.08	0.06	0.12	0.22	0.01	0.18
B. Wheat varieties												
UP 2684	0.37	1.63	1.12	2.94	2.48	3.71	3.79	3.23	4.14	4.17	0.72	2.02
UP 2526	0.40	1.38	1.19	2.84	3.07	3.07	4.35	3.17	4.39	3.46	0.79	1.91
UP 2565	0.36	1.78	1.06	3.26	2.26	5.18	3.96	3.23	3.60	4.30	0.65	2.36
UP 2113	0.42	1.36	1.35	2.41	3.27	3.50	4.27	2.65	4.61	4.14	0.85	1.90
PDW 233	0.38	1.79	1.17	3.09	2.77	4.49	3.94	3.08	4.32	4.25	0.67	2.15
SEm±	0.01	0.02	0.01	0.05	0.04	0.07	0.06	0.07	0.07	0.08	0.01	0.11
CD at 5 %	0.01	0.06	0.04	0.16	0.11	0.19	0.17	0.19	0.19	0.22	0.03	0.31
CV (%)	3.30	3.80	3.60	5.60	4.20	4.90	4.30	6.50	4.80	5.60	3.90	15.50
Interaction(Ax B)	NS	S	S	S	S	S	S	S	S	S	S	NS

S - Significant NS - Non-significant

TABLE 2: Crop growth rate (g m^{-2} day^{-1}) and Relative growth rate (mg g^{-1} day^{-1}) of different wheat varieties and under varying degree of shades at various growth stages during the growing season

Treatment	2010-11									
	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	CGR	RGR	CGR	RGR	CGR	RGR	CGR	RGR	CGR	RGR
A. Degree of shades										
L0 – Full sun light	2.90	21.90	12.16	57.59	23.53	90.48	18.79	58.18	5.05	6.92
L1 – Mild shade	2.48	21.34	7.89	56.77	20.01	84.66	17.38	56.32	3.23	5.23
L2 – Severe shade	2.02	19.54	6.78	56.62	17.72	77.19	15.09	55.49	1.82	3.74
SEm±	0.03	0.10	0.11	0.16	0.19	0.18	0.17	0.39	0.11	0.02
CD at 5 %	0.12	0.39	0.42	0.60	0.77	0.69	0.66	1.56	0.42	0.07
B. Wheat varieties										
UP 2684	2.41	20.74	8.25	53.02	19.15	82.47	16.15	51.36	4.72	7.99
UP 2526	2.44	20.29	10.29	57.87	20.02	84.47	16.39	57.86	3.39	5.19
UP 2565	2.55	24.11	9.02	56.72	19.62	87.34	19.38	56.72	2.22	3.46
UP 2113	2.34	18.77	7.78	59.88	22.48	81.54	15.93	59.88	3.35	4.94
PDW 233	2.62	20.71	9.37	57.49	21.83	84.73	17.56	57.49	3.15	4.92
SEm±	0.04	0.23	0.17	0.42	0.26	0.84	0.26	0.57	0.12	0.04
CD at 5 %	0.12	0.68	0.51	1.22	0.75	2.46	0.75	1.67	0.34	0.12
CV (%)	4.9	3.3	5.8	2.2	3.8	3.0	4.5	3.0	10.3	2.3
Interaction (A x B)	NS	S	S	S	S	S	S	NS	S	S

S - Significant NS - Non-significant

Crop Growth Rate (CGR)

The crop growth rate (CGR) in wheat was significantly influenced by varying degree of shades and wheat varieties at 20-40, 40-60, 60-80, 80-100 and 100-120 DAS during 2010-11.

The maximum (2.90, 12.16, 23.53, 18.79 and 5.05 g m^{-2} day^{-1} in 2010-11)and significantly higher CGR was obtained under full sunlight at 20-40, 40-60, 60-80, 80-100 and 100-120 DAS, which reduced significantly with each increase in shade at all the crop growth stages during 2010-11. The interaction between magnitude of shades and wheat varieties was found to be significant at 40-60, 60-80, 80-100 DAS during the growing seasons *i.e.* 2010-11. The CGR in wheat varieties varied significantly at 40-60, 60-80, 80-100 and 100-120 DAS during 2010-11. Variety PDW 233 obtained maximum (2.62 and 21.83 g m^{-2} day^{-1} in 2010-11) and significantly higher CGR in 20-40 DAS, being at par with the variety UP 2113 (22.48 g m^{-2} day^{-1}) at 60-80 DAS during 2010-11. Whereas, UP 2526, UP 2565 and UP 2684 measured significantly higher CGR at 40-60, 80-100 and 100-120 DAS, respectively. The minimum (2.34, 7.78 and 17.56 g m^{-2} day^{-1} in 2010-11 and 2.37, 7.81 and significantly lowest CGR was recorded. In general, the mean crop growth rate (i.e. the biomass produced per unit area and time), increased rapidly upto the period of 80th day is in conformity with the results obtained Vrkoc (1973) who observed maximum CGR values at spike emergence stage in cereals like, spring and winter wheat, spring barley and oat. The CGR, which is the function of photosynthetic efficiency of available photosynthetic surface area, increased rapidly upto 60-80 days period and then declined at slower pace during 80-100 and rapidly during 100-120 DAS with significant variations among wheat varieties during all the crop growth stages (Table 2). Sarma (1977) also predicted poor CGR during early vegetative growth stage due to poor development of photosynthetic surface i.e. leaf area that peaked 60-75 days after sowing irrespective of wheat varieties.

Relative Growth Rate (RGR)

The relative growth rate (RGR) in wheat was significantly influenced by varying degree of shades and wheat varieties at all the crop growth stages during 2010-11. The interaction between degree of shades and wheat varieties was influenced significantly at all the stages of crop growth, except 80-100 DAS during 2010-11. The maximum (21.90, 57.59, 90.48, 58.18 and 6.92 mg g^{-1} day^{-1} in 2010-11 and significantly higher RGR was obtained under full sunlight (i.e. control) at all the crop growth stages, which reduced significantly with each successive increase in shades during the years *i.e.* 2010-11, with no significant difference between 2/3 and 1/3 of full sunlight availability at 40-60 and 80-100 DAS during 2010-11.

The wheat varieties showed significantly difference in their RGR at all the stages during 2010-11. The variety UP 2565 recorded significantly higher RGR at 20-40 (24.11 mg g^{-1} day^{-1}) and 60-80 DAS (87.34 mg g^{-1} day^{-1}); UP 2113 measured at 40-60 (59.88 mg g^{-1} day^{-1}) and 80-100 DAS (59.88 mg g^{-1} day^{-1}) and also UP 2684 at 100-120 DAS (7.99 mg g^{-1} day^{-1}) during 2010-11. The minimum and significantly lower RGR was obtained in UP 2113 at 20-40 and 60-80 DAS; UP 2684 at 40-60 and 80-100 DAS and also UP 2565 at 100-120 DAS during 2010-11.The mean relative growth rate (mean RGR) which is net increase in dry matter per unit of dry matter already present, increased and peaked during early growth periods (from 20-40 to 60-80 DAS) and then decreased with advancement in age due to increased mutual shading between and within plant organs, probably due to increased proportion of non-photosynthetic to photosynthetic plant tissue (Table 2). Narwal (1971) also observed peak in relative growth rate (RGR) during 37 to 44 days in wheat, which declined sharply between 45 to 51 days basically due to decrease in leaf area ratio with age of crop plant.

Net Assimilation Rate (NAR)

The net assimilation rate (NAR) in wheat was also significantly influenced by varying degree of shade at 40-60, 60-80, 80-100 and 100-120 DAS and different wheat varieties at all the crop growth stages during 2010-11. The interaction between degree of shade and wheat varieties was influenced significantly at all the stages of crop growth except at 60-80 DAS in 2010-11.The wheat NAR was maximum (0.115, 0.189. 0.313 and 0.120 mg cm^{-2} day^{-1} in 2010-11) and significantly higher under full sunlight at 40-60, 60-80, 80-100 and 100-120 DAS, which reduced significantly with each successive increase in shade during 2010-11, with no significant difference between 2/3 and 1/3 of full sunlight availability at 40-60 DAS in 2010-11. The wheat varieties differed significantly in their net assimilation rate at all the crop growth stage during the years. The maximum and significantly higher NAR was recorded varieties UP 2565 at 20-40 (0.160 mg cm^{-2} day^{-1}) and 100-120 DAS (0.142 mg cm^{-2} day^{-1}), respectively; varieties UP 2113 at 60-80 DAS (0.198 mg cm^{-2} day^{-1}) and also UP 2684 at 80-100 DAS (0.316 mg cm^{-2} day^{-1}) during the years, respectively.

TABLE 3: Net assimilation rate (mg cm^{-2} day^{-1}) and Leaf area ratio (cm^2 g^{-1}) of different wheat varieties and under varying degree of shades at various growth stages during the growing season

Treatment	2010-11									
	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	NAR	LAR	NAR	LAR	NAR	LAR	NAR	LAR	NAR	LAR
A. Degree of shades										
L0 – Full sun light	0.170	286.1	0.115	135.8	0.189	82.0	0.313	50.8	0.120	43.9
L1 – Mild shade	0.159	338.6	0.112	185.5	0.178	145.8	0.227	75.2	0.118	63.3
L2 – Severe shade	0.147	415.1	0.111	287.8	0.168	232.4	0.124	92.3	0.114	91.5
SEm±	0.001	1.3	0.001	0.9	0.001	2.3	0.001	0.4	0.001	0.6
CD at 5 %	0.001	5.1	0.001	3.6	0.003	8.9	0.002	1.6	0.001	2.2
B. Wheat varieties										
UP 2684	0.159	323.0	0.111	193.4	0.165	151.4	0.316	77.2	0.111	67.7
UP 2526	0.161	363.1	0.122	208.1	0.177	170.5	0.229	77.6	0.120	69.5
UP 2565	0.160	337.4	0.114	178.9	0.186	125.4	0.172	65.0	0.142	60.6
UP 2113	0.160	380.0	0.112	243.4	0.198	178.0	0.221	76.2	0.101	68.1
PDW 233	0.153	329.6	0.105	191.3	0.165	141.7	0.169	67.9	0.114	65.3
SEm±	0.001	3.4	0.001	3.1	0.003	2.7	0.002	1.0	0.001	0.8
CD at 5 %	0.003	9.9	0.002	9.1	0.007	7.9	0.005	2.8	0.003	2.3
CV (%)	2.2	2.9	2.2	4.6	3.8	5.3	2.4	3.9	2.3	3.5
Interaction (A x B)	S	S	S	S	NS	S	S	S	S	S

S - Significant NS - Non-significant

Whereas, the variety UP 2526 was at par with UP 2684, UP 2565 and UP 2113 at 20-40 DAS in 2010-11. The minimum and significantly lowest NAR was observed in PDW 233 at 20-40, 40-60 and 60-80 DAS; UP 2565 at 80-100 DAS and also UP 2113 at 100-120 DAS during 2010-11. The mean Net assimilation rate (NAR), an indicator of photosynthetic efficiency per unit surface area of a plant, increased with time i.e. from 40-60 DAS under all shaded treatment (*i.e.* full, 2/3 and 1/3 light availability) and varied significantly amongst wheat varieties (Table 3). Vrkoc (1973) also reported maximum NAR at spike emergence stage in wheat and barley and is said to be influenced mainly by leaf area index. However, the mean NAR was not influenced significantly by varying degree of shades, meaning, thereby, that shade did not influence the photosynthetic sufficiency in early growth periods or even low light intensity was enough to saturate the rate of photosynthesis.

Leaf Area Ratio (LAR)

The leaf area ratio (LAR) in wheat was significantly influenced by varying degree of shade, different wheat varieties and interaction between them at all the crop growth stages during season *i.e.* 2010-11, The maximum (415.1, 287.8, 232.4, 92.3 and 91.5 cm^2 g^{-1} in 2010-11) and significantly higher leaf area ratio was obtained under severe shade at all the crop growth stages, which reduced significantly with each successive reduction in shade at all the crop growth stages during 2010-11.

The leaf area ratio of wheat varieties significantly varied at all the stages during 2010-11. The variety UP 2113 recorded maximum (380.0, 243.4, 178.0, 76.2 and 68.1 cm^2 g^{-1} in 2010-11) and significantly higher leaf area ratio at all the crop growth stages, being at par with UP 2684 and UP 2526 at 80-100 and 100-120 DAS during 2010-11. The minimum and significantly lowest leaf area ratio was obtained in UP 2565 at 40-60, 60-80, 80-100 and 100-120 DAS during 2010-11. Whereas, UP 2684 obtained significantly lowest leaf area ratio at 20-40 DAS being at par with PDW 233 during 2010-11.

Mean leaf area ratio (LAR), which is the amount of leaf area supporting unit dry weight of plant or the ratio between photosynthetic to non photosynthetic biomass. The mean leaf area ratio was maximum during 20-40 which decreased rather rapidly during 60-80, 80-100 and 100-120 DAS during 2010-11 (Table 3). Although during all the crop growth periods, severe shades favored the mean LAR due to better leaf expansion under shade with low specific leaf weight. Similar pattern of LAR was obtained by Thomas and Yaduraju (2000) who observed that LAR of wheat and wild oat peaked by 60 days and then started declining. The increase in LAR during early growth and decrease in later stage also indicates the leaves to be the priority sink initially for better development of photosynthetic surface area (Friend *et al*., 1965).

Specific Leaf Weight (SLW)

The specific leaf weight (SLW) in wheat was influenced significantly by varying degree of shades at 40, 60, 80, 100 and 120 DAS and wheat varieties at all the stages of crop growth during 2010-11,(Table 1). The interaction between degree of shades and wheat varieties was influenced significantly at 40, 60, 80 and 100 DAS, except at 120 DAS during the year (*i.e.* 2010-11). The significantly higher (3.97, 6.42, 4.14, 5.32 and 3.42 mg cm^{-2} in 2010-11 specific leaf weight was obtained under full sunlight (i.e. control) at 40, 60, 80, 100 and 120 DAS, which reduced significantly with each successive increase in shade during 2010-11. The specific leaf weight of wheat varieties significantly varied at all the crop growth stages during 2010-11. The variety UP 2565 obtained maximum (1.78, 3.26, 5.18, 3.23, 4.30 and 2.36 mg cm^{-2} in 2010-11) and significantly highest specific leaf weight at all the crop growth stages, being at par with PDW 233 at 20, 80 and 100 DAS; UP 2684 at 80 and 100 DAS; UP 2526 at 80 DAS and also UP 2113 at 100 DAS during 2010-11. However, the variety UP 2113 obtained significantly lowest specific leaf weight at 20, 40, 80 and 120 DAS and also UP 2526 at 60 DAS during 2010-11.

The specific leaf weight (SLW), a measure of leaf thickness, was relatively higher at 60^{th} day which slightly decreased at 80^{th} day and again increased to the maximum at 100^{th} day, indicating the maximum leaf area development/expansion during tillering and early jointing stage of crop i.e. around 80 days stage (Table 1) during 2010-11. The increased degree of shade (from full to 2/3 and than to 1/3 light availability) decreased the mean SLW at all the crop growth stages during 2010-11. Among the varieties; UP 2565 had highest SLW at all the stages but it was not found to be significantly different than PDW 233 at 20, 80 and 100 DAS; UP 2684 at 80 and 100 DAS UP 2113 at 100 DAS during 2010-11. Shyam (1986) also reported slight increase in SLW after anthesis with significant varietal differences.

YIELD

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 4). The reductions 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.

TABLE 4: Biological, Grain and Straw yield (q ha^{-1}) and Harvest index (%) in different wheat varieties and under varying degree of shades during the growing season

Treatment	2010-11			
	Biological yield	**Grain yield**	**Straw yield**	**Harvest Index**
A. Degree of shades				
L0 – Full sun light	104.1	42.9	61.2	41.1
L1 – Mild shade	78.8	29.9	48.9	38.1
L2 – Severe shade	60.2	20.6	39.6	34.4
SEm±	0.4	0.1	0.1	0.3
CD at 5 %	1.7	0.6	0.5	1.0
B. Wheat varieties				
UP 2684	79.4	29.4	49.9	36.4
UP 2526	85.8	32.5	53.3	37.2
UP 2565	87.1	33.6	53.5	37.9
UP 2113	67.9	25.7	42.2	37.9
PDW 233	87.9	34.3	53.5	39.7
SEm±	0.8	0.4	0.5	0.4
CD at 5 %	2.2	1.1	1.6	1.2
CV (%)	2.8	3.5	3.3	3.1
Interaction (A x B)	S	S	S	S

S - Significant NS - Non-significant

CONCLUSION

Higher grain yields of the variety PBW 233 can be ascribed to its higher crop growth rate and specific leaf weight among the varieties. Moreover, these characters were unaffected by different levels of shades in the same variety. 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 crop growth rate and specific leaf weight.

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