MORPHO-PHYSIOLOGICAL BASES OF SHADE TOLERANCE IN WHEAT VARIETIES

Thesis

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By

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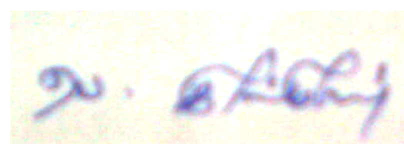

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CERTIFICATE

This is to certify that the thesis entitled **"MORPHO-PHYSIOLOGICAL BASES OF SHADE TOLERANCE IN WHEAT VARIETIES",** submitted in partial fulfillment of the requirements for the degree of **Doctor of Philosophy** with major in **Agronomy** and minor in **Plant Physiology** of the College of Post Graduate Studies, G.B. Pant University of Agriculture and Technology, Pantnagar, is a record of *bona fide* research carried out by **Mr. P. Lakshmanakumar, Id. No. 39349,** under my supervision, and no part of the thesis has been submitted for any other degree or diploma.

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Pantnagar
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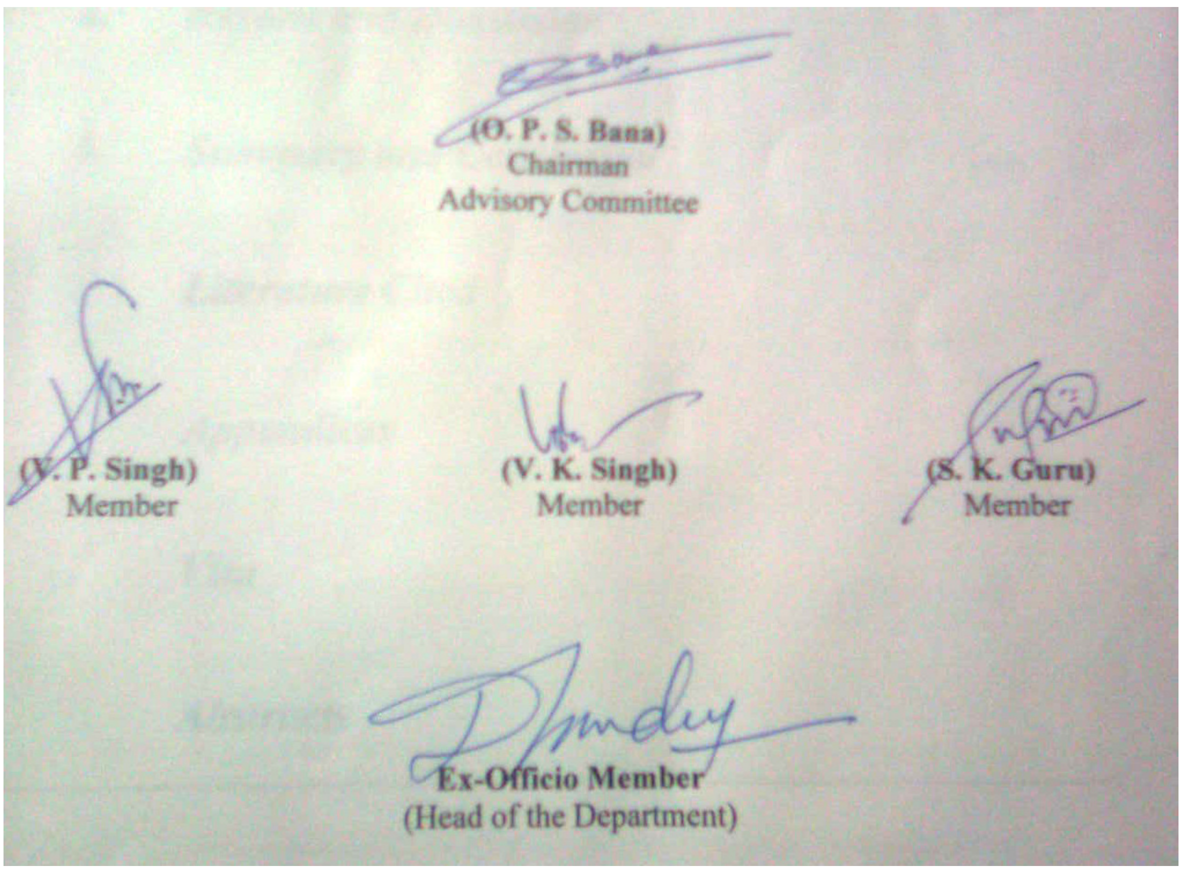
We, the undersigned, members of the advisory committee of **Mr. P. Lakshmanakumar, Id. No. 39349**, a candidate for the degree of **Doctor of Philosophy**, with major in **Agronomy** and minor in **Plant Physiology**, agree that the thesis entitled **"MORPHO-PHYSIOLOGICAL BASES OF SHADE TOLERANCE IN WHEAT VARIETIES",** may be submitted in partial fulfillment of the requirements for the degree.



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LIST OF ABBREVIATIONS

N	:	Nitrogen
P	:	Phosphorus
K	:	Potassium
^oC	:	Celsius
m	:	Metre
g	:	Gram
ha	:	Hectare
m^{-2}	:	Square metre
cm	:	Centimetre
cm^2	:	Square centimetre
mm	:	Millimetre
nm	:	Nanometre
CD	:	Critical difference
NS	:	Non significant
Fig.	:	Figure
Max.	:	Maximum
Min.	:	Minimum
RH	:	Relative humidity
RF	:	Rainfall
SEm	:	Standard error of means
CAP	:	Canopy apparent photosynthesis
PAR	:	Photosynthetically active radiation
LIE	:	Light interception efficiency
LAI	:	Leaf area index
CGR	:	Crop growth rate
RGR	:	Relative growth rate
NAR	:	Net assimilation rate

LAR	:	Leaf area ratio
SLW	:	Specific leaf weight
DAS	:	Days after sowing
DAA	:	Days after anthesis
HI	:	Harvest index
pH	:	Negative logritham of hydrogen ion
Kg ha^{-1}	:	Kilogram per hectare
q ha^{-1}	:	Quintal per hectare
No. m^{-2}	:	Number per square metre
g m^{-2} day^{-1}	:	Gram per square metre per day
mg g^{-1} day^{-1}	:	Milligram per gram per day
mg cm^{-2} day^{-1}	:	Milligram per square centimetre per day
cm^2 g^{-1}	:	Square centimetre per gram
mg cm^{-2}	:	Milligram per square centimetre
g $shoot^{-1}$	:	Gram per shoot
g m^{-2}	:	Gram per square metre
g $plant^{-1}$	:	Gram per plant
lux cm^{-2} s^{-1}	:	Lux per square centimetre per second
mmol CO_2 m^{-2} s^{-1}	:	Millimole carbon dioxide per square metre per second
µmol CO_2 m^{-2} s^{-1}	:	Micromole carbon dioxide per square metre per second
mmol H_2O m^{-2} s^{-1}	:	Millimole water per square metre per second
mg g^{-1} F.wt.	:	Milligram per gram fresh weight
chl a/b	:	Chlorophyll a/ chlorophyll b ratio
%	:	Per cent
PS II	:	Photosystem II

Introduction

India harvested 81.0 million tonnes of wheat from 29 million hectare with the average yield of 2.8 tonnes per hectare (Economic Survey, 2010-11). Besides due to ever increasing population, the land resources are not capable of fulfilling the associated demands for food, fodder, timber, fuel etc and hence, increased pressure on the world's resources and natural ecosystems were inevitable, predictable and will become more severe in future. These increased pressures on a fixed land base form the context within which forestry with agriculture (Agroforestry land-use) seems to be a logical solution to meet the requirements of fast growing population in sustainable manner and also ensure environmental stability and provide socio-economic security (Yadav, 1990). Wheat production needs to be augmented to meet food and nutritional security of the burgeoning population largely through enhanced productivity.

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 CO_2 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).

Changes in radiation influence both photosynthetic light- and carbon-use efficiency, and will ultimately affect total grain yield. Shading during any developmental stage significantly impairs net photosynthesis in wheat leaves via changes in the functioning of chloroplast and inhibition of the activity of photosystem II (PSII) (Mu *et al*., 2010). The leaf chlorophyll content increases and chlorophyll a/b ratios decrease under these conditions. Thus the proportion of antenna pigments in the light-harvesting complex is increased in order to improve the light-use efficiency of the PSII reaction centres. However, this strategy is not universal as decrease in chlorophyll content and increase in chlorophyll a/b ratios have also been found in other varieties (i.e. seashore paspalum and bermudagrass) (Jiang *et al*., 2004).

It should be noted that canopy photosynthetic rate is considered to be more important than single leaf photosynthesis (Pn) in determining constraints to crop production (Zelitch, 1982). 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). In addition, light fractions distributed differently within the plant canopy as the upper sunlit leaves usually receive both diffuse and direct radiation while the lower shaded leaves receive more diffuse light. Thus, low light level is common for lower leaves, which are more shade tolerant and can use diffuse light more efficiently than direct irradiance (Gu *et al*., 1999). For instance, Pn of the lower leaves increased to partially compensate the Pn reductions of the flag leaf, which could account for the slight decrease in canopy photosynthesis in wheat (Mu *et al*., 2010).

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 management could be agronomically manipulated, the crop/varietal selection is more important for shade tolerance in agroforestry. Yield reductions in various vegetative and grain crops have been reported due to such interactions but the crop yield loss may well be compensated bio-economically through growth/yield of tree component. 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). According to an estimate (Ranganathan, 1979)**,** agroforestry can increase the Gross Net Production (GNP) of our country by about Rs. 10,000 crores, provide employment to 30 million people and if seriously practiced for years, can banish poverty forever.

Genotypic variations exist in their performance with respect to agro-climatic conditions in general and availability of radiation in particular. The process of yield formation begins with seed sowing. The number of seedlings established, their assimilatory capacity in terms of leaf area and duration decide potential sink size in terms of number and size of wheat spikes. The environmental conditions prevailing during vegetative crop growth period determine the establishment of sink potential. The environment prevalent at the time of pollination, fertilization and seed development determines utilization of sink potential by influencing the rate and duration of assimilate supply to developing grains through photosynthesis mainly by flag leaf.

Since, the productivity in any agroforestry system depends primarily on selection of the component species, their number or population or proportion, arrangement (spatial or temporal) and management. Hence, the efforts are required to identify crops and their varieties suitable for sub-optimal growth conditions (particularly the light) in agroforestry like situations and develop alternate production technologies to minimize the yield losses. Good vegetative growth is prerequisite for economic yield in any grain crop as it determines the ultimate sink size. In most important *rabi* cereal crop i.e. wheat, the yield is determined by the number of spikes per unit area, number of grains per spike and 1000 grain weight. Therefore, any practice which influences these characters, will also affect the yield. So, in order to achieve maximum yield potential of wheat, it is necessary to select suitable crop variety under varying degree of shades which may vary with tree species, their age, arrangement, tree density etc, of agroforestry systems

Thus, it is essential to understand the variations in morphological and physiological process affecting yield and yield contributing characters owing to varying degrees of shade. Therefore, the present investigation was planned with following objectives:

1. to study the effect of varying degree of shades on morphological and physiological characteristics of wheat varieties,
2. to study the effect of varying degree of shades on the growth, yield and yield attributes in different cultivars of wheat, and
3. to identify the wheat variety tolerant to shade for use in agroforestry.

Review of Literature

In this chapter, an attempt has been to review the related work carried out in the past on wheat and other field crops in sole crop system and under partial shade conditions in general and agroforestry system, i.e., in agrisilvicultural system in particular. The literature is being presented under the heads of effect of reduced light availability on morphological characters, growth, physiological processes, light intensity and quality in crop canopies and yield and yield attributes with respect to the performance of wheat and other field crops.

2.1 Effect on morphological characters

2.1.1 Leaf size

Singh and Gupta (1990) opined that leaf area played a significant role in the growth and development of the plant and was virtually important character which contributed finally towards yield. Yoshida (1972) found that increased LAI raised dry matter production but this relation did not hold indefinitely because of increased mutual shading of leaves. However, Jain (1998) in an experimental conducted under poplar based agroforestry found that LA increased slowly upto 20 days after sowing and then with faster rate upto 80th days and declined then after with significant varietal differences. The varieties, UP 2338 and PBW 226 had maximum and minimum LA, respectively, at all the stages of crop growth both during 1995-96 and 1996-97.

Leaf size of a crop is a good indicator of the ultimate yield. In order to capture more light under shading conditions, plants are able to increase light interception efficiency by improving canopy cover, which can be expressed well in terms of leaf area index (LAI) (Li *et al*., 2010). In addition, higher tolerance to low light conditions is achieved through enhanced plasticity of light-harvesting variables (e.g. crown morphology and chlorophyll content (Valladares *et al*., 2002, 2003).

Single leaf area of the top three leaves increased in the shading treatments (Li *et al*., 2010), which was consistent with the response of LAI to shading. Thus, the increase in leaf area was highest in the flag leaf, followed by the penultimate leaf and the third leaf and the larger leaf area increase in the shade tolerant cultivar could contribute to effective interception of the limited light available.

2.1.2 Internodal length and weight

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). They also observed that where stems were found to be longer with lower specific internode weight, leaves to be thinner and leaf area to be larger under the applied shading treatments. The enlarged leaf area could partially compensate for the reduction in intercepted photosynthetically active radiation (PAR). In addition, the increment in the leaves area and larger internodes (e.g. the flag leaf area enlarged while the lengthened peduncle internode), indicated that higher plasticity to cope with shading treatments (Li *et al*., 2010).

Cruz-Aguado *et al*. (2000) reported that the loss of dry mass 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. The difference in the net loss of dry matter between the upper internodes and the lower internodes may be ascribed to the change in availability of photo-assimilates. Shading reduced the maximum weight of all the internodes, while increased the maximum weight of the first and penultimate internodes and it reduced the weight of all the internodes (Li *et al*., 2010).

2.1.3 Shoot height

Changes in red/far-red ratio have been shown to influence many aspects of crop development such as shoot length, tiller number and leaf angle (Smith and Whitelam, 1997).

Rai *et al.* (1990) reported decrease of varying magnitudes in plant height of various crops when intercropped with year old coppice crop of *Eucalyptus tereticornis*, compared to monocrop control. The reduction was highest in sorghum and least in fodder grains.

Nazir *et al.* (1993) studied the influence of *Dalbergia sissoo* on wheat crop and found that height was decreased under the canopy with increasing the duration of shading.

Sharma *et al.* (1996) investigated the influence of 25 year old *Syzygium cumini* shelterbelts on sorghum crop and recorded reduction in crop height numerically by 36.64 per cent upto 5 metre from tree belt as compared to plots located at 20.5 metre distance considered to be the open (control). In general, however, the impact of tree belt on crop growth was observed upto 8 metre and almost no impact beyond 8 metre. Slafer *et al*. (1996) claimed that the shading during stem elongation may reduce the number of spikes m^{-2} or not, will strongly depend upon the canopy structure in the particular situation in which shading is imposed; if the number of shoots m^{-2} is not much higher than the sowing rate, shading can scarcely affect this component, whereas in cases of profuse tillering, increased tiller mortality is caused due to shading during stem elongation.

2.1.4 Flag leaf area

Flag leaf area is the main source of photosynthetic activity contributing towards grain filling as compared to the lower leaves (Ali *et al*., 2010).

Ali *et al*. (2010) suggested that the flag leaf removal established a lesser effect on grain yield and its attributes in contrast to awns detachment and the detachment of both flag leaf + awns exhibited the maximum reduction in grain yield per plant through reduction in various spike components. Khaliq *et al*. (2008) revealed 18.32% decrease in yield due to the detachment of flag leaf blade and awns. Similarly, Birsin (2005) reported that flag leaf removal also resulted in significant reduction in the yield attributes like number and grain weight $spike^{-1}$ and 1000-grain weight. Gelang *et al*. (2000) suggested that the contribution of the flag leaf blade to grain filling increased over time. Similarly, longer green flag leaf area duration was related with the ability to maintain yield under drought (Li *et al*., 2010). However in drought conditions optimum flag leaf area is important for optimum photosynthetic activity as more area causes more transpiration losses (Ali *et al*., 2009).

Flag leaf and ear awn considerably affected grain yield and its attributes during grain filling stage (Ahmed *et al*., 2004; Khaliq *et al*., 2008) as the removal of either flag leaf, awns or both flag leaf + awns displayed substantial decline in grain yield $plant^{-1}$ and its related parameters.

2.1.5 Maximum number of shoots

Sharma *et al*. (1996) studied the influence of eucalyptus shelterbelt on sorghum (fodder crop) and noticed considerable reduction in plant density in the vicinity of tree row. Sharma *et al*. (1996) also reported significant reduction in plant density per unit area and number of tillers per plant in wheat and paddy intercropped with *Dalbergia sissoo*. Singh *et al*. (1996) in an experiment on wheat crop under shelter belts of poplar and shisham recorded significant reduction in crop density in fields sheltered by *P. deltoides* (30-50%) and *D. sissoo* (9-17%) as compared unsheltered fields.

Tiller senescence occur before the last tiller appeared, i.e. there was no overlap between tiller appearance and senescence (Evers *et al*., 2006). A tiller was considered to be senescing, when the youngest leaf stopped expending (Kirby and Riggs, 1978). The emergence of new tillers has been found to decrease strongly at a leaf area index (1.02) on 90 days after sowing (Simon and Lemaire, 1987; Lafarge and Hammer, 2002).

2.2 Effect of light on crop Growth

2.2.1 Shoot development and mortality

Establishment, growth and development of any crop (reflected by emergence count, maximum shoot and effective shoot count) is a good indicator of its ultimate yield of the crop. Randhawa and singh (1973) reported significant genotypic variation in number of tillers per plant which increased upto 90 days from sowing and then started decreasing. Significant difference in effective tillers per unit area of different varieties was also observed by Patel *et al.* (1982).

Park *et al.* (1986) recorded marked reduction (more than 25 per cent) in number of tillers and decreased number and length of root in grasses under forest shade compared to open. Singh (1993) in a study on wheat under E*ucalyptus* at pantnagar observed significant differences in number of shoots due to shade effect at all the growth stages, except 80 and 100 days after sowing.

Saxena (2002) also observed reduction in shoot count m^{-1} row under various poplar clone's plantation with least reduction under clone L52.

2.2.2 Dry matter accumulation and its partitioning

The net productivity or net assimilate accumulation (often approximated by total dry weight) by a crop is the function of the size of photosynthetic system and it's activity during the span of crop growth, while the latter implies for the rate of photosynthesis of leaf canopy, is a function of radiant energy, leaf are index and its display and diffusion of CO_2 in crop canopy.

Rao and Reddy (1984) reported that the application of *Eucalyptus* leaf extracts reduced the total dry matter/biomass produced by same food crops compared to control.

Hazra (1989) studied the effect of 20-30 per cent reduction in light intensity and recorded a decrease in the dry matter yields of *Trifolium alexandrinum* by 6 and 22 percent growth under *Acacia nilotica* and *Leucaena leucocephala* compared to open field, respectively. Similarly, while studying the effect of shading on the yield of dry matter in an Argentinian wheat cultivars, Savin and Slafer (1991) observed considerable decrease in above ground dry matter production of field grown wheat with increased shading upto 50 per cent of incident radiation. Nazir *et al*. (1993) established the shading effect of *D. sissoo* on wheat crop and found that increasing the duration of shading decreased the percentage of dry matter accumulation in plants. Patil *et al*. (1994) also detected significant differences in total dry matter accumulation per plant among wheat genotypes at all the growth stages of crop. Bana (1984) revealed that the dry matter accumulation as a function of time followed the sigmoid path in mungbean varieties. There was an "initial lag phase" upto 40^{th} days followed by 'log phase' from 41 to 60^{th} day and a phase of decreasing growth rate upto 70^{th} days. Thus the maximum dry matter accumulation obtained on the 70^{th} day.

Stem dry weight plant^{-1} in wheat cultivars was significantly affected under various tree species. Hossain *et al*. (2006) stated that the variation in leaf dry weight was significantly affected by trees. The highest leaf dry weight was produced (1.84 g) under open field which was statically similar to *Albizia lebbeck*. The lowest leaf dry weight (1.51 g) was found under *Psidium guajava* which was statistically similar to *Mangifera indica*. The leaf dry weight plant^{-1} varied significantly amongst the wheat varieties. The maximum leaf dry weight was produced (1.98 g) by Shotabdi in open field and the minimum leaf dry weight was found (1.18 g) in Protiva under *Psidium guajava*.

Chandra (2005) noticed that the dry weight of leaves of the mother shoot remained more or less constant until anthesis, but decreased thereafter more rapidly in Kalyansona than in PBW 273. Singh *et al*. (2002) measured total dry weight of upper three leaves and leaf sheath of flag leaf from anthesis onwards and found that their weight was relatively constant during most of the grain filling period.

Karnataka (1996) envisaged the positive correlation of grain yield with dry weight of leaves and spikes, while it was negatively correlated with that of stem dry weight. Spike dry weight continuously increased from ear emergence upto physiological maturity of the crop but was significantly reduced under various poplar clones, except under G48 (Saxena, 2002).

Dalirie *et al*. (2010) investigated the variation amongst winter wheat genotypes for dry matter accumulation and indicated the similar pattern under all the treatments (shading and non-shading) which slowly increased until 190-200 days after sowing and then increased rapidly until 270-280 days after sowing. Thereafter, until harvest time, it decreased due to hastened leaf senescence and decrease of LAI. Similar results were also reported by Stone and Nicolas (1995) and Guttieri *et al.* (2001) in spring wheat.

Increasing LAI is one of the ways of increasing the capture of solar radiation within the canopy and production of dry matter, as the dry matter accumulation was found to decrease with the decrease in LAI (Dalirie *et al*., 2010). Moreover, the LAI decreased with crop age due to aging of leaves which hastens leaf senescence, shading and competition between plants for light and other resources, especially when wheat encounters stresses like drought, high temperatures etc.

The total biomass at maturity was characterized by a consistent decrease as PAR intercepted by the crop was reduced due to between and within plants mutual shading. The shading treatment at jointing-anthesis also reduced harvest index, a fact that revealed that shading had greater effect on the grain number m^{-2} (and so grain yield) than on total biomass. Above-ground including spike dry weight at anthesis were consistently and similarly reduced by shading, and the survival of floret primordia was observed to be related to pre-anthesis spike growth (Fischer and Stockman 1986; Miralles *et al*. 1998; Gonzalez *et al*. 2005). It was, therefore, apparent that pre-anthesis shading would have affected grain number m^{-2} through concomitantly reducing the number of florets developing normally to fertility.

Photosynthesis of the exposed green parts could compensate the depletion of the remobilized dry matter from the peduncle internode. In contrast, losses of dry matter from the penultimate and lower internodes are hardly compensated by photosynthesis of lower leaves, which have much lower photosynthetic activity than the flag leaf (Takahashi and Nakaseko, 1993). Grain filling in the shade tolerant cultivar depended more on the assimilate supply from photosynthesis after anthesis than sensitive cultivar. Because it could remobilize more dry matter stored in vegetative organs into grains to alleviate the damage of low light when photosynthesis was impaired by shading.

Li *et al*. (2010) postulated the substantial redistribution of dry matter from stems into grains was found in both (YM 158 and YM 11) cultivars. The amount of redistributed dry matter from stems into grains increased in shaded treatment. This increase was mainly originating from the penultimate internodes under the relative low shading intensities, however, the amount of redistributed dry matter from lower portions of stems into grain decreased in lower shades. The contribution of remobilized dry matter to grain mass was found to be higher in lower shaded treatment. The increment of remobilized dry matter from stems into grains was much higher before anthesis than after anthesis (the contribution of before anthesis increased 4.62% in YM 158 and 1.39 % in YM 11), and this increase mainly originated from the lower internodes. This indicated that severe shading promoted the redistribution of stored dry matter from the lower internodes into the grains. Higher degree of shading had no significant effects on the amount of redistributed dry matter in leaves and showed limited contributions to grain filling (Li *et al*., 2010).

2.2.3 Growth indices

The concept of quantitative analysis of plant growth provides a critical approval to ecological and physiological interpretation of plant performance. Radford (1967) reviewed critically the mathematics involved in growth analysis. The crop growth rate (CGR) of any crop is influenced by leaf area index (LAI) under best light intensity.

Sharifi *et al.* (2011) noticed that the decrease in CGR towards maturity is due to senescence of lower leaves resulting decreased LAI and the mean CGR is linearly related to the mean growth rate of spikes. The light interception was positive and partitioning to the spikes were negatively related to CGR (Abbate *et al*., 1997). Similar results were also reported from other field experiments by Wall (1979) Fischer (1985) and Abbate *et al*. (1997) but the results may have been biased by the inaccurate determination of the duration of spike growth and because grain weight was not deducted from spike dry weight.

Total dry matter accumulation was reported to be influenced by relative growth rate (RGR), crop growth rate (CGR) and net assimilation rate (NAR) (Egli and Guffy 1997). The CGR is directly related to the amount of radiation intercepted by the crop (Jeffrey *et al.,* 2005). Dwyer *et al.* (1999) reported that increasing in plant population decreased LAI and NAR plant^{-1}, but increased these on per unit area.

Abbate *et al*. (1997) stated that during the spike growth period stems were the major sinks that grew the most (58-72% of crop growth) in unshaded treatments, followed by spikes (26-34%). But when CGR declined because of shading, spikes were a higher priority sink than stems and growth rate of spikes was affected less than that of stems. Earlier (1995) they also reported that partitioning to the spikes at 10 to 20 day intervals was maximum 5 to 10 days before anthesis, both with and without shading, while the maxima were higher with shading (up to 65%) than without shading (less than 40%), however, that the main effect of radiation on dry weight of spikes operated through crop and spike growth rates rather than by modifying partitioning.

De Costa and Rozana, (2000) noticed even in seedlings of forest tree species that there was a significant decrease of RGR with increasing shade level under both well watered and water stressed condition. The decrease in biomass of gains with increasing shade was probably because of the lower total photosynthesis resulting from reduced radiant energy receipt.

RGR decreased with the advancement of plant growth with decreasing plant population and reached to a minimum level at 284-298 days after planting . The reason of decreasing in RGR during later growth stages can be related to increased Non-photosynthetic biomass to photosynthetic biomass ratio. Similar observations have been reported by Jeffrey *et al*., (2005) and (Sharifi *et al*., 2011).

Net assimilation rate (NAR) was nearly the same for several species studied and remained almost constant during the vegetative phase (Heath and Gregory, 1938). Variation in NAR was in consequential and relative to variation in leaf area. Hence, importance but yet it is difficult to measure NAR and its use in accounting for change in relative growth rate (RGR) with plant development and environmental influences as compared to leaf area (Watson, 1952) Net assimilation rate decrease with age, as a result of decrease in rate of photosynthesis and not due to increased rate of respiration (Watson *et al.,* 1966), relative growth rate and net assimilation rate of wheat were the greatest during 37-44 days and there was a very sharp decline in RGR and LAR between 41-51 days after which the value increased, again followed by further declines depending upon the plant concentration (Narwal and Sarma, 1992).

Rao *et al.* (2002) suggested that LAI and leave's architecture are the two main characteristics that define light interception in the canopy. Plant population modifies the canopy structure and influenced light interception, dry matter production and hence the crop yield in barley cultivars (Fukai *et al*., 1990).

Grace and Russell, (1982) reported that the shelter and shade appeared to act together to increase the specific leaf area (SLA). There was a general trend for SLA to decline with distance away from the windbreaks i.e. a response to shelter, and within 1 hour, SLA was greater on the more shaded southern and eastern aspects than on the less shaded and sheltered northern aspect. Chirko *et al*. (1996) found that the time of day and growth stage of wheat when shaded by tree was critical in setting yield. Greater shade will affect tillering limiting both carbohydrate sources and sinks and subsequently grain yield. They also observed that the SLW of the flag and penultimate leaves was higher in shaded treatments than control, while SLW of other leaves was higher in control than in shaded treatments. The results obtained by them indicated that shading increased single leaf areas and that shading intensities higher than 15% could reduce leaf thickness, while a low shading intensity of 8% could thicken the flag leaf and the penultimate leaf.

Canopy size (in terms of leaf area index) is related to the light interception efficiency (LIE) (Ariosa *et al*., 2006). Canopy structure or spatial distribution of leaf area would change to improve LIE and then to compensate the decrease in canopy size

(LAI) to improve inception of incident radiation under shading (Delagrange *et al*., 2006). The LAI, defined, as the total one-sided leaf area per unit ground area, is one of the most important parameters characterizing a canopy. Because LAI most directly quantifies the plant canopy structure, it is highly related to a variety of canopy processes, such as evapo-transpiration, light interception, photosynthesis, respiration and leaf litterfall. LAI increased with increasing shading intensity at both 10 and 30 days after anthesis (DAA) (Li *et al*., 2010) and noted that LAI of both the upper and lower leaf layers increased under the shading treatments, as compared to the control. From 10 to 30 DAA, the LAI in all treatments decreased rapidly, but the rate of decline was slower in the shaded treatments than in the control.

Sharifi *et al.* (2011) found that LAI increased during plant growth with increasing plant population and reached to a maximum level at 228-242 days after planting. From 242 days after sowing, LAI decreased due to increasing aging of leaves, shading and competition between plants for light and other resources.

Canopy Apparent Photosynthesis (CAP) depends on canopy size (LAI) and average single leaf Photosynthesis. A compensation effect was found between Pn and leaf area ratio (LAR, i.e. leaf area per unit leaf dry matter) and Pn decreased proportionally while LAR increased with decreasing light intensity (Blackman and Wilson, 1951). Relatively low-intensity shading improved growth of winter wheat through improved capacity of capturing light due to the enlarged canopy size (higher LAI), resulted from changed canopy architecture such as lengthened peduncle internode, enlarged and thinned upper leaves, and increased pigment contents.

2.3 Effect of light on Physiological processes

More than 90% of crop biomass is derived from photosynthetic products. Therefore, many crop scientists believe that enhancing photosynthesis at the level of the single leaf would increase yields (Makino, 2011). Evans (1989) found that rice and wheat show the highest rates of photosynthesis per unit of leaf N content which has been upto 10 times higher than some evergreen trees. This variation is also evident in the data when expressed on a dry weight basis. Such higher rates of photosynthesis in both crops may be caused by greater N allocation to Rubisco (Makino *et al*., 1992) and higher mesophyll conductance (Von Caemmerer and Evans, 1991) compared to other plants.

2.3.1 Intercellular CO_2 concentration, photosynthesis, transpiration and stomatal conductance in canopy

CO_2 gas exchange of a leaf is influenced by number of environmental factors. Photosynthesis taking place in ear produces assimilates, which are directly deposited in the grains at grain filling stage. The leaf photosynthesis rate of a given plant is subjected to great variation due to changes in the environment under which it is grown, age, and demand by sink.

Loreto *et al*. (1994) envisaged that the rate of photosynthesis declined as flag leaf senesced which could be attributed in part to the reduction of mesophyll conductance of CO_2.

Li *et al*. (2010) made attempts to know where any variation existed in photosynthetic rates among wheat varieties and found that the range of photosynthetic rates in flag leaf of 61 varieties was 19.97 to 32.66 mg CO_2 dm^{-2} h^{-1}. The photosynthetic rate was maximum at flowering. The responses of Photosynthesis (Pn) to shading differed between leaf positions and amongst the cultivars (Li *et al*., 2010). Pn of the third leaf was increased by the shading treatments. During the last 10 functional days (20–30 days after anthesis (DAA) for flag leaf, and10–20 DAA for penultimate and the third leaf), Pn of the top three leaves dropped rapidly. However, the decline was much slower under shaded conditions than in the control. As a result, Pn was the highest in shading, indicating that shading potentially prolonged the functional duration of the uppermost three leaves.

Stomatal conductance (Gs) is a measure of the maximum rate of passage of carbon dioxide into the leaf. Diffusion of CO_2 into the leaves is mainly driven by the stomatal aperture and linearly correlates with photosynthetic capacity (Wong *et al*., 1979). It plays an important role in the physiological processes of plant modulated by the environmental regime (Korner *et al*., 1979). Stomatal conductance for CO_2 could be the measure of carbon-dioxide availability and changes in nearly the same proportion as the rate of assimilation of CO_2. The Pn decrease could be explained by reduction in stomatal conductance, which reduced CO_2 diffusion into the leaves (Condon *et al.* 2002). However, the internal CO_2 concentration remained stable under water deficit condition and was similar to that observed in well-watered condition (Bogale *et al*., 2011). Thus, they enunciated that the reduced stomatal conductance was not supposed to be a major cause for the reduced Pn and the effect of water deficit on photosynthesis may be due to enzyme inactivation resulted from high leaf temperature and low leaf water potential (non-stomatal limitation) (Bogale *et al*., 2011).

Shading generally decreases crop yields by reducing photosynthetic photon flux density (Qp) and correspondingly, the crop photosynthesis (Monteith 1972). Canopy photosynthetic rate is considered to be more important than single leaf net photosynthesis (Pn) in determining constraints to crop production (Zelitch 1982). It is interesting that decrease of 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 (Schulze and Caldwell, 1994).

Wheat grain yield losses and LAI reduction were less than the reduction in solar radiation under shading. The decrease in flag leaf Pn of flag leaf was partially compensated by the increase in Pn of third leaf from top. More of excitation energy was dispersed via the non-photochemical approaches in the photosystem II (PSII) of flag leaf after long term shading (Mu *et al*., 2010). For instance, Pn of the lower leaves increased to partially compensate the Pn reductions of the flag leaf, which could account for the slight decrease in canopy photosynthesis in wheat. Small reduction in radiation showed that shading reduced Pn of wheat flag leaf (Mu *et al*., 2010). However, the enhanced use efficiency of the absorbed light due to increase in diffusion radiation, especially of blue light, increased Chlorophyll *b* content as well as improved PSII activity as indicated by the measured chlorophyll fluorescence parameters and the enhanced redistribution of dry matter into grains (Li *et al*., 2010). The increase in Fo/Fm under shading suggested that the excitation energy used for photochemical conversion in PS II declined after long-term treatment of shading in wheat (Mu *et al*., 2010).

The reduction in PAR via shading was accompanied by an increase in the fraction of diffused light and also changed spectral fractions (decrease in red light and increase in blue light), which is consistent with other experiments (Bell *et al*., 2000).

These changes in the fractions of the diffused light and the visible spectra in the canopy could help compensate PAR reduction by improving leaf Pn under shading (Sinclair *et al*., 1992; Rochette *et al*., 1996; Gu *et al*., 1999, 2002). Blue light is reported to improve the formation of the photosynthetic apparatus of chloroplasts (Weston *et al*., 2000), and is more effective than red light in promoting chlorophyll synthesis (Bach and Krol, 2001). Accelerated CO_2 gas exchange, and increased activities of photosynthetic electron transport and of Rubisco by blue light have also been reported by several workers (Sharkey and Raschke, 1981; Eskins *et al*., 1991; Talbott *et al*., 2002).

An increase in the photosynthetic pigment content is established for long now to contribute capture and use light more effectively (Possingham and Smith, 1972; Kasemir, 1979; Shaver *et al*., 2008). Reduction in light intensity and changes in light spectrum under shade have been shown to alter chloroplast ultrastructure and chlorophyll components (Nii and Kuroiwa, 1988; Zhang et al., 1995; Hikosaka, 1996; Evans and Poorter, 2001). In addition, changes of light absorption, electron transport and of the primary light energy conversion in PS II have also been reported by several other workers (Anderson, 1982; Van-Rensen and Curwiel, 2000; Govindjee, 2002; Minagawa and Takahashi, 2004).

Changes in radiation influence both photosynthetic light- and carbon-use efficiency, and will ultimately affect total grain yield (Bell *et al*., 2000; Jiang *et al*., 2002; Greenwald *et al*., 2006; Zhang *et al*., 2007). Shading applied during any developmental stage significantly impaired net photosynthesis in wheat leaves (Wang et al., 2003; Mitchell et al., 2006; Acreche *et al*., 2009; Mu *et al*., 2010) probably via changes in the functioning of chloroplasts (Burkey and Wells, 1991) and inhibition of the activity of photosystem II (PSII) (Mu *et al*., 2010). It has been found that leaf chlorophyll content increases and chlorophyll a/b ratios decrease shading under developmental stage conditions (Zhang *et al*., 1995; Hikosaka, 1996; Evans and Poorter, 2001; Dai *et al*., 2009). Thus the proportion of antenna pigments in the light-harvesting complex is increased in order to improve the light-use efficiency of the PSII reaction centres (Dai *et al*., 2009). However, this strategy is not universal as decreases in chlorophyll content (Mu *et al*., 2010) and increases in chlorophyll a/b ratios have been found in other species/varieties (Jiang *et al*., 2004).

2.3.2 Chlorophyll content

The relationship between chlorophyll content and leaf age is non-linear and the rate of decrease in chlorophyll could denote the duration of functional period of leaf which was found to be closely related to the accumulation of photosynthates. Chlorophyll content was positively correlated with individual leaf area, leaf dry weight, net assimilation rate and dry matter accumulation in wheat, and also a positive correlation between chlorophyll content and yield and leaf area index was observed in wheat (Kler and Bains, 1989). Chlorophyll 'a' may be considered as an index for screening of germplasm for higher productivity at early stages of crop growth in wheat (Khallak *et al*., 1992).

Li *et al*. (2010) reported that the shading enhanced the pigment content in the uppermost three leaves by increasing the contents of chlorophyll a and b (Chl a and Chl b). However, the ratio of Chl a/b under the shading treatments to that under the control was lower than 1, and decreased with increasing shading intensity. This indicated that shading reduced Chl a/b, and that the increase of Chl b content due to shading was higher than the Chl a content. The pigment content and Chl a/b in the penultimate and the third leaves showed similar patterns to the flag leaf and the increases in Chl b contents were even of higher magnitude than in the flag leaf (Li *et al*., 2010). The increase in Chl b content would improve the proportion of the antenna pigments in light-harvesting complex II, and enable the leaves to effectively catch light, especially the blue light fraction (Zhang *et al*., 1995; Hikosaka, 1996). Due to the larger interception of radiation by the uppermost leaves, only little radiation reached the leaves in the lower canopy with high shading tolerance (Stanhill and Cohen, 2001; Greenwald *et al*., 2006). This also could help explain the compensation effect of the improved Pn in the penultimate and third leaves (Mu *et al*., 2010).

These adaptations appear to enhance light absorption and energy transfer in shady environments, where far-red light is more abundant. The sieve effect of light in leaf due to the fact that chlorophyll is not uniformly distributed throughout cells but instead is confined to the chloroplasts. The packaging of chlorophyll results in shading between the chlorophyll molecules and creates gaps between the chloroplasts, where light is not absorbed-hence the reference to a sieve. Because of the sieve effect, the total absorption of light by a given amount of chlorophyll in a palisade cell is less than the light absorbed by the same amount of chlorophyll in a solution (Taiz and Zeiger, 2002). Greater chlorophyll contents enhance light capture and when combined with greater stomatal conductance and water potential allows greater photosynthesis (De Costa and Rozana, 2000).

2.4 Light intensity and quality in crop canopy

Light environment in agroforestry is modified and become different than of sole crop, as tree canopy is first to intercrop the radiation and the remaining transmitted radiation is available for the understorey crop.

Nandal *et al*. (1999) reported adverse effect on yield of wheat in shisham based agri-silviculture system and concluded that reduction might be attributed mainly to reduced availability of PAR to wheat crop because the rate of biomass in many cereal crops has been found to be proportional to the intercepted radiation (Boscoe and Gallagher, 1977). Sheikh and Chima (1976) and Sheikh and Haq (1978) have also attributed poor growth of wheat under closely spaced shisham to decreased light availability. However, Pant and Bana (1998) reported that the reduction in light availability has been of greater magnitude than the relative loss in grain and straw yields.

Dimming or shading not only reduced radiation but also increased the fraction of diffuse light (Greenwald *et al*., 2006) and altered the spectral quality (Bell *et al.,* 2000). Diffused light was found to be more efficiently utilized by plants (Gu *et al*., 2002), and could offset small decreases in direct radiation and actually enhance leaf CO_2 uptake, photosynthesis and plant growth (Cohan *et al*., 2002). Meanwhile, with increasing intensity of shading, the fraction of blue light (400–500 nm) increased while that of red light (600-700 nm) decreased (Bell *et al*., 2000), to affect both the physiological parameters (i.e. photosynthesis and chlorophyll synthesis (Blackwell, 1966)) as well as plant morphology (i.e. main culm development (Barnes and Bugbee, 1992), tillers appearance (Casal, 1988) and stomatal conductance (Furuya *et al*., 1997).

When photosynthetic CO_2 uptake and respiratory CO_2 release are in equilibrium, there is no net gas exchange detectable, light compensation point (Ic) can be determined. Plants that respire more intensely, require more light for compensation. Several earlier studies revealed that shading could reduce crop dry matter accumulation and yield (Wang *et al*., 2003; Demotes-Mainarda and Jeuffroy 2004) in wheat. The variations in spectral quality also affect crop physiological process, growth and yield under shading (Causin *et al*. 2006).

Pearcy, (2007) has stated reported that longer and thinner plants, increased area of leaf blades, and increased shoot to root ratios have been observed under shading. In addition, light fractions is distributed differently within the plant canopy as the upper sunlit leaves usually receive both diffuse and direct radiation while the lower shaded leaves receive more diffuse light (Spitters *et al*., 1986). Thus, low light level is common for lower leaves, which are more shade tolerant (Stanhill and Cohen, 2001) and can use diffused light more efficiently than direct irradiance (Gu *et al*., 1999) as when relatively heavy shading treatments were applied (22% or 33% of the total radiation), the decrease in grain yield was lower than the reduction in radiation. Therefore, it may be presumed that low shading might not reduce or even increase wheat grain yield due to high efficient light capture brought about by the morphological modifications and changes of light fractions.

2.5 Yield and yield contributing characters

2.5.1 Potential shoots

Number of tillers per unit area is the most important component of yield. Thome and Wood (1987) suggested that, because of their position in the canopy, tillers are often shaded by taller shoots, and tillers might, therefore, be expected to be more affected by shading than the main shoots and higher rates of mortality be observed.

Sharma *et al.* (1996) also observed significant reduction in both the number of tillers and potential shoots per plant in wheat and paddy intercropped with *Dalbergia sissoo*, whereas, Pant and Bana (1998) observed that the non-significant yield reduction in wheat and urd under tree species was mainly attributed to reduced number of plants, potential shoots per unit area and plant height (all vegetative characters).

2.5.2 Spike length

The beginning of the spike growth period was defined as the time when the spikes reached 5% of the dry weight they attained at the end of the period. This criterion is easier to apply than the moment when partitioning to the spikes exceeds 5%, as proposed by Fischer (1993). The effects of shading on number of grains m^{-2} could be traced back to reductions in both ear dry weight and number of fertile flowers at anthesis (Stockman *et al.* 1983). The most sensitive period for the effect of shade was the 20 days before anthesis (Fischer & Stockman, 1980), when the stem and ear were elongating rapidly and the florets were being differentiated and maturing. Shading during that critical phase reduced spike length per unit land area at anthesis, resulting in a proportional reduction in the number of grains m^{-2}.

Kiran and Agnihorti (2001) studied the effect of partial shading on yield and yield attributes of wheat intercropped with *Dalbergia* sissoo and found that spike length was highest with 45 per cent crown pruning in trees, while 1000-grains was highest with 60 per cent pruning of tree crowns as compared to other treatments of partial shading and control.

2.5.3 Fertile spikelets per spike

Under low light a direct effect was observed on the fate of 'labile' primordia that are initiated as vegetative primordia (Brooking and Jamieson, 2002). The effects of shading on number of grains m^{-2} could be traced back to reductions in both ear dry weight and number of fertile flowers at anthesis (Stockman *et al.,* 1983). When water and nutrients are non-limiting changes in radiation level during the spike growth period can be expected to affect grain number m^{-2} through carbohydrate supply to reproductive organs.

Jain (1998) reported wheat variety UP-2338 to have significantly lesser number of sterile spikelets and significantly more number of fertile spikelets compared to all other varieties tested under poplar.

The relationship between the number of grains m^{-2} and spike dry weight at anthesis, although significant but scanty from literature reports on wheat. The number of grains depends upon the number of fertile florets at anthesis and the efficiency of these florets for setting grains afterwards. In fact, the relationship between the number of fertile florets was quite closely associated with the spike dry weight at anthesis (Estrada-Campuzano *et al*., 2008). The relationship of the number of grains per spike with the spike dry weight loose part of the matching due to an increased abortion when the number of fertile florets increased.

2.5.4 Sterile spikelets per spike

Fischer (1985) stated that continuous high humidity (70%) around meiosis could reduce grain set in certain wheat cultivars. Campbell and Read (1968) mentioned that high humidity and low light intensity together affected grain set of wheat probably due to less transpiration that ultimately affected the translocation of assimilates. They also mentioned low light alone affected the grain set, but high humidity plus low light intensity affected grain set more. Moreover, there is a relationship between environment, like high humidity and low light intensity due to fogginess and phenological development of wheat at reproductive stage. There may also be a chance of genotype and environmental interactions in causing spikelet sterility. It may happen due to the differences of phenological differences among the varieties.

Scheeren *et al*. (1995) reported that shading (40% light reduction) significantly reduced the yield components i.e., increased the number of sterile spikelets per spike. Sharma (1992) observed the number of grains per spike of wheat to be adversely affected in close proximity to trees (*Acacia nilotica*) upto four metre distance from the tree line. Nazir *et al*. (1993) also noticed significant reduction in the number of grains per spike in wheat with increased duration of shading by the shisham trees.

2.5.5 Grains per spike

Fischer (1985) reported that the number of grains m^{-2} has been shown to be reduced by shading during ear growth. It might be radiation seems to affect number of grains m^{-2} through its effect on crop growth rate and light intensity had positively affected the rate of crop development.

Abbate *et al*. (1997) found that the major effect of shading was to reduce number of grains m^{-2} without any effect on weight $grain^{-1}$. Pre-anthesis shading could have reduced the reserves of assimilates by the beginning of grain filling, but pre-anthesis assimilate contribution to yield is just a small proportion in crops with no water stress (9-12% of anthesis dry weight according to Bidinger *et al*. (1977). Thus, shading during the spike growth period is not likely to have produced a more important change in source during grain filling than in sink number. In spite of this, weight $grain^{-1}$ in shading treatments did not increase. This stability in weight grain^{-1} under changes in radiation during the spike growth period can be attributed to yield being limited by number of sinks (grains), both in shaded and unshaded treatments, for the sink range obtained in the experiments reported. The fact that weight per grain (basal and apical) of individual spikes did not increase with the major reduction in number of grains in trimmed spikes without lodging.

Fischer (1985) and Thome and Wood (1987) established quantitative relationships between grain number m^{-2} on both radiation and light intensity during the 30-day period prior to anthesis. Responses in grain number m^{-2} were interpreted in terms of dry weight of spikes m^{-2} near anthesis and number of grains per unit of spike weight. Dry weight of spikes reflects the quantity of assimilates partitioned by the crop to the production of reproductive organs until anthesis. That determines the survival of initiated flowers and subsequently, the number of grains m^{-2} (Rawson and Bagga, 1979; Brooking and Kirby, 1981; Fischer, 1985; Abbate *et al*., 1995). Then, the number of grains m^{-2} was strongly reduced by pre-anthesis shading. The reduction in incoming PAR during different periods of spike growth decreased the grain number unit area^{-1} by reducing the number of grains spikelet^{-1}, leaving the number of spikes m^{-2} unaltered. The shading effect on the number of grains per spikelet has been widely reported (Kemp and Whingwiri 1980; Slafer *et al*. 1996; Wang *et al*. 2003). However, the effect of shading on the number of spikes m^{-2}, while some results are in line with those reported here in (Savin and Slafer 1991; Wang *et al*. 2003), others have demonstrated reductions in the number of spikes m^{-2} due to shading (Fischer and Stockman 1980; Kemp and Whingwiri 1980; Slafer *et al*. 1996) as well as increases in this component is reported to be associated with higher pre-anthesis incident radiation (Thome and Wood 1987). Whether shading during stem elongation may reduce the number of spikes m^{-2} or not, may strongly depend upon the canopy structure in the particular situation in which shading is imposed: if the number of spikes m^{-2} is not much higher than the sowing rate (e.g. because tillerin is inhibited genetically or due to high sowing rates), shading can scarcely affect this component, whereas in cases of profuse tillering, increased tiller mortality due to shading during the stem elongation is more likely (Slafer *et al*. 1996).

2.5.6 Grain weight per spike

Grain weight is primarily a genetically controlled trait, which is greatly influenced by environment during the process of grain filling (Kausar *et al.*, 1993). There is a very close relation between the yield and its components, especially with number of filled grains per ear, as reported by De Datta (1986). The improved growth attributes, *viz.* plant height and drymatter production, might be responsible for improved yield attributes.

The effect of shading immediately after anthesis on grain number due to its effects in grain setting has been reported in wheat (Savin and Slafer, 1991), and lack of major effects of post-anthesis shading on average grain weight has been reported not only in wheat (Fischer, 1985; Savin and Slafer, 1991) but also in triticale (Cantarero and Badiali, 1998; Aguirre *et al.*, 2006). Excluding the 85% shading treatment, which increased the most, the percentage change of spike dry weight during grain filling was linearly associated to the percentage change of dry weight of non-grain crop organs during this period. This indicates that the greater the availability of assimilates during grain filling, the greater the increase in spike dry weight. Fischer and Stockman (1980) also noticed that dry weight of the non-grain portion of the spike increased from anthesis to maturity. Wall (1979), Fischer and Stockman (1980), Fischer (1985) and Abbate *et al*. (1995) concluded that shading during spike growth reduction in number of grains m^{-2} proportionally was less than it reduced crop growth. Main effect of radiation on number of grains m^{-2} was on dry weight of spikes rather than on number of grains per unit of dry weight of spikes.

2.5.7 1000-grain weight

Thousand grain weight (TGW) is determined by the cultural and environmental conditions that occur during the sequential development (pre-anthesis or grain setting and post-anthesis or grain filling stages) of wheat yield components in agroforestry system (Chirko *et al*., 1996).

Shading reduced grain number m^{-2}, the reduced number of sinks was partially compensated by some increases in AGW (Average Grain Weight), suggesting that there was some sort of source-limitation for grain filling in the modern line. The reduction in grain number per unit area might have brought increases in AGW irrespective of any change in competition. For instance, the reduction in grain number m^{-2} by shading necessarily reduced the contribution of distal grains to the total number of grains m^{-2} (e.g. Slafer *et al*. 1996), and distal grains have lower potential grain weight (Acreche and Slafer, 2006), so AGW might increase in the absence of any reduced competition among grains. Number of grains m^{-2} reduced by shading during ear growth periods as observed by several workers (Fischer 1975; Fischer & Stockman 1980; Stockman *et al.* 1983; Fischer 1985). Willey and Holliday (1971a & b) reported that shading before anthesis did not affect (raise or lower) the l000-GW (Test weight) in low light conditions.

The removal of awns also affected number of grains per spike grain weight per spike and 1000 grain weight as observed by Birsin (2005) and Khaliq *et al*. (2008). Furthermore, removal of both photosynthetic machineries (flag leaf + awns) exerted the most declining effects on grain yield and its related parameters especially 1000 grain weight as compared to detachment of awns and flag leaf individually. The report of Khaliq *et al*. (2008) also demonstrated more decrease in grain yield, when both of the photosynthetic organs were removed at post spike or ear emergence stage.

The single grain weight in rice was about 35% larger. Since single grain weight is genetically governed in rice, such a large grain size without reducing the grain number directly enhances the sink capacity, and the amount of N required for achieving a sink capacity necessary for a high yield was less than in the common cultivar (Wada and Matsushima, 1962; Makino 2011).

2.5.8 Biological yield

Greater biological yield depends on the amount of resource captured and the efficiency with which that resource is used to produce dry matter. The greatest scope for biomass increases probably lies in increasing the amount of resource captured (De Costa and Rozana, 2000).

Savin and Slafer, (1991) reported that the biological yields decreased in direct proportion to the decrease in incident PAR. It has been suggested by Gallagher & Biscoe (1978) that biological yields are strongly correlated with the total amount of intercepted PAR from emergence to maturity. Grain yields also decreased in direct proportion to the decrease in incident PAR. They also observed that the pre-anthesis shading reduced grain yield by decreasing the number of grains m^{-2} and post-anthesis shading reduced grain yield by decreasing both grain weight and number of grains m^{-2}.

The flag leaf characteristics are considered as an important selection criterion for high grain yields in wheat as most of the lower leaves are shaded by the upper ones and are not directly involved in the absorption of solar radiation (Briggs and Aytenfisu, 1980; Birsin, 2005). There is real source-sink relationship between leaves and development of grains in wheat because healthy grain formation depends upon the potential assimilation of CO_2 and accumulation of photosynthates during grain filling period (Li *et al.*, 2006). Although the lower leaves also supply assimilates to grain, but the detachment of flag leaf considerably influenced the grain yield (Khaliq *et al.*, 2008). Thus, the flag leaf is the primary source of assimilates for grain filling and grain yield due to its short distance from the spike and it also stays green for longer time than other leaves (Briggs and Aytenfisu, 1980; Khaliq *et al.*, 2004). Moreover, Gelang *et al.* (2000) reported that leaf area duration was positively associated with grain weight and grain filling duration.

2.5.9 Grain yield

Grain yield is the main target of crop production. Many studies have shown that shading as in agroforestry land use, reduces grain yield (Gill *et al.*, 2009; Mu *et al.*, 2010), indicating that the effect on grain yield is dependent on the degree of shading and that the effect is also cultivar-dependent. Heavy shading particularly was found to reduce grain yield. In contrast, low-intensity shading increased grain yield. Thus, the yield losses were of much lower magnitude than the reduction in radiation indicating thereby some physiological and morphological compensation mechanisms operating both at leaf and canopy levels to mitigate the adverse effect on grain yield under shading (Mu *et al*., 2010). Satish *et al*. (2003) reported that wheat grain yield decreased significantly with the increase in shade duration due to *Eucalyptus* plantation on eastern side of the wheat field. The influence of *Acacia nilotica* on the growth and yield of associated wheat crop under irrigated condition were reported by Sharma (1992), Khan and Ehrenreich (1994). Puri and Bangarwa, (1993) found that *Azadirachta indica* and *Prosopis cineraria* did not make any significant difference to wheat yield. While *Acacia nilotica* reduced yield by 4-30% but reduction was only up to a distance of 3 m from tree row. Khan and Ehrenreich (1994) found that close proximity to trees adversely affected tillers m^{-2}, grains $spike^{-1}$ or 1000 grain weight, but grain yield reduced slightly near the largest trees. Khan and Aslam (1974) studied the effect of single sissoo (*Dalbergia sissoo*) tree on the yield of wheat crop and reported that the grain yield showed a decrease of 30.9, 23.6 and 12.7% at the distance of 3, 4.3 and 6 m from tree, respectively as compared to the open field.

Hossain *et al.* (2006) found that the wheat grain yield was significantly influenced under various tree species. The highest grain yield (2.92 t ha^{-1}) was produced in the open field and the lowest yield (2.53 t ha^{-1}) was found under *Psidium guajava*. All the tree species produced statistically similar yield but lower compared to the open field (3.04 t ha^{-1}). Crop yield was reduced under the *Albizia lebbeck, Mangifera indica* and *Psidium guajava* tree canopy by 11, 12 and 13 % compared to the open field, respectively. Nandal *et al.* (1999) investigated the performance of five wheat cultivars under sissoo trees and found that grain yield, dry matter yield, leaf area index, spikelets m^{-2} and grains $spike^{-1}$ were reduced under tree canopy compared to crops growing in the open field. As far as wheat crop is concerned, it was found that morphological growth and yield attributing characters as well as grain yield were all significantly higher in sole wheat crop than when intercropped with *Tectona grandis* . The grain yield in sole wheat crop was 30.9q ha^{-1} compared with 24.7q ha^{-1} under agroforestry system. While Nazir *et al.* (1993) and Sharma *et al*. (1996) reported a decrease in number of fertile or effective tillers per unit area and number of tillers per plant in wheat under *Dalbergia sissoo*, reduction in yield of wheat crop under *Tectona grandis* in comparison with sole wheat crop.

Artificial shading treatments have been more successful in identifying stages when radiation is most critical for grain yield of wheat (Pendleton and Weibel, 1965; Willey and Holliday, 1971a & b). Shading has been used particularly to examine whether grain yield is more limited by post-anthesis photosynthate supply (source) than by the combined carbohydrate storage capacity to the growing grains i.e. sink (Welbank *et al*., 1968; Gifford and Marshall, 1973).

Grain weight in cereals seems to be strongly sink-limited (e.g. Borras *et al*., 2004; Bingham *et al*., 2007a & b) and, therefore, no clear compensations were expected from reductions in the number of grains growing after anthesis. Shading during post-anthesis also affected grain number m^{-2} more strongly than average grain weight. The effect of shading immediately after anthesis on grain number due to its effects in grain setting has been reported in wheat (Savin and Slafer, 1991), and lack of major effects of post-anthesis shading on average grain weight has been reported not only in wheat (Fischer, 1985; Savin and Slafer, 1991) but also in triticale (Cantarero and Badiali, 1998; Aguirre *et al*., 2006). In fact, the minor effect on grain weight found in this study might well be due to a small reduction in potential grain size (Bingham *et al*., 2007b) than a reduction in availability of assimilates needed to match grain growth requirements during the effective grain filling period, as was reported in wheat (Slafer and Savin, 1991) and barley (Voltas *et al*., 1997). This lack of responsiveness on average grain weight to intense shading during grain filling reinforces the conclusion that grain growth in triticale would be strongly sink-limited, like it is the most common case both in wheat and barley.

2.5.10 Straw yield

Monocarpic plants such as wheat and rice need the initiation and undergo whole plant senescence so, that stored carbohydrates in stems and leaf sheaths can be re-mobilized and transferred to their grains (Ali *et al*., 2007). Delayed but quicker whole plant senescence leads to poorly filled grains and unused carbohydrate in straws (Zhang and Yang, 2004). Slow grain filling may often be associated with delayed whole plant senescence (Ali *et al*., 2007).

Total biomass at maturity was characterised by a consistent decrease in biomass as PAR intercepted by the crop was reduced by shading. This biomass reduction was evident in the pre-anthesis radiation use efficiency (RUE) as shading period increased, as theoretically expected (Gallagher and Biscoe 1978) and the results obtained agreed with those reported by Fischer (1975), Stockman *et al*. (1983), and Savin and Slafer (1991) in regards with the shading effects on wheat growth. The shading during the periods of jointing–anthesis also reduced harvest index (HI), a fact that revealed that shading had greater effect on the grain number m^{-2} (and sograin yield) than on total biomass. However, no effect of shading was observed on biomass partitioning at anthesis. As above-ground and spike dry weight at anthesis were consistently and similarly reduced by shading, and the survival of floret primordia is determined by the pre-anthesis spike growth (Fischer and Stockman, 1986; Miralles *et al*., 1998; Gonzalez *et al*., 2005), as it is apparent that pre-anthesis shading would have affected grain number m^{-2} through concomitantly reducing the number of florets developing normally to fertility.

2.5.11 Harvest index (HI)

Harvest index, defined as the ratio of grain mass to total aboveground biomass at harvest (Evans, 1997; Sinclair, 1998).

Yield variations, due to shading during different crop phases, were associated with changes in both above-ground dry matter biomass accumulateon during the crop cycle and harvest index (Estrada-Campuzano *et al*., 2008). Ravi kiran *et al.,* (2002) reported that the harvest index was found to be higher below *Dalbergia sissoo* than underneath *Eucalyptus tereticornis,* except in treatment (higher net radiation availability). The reduction in light availability has been of greater magnitude than the relative loss in grain and straw yield. This may be due to improved conversion coefficient of available energy under partial shade (Corlette *et al*, 1987). The reduction in the grain yield and biological yield was more pronounced below *Eucalyptus* than that of shisham, due to longer period of shading by evergreen *Eucalyptus* tree. Higher harvest index was recorded to some extent below *Eucalyptus* and well pronounced below shisham canopies compared to the control, Savin and Slafer, (1991) reported a decline in harvest index under shade when shade provided close to the stage of maximum crop weight and, therefore, affected grain yield more than biological yield. The similar results were also reported earlier by Fischer (1975) and Stockman *et al.* (1983).

Grain mass in the modern high-yielding rice and wheat varieties has reached about 60% of the total biomass aboveground at harvest (Evans, 1997; Long *et al*., 2006). This is the highest in all cereal crops. Although it is not apparent whether further increase in the harvest index is feasible, to substantially enhance yield in both crops will be difficult unless source capacity including photosynthesis is improved by genetic engineering (Miura *et al*., 2010). In addition, since improving source capacity could lead to a decrease in the amount of N required for a high yield, it will reduce the adverse environmental impact of agriculture (Makino 2011).

Shading effects on the crop were the consequences of reductions in crop photosynthesis during the shading period which were in turn more or less proportional to the product of the shading intensity and the length of the period (Fischer, 1975). The net effect of the yield component in response to radiation is reflected in the grain yield-radiation relationship.

Above literature scanning clearly indicated that the morphological and physiological aspects of yield reduction in under varying degree of shade are of rare occurrence or scanty literature. Therefore, with this background, the present investigation was carried out in order to make morphological and physiological comparison amongst different varieties under varying degree of shade or light availability besides exploring their impact for enhancing the grain productivity of wheat under shaded agro-ecosystem such as agroforestry.

2.6 Character Association

Grain yield in wheat, as on any other crop, is a complex character and is dependent upon a number of yield contributing factors, such as, number of spikes plant^{-1}, grains spike^{-1}, thousand grain weight and days to heading.

According to Graffius (1956), improvement in grain yield, not only depends on selection of yield *per se*, nut selection based on components characters appears to be more useful. Therefore, in order to obtain a higher yield, it is necessary to have information on relationship between yield and its components (Paroda and Joshi, 1970). The correlation coefficients give an idea about the various associations existing between yield and yield componenets and amongst yield components.

Saini e*t al*. (1990) reported positive correlation of days to maturity with grain yield. In wheat, a positive correlation of grain yield with ear length, number of ears plant^{-1} and number of spikelets spike^{-1} were observed by Tiwari and Rawat (1993). Deswal *et al.* (2000) also reported a positive correlation of grain yield spike^{-1} with total biomass spike^{-1}, number of grains spike^{-1} and 1000 grain weight. Tammam *et al.* (2000) observed a positive correlation between days to heading and grain yield in bread wheat.

Whereas, Subhani (2000) reported negative correlation between these two characters and positive correlation of grain yield with ear length and grains spike^{-1}.

2.7 Path Coefficient Analysis

By path coefficient analysis, correlation coefficient can be partitioned into two components i.e. direct and indirect effects. It helps to elucidate the intrinsic nature of the observed associations for complex characters like grain yield.

Jaimini *et al.* (1974) observed that the test weight, which had the highest correlation with yield had the lowest direct effect. A high positive direct effect of the number of spikes plant^{-1} revealed that this character was responsible for the high degree of association between grain yield and spikes plant^{-1}.

Deswal *et al.* (1997) reported that number of grains per spike, 1000-grain weight, number of spikelets spike^{-1} and harvest index had the greatest contribution towards grain yield in wheat. Nirmala and Jha (1997) also reported that number of effective tillers plant^{-1} followed by 1000-grain weight and days to flowering showed the greatest positive effects on grain yield.

Materials and Methods

The field study was undertaken to workout the morpho-physiological bases of yield reduction in wheat varieties under varying degree of shades. The details of the experimental site, climatic conditions, experimental details, material used, procedures and techniques followed during the course of this investigation are described in this chapter.

3.1 Site of the experiment

The field experiment was conducted in D3 plot at the Norman E. Borlaug Crop Research Centre, G.B Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand during winter (*rabi*) seasons of 2010-11 and 2011-12. Pantnagar is located at 29^{o}N latitude, 79.3^{o}E 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.

3.2 Soil characteristics

The soil of this region (*tarai*) have developed from calcareous, medium to moderately coarse textured materials under pre-dominant influence of tall vegetation and moderate to well drained conditions.

A composite soil sample was drawn from 0-15 cm soil depth for each main plot treatment (i.e. varying degree of shades) by mixing replication-wise and analysed for important physio-chemical properties of soil both during 2010-11 and 2011-12 (Table 3.1). Soil texture of the experimental site was silt loam and belonged to Edgewick Series 39 (Deshpande *et al.*, 1971).

3.3 Climate and weather conditions

The climate of Pantnagar is humid subtropical with distinct dry hot summers and cool winters having average annual rainfall of about 1350 mm, received mainly (> 80 per cent) from July to September. The maximum daily temperature in summer may reach up to 43^{0}C and minimum temperature in winter may fall up to -0.5^{0}C. The monsoon generally sets around third or fourth week of June and lasts upto September end. A few showers occur generally during winter and occasionally during summer. Frost generally occurs towards the end of December and may continue till the end of January.

Table 3.1: Physico-Chemical properties of experimental soil

Particulars	Values obtained		Method employed
	2010-11	2011-12	
Soil texture	Silt loam	Silt loam	
Sand (%)	28.6	27.2	International pipette method (Kilmer and Alexander, 1949)
Silt (%)	52.2	54.0	
Clay (%)	19.2	18.8	
Available nitrogen (kg N ha^{-1})	214.6	227.5	Alkaline $KMnO_4$ method (Subbiah and Asija, 1956)
Available phosphorus (kg P ha^{-1})	20.8	21.6	Olsen's method (Jackson, 1973)
Available potassium (kg K ha^{-1})	140.8	152.3	Flame emission Spectrophotometry (Jackson, 1973)
pH (1:3 soil : water)	6.9	7.2	Beckman glass electrode pH meter (Jackson, 1973)

The weekly average data on weather conditions during the experimental periods i.e. (2010-11 and 2011-12), as recorded at the meteorological observatory located at Norman E. Borlaug Crop Research Centre, Pantnagar are presented in Appendix I & II and Fig 3.1 & 3.2, respectively.

The mean maximum weekly temperature during the crop season ranged from 12.4 and 17.9^{0}C during January to 35.9 and 36.4^{0}C in April and the mean minimum weekly temperature from 4.4 and 3.7^{0}C during December and January to 20.3 and 19.4^{0}C in April during 2010-11 and 2011-12, respectively. The total rainfall received during the crop season was 92.0 and 30.7 mm and the major rainfall 22.0 and 19.4 mm received during first week of January during corresponding years. The average relative humidity at 7.00 AM and 2.00 PM ranged from 65 and 22 and 60 and 22 per cent during April to 96.0 and 94 per cent in December and 81 and 72 per cent in January, during both the years, respectively. The range of bright sunshine hours during the growth period varied from 1.0 hrs during December during both years to 9.6 and 11.2 hrs in April, during 2010-11 and 2011-12, respectively.

3.4 Experimental details

The details of treatments used and design adopted during the experimentation are given below.

3.4.1 Treatments

Treatments consisted of three different amount of light transmission/availability/ shading conditions created using cloths with varying transmissivity and full sunlight i.e. control (open plots) and five wheat varieties. The details of treatments are as follows;

a)	**Main plot treatme**nt (varying degrees of shade/light availability): 03	Symbols used
i.	Control (open plot - full sunlight) – No shade (Plate 1)	L0
ii.	Lower degree/ mild shade (Approx. 2/3 of full sunlight) (using poplin cloth) (Plate 1)	L1
iii.	Higher degree/ severe shade (Approx. 1/3 of full sunlight) (using muslin cloth) (Plate 2)	L2

Note: At the time of shade treatment execution with new cloth covers, the light transmission was 65 to 66 per cent of full sunlight in L1 (i.e. through poplin cloth) and 32 and 33 per cent in L2 (i.e. through muslin cloth). However, with passage of time the per cent light transmission reduced little bit as measured on 81 DAS and reported in Table 4.5.1.

b)	**Sub plot treatment** (wheat varieties): 05	
i.	UP 2684	V1
ii.	UP 2526	V2
iii.	UP 2565	V3
iv	UP 2113	V4
v	PDW 233	V5

Some important characteristics of these varieties, their year of release and area of adaptation are given in Table 3.2.

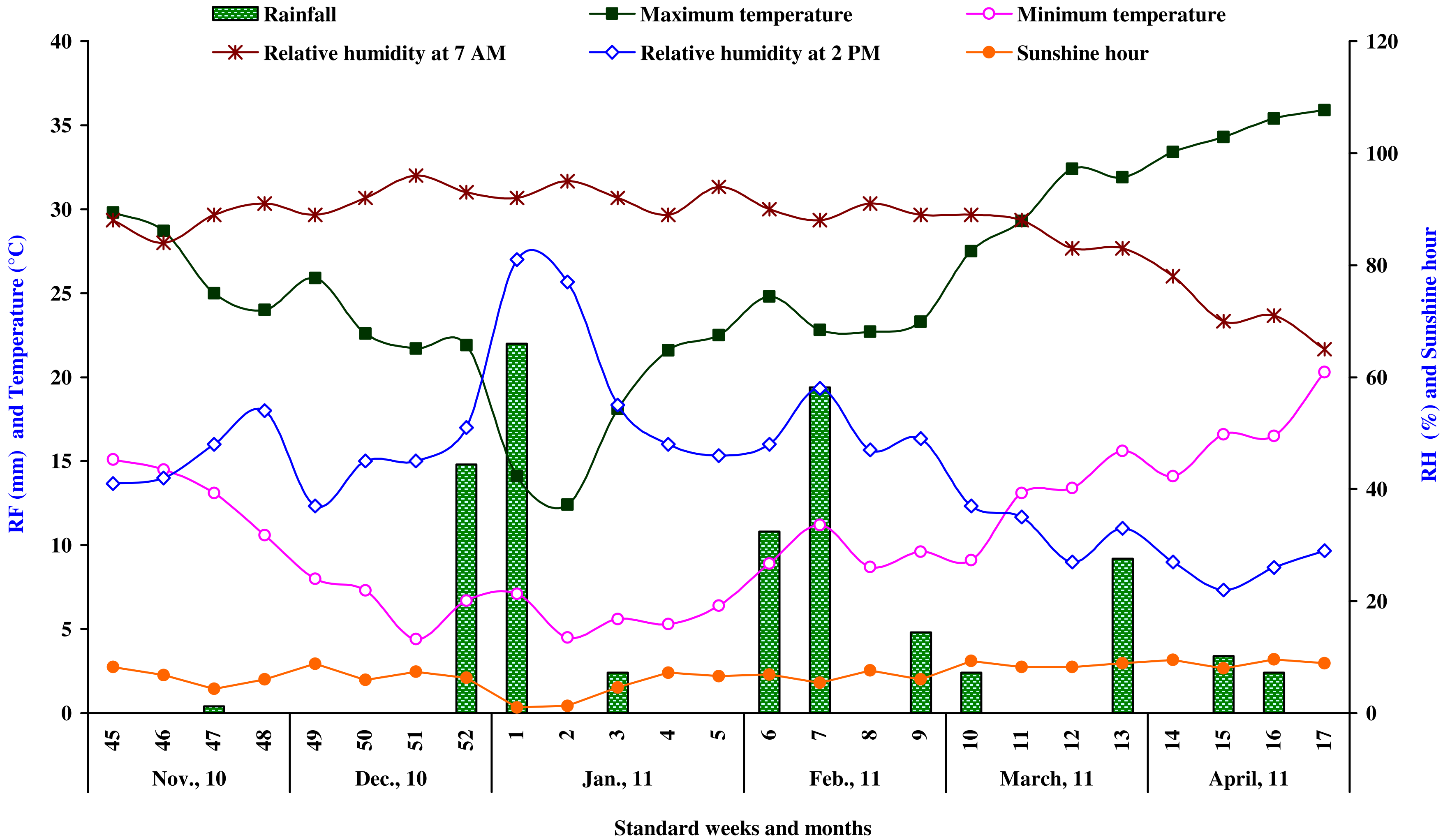


Fig. 3.1 Weekly weather condition during the crop period (Nov. to April, 2010-11)

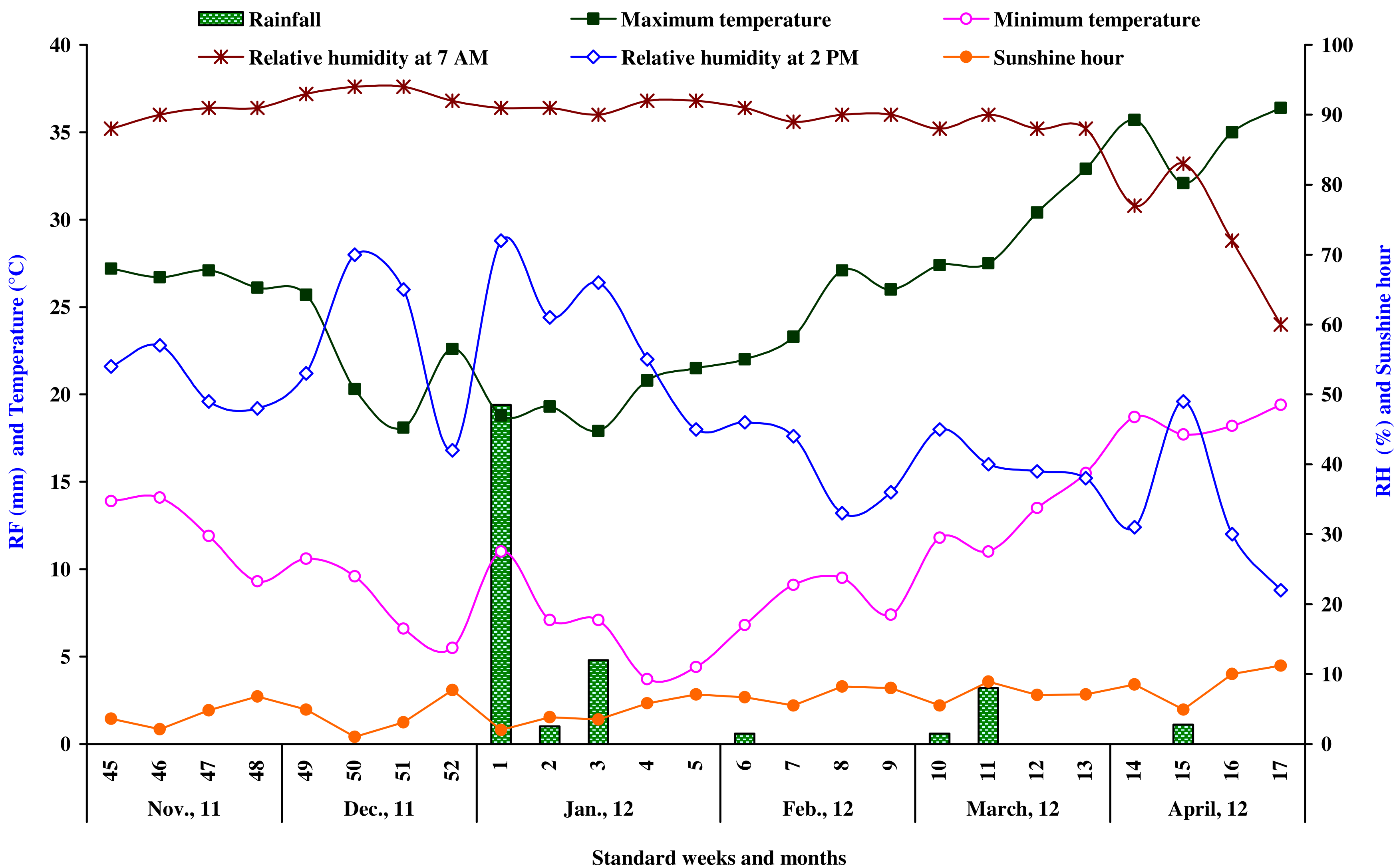


Fig. 3.2 Weekly weather condition during the crop period (Nov. to April, 2011-12)

Table 3.2 Important characteristics of wheat varieties used in experiment

Varieties	Year of release	Recommended for	Maturity (days)	Area of adaptation	Other important features
UP 2684	2010	TS, IR	130-140	Uttarakhand Hills	It holds satisfactory level of resistance to both leaf and stripe rusts and powdery mildew and possesses good quality traits
UP 2526	2005	LS, IR	125-130	Uttarakhand Plains	Holds high degree of resistance to different disease of wheat and has good grain appearance.
UP 2565	2004	LS, IR	125-135	Bhabar, Tarai and Plains of Uttarakhand	Holds high degree of resistance to yellow as well as brown rust. Moderately tolerant to terminal heat stress.
UP 2113	1985	RF, TS	145-150	Central and western UP	It holds satisfactory level of resistance and have profuse tillering
PDW 233	1997	TS, IR	135-145	North western plains zone	Bold grains durum wheat variety

TS = Timely sown LS = Late sown

IR = Irrigated condition RF = Rainfed condition

3.4.2 Experimental design and layout

The experiment was laid out in split plot design comprising three different amounts of light transmission/availability/shading as main plot and five varieties of wheat as sub-plot treatment with three replications as detailed below. The layout plan of experiment is shown in Fig 3.3.

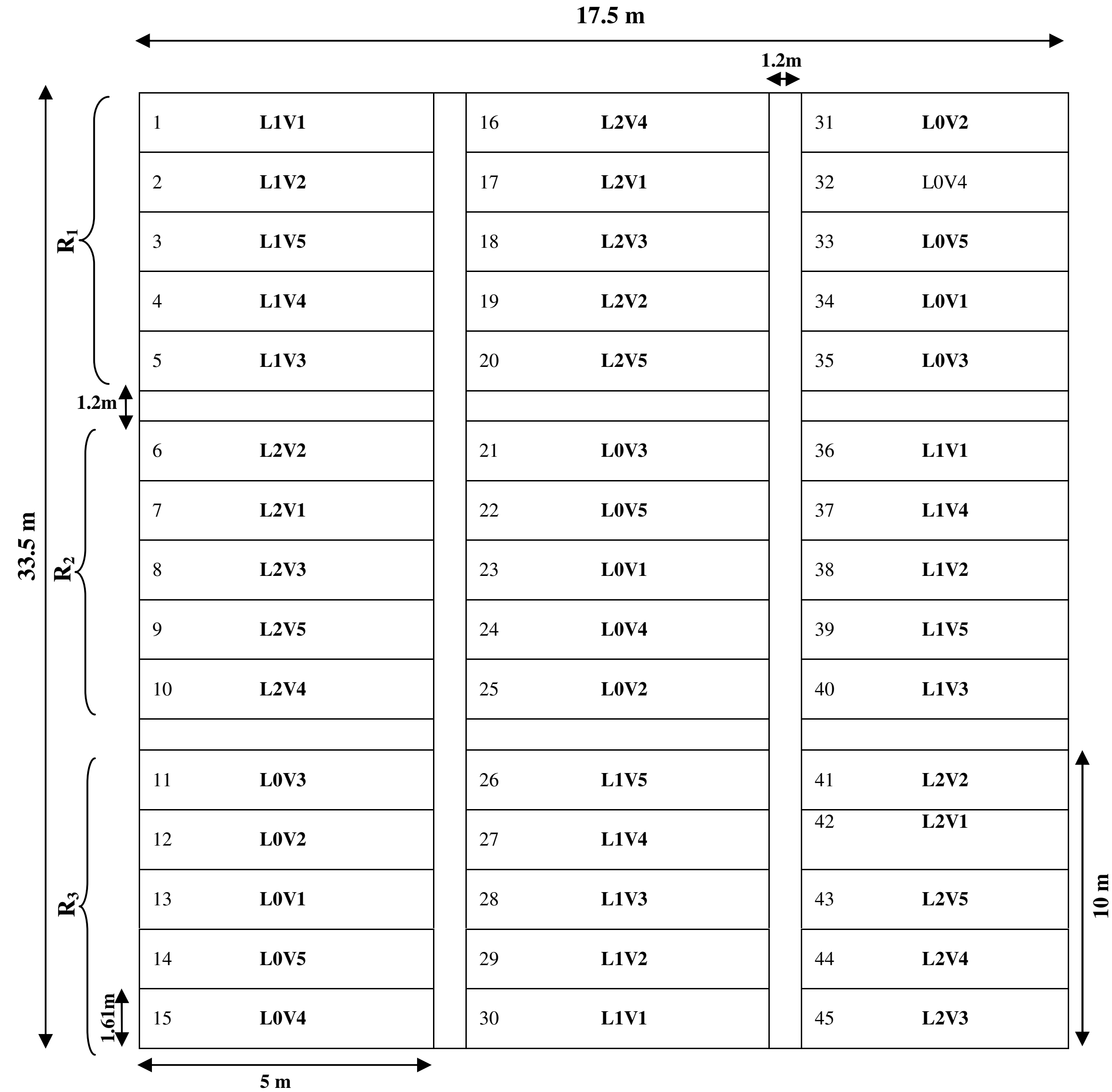
Gross plot size	:	8.05 m^2 (1.61m x 5.0m)
Net plot size	:	4.60 m^2 (1.15m x 4.0m)
Row spacing	:	23 cm
Seed rate	:	100 kg ha^{-1}
Space between two main plot	:	1.2 m
Space between two sub plots	:	0.5 m

3.5 Cultural operation

The details of pre and post sowing cultural operations carried out during the experimental periods are detailed below under different sub-heads and listed in Table 3.3.

3.5.1 Seed bed preparation, layout and sowing

After harvesting of soybean (*kharif*) crop, the field was prepared by one deep ploughing using tractor drawn soil turning plough followed by two cross harrowing and levelling. In order to create ideal conditions for seed germination, pre-sowing irrigation was given and seed bed prepared by cross harrowing and levelling. The layout in field was done by marking main and sub-plots with the help of lime dust. Three soil samples were taken in an each replication for physic-chemical analysis, calculated and pre-weight quantity of fertilizers was broad casted and mixed with spade plot wise. For sowing, about three cm deep furrows were manually opened 23 cm apart and each furrow was uniformly sown with pre-weighed seed row-wise and covered immediately. The crop was sown on 29th Nov in 2010-11 and on 21th Nov in 2011-12.



Main plot (varying degrees of shade by using cloth) **:03**

L0 – Control (full sunlight)

L1 – Lower degree/Mild shade (Approx. 2/3 of full sunlight)

L2 – Higher degree/Severe shade (Approx. 1/3 of full sunlight)

Number of replication: Three

Design: Split plot

Sub plot (wheat varieties)**:05**

V1 – UP 2684

V2 – UP 2526

V3 – UP 2565

V4 – UP 2113

V5 – PDW 233

Fig 3.3 Layout plan of the experiment

Table 3.3 Schedule of cultural operations

S.No	Operations	Date		Remarks
		2010-11	2011.12	
1	Harrowing	26.11.2010	19.11.2011	Three times
2	Planking and leveling	26.11.2010	19.11.2011	Two times
3	Soil sampling	27.11.2010	20.11.2011	
4	Layout, Fertilizer application and mixing	27.11.2010	20.11.2011	
5	Furrow opening and sowing	29.11.2010	21.11.2011	
6	Preparation of bunds and irrigation channels	30.11.2010	24.11.2011	
7	Marking of observation rows by sticks	05.12.2010	01.12.2011	
8	Hanging the cloths/shading	21.12.2010	12.12.2011	
9	Tagging	25.12.2010	17.12.2011	
10	Top dressing of nitrogen	19.12.2010	21.12.2011	
11	Irrigation	20.12.2010	22.12.2011	Thrice
		10.02.2011	06.02.2012	
		17.03.2011	10.03.2012	
12	Weeding	30.12.2011	21.12.2011	Twice
		15.02.2011	28.01.2012	
13	Removing of cloths	15.04.2011	10.04.2012	
14	Harvesting	19-20.04.2011	17-18.04.2012	
15	Threshing	23.04.2011	21.04.2012	

3.5.2 Fertilizer application

The crop was fertilized with 120 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare using urea, single super phosphate and murate of potash as source, respectively. Half dose if nitrogen plus full dose of phosphorus and potash were applied as basal uniformity and mixed through manual with the help of spade before sowing and remaining half dose of nitrogen was top dressed a day before first irrigation.

3.5.3 Irrigation and weed management

To maintain adequate soil moisture, irrigations were given at different critical physiological growth stages taking rainfall and wind conditions into consideration during reproductive stage. Weeds were removed manually with the help of *khurpi*, whenever necessary to maintain weed free conditions.

3.5.4 Harvesting and threshing

The crop was harvested manually with the help of sickle. At maturity, one row from both sides and 0.5 m row length from both ends of the plot was harvested as border and removed from the plots. Then remaining plot (net plot) also was harvested manually with the help of sickle and the produce was tied into bundles and tagged. The bundles were allowed to dry in sun for four sunny days and weighted. After weighing, threshing of bundles from each plot was separately done by a Pullman thresher.

3.6 Observations recorded

3.6.1 Morphological studies

The morphological characters viz. emergence count, leaf length, leaf width, internode length, internode dry weight, shoot height, flag leaf area, days taken to 50 per cent heading, days taken to 80 per cent maturity, maximum number of shoots and shoot mortality % were studied one metre second marked row from border in each plot to utilize for plant sampling.

3.6.1.1 Emergence count

Fully emerged seedlings of wheat were counted on alternate day starting from the day few seedlings were seen in the marked 1 m row length until the count became constant. The final count was taken as emergence count and converted to emergence count m^{-2}.

3.6.1.2 Maximum shoot count

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.

3.6.1.3 Leaf size

The leaf length (cm) and width (cm) of the youngest fully expanded leaf on five randomly selected shoots in each of the one meter marked row were measured undestructively with the help of scale and averaged to report at 30, 60, 90 and 120 days after sowing.

3.6.1.4 Internodal length and dry weight

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 ± 2^0C 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.

3.6.1.5 Shoot height

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.

3.6.1.6 Flag leaf area

Flag leaves of ten randomly selected shoots were picked up and their leaf area measured with the help of leaf area meter ten days after anthesis and average flag leaf area (cm^2) was computed.

3.6.1.7 Days taken to heading

The number of fully emerged spikes was counted on alternate day from the day few spikes were seen in marked 1 m row till their number became constant. Thereafter, the day on which 50 per cent of total spike emerged was taken as date of heading and days taken to heading computed and recorded.

3.6.1.8 Days to physiological maturity

The physiological mature shoots (the peduncle turned yellow) were counted on alternate day starting from the day few mature shoots were seen until their number became constant and the date on which 80% mature shoots observed was recorded days taken from sowing to the date computed to present the days taken to 80 per cent maturity.

3.6.1.9 Dry matter accumulation studies

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 following observations.

i) Dry matter accumulation in stem

ii) Dry matter accumulation in leaves

iii) Dry matter accumulation in spikes (after spike emergence only)

iv) 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}).

3.6.1.10 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}.

3.6.2 Growth studies

The following growth indices were computed using following the formulae as suggested by Radford (1967).

Mean Crop Growth Rate

Mean crop growth rate ($\overline{CGR}$) (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 ($\overline{RGR}$) was calculated using the following formula;

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

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

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

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;

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

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

3.6.3 Physiological studies

3.6.3.1 Intercellular CO_2 concentration, photosynthesis, transpiration and stomata conductance in canopy

These observations were recorded at boot stage, anthesis and 10 days after anthesis in between 12:00 to 14:00 hrs on sunny days with the help of Potable Photosynthesis and Transpiration Measurement system (Model: Portable photosystem, united kingdom). The instrument is based on infra red gas analysis technique. There are four Infra-Red Gas Analyzers (IRGA) in the instrument. Two for separate measurement of carbon dioxide concentrations of the air going into leaf cuvette and another for CO_2 leaving the cuvette. Similarly, other two IRGA for water vapour concentrations of the incoming and outgoing air. Topmost fully expanded leaf was taken for measuring the photosynthetic rate. The observations were separately recorded on 3 leaves from each plot and mean value is presented. All these observations were recorded under natural light (as per treatments) and atmospheric CO_2 concentration on intact leaves with flow rate of 300 ml per minute. The intercellular CO_2 concentration (ppm); rate of photosynthesis (µmol CO_2 m^{-2} s^{-1}); stomatal conductance (mmol CO_2 m^{-2} s^{-1}) and transpiration rate (mmol H_2O m^{-2} s^{-1}) were recorded.

3.6.3.2 Total chlorophyll content

Chlorophyll content of leaves was estimated by the following procedure described by Hiscox and Israelsam (1979).

a) Extraction of chlorophyll and Spectrophotometry

Five top most fully expanded leaves were randomly selected, cut at the base and taken to lab with cut end dipped in water in test tubes to keep them fresh. The leaves were cleaned by running tap water and blot dry. The blot dried leaves were chopped into small pieces of about 0.5cm. Then, leaf tissue weighing 0.5g±2mg was put in a vial or test tube containing 10ml dimethyl sulfoxide (DMSO) and vial was kept at about 60^0C temperature for 12 hours to extract chlorophyll. Then the samples were cooled, at room temperature, 2 ml representative extract taken in a test tube and diluted 5 times. The absorbance (A) was read at 645 and 663ηm wavelength using DMSO as blank with the help of spectrophotometer (Model: UV-VIS Spectrophotometer 118).

b) Calculation

The quantity of chlorophyll present in leaf tissues was calculated with following formulae as proposed by Hiscox and Israelsam (1979).

i. Chlorophyll ‘a’ (mg g^{-1} F.wt.)

$$= \{(12.3A_{663} - 0.86A_{645}) \div (a \times 1000 \times W)\} \times V$$

ii. Chlorophyll ‘b’ (mg g^{-1} F.wt.)

$$= \{(19.3A_{645} - 3.6A_{663}) \div (a \times 1000 \times W)\} \times V$$

iii. Total Chlorophyll = Chlorophyll ‘a’ + Chlorophyll ‘b’

iv. Chlorophyll a/b ratio = Chl a / Chl a

3.6.4 Light transmission pattern

Photosynthetically Active Radiation (PAR) was measured, at base of the plant (ground level) and middle height of the plant canopy between rows and also at top of the canopy 81 days after sowing. The PAR measurement was made at 3 randomly selected spots in each treatment by light meter (lux meter) 81 DAS. Per cent transmission was calculated as follows.

$$\text{Per cent transmission} = \frac{I_i}{I_o} \times 100$$

Where I_i and I_o are light intensities inside at i^{th} level in canopy i.e. either middle or bottom and top of the crop canopy under respective treatment, respectively.

3.6.5 Yield and yield attributes

3.6.5.1 Yield

a) Biological yield

The above ground biomass of crop (grain and straw) excluding root mass of each net plot was harvested, bundled, labeled, and sun dried in the field for four sunny days and weighed (kg) before threshing to record the biological yield and converted to report as q ha^{-1} using appropriate conversion factor.

b) Grain yield

Produce of net plot was threshed using Pullman thresher and clean grain weighed after winnowing. The grain yield initially recorded as kg per plot was finally reported as q ha^{-1} after appropriate.

c) Straw yield

Straw yield per plot was obtained by subtracting the grain weight from that of the biological produce per net plot. Straw yield recorded as kg per net plot was finally converted to q ha^{-1} using conversion factor.

d) Harvest index (%)

Harvest index (HI) which is the ratio of economic yield (grain yield) to biological yield was calculated using the following formula.

$$HI = \frac{\text{Economic yield}}{\text{Biological yield}} \times 100$$

3.6.5.2 Yield attributes

a) Number of potential shoots

Potential (ear bearing) shoots at maturity were counted from the marked one meter row length in each plot at maturity before harvesting and converted to get number of potential shoots (ear bearing shoots) per square meter.

b) Spike length

Length of ten randomly selected and collected spikes was measured from the base to the tip of upper most spikelets with the help of scale and average spike length was computed in cm per spike.

c) Fertile spikelets

The total number of grain bearing spikelets were counted in all the ten randomly selected spikes in sample and average per spike calculated.

d) Sterile spikelets

All the spikelets, which do not bear grains, were counted from all the ten randomly selected spikes of the sample and averaged to record the number of sterile spikelets per spike.

e) Grain per spike

All the spikes of the sample, i.e., ten randomly selected spikes were threshed manually, clean grain obtained and the total number of grains counted to compute the average number of grains per spike.

f) Grain weight per spike

All the grains obtained from the ten randomly selected spike sample as above were weighed and averaged to get the grain weight (g) per spike.

g) 1000-grain weight

After threshing and weighing the net plot grain yield, a random sample of grains was drawn from the net plot produce. One thousand grains were counted and weighed to record 1000-grain weight (g).

3.7 Statistical analysis

3.7.1 Analysis of variance

The data obtained during the course of investigation were analyzed using standard statistical procedure for a split plot design with the help of computer programme (STPR 1), designed and developed by department of mathematics and statistics of college of basic science and humanities (CBSH), Pantnagar.

3.7.2 Character association

To find the association between two characters, the correlation coefficients were worked out with the help of computer programme (STPR 5), designed and developed by department of mathematics and statistics of college of basic science and humanities (CBSH), Pantnagar.

3.7.3 Path coefficient analysis

Path coefficient analysis to evaluate the relative influence of yield attributes on economic (grain) yield was used to measure the direct and indirect effects with the help of computer programme (STPR 157), designed and developed by department of mathematics and statistics of college of basic science and humanities (CBSH), Pantnagar. The grain yield was taken as dependent variable (effect), and assumed to be influenced by other independent characters or variables (causes) contributing directly as well as indirectly. The path coefficients were estimated by solving the following simultaneous equation indicating the basic relationship between correlation and path coefficient (Dewey and Lu, (1959).

$$r_{1y}=P_{1y}+r_{12}P_{2y}+r_{13}P_{3y}+\ldots\ldots\ldots\ldots+r_{1n}P_{ny}$$

$$r_{1y}=P_{2y}+r_{21}P_{1y}+r_{23}P_{3y}+\ldots\ldots\ldots\ldots+r_{2n}P_{ny}$$

$$\vdots \qquad\qquad\qquad\qquad \vdots$$

$$r_{ny}=P_{ny}+r_{n1}P_{1y}+r_{n2}P_{2y}+\ldots\ldots\ldots\ldots+r_{n(n-2)}P_{ny}$$

where, r_{1y} to r_{ny} denote coefficient of correlation between causal factors 1 to n and dependent character $_y$, r_{12} to $r_{n(n-2)}$ denote the coefficient of correlation among all possible combinations of causal factors and P_{1y} to P_{ny} denote direct effects of characters 1 to n on the character $_y$.

Plate 1 Experimental view showing open or control and mild shade

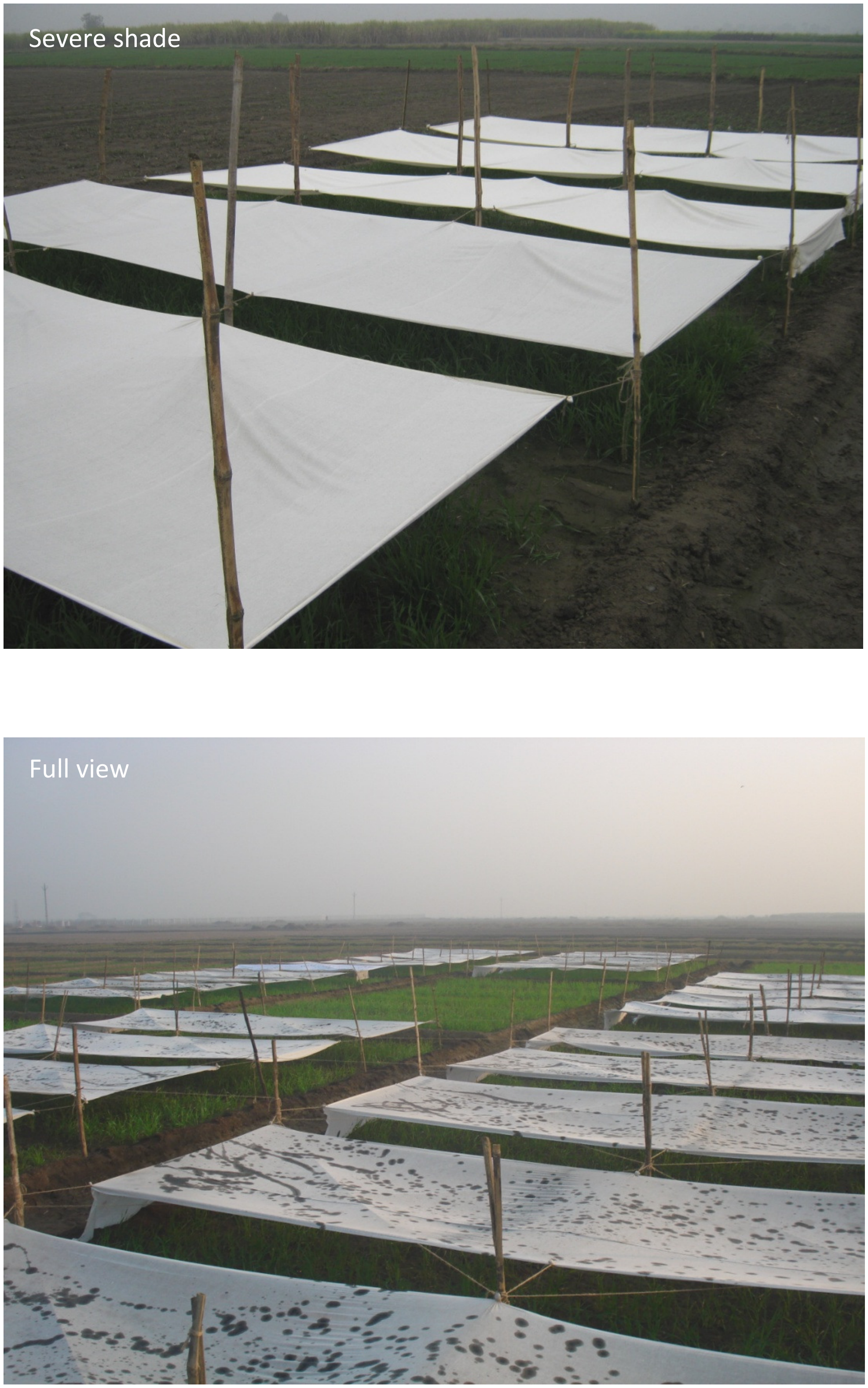


Plate 2 Experimental view showing severe shade (muslin cloths) and Field over all view

Results and Discussion

The results of the experiment entitled "Morpho-physiological bases of shade tolerance in wheat varieties" have been presented in detail and also the salient findings of the experiment are being discussed in this chapter giving experimental evidences for the variations observed with the findings of other workers. Attempts have also been made here to evaluate and explain the important observations recorded during the course of present investigation in terms of "cause" and "effect" relationship as far as possible in the light of scientific reasoning and to find out information of practical significance.

The ultimate yield in a crop is a result of the extent of successful completion of the growth and developmental activities in individual plant, which in turns, would depend upon the genetic potential of the agro-type and the environmental conditions to which it is exposed during the course of its life cycle. Several agronomical manipulations are possible to change the local environmental conditions to such an extent that the yielding ability of the agro-type could be exploited to its maximum. In order to get the maximum yield potential under a set of agro-climate conditions, it is essential that various factors of local plant environment are maintained at optimum level. The final yield is a cumulative function of preparatory net vegetative growth and then it partitioning of growth into yield components and characters directly, or indirectly contributing towards the yield.

4.1 Morphological studies

4.1.1 Crop emergence

The crop emergence (germinants m^{-2}) was not influenced by varying degree of shades and the interaction between levels of shade and varieties but varied significantly amongst wheat varieties both during 2010-11 and 2011-12 (Table 4.1.1 and Appendix III).

The wheat variety UP 2526 in 2010-11 and UP 2113 in 2011-12 recorded maximum (228 and 231 m^{-2}) number of germinants m^{-2} which have been significantly superior than other varieties during both the years i.e. 2010-11 and 2011-12,

Table 4.1.1 Crop emergence (germinants m^{-2}) as influenced by varying degree of shades and wheat varieties during 2010-11 and 2011-12

Treatment	Number of germinants m^{-2}	
	2010-11	2011-12
A. Degree of shades		
L0 – Full sun light	217	213
L1 – Mild shade	223	217
L2 – Severe shade	218	212
SEm±	2.0	5.0
CD at 5 %	NS	NS
B. Wheat varieties		
UP 2684	222	208
UP 2526	228	213
UP 2565	207	207
UP 2113	223	231
PDW 233	217	211
SEm±	4.0	5.0
CD at 5 %	11.0	14.0
CV (%)	5.1	7.2
Interaction (A x B)	NS	NS

S - Significant   NS - Non-significant

respectively, except UP 2684, UP 2526 and PDW 233 during 2010-11. The minimum (207 m^{-2}) numbers of germinants were recorded in the variety UP 2565 during both the years which was significantly poorer than all the other varieties, except PDW 233 during 2010-11 and also UP 2684, PDW 233 and UP 2526 during 2011-12.

For best performance of a crop, it is necessary that it establishes itself quickly and then grows at the faster pace. The germination (i.e. per cent and its speed) was not expected to be influenced either by degree of shades or its interaction with varieties (Table 4.1.1) both during 2010-11 and 2011-12, because shade treatments were executed only after germination of crop. However, the trees have been reported to moderate microclimate more under extreme climatic (particularly the temperature and soil moisture) conditions than under mild ones (Sharma *et al.,*2002). Puri and Khara (1991) also observed no significant differences in germination percentage of *Phaseolus vulgaris* inder *Eucalyptus tereticornis* plantation.

The crop emergence (germinants m^{-2}) was influenced significantly by different wheat variety (Table 4.1.1) indicating marked variation in seed quality amongst varieties in terms of seed size, germination etc. The variety UP 2526 recorded 9.2 percent higher germinants m^{-2} as compare to UP 2565 in 2010-11. Whereas, in 2011-12 UP 2113 obtained 10.4 per cent higher germinants m^{-2} than UP 2565. Puri and Khara (1991), however, found no significant differences in germination percentage of *Phaseolus vulgaris* under *Ecualyptus tereticornis* plantation but further development of seedlings was adversely affected. Pannu and Dhillon (1999) also reported that the wheat varieties differed significantly in their germination under poplar trees.

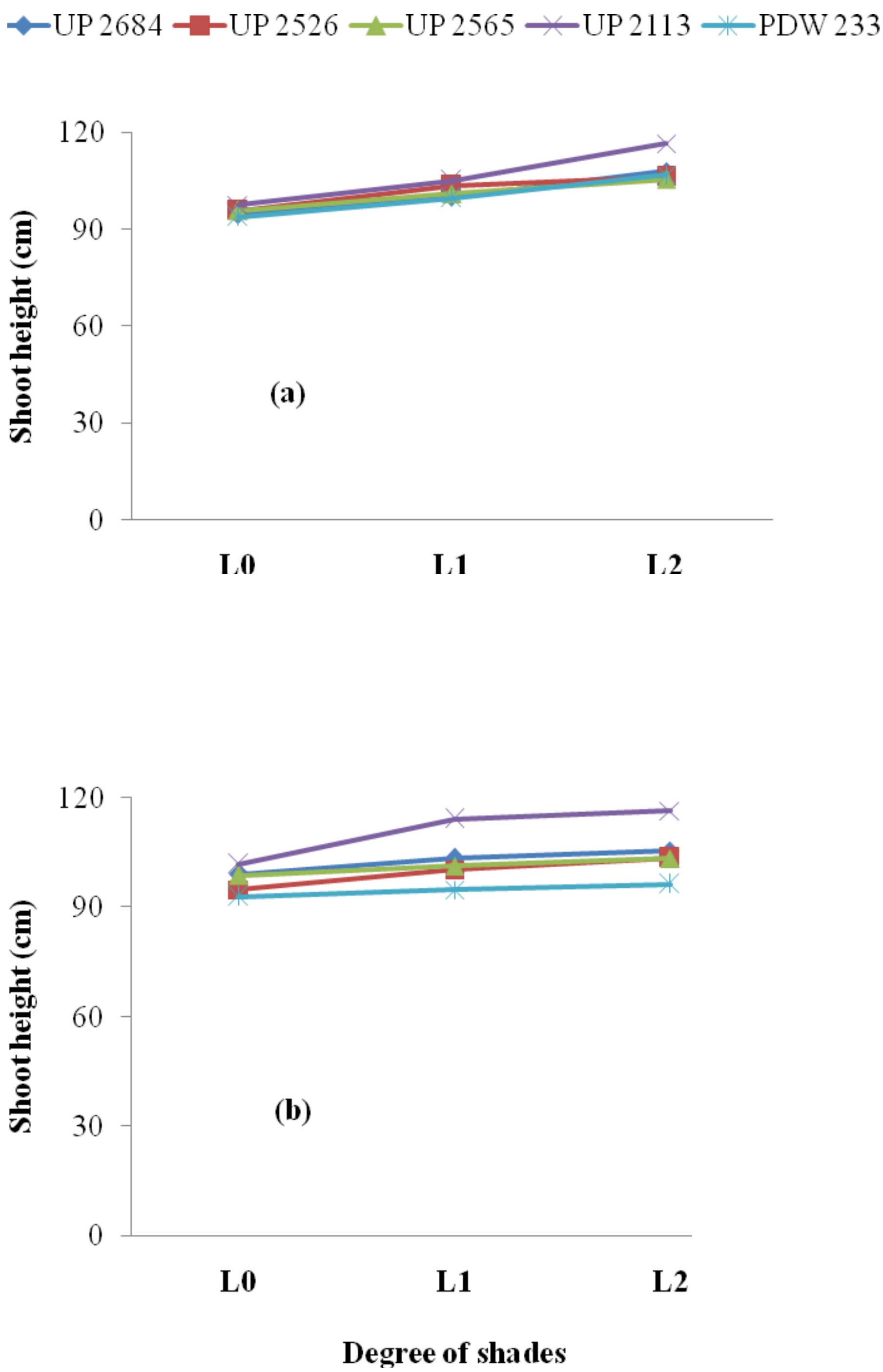
4.1.2 Shoot height

The shoot height (cm) in wheat was significantly influenced by varying degree of shades and wheat varieties all at 30, 60, 90 and 120 DAS during both the years, except by light conditions 30 DAS during 2011-12 (Table 4.1.2, Fig 4.1 and Appendix IV). However, the interaction between magnitude of shades and wheat varieties was found to be significant only 120 DAS during both the growing seasons i.e. 2010-11 and 2011-12.

Table 4.1.2 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



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig. 4.1 Shoot height (cm) of wheat varieties and under varying degree of shades 120 DAS during 2010-11(a) and 2011-12(b)

The maximum (46.1, 92.4 and 108.7 cm in 2010-11 and 45.9, 92.0 and 107.0 cm in 2011-12) 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.

The wheat varieties differed significantly in their shoot height (cm) at all growth stages i.e.30, 60, 90 and 120 DAS during both the years i.e. 2010-11 and 2011-12. The maximum (18.5, 44.5, 89.9 and 106.5 cm in 2010-11 and 22.1, 46.8. 93.2 and 110.9 cm in 2011-12) and significantly taller shoots were recorded in UP 2113 at 30, 60, 90 and 120 DAS, respectively, than other varieties, except UP2526 at 60 DAS during both the years; UP 2565 at 60 DAS in 2011-12 and UP 2526 at 30 DAS in 2010-11. The minimum (17.1, 41.9, 83.9 and 100.2 cm in 2010-11 and 17.1, 41.1, 83.4 and 98.6 cm in 2011-12) and significantly shorter shoot height was attained in variety PDW 233 at 30, 60, 90 and 120 DAS, respectively. Whereas, the varieties UP 2684, UP 2526 and UP 2565 did not differ from each other significantly at 90 DAS both during 2010-11 and 2011-12.

The interaction between varying degree of shades and wheat varieties was found to be significant 120 DAS both during 2010-11 and 2011-12 and the variety UP 2113 exhibited maximum shoot height not only under full sunlight but also under both the shaded treatments but remained at par with all other varieties at 120 DAS under full sunlight and UP 2526 under mild shade in 2010-11. Whereas, in 2011-12 it was at par with UP 2684 and UP 2565 under full sunlight at 120 DAS. The minimum and significantly shorter shoot height was observed in PDW 233 at 120 DAS during both the years i.e. 2010-11 and 2011-12, except under full sunlight during 2010-11 (Table 4.1.2a).

The variety UP 2113 under severe shade showed its superiority in shoot height over all other combination of degree of shades and varieties, while, the variety PDW 233 all under full sunlight, mild and severe shaded treatments has been significantly inferior in shoot height to all other combinations of degree of shades and varieties (Table 4.1.2a).

Table 4.1.2a Shoot height (cm shoot^{-1}) in wheat varieties as influenced by varying degree of shades 120 DAS during both the growing seasons

Wheat varieties (B)	Degree of shades (A)					
	2010-11			2011-12		
	L0	L1	L2	L0	L1	L2
UP 2684	94.7	100.1	108.1	99.1	103.6	105.4
UP 2526	95.8	103.6	106.3	94.8	100.3	103.6
UP 2565	95.8	101.1	105.6	98.7	101.4	103.4
UP 2113	97.6	105.2	116.6	101.9	114.3	116.4
PDW 233	93.9	99.7	106.9	92.9	94.8	96.4
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		1.3	3.8		1.3	3.8
To compare means of two 'A' at the same or different 'B'		1.2	3.7		1.2	3.5

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

The plant height is important for proper distribution and display of photosynthetic apparatus i.e. leaves. The data on shoot height (Table 4.1.2) 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.

4.1.3 Leaf length

The mean leaf length (cm) was significantly influenced by varying degree of shades at 60, 90 and 120 DAS but not at 30 DAS, wheat varieties at all the stages and by the interaction between them at 90 and 120 DAS during both the growing seasons i.e. 2010-11 and 2011-12 and also due to interaction at 60 DAS in 2010-11 (Table 4.1.3 and Appendix V).

The maximum (25.8, 30.4 and 26.4 cm in 2010-11 and 26.0, 32.4 and 26.7 cm in 2011-12) and significantly longer mean leaf length was recorded under 1/3 light availability (i.e. 2/3 shading) at 60, 90 and 120 days after sowing (DAS), respectively, which shortened significantly with each successive decrease in degree of shade with no significant differences between 1/3 and 2/3 of full sunlight availability at 90 and 120 DAS in 2010-11 and at 60, 90 and 120 DAS in 2011-12.

The wheat varieties differed significantly in their mean leaf length during both the years i.e. 2010-11 and 2011-12. The variety UP 2113 had maximum (15.4, 26.5, 30.9 and 26.9 cm in 2010-11 and 16.3, 26.6, 32.7 and 27.2 cm in 2011-12) and significantly longer mean leaf length at 30, 60, 90 and 120 DAS, respectively, than other varieties, except with UP 2526 at 60 DAS and UP 2684 at 90 and 120 DAS in 2010-11 and also UP 2684 at 30 and 120 DAS; UP 2526 at 30 DAS and UP 2565 at 60 DAS in 2011-12. The minimum and significantly shorter mean leaf length was recorded in variety PDW 233 at 60 and 90 DAS both during 2010-11 and 2011-12 being at par with UP 2526 at 90 DAS during both the years. Whereas, the variety UP 2565 recorded shorter mean leaf length than all other varieties at 120 DAS both during 2010-11 and 2011-12.

The interaction between degree of shade and different wheat varieties was found to be significant at 90 and 120 DAS both during 2010-11 and 2011-12 and at 60 DAS only during 2010-11 (Table 4.1.3a). The variety UP 2113 found best and significantly longer leaf length than all other combination of shade and varieties under all the light availability conditions i.e. full sunlight, mild and severe shaded treatment at 60 DAS in 2010-11 and at 90 and 120 DAS both during 2010-11 and 2011-12, except under full sunlight at 120 DAS in 2010-11, being at par with UP 2565 under all shaded treatment at 90 DAS in 2010-11. The minimum and significantly shorter leaf length was recorded from UP 2526 at 60 DAS under full sunlight, mild and severe shade at 90 and 120 DAS both during 2010-11 and 2011-12 and at 60 DAS in 2010-11, except under severe shade at 60 and 90 DAS during 2010-11 and 2011-12, respectively.

Table 4.1.3 Average leaf length (cm leaf^{-1}) of different wheat varieties and under varying degree of shades at different crop growth stages during both the growing seasons

Treatment	2010-11				2011-12			
	30 DAS	**60 DAS**	**90 DAS**	**120 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**120 DAS**
A. Degree of shades								
L0 – Full sun light	14.0	24.0	26.5	22.9	14.9	23.9	28.1	23.2
L1 – Mild shade	13.8	24.9	30.3	25.8	14.1	25.1	31.3	26.2
L2 – Severe shade	14.3	25.8	30.4	26.4	15.7	26.0	32.4	26.7
SEm±	0.1	0.2	0.3	0.2	0.2	0.3	0.4	0.2
CD at 5 %	NS	0.8	1.1	0.6	NS	1.0	1.5	0.6
B. Wheat varieties								
UP 2684	12.7	24.5	30.1	27.0	15.4	24.5	31.7	27.3
UP 2526	14.4	25.6	27.1	24.2	15.9	24.7	29.5	24.5
UP 2565	13.9	25.3	29.8	22.4	14.3	25.3	30.4	22.7
UP 2113	15.4	26.5	30.9	26.9	16.3	26.6	32.7	27.2
PDW 233	13.6	23.6	27.2	24.8	14.0	23.8	28.7	25.2
SEm±	0.2	0.4	0.3	0.4	0.5	0.5	0.3	0.5
CD at 5 %	0.5	1.1	1.0	1.1	1.4	1.3	0.9	1.5
CV (%)	3.4	4.7	3.5	4.7	9.8	5.3	3.0	5.9
Interaction (A x B)	NS	S	S	S	NS	NS	S	S

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

Table 4.1.3a Average leaf length (cm leaf^{-1}) in different wheat varieties as influenced by varying degree of shades during both the growing seasons

Wheat varieties (B)	Degree of shades (A)														
	60 DAS			90 DAS						120 DAS					
	2010-11			2010-11			2011-12			2010-11			2011-12		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	24.05	26.05	23.50	27.83	30.93	31.60	30.90	30.46	33.60	25.07	26.07	29.76	25.42	26.40	30.10
UP 2526	22.44	25.11	26.21	23.63	29.13	28.60	26.27	29.00	33.37	22.28	24.84	25.47	22.61	25.17	25.80
UP 2565	23.80	26.98	25.27	26.50	31.28	31.70	26.60	31.27	33.33	20.49	23.31	23.33	20.82	23.65	23.67
UP 2113	26.13	27.36	25.89	28.03	32.83	31.97	30.00	35.07	32.90	22.87	29.02	28.73	23.20	29.35	29.07
PDW 233	23.55	23.69	23.64	26.30	27.26	28.04	26.57	30.80	28.73	23.80	26.00	24.64	24.13	26.33	24.97

	60 DAS 2010-11 SEm±	60 DAS 2010-11 CD at 5%	90 DAS 2010-11 SEm±	90 DAS 2010-11 CD at 5%	90 DAS 2011-12 SEm±	90 DAS 2011-12 CD at 5%	120 DAS 2010-11 SEm±	120 DAS 2010-11 CD at 5%	120 DAS 2011-12 SEm±	120 DAS 2011-12 CD at5%
To compare means of two B at the same 'A'	0.68	1.99	0.59	1.74	0.54	1.57	0.68	1.98	0.87	2.54
To compare means of two 'A' at the same or different 'B'	0.64	1.92	0.61	1.91	0.61	1.99	0.62	1.86	0.79	2.36

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

The variety UP 2113 at par with UP 2684 and UP 2565 under mild and severe shaded treatment showed its superiority in mean leaf length over all other combinations of shades and varieties. Whereas, UP 2526 under full sunlight at 60 and 90 DAS and UP 2565 at 120 DAS proved to be inferior most than all the other combination of light and varieties, except UP 2684, UP 2565 and PDW 233 under full sunlight and also PDW 233 under mild and severe shades 60 DAS in 2010-11; UP 2565 and PDW 233 under full sunlight at 90 DAS in 2011-12 and UP 2526 under full sunlight 120 DAS both in 2010-11 and 2011-12.

Leaf size (length and width) and their number plant^{-1} (a genetically governed parameter) of a crop is good indicator of ultimate photosynthetic surface area. In order to capture more light under shading conditions, plants are able to increase light interception efficiency by improving canopy cover through increased leaf size, which can be expressed well in terms of leaf area index (Li *et al*., 2010). The leaf length improved but only under mild shade, as was recorded significantly higher under 1/3 light availability than 2/3 and full sunlight available condition (Table 4.1.3). The small leaf length was observed and the per cent reduction was greater (7.0, 12.8 and 13.3 in 2010-11and 8.1, 13.3 and 13.1 in 2011-12) under full sunlight at 60, 90 and 120 DAS, respectively, over 1/3 light available condition. Among the wheat varieties UP 2113 getting maximum leaf length 30.9 cm at 90 DAS which was 12.3 and 12.0 per cent longer than in the UP 2526 (27.1 cm) and PDW 233 (27.3 cm), respectively, in 2010-11. Whereas, in 2011-12, the longer leaf was observed in the variety UP 2113, while it was smaller in PDW 233, which was 12.2 per cent smaller than the UP 2113.

4.1.4 Leaf width

The mean leaf width (cm) in wheat was significantly influenced by the varying degree of shade and wheat varieties at 30, 60 90 and 120 DAS both during 2010-11 and 2011-12, however, the interaction between degree of shades and wheat varieties was influenced significantly only 30 and 60 DAS during both the years (Table 4.1.4 and Appendix VI).

The maximum (0.60, 1.30, 1.59 and 1.90 cm in 2010-11 and 0.62, 1.32, 1.61 and 1.92 cm in 2011-12) and significantly higher mean leaf width was recorded under

Table 4.1.4 Average leaf width (cm leaf^{-1}) as influenced by wheat varieties and under varying degree of shades at various crop growth stages during both the growing seasons

Treatment	2010-11				2011-12			
	30 DAS	60 DAS	90 DAS	120 DAS	30 DAS	60 DAS	90 DAS	120 DAS
A. Degree of shades								
L0 – Full sun light	0.53	1.23	1.51	1.67	0.55	1.23	1.53	1.68
L1 – Mild shade	0.59	1.21	1.55	1.82	0.61	1.25	1.56	1.84
L2 – Severe shade	0.60	1.30	1.59	1.90	0.62	1.32	1.61	1.92
SEm±	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01
CD at 5 %	0.01	0.02	0.02	0.02	0.05	0.03	0.06	0.02
B. Wheat varieties								
UP 2684	0.65	1.30	1.56	1.81	0.67	1.32	1.57	1.82
UP 2526	0.63	1.18	1.45	1.78	0.65	1.20	1.46	1.80
UP 2565	0.55	1.34	1.64	1.81	0.56	1.36	1.66	1.83
UP 2113	0.60	1.27	1.54	1.74	0.62	1.28	1.56	1.76
PDW 233	0.44	1.14	1.57	1.86	0.46	1.16	1.58	1.87
SEm±	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02
CD at 5 %	0.03	0.04	0.04	0.04	0.04	0.06	0.06	0.05
CV (%)	4.5	3.1	2.5	2.2	7.6	4.9	3.8	3.1
Interaction (A x B)	S	S	NS	NS	S	S	NS	NS

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

Table 4.1.4a Average leaf width (cm leaf^{-1}) in different wheat varieties as influenced by varying degree of shades 30 and 60 DAS during both the growing seasons

Wheat varieties (B)	Degree of shades (A)											
	30 DAS						60 DAS					
	2010-11			2011-12			2010-11			2011-12		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	0.58	0.67	0.71	0.59	0.68	0.73	1.18	1.36	1.36	1.38	1.19	1.38
UP 2526	0.59	0.62	0.67	0.61	0.64	0.69	1.11	1.29	1.13	1.15	1.13	1.31
UP 2565	0.50	0.57	0.57	0.52	0.59	0.57	1.40	1.35	1.28	1.29	1.42	1.37
UP 2113	0.54	0.69	0.59	0.56	0.70	0.60	1.30	1.27	1.23	1.24	1.32	1.28
PDW 233	0.45	0.48	0.40	0.47	0.50	0.42	1.16	1.23	1.36	1.06	1.18	1.24
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		0.02	0.04		0.03	0.07		0.02	0.07		0.04	0.10
To compare means of two 'A' at the same or different 'B'		0.01	0.04		0.03	0.08		0.02	0.06		0.03	0.09

DAS = Days after sowing **L0** –Full sun light **L1** – Mild shade **L2** - Severe shade highest degree of shade (i.e. 1/3 of full sunlight) at 30, 60, 90 and 120 DAS, respectively, which reduced significantly with each successive decrease in shade at all these four growth stages both during 2010-11 and 2011-12 with no significant difference between severe and mild shades at 30 and 90 DAS during both the years. Whereas, the lower degree of shade and full sunlight did not differ significantly at 60 and 90 DAS during both the years i.e. 2010-11 and 2011-12.

The wheat varieties differed significantly in their leaf width at 30, 60, 90 and 120 DAS during both the years. The variety UP 2565 recorded maximum (1.34 and 1.64 cm in 2010-11 and 1.36 and 1.66 cm in 2011-12) and significantly higher mean leaf width at 60 and 90 DAS, respectively, than other varieties, except UP 2684 at 60 DAS during both the years. Whereas, the varieties UP 2684 and PDW 233 had higher mean leaf width at 30 and 120 DAS, during both the years, respectively. However, the variety PDW 233 was at par with UP 2565 and UP 2684 at 120 DAS in 2011-12. The minimum and significantly narrower mean leaf width was recorded in variety PDW 233 at 30 and 60 DAS; UP 2526 at 90 and UP 2113 at 120 DAS during 2010-11 and 2011-12, respectively, than other varieties, except UP 2526 at 60 and 120 DAS.

The interaction between magnitude of shade and different wheat varieties was found to be significant at 30 and 60 DAS both during 2010-11 and 2011-12 (Table 4.1.4a). While, the variety UP 2684 recorded significantly higher leaf width under full sunlight, mild and severe shade at 30 and 60 DAS both during 2010-11 and 2011-12 than other combinations of light conditions and varieties, except UP 2526 under full sunlight and UP 2113 mild shade at 30 DAS both during 2010-11 and 2011-12. Whereas, UP 2565 under full sunlight than all other varieties; under mild shade at par with UP 2684 in 2010-11 and UP 2684 at par with PDW 233 in 2010-11 and UP 2565 in 2011-12 under severe shade exhibited significantly wider leaf than test of the varieties. The minimum and significantly lowest leaf length was observed in PDW 233 under all the light availability conditions (i.e. full, 2/3, 1/3 available light) at 30 and 60 DAS during both the growing season, except at 60 DAS under severe shade in 2010-11. While, the variety UP 2684 under mild and severe shades showed its superiority in their leaf width at 30 and 60 DAS during both the years, except under mild shade at 60 DAS in 2011-12, than all other combinations of degree of shades and varieties. Whereas, PDW 233 under all the treatments i.e. full, 2/3 and 1/3 of full sunlight, has been significantly inferior than all other combination of degree of shades and varieties at 30 and 60 DAS during both the years.

The leaf width was greatly influenced by varying degree of shades, with the values increasing with crop age i.e. from 30 to 120 DAS (Table 4.1.4). However, the value was higher (0.60, 1.30, 1.59 and 1.90 cm in 2010-11 and 0.62, 1.32, 1.62 and 1.92 cm in 2011-12) with higher degree of shade (i.e. 2/3 shading) at 30, 60, 90 and 120 DAS, respectively. The leaf width under higher degree of shade was greater by 4.4 and 13.8 per cent in comparison with lower degree of shade (i.e. 1/3 shading) and full sunlight, respectively, 120 DAS in 2010-11 and 4.3 and 14.3 per cent in 2011-12. Whereas, the leaf width was greater by 9.0 and 9.5 per cent under mild shade as compare to full sunlight both during 2010-11 and 2011-12, respectively. For the varieties, UP 2684 recorded higher leaf width of 0.65 and 1.30 cm and 0.67 and 1.32 cm at 30 and 60 DAS during both the years, respectively, which was wider by 47.7 and 14.0 in 2010-11 and 47.7 and 13.3 in 2011-12 at 30and 60 DAS, respectively over PDW 233. This was in conformity with the findings of Yoshida (1972) and Jain (1998), who demonstrated varietal differences among wheat varieties with increase leaf size and LAI under shade/under poplar based agroforestry system.

4.1.5 Internode length on 90 DAS

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 4.1.5 and Appendix VII).

The maximum (12.3, 14.3, 12.1 and 9.2 cm in 2010-11 and 12.5, 14.5, 12 and 9.5 cm in 2011-12) and significantly longer internode length was measured under higher degree of shade (i.e. 2/3 shading) for the first, second, third and fourth internodes from top at 90 DAS, respectively, which reduced significantly with each successive reduction in shade, with no significant difference between 1/3 and 2/3 of full sunlight availability in fourth internode from top at 90 DAS during both the years i.e. 2010-11 and 2011-12.

Table 4.1.5 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

Table 4.1.5a Average internodal length (cm) from top downward in different wheat varieties as influenced by varying degree of shades 90 DAS during both the growing seasons

Wheat varieties (B)	Degree of shades (A)											
	First internode						Second internode					
	2010-11			2011-12			2010-11			2011-12		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	9.9	11.7	13.1	10.0	11.8	13.3	12.4	14.6	15.7	12.6	14.8	15.9
UP 2526	10.7	12.4	13.5	10.9	12.6	13.7	12.0	13.3	14.9	12.2	13.5	15.1
UP 2565	11.3	13.0	14.5	11.5	13.2	14.7	13.9	15.9	16.7	14.1	16.1	16.9
UP 2113	10.4	10.5	12.5	10.9	10.7	12.7	12.8	12.9	14.6	13.0	13.1	14.8
PDW 233	6.1	6.8	7.8	6.2	6.9	7.9	8.4	9.2	9.8	8.6	9.4	10.0
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		0.2	0.7		0.2	0.7		0.3	0.9		0.3	0.9
To compare means of two 'A' at the same or different 'B'		0.2	0.7		0.2	0.7		0.3	0.8		0.3	0.9

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

The wheat varieties differed significantly in their mean internodal length during both the years i.e. 2010-11 and 2011-12. The variety UP 2565 (12.9, 15.5, 13.1 and 7.0 cm in 2010-11 and 13.1, 15.7, 13.0 and 7.1 cm in 2011-12) recorded significantly more internode length of first, second, third and fifth internode, respectively, being at par with PDW 233 of fifth internode from top during both the years. Whereas, the variety UP 2113 recorded higher length for fourth internodes from top at 90 DAS during both the years. However, the variety PDW 233 observed significantly lower length of the first, second, third and fourth internodes from top, except fifth internode from top during both the years.

The interaction between degree of shade and different wheat varieties was found to be significant (Table 4.1.5a) for first and second internodes in both the years. While, the variety UP 2565 had longest and significantly longer internode lengths than all other combinations of shades and varieties for the length of first and second internodes from top under all the light available conditions i.e. full, 2/3 and 1/3 available light 90 DAS during both the seasons i.e. 2010-11 and 2011-12, except UP 2526 for first internode from top under full sunlight and mild shade both during 2010-11 (10.7 and 12.4 respectively) and 2011-12 (10.9 and 12.6, respectively).

The minimum and significantly shorter internode length was observed in PDW233 in first and second internode from top under all the light available conditions i.e. full, mild and severe shade, both during 2010-11 and 2011-12. While, the variety UP 2565 under mild and severe shades showed its superiority in their internode length over all other combination of degree of shades and varieties, the variety PDW 233 under full and mild shaded treatment has been significantly inferior than all other combination of degree of shades and varieties.

4.1.6 Internode length on 128 DAS

The mean internode length (cm) in wheat 128 DAS was influenced significantly by degree of shades and wheat varieties for first, second, third, fourth and fifth internode from top both during 2010-11 and 2011-12, whereas, the interaction between degree of shades and wheat varieties was not influenced significantly for any of the internode from top during both years i.e. 2010-11 and 2011-12 (Table 4.1.6 Appendix VIII).

Table 4.1.6 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

The maximum (35.1, 19.6, 15.1, 10.5 and 7.9 cm in 2010-11 and 35.4, 19.8, 15.3, 10.3 and 8.6 cm in 2011-12) 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.

The wheat varieties significantly differed in their internode lengths 128 DAS during both the years i.e. 2010-11 and 2011-12. The variety UP 2113 had longest (35.1, 16.3, 12.5 and 8.9 cm in 2010-11 and 35.4, 16.4, 12.3 and 8.1 cm in 2011-12) mean internode length amongst all other varieties of the first, third, fourth and fifth internode, respectively, except UP 2684 for first internode from top both during 2010-11 and 2011-12 and also UP 2565 in 2011-12. The first and second internode in variety PDW 233 and third, fourth and fifth internodes from top in variety UP 2526 were observed to be significantly shorter in their mean internodal lengths than others. However, the variety UP 2526 was at par with PDW 233 for third and fourth internodal length from top at 128 DAS both during 2010-11 and 2011-12 and also fifth internode in 2011-12.

The average length (Table 4.1.5) 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 4.1.6) 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.

4.1.7 Dry weight internode 90 DAS

The mean internodal dry weight (mg) of first, second, third, fourth and fifth internode from top in wheat was influenced significantly by the varying degree of shads and different wheat varieties 90 DAS during both the years i.e. 2010-11 and 2011-12 (Table 4.1.7 and Appendix IX). However, the interaction between varying degree of shades and different wheat varieties was influenced significantly for first, second and third internodes from top this stage during both the years.

The maximum (262.0, 823.5, 913.3, 820. and 677.9 mg in 2010-11 and 268.6, 832.6, 912.0, 824.7 and 667.9 mg in 2011-12) and significantly higher mean internodal dry weight was recorded under full sunlight (i.e. control) all for first, second, third, fourth and fifth internodes from top at 90 DAS, respectively, which reduced significantly with each successive increase in shade at 90 DAS during both the years.

The wheat varieties differed significantly in their mean internode dry weight (mg) at 90 days stage during both the years i.e. 2010-11 and 2011-12 and the variety UP 2565 in second and third internode dry weight from top and UP 2113 in fourth and fifth internode accumulated more dry weight at 90 DAS both during 2010-11 and 2011-12. Whereas, in first internode from top the variety PDW 233 (243.3 and 250.0 mg) recorded highest and significantly more dry weight at 90 DAS both during 2010-11 and 2011-12, respectively, being at par with UP 2113 and UP 2684. The minimum and significantly lower mean internode dry weight was observed in second, third and fifth internode from top from PDW 233 and in fourth and fifth internode from top for UP 2526 at 90 DAS during both the years.

The interaction between degree of shades and different wheat varieties in their mean internode dry weight was found to be significant (Table 4.1.7a). While, the variety UP 2565 accumulated maximum and significantly more dry matter under mild and severe shade in second and third internode from top at 90 DAS in 2010-11 then all other combinations of shades and varieties, being at par with all other varieties, except PDW 233 under mild shade in second internode from top; UP 2526 under full sunlight

Table 4.1.7 Mean internode dry weight (mg) from top downwards in different wheat varieties and under varying degree of shades 90 DAS during both the growing seasons

Treatment	First		Second		Third		Fourth		Fifth	
	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	262.0	268.6	823.5	832.6	913.3	912.0	820.0	824.7	677.9	667.9
L1 – Mild shade	217.9	224.6	638.1	648.1	727.9	717.9	713.8	721.2	571.9	565.9
L2 – Severe shade	188.0	194.0	536.2	543.5	629.7	620.4	648.0	654.7	507.8	497.7
SEm±	0.7	5.7	4.5	8.7	5.0	4.6	4.9	7.5	3.7	10.9
CD at 5 %	2.7	22.3	17.6	33.9	19.6	17.9	19.0	29.3	14.7	43.0
B. Wheat varieties										
UP 2684	243.3	249.9	646.3	655.2	774.4	769.9	696.7	699.9	496.5	487.5
UP 2526	173.3	179.9	743.3	752.2	720.0	715.6	600.0	606.8	540.0	530.0
UP 2565	210.0	216.6	737.1	746.0	933.9	927.3	823.3	831.1	690.0	680.0
UP 2113	243.3	248.9	680.0	690.0	716.6	707.8	853.3	860.1	816.7	805.6
PDW 233	243.3	250.0	521.4	530.3	639.9	629.9	663.0	669.6	386.2	382.9
SEm±	1.6	2.7	10.8	14.5	12.3	14.5	9.0	10.9	10.2	11.4
CD at 5 %	4.8	7.9	31.6	42.3	35.9	42.3	26.3	32.1	29.7	33.2
CV (%)	2.2	3.6	4.9	6.4	4.8	5.8	3.7	4.5	5.2	5.9
Interaction (A x B)	S	S	S	S	S	S	NS	NS	NS	NS

S - Significant NS - Non-significant

Table 4.1.7a Mean internode dry weight (mg) from top downwards in different wheat varieties as influenced by varying degree of shades 90 DAS during 2010-11

Wheat varieties (B)	Degree of shades (A)								
	First internode			Second internode			Third internode		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	280.0	240.0	210.0	780.0	658.9	500.0	913.3	730.0	680.0
UP 2526	210.0	170.0	140.0	900.0	700.0	630.0	850.0	680.0	630.0
UP 2565	240.0	210.0	180.0	850.0	711.4	650.0	725.3	840.0	708.6
UP 2113	280.0	230.0	220.0	830.0	670.0	540.0	800.0	710.0	640.0
PDW 233	300.0	239.9	190.0	753.3	450.0	360.9	750.0	679.9	490.0

	First internode SEm±	First internode CD at 5%	Second internode SEm±	Second internode CD at 5%	Third internode SEm±	Third internode CD at 5%
To compare means of two B at the same 'A'	2.9	8.3	18.8	54.8	21.3	62.1
To compare means of two 'A' at the same or different 'B'	2.6	7.9	17.4	51.8	19.7	58.7

Table 4.1.7b Mean internode dry weight (mg) from top downwards in different wheat varieties as influenced by varying degree of shades 90 DAS during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	First internode			Second internode			Third internode		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	286.6	246.7	216.6	790.0	668.9	506.6	916.7	719.8	673.2
UP 2526	216.6	176.7	146.6	910.0	710.0	636.7	853.3	669.8	623.5
UP 2565	246.7	216.6	186.7	860.0	721.4	656.6	1250.0	830.0	701.9
UP 2113	286.7	236.5	223.5	840.1	680.0	550.0	793.3	700.0	630.0
PDW 233	306.6	246.6	196.7	763.3	460.0	367.6	746.7	669.8	470.3

	First internode SEm±	First internode CD at 5%	Second internode SEm±	Second internode CD at 5%	Third internode SEm±	Third internode CD at 5%
To compare means of two B at the same 'A'	4.7	13.8	25.1	73.3	25.1	73.3
To compare means of two 'A' at the same or different 'B'	7.1	25.3	27.1	73.4	22.9	67.9

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

and severe shade in second internode from top and also UP 2684 under severe shade in third internode from top at 90 DAS in 2010-11. The minimum (210.0, 170.0 and 140.0 mg) and significantly lower dry weight was recorded in variety UP 2526 under all the light availability conditions in first internode from top at 90 DAS. Whereas, in second and third internode from top, the variety PDW 233 had lower internode dry weight at 90 DAS in 2010-11.

During, 2011-12, the internode dry weight in UP 2565 found to be more than other varieties all under full sunlight, mild and severe shaded treatment in second and third internode from top at 90 DAS in 2011-12, except UP 2526 under both the shaded treatment; UP 2113 under full sunlight; UP 2684 under mild shade in second internode from top and also UP 2113 and UP 2684 under severe shade in third internode from top. Whereas, in first internode from top the variety PDW 233 attained significantly higher dry weight under full sunlight and mild shade, while under severe shade by UP 2113 at 90 DAS in 2011-12. The minimum internode dry weight was attained in UP 2526 in first internode and in PDW 233 in second and third internode from top at 90 DAS (Table 4.1.7b).

The variety PDW 233, UP 2526, UP2684 and UP 2565 under full sunlight showed their superiority in internode dry weight over all other combinations of degree of shade and varieties in first, second and third internodes 90 DAS. Whereas, the variety UP 2526 under severe shade in first internode and PDW 233 under severe shade in second and third internode from top have been significantly inferior to all other combination of degree of shades and varieties at 90 DAS.

4.1.8 Dry weight internodes 128 DAS

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 4.1.8 and Appendix X). 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.

Table 4.1.8 Mean internode dry weight (mg) from top downwards in different wheat varieties and under varying degree of shades 128 DAS during both the growing seasons

Treatment	First		Second		Third		Fourth		Fifth	
	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	1146.5	1160.6	900.0	916.7	701.5	686.2	629.4	636.1	538.0	528.0
L1 – Mild shade	944.1	956.8	786.0	802.7	598.7	585.4	560.0	563.3	465.9	455.9
L2 – Severe shade	821.4	832.0	670.3	686.9	519.3	505.1	507.3	511.0	407.9	397.9
SEm±	7.4	12.2	5.2	12.5	8.3	15.4	2.7	6.1	5.5	5.5
CD at 5 %	28.9	47.8	20.3	48.9	32.3	60.3	10.5	23.9	21.6	21.6
B. Wheat varieties										
UP 2684	937.8	949.1	736.7	753.3	530.3	517.0	554.2	558.0	380.0	370.0
UP 2526	1033.3	1045.6	843.3	860.0	623.4	608.9	423.3	427.3	463.2	453.2
UP 2565	1150.0	1164.4	1060.0	1076.7	668.9	653.4	553.3	557.2	446.5	436.4
UP 2113	836.2	847.3	777.1	793.8	694.4	678.4	693.3	697.2	633.3	623.3
PDW 233	896.1	909.4	510.0	526.7	515.6	503.3	603.7	610.9	430.0	420.0
SEm±	12.8	13.3	12.3	15.8	11.8	11.9	11.8	12.4	8.6	8.6
CD at 5 %	37.5	38.8	36.0	46.1	34.5	34.9	34.5	36.3	25.2	25.2
CV (%)	4.0	4.1	4.7	5.9	5.8	6.1	6.3	6.5	5.5	5.6
Interaction (A x B)	S	S	S	S	NS	NS	NS	NS	S	S

S - Significant NS - Non-significant

Table 4.1.8a Mean internode dry weight (mg) from top downwards in different wheat varieties as influenced by varying degree of shades 128 DAS during 2010-11

Wheat varieties (B)	Degree of shades (A)								
	First internode			Second internode			Fifth internode		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	1092.6	900.7	820.0	850.0	720.0	640.0	480.0	360.0	300.0
UP 2526	1200.0	1000.0	900.0	930.0	830.0	770.0	540.0	449.7	400.0
UP 2565	1430.0	1100.0	920.0	1260.0	1100.0	820.0	490.0	430.0	419.5
UP 2113	960.0	820.0	728.4	840.0	780.0	711.4	720.0	660.0	520.0
PDW 233	1050.0	900.0	738.4	620.0	500.0	410.0	460.0	430.0	400.0

	First internode SEm±	First internode CD at 5%	Second internode SEm±	Second internode CD at 5%	Fifth internode SEm±	Fifth internode CD at5%
To compare means of two B at the same 'A'	22.3	65.0	21.4	62.4	15.0	43.7
To compare means of two 'A' at the same or different 'B'	21.2	64.5	19.8	59.2	14.5	44.4

Table 4.1.8b Mean internode dry weight (mg) from top downwards in different wheat varieties as influenced by varying degree of shades 128 DAS during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	First internode			Second internode			Fifth internode		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	1103.3	914.0	830.0	866.6	736.6	656.6	470.0	350.0	290.0
UP 2526	1210.0	1013.3	913.3	946.6	846.6	786.6	530.1	439.6	390.0
UP 2565	1453.3	1110.0	930.0	1276.6	1116.6	836.6	480.0	419.8	409.3
UP 2113	973.4	830.0	738.4	856.6	796.6	728.1	710.1	649.9	510.0
PDW 233	1063.3	916.7	748.3	636.8	516.6	426.6	450.0	420.0	390.0
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	23.1	67.3		27.3	79.8		15.0	43.7	
To compare means of two 'A' at the same or different 'B'	24.0	76.2		27.5	85.8		14.5	44.4	

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

The maximum (1146.5, 900.0, 701.5, 629.4 and 538.0 mg in 2010-11 and 1160.6, 916.7, 686.2, 636.1 and 528.0 mg in 2011-12) and significantly more mean internode dry weight (mg) was found accumulating under full sunlight (i.e. control) in first, second, third, fourth and fifth internode from top at 128 DAS, respectively, which reduced significantly with each successive increase in shade during both the years.

The wheat varieties differed significantly in their mean dry weight in first, second, third, fourth and fifth internode from top 128 DAS during both the years i.e. 2010-11 and 2011-12. 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 4.1.8a & b). Though, the variety UP 2565 found to accumulate higher dry weight not only under full sunlight but also under both the shaded treatment in first and second internodes from top at 128 DAS both during 2010-11 and 2011-12. Whereas, in fifth internode, the variety UP 2113 accumulated significantly more dry weight under all the light availability condition. The lower dry weight was obtained for UP 2113 in first internode; PDW 233 in second internode and UP 2684 in fifth internode from top under full, 2/3 and 1/3 light available conditions at 128 DAS during both the years i.e. 2010-11 and 2011-12, respectively.

While, the variety UP 2526 under full sunlight showed its superiority in an internode dry weight over all other combinations of degree of shades and varieties in first and second internodes, but the variety UP 2113 in fifth internode. However, the variety PDW 233 and UP 2684 under severe shaded treatment in first and second and fifth internodes has been significantly inferior dry weights than all other combinations of degree of shades and varieties, respectively.

The data revealed that (Table 4.1.7 and 4.1.8) 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).

4.1.9 Flag leaf area

The mean flag leaf area (cm^2 $leaf^{-1}$) in wheat was influenced significantly by degree of shades, wheat varieties and the interaction between them 10 days after anthesis both during 2010-11 and 2011-12 (Table 4.1.9, Fig 4.2 and Appendix XI).

The minimum (38.0 and 37.4 cm^2 $leaf^{-1}$) and significantly lower flag leaf was observed under full sunlight (i.e. control) 10 days after anthesis which increased significantly with each successive increase in shade during both the growing seasons i.e. 2010-11 and 2011-12 with no significant difference between 2/3 and 1/3 of full sunlight availability during 2010-11.

Table 4.1.9 Flag leaf area (cm^2 $leaf^{-1}$) 10 days after anthesis in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Flag leaf area (cm^2 $leaf^{-1}$)	
	2010-11	**2011-12**
A. Degree of shades		
L0 – Full sun light	38.0	37.4
L1 – Mild shade	50.3	48.3
L2 – Severe shade	49.8	49.1
SEm±	0.3	0.1
CD at 5 %	1.2	0.5
B. Wheat varieties		
UP 2684	49.4	46.4
UP 2526	44.9	45.4
UP 2565	42.1	41.2
UP 2113	48.6	45.8
PDW 233	45.2	45.6
SEm±	0.4	0.5
CD at 5 %	1.2	1.5
CV (%)	2.8	3.4
Interaction (A x B)	S	S

S - Significant NS - Non-significant

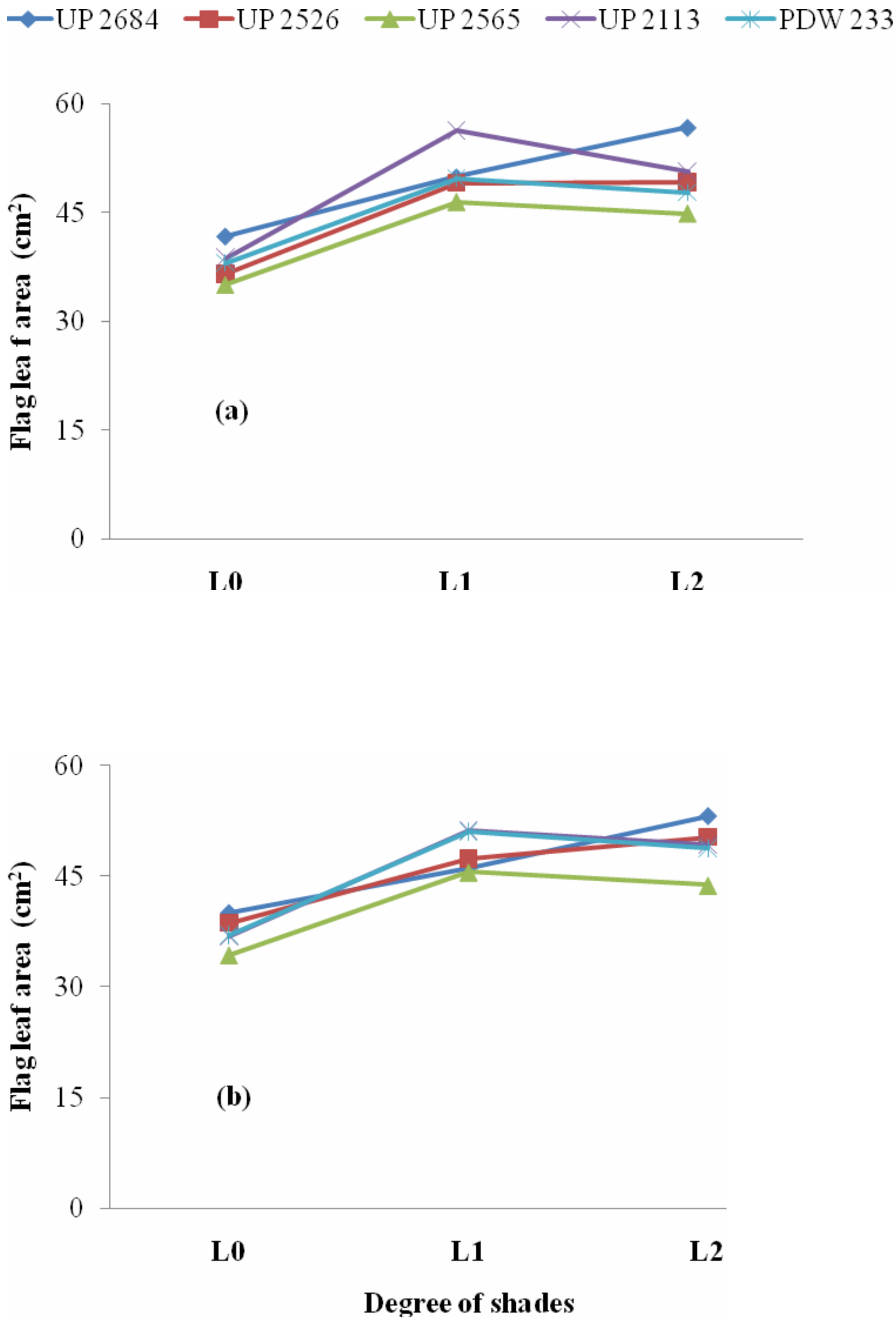
Table 4.1.9a Flag leaf area (cm^2 $leaf^{-1}$) 10 days after anthesis in different wheat varieties as influenced by varying degree of shades during both the growing seasons

Wheat varieties (B)	Degree of shades (A)					
	2010-11			2011-12		
	L0	**L1**	**L2**	**L0**	**L1**	**L2**
UP 2684	41.78	49.92	56.76	40.03	46.09	53.13
UP 2526	36.52	49.04	49.17	38.66	47.37	50.29
UP 2565	35.02	46.51	44.90	34.33	45.57	43.78
UP 2113	38.74	56.32	50.65	36.83	51.26	49.29
PDW 233	38.06	49.76	47.80	37.00	51.00	48.80
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		0.74	2.17		0.87	2.55
To compare means of two 'A' at the same or different 'B'		0.73	2.26		0.79	2.32

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

The wheat varieties differed significantly in their flag leaf area at 10 days after anthesis during both the years i.e. 2010-11 and 2011-12. Though, the variety UP 2684 produced maximum (49.4 and 46.4 cm^2 $leaf^{-1}$) and significantly more flag leaf area both during 2010-11 and 2011-12, respectively, than other varieties, except UP 2113 during both the years and UP 2526 and PDW 223 in 2011-12. The minimum (42.1 and 41.2 cm^2 $leaf^{-1}$) and significantly lower flag leaf area was recorded in UP 2565 during both the years i.e. 2010-11 and 2011-12, respectively.

The flag leaf area (cm^2 $leaf^{-1}$) in wheat varieties interacted with degree of shades significantly (Table 4.1.9a). The variety UP 2684 both under full sunlight and severe shade had larger flag leaf than all other combinations of shades and varieties during both



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig. 4.2 Flag leaf area (cm^2) of wheat varieties as influenced by varying degree of shades during 2010-11(a) and 2011-12(b)

the growing seasons i.e. 2010-11 and 2011-12. Whereas, the variety UP 2113 found to have larger flag leaves under mild shaded treatment both during 2010-11 and 2011-12 than other varieties under mild shade, except PDW 233 in 2011-12. However, the variety UP 2565 was found to have smallest flag leaf area (cm^2 $leaf^{-1}$) at this stage all under full sunlight, 2/3 and 1/3 light availability conditions during both the years i.e. 2010-11 and 2011-12.

The variety UP 2684 under severe shade observed higher flag leaf area than other varieties under any other light condition, except UP 2113 under mild shade. Whereas, variety UP 2565 under full sunlight had significantly smaller flag leaves than all the other combination of light and varieties, except UP 2526 under full sunlight in 2010-11 and UP 2684 and UP 2526 under mild shade in 2011-12.

Flag leaf area significantly influenced by varying degree of shades when compared with the full sunlight (i.e. control) in 2011-12. Whereas, in 2010-11 no significant difference observed between 2/3 and 1/3 available light conditions (Table 4.1.9). The flag leaf area increased with successive increase in intensity of shade. The wheat varieties exhibited differential response in their flag leaf area under varying degree of shades. Varieties UP 2565, UP 2113 and PDW 233 had highest flag leaf area under mild shade conditions as compared to both the severe shade and full sunlight during both the years. Li *et al*. (2010) also observed increase in flag leaf area under 40 per cent shade as compare to control.

4.1.10 Maximum number of shoots/m^2

The maximum number of shoots m^{-2} was significantly influenced by varying degree of shades, different wheat varieties and the interaction between them during the both the years i.e. 2010-11 and 2011-12 (Table 4.1.10 and Appendix XII).

The maximum number of shoots (622 and 629 m^{-2}) attained by wheat crop was observed under full sunlight, which reduced significantly with each successive increase in shade during both the growing seasons i.e. 2010-11 and 2011-12.

The wheat varieties differed significantly in their maximum number of shoots m^{-2} produced during both the years and the variety UP 2113 produced maximum (637 and

644 m^{-2}) and significantly higher number of shoots than other varieties, except PDW 233 during both the years i.e. 2010-11 and 2011-12. The minimum numbers of shoots m^{-2} were produced by the variety UP 2526 than all the other varieties during both the growing seasons i.e. 2010-11 and 2011-12.

The interaction between varying degree of shade and wheat varieties appeared to be significant. While, the variety UP 2113 produced maximum and significantly more shoots m^{-2} than all other varieties under all the light availability conditions during both the years i.e. 2010-11 and 2011-12, except PDW 233 under all light conditions i.e. full sunlight, mild and severe shade; UP 2684 under full sunlight and also UP 2565 under mild shade during both the growing seasons i.e. 2010-11 and 2011-12. The minimum and significantly fewer number of shoots m^{-2} were produced in UP 2526 both under full sunlight and lower degree than other varieties and light conditions, except UP 2684 under severe shade during both the years i.e. 2010- 11 and 2011-12. While, the variety UP 2113 with full sunlight, with no significant difference with PDW 233 and UP 2684 under full sunlight and also UP 2113 with mild shade, produced significantly more number of shoots m^{-2} compared to all other combinations of degree of shades and varieties. The variety UP 2684 under severe shaded treatment had produced significantly fewer shoots than all other combinations of degree of shades and varieties (Table 4.1.10a & b), except UP 2526 under severe shade.

4.1.11 Shoot Mortality (%)

The per cent shoot mortality was influenced significantly by varying magnitude of shade, different wheat varieties and the interaction between them during both the growing seasons i.e. 2010-11 and 2011-12 (Table 4.1.10 and Appendix XII).

Under higher degree of shades maximum (46.2 and 45.7 %) and significantly higher shoot mortality was observed, which reduced significantly with each successive decrease in degree of shades to became least under full sunlight during both the years i.e. 2010-11 and 2011-12.

Table 4.1.10 Maximum number of shoots m^{-2} and Shoot mortality (%) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Maximum shoots m^{-2}		Shoot mortality (%)	
	2010-11	**2011-12**	**2010-11**	**2011-12**
A. Degree of shades				
L0 – Full sun light	622	629	18.99	18.91
L1 – Mild shade	603	610	38.04	37.70
L2 – Severe shade	544	551	46.17	45.72
SEm±	3.0	3.0	0.4	0.30
CD at 5 %	11.7	11.0	1.4	1.00
B. Wheat varieties				
UP 2684	575	583	34.16	33.84
UP 2526	531	538	33.13	32.86
UP 2565	586	593	36.91	36.54
UP 2113	637	644	35.23	34.95
PDW 233	620	627	32.58	32.34
SEm±	8.0	7.0	0.70	0.40
CD at 5 %	23.0	20.0	1.90	1.10
CV (%)	3.9	3.4	5.7	3.2
Interaction (A x B)	S	S	S	S

S - Significant NS - Non-significant

Table 4.1.10a Maximum number of shoots m^{-2} and Shoot mortality (%) of different wheat varieties as influenced by varying degree of shades during 2010-11

Wheat varieties (B)	Degree of shades (A)					
	Maximum shoots m^{-2}			Shoot mortality (%)		
	L0	L1	L2	L0	L1	L2
UP 2684	651.0	584.7	490.0	26.27	33.62	42.60
UP 2526	545.7	544.0	503.0	26.29	35.64	37.46
UP 2565	606.0	622.0	529.3	18.00	37.83	54.89
UP 2113	669.3	641.7	599.0	16.30	40.35	49.04
PDW 233	640.0	622.0	598.0	8.10	42.75	46.89
		SEm±	**CD at 5%**	**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'		13.4	39.1	1.13	3.30	
To compare means of two 'A' at the same or different 'B'		12.3	36.7	1.10	3.20	

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

Table 4.1.10b Maximum number of shoots m^{-2} and Shoot mortality (%) of different wheat varieties as influenced by varying degree of shades during 2011-12

Wheat varieties (B)	Degree of shades (A)					
	Maximum shoots m^{-2}			Shoot mortality (%)		
	L0	L1	L2	L0	L1	L2
UP 2684	658.8	592.1	497.7	26.13	33.30	42.10
UP 2526	553.0	551.4	510.8	26.13	35.30	37.10
UP 2565	613.3	629.5	536.8	17.83	37.50	54.30
UP 2113	676.7	649.0	606.7	16.30	40.00	48.60
PDW 233	647.4	629.5	605.1	8.13	42.40	46.50
		SEm±	**CD at 5%**	**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'		11.9	34.6	0.64	1.86	
To compare means of two 'A' at the same or different 'B'		10.9	32.7	0.63	1.95	

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

The wheat varieties showed significant differences in their shoot mortality during both the years i.e. 2010-11 and 2011-12. The variety UP 2565 showed highest (36.9 and 36.5 %) and significantly higher shoot mortality as compared to other varieties in both the years, respectively, except UP 2113 only during 2010-11. The lowest (32.6 and 32.3 %) and significantly lower shoot mortality was observed in PDW 233 during both the years, respectively, than other varieties, except UP 2684, UP 2565 and UP 2113 in 2010-11 and UP 2526 in 2011-12.

The interaction between degree of shades and wheat varieties was found to be significant in both the seasons (Table 4.1.10 a& b). While, the varieties UP 2526 and UP 2684; PDW 233 and UP 2565 showed maximum shoot mortality under full sunlight, mild and severe shade, respectively both during 2010-11 and 2011-12 than all other with corresponding light condition, except UP 2113 under mild shade in 2010-11. The minimum and significantly lower shoot mortality was observed in PDW 233, UP 2684 and UP 2526 under full sunlight, mild and severe shade, respectively, both during 2010-11 and 2011-12.

The variety PDW 233 under full sunlight had the lowest and significantly lower shoot mortality than all other combinations of and degree of varieties shades in both the seasons. However, UP 2565 under severe shade had highest rate of shoot mortality than all the other combinations of light conditions and varieties during both the years.

4.1.12 Days taken to 50% heading

Days taken to 50 per cent heading in wheat were influenced significantly both by magnitude of shades and wheat varieties, however, the interaction between various degree of shades and wheat varieties was not found to be significant during both the years (i.e. 2010-11 and 2011-12) (Table 4.1.11 and Appendix XIII).

The maximum (103 and 101 days) and significantly more days were taken for heading under 1/3 light available condition (i.e. 2/3 shading), which reduced significantly with each successive reduction in degree of shade both during 2010-11 and 2011-12.

The wheat varieties differed significantly in their days taken to 50 per cent heading during both the growing season i.e. 2010-11 and 2011-12. The variety PDW 233 took more days to heading during both the growing seasons i.e. 2010-11 and 2011-12 than others, except UP 2113 both during 2010-11 and 2011-12 and also UP 2526 in 2010-11. Whereas, the minimum (97 and 94 days) and significantly fewer days were taken by variety UP 2565 during both the years i.e. 2010-11 and 2011-12 than other varieties, except UP 2684, UP 2526 and UP 2113 in 2010-11.

The developmental changes in a crop determine the length of period required to attain various growth phases. The vegetative period measured in terms of the number of days taken to 50 per cent heading was significantly affected by various treatments (Table 4.1.11) during both the years. There was a small increase in number of days taken to 50 per cent heading under 2/3 shading (i.e. 1/3 light availability) compared to both full sunlight and mild shade. The wheat varieties also differed in their days taken to 50 per cent heading and UP 2526 in 2010-11 and variety PDW 233 had longer vegetative period than other varieties, except UP 2113. This may be due to shading effects which must have slowed down the differentiative activities of plants and higher moisture availability under shade. Similar extended vegetative period under shade was also reported found by Puri and Bangarwa (1992), Bhakuni (1998) and Kumar (1999).

4.1.13 Days taken to 80% maturity

Alike day taken to 50 per cent heading, the days taken to 80 per cent physiological maturity in wheat was influenced significantly by degree of shades and wheat varieties both during 2010-11 and 2011-12, however, the interaction between varying degree of shades and wheat varieties was not found to be significant during the both the years (Table 4.1.11 and Appendix XIII).

The minimum (124 and 127 days) and significantly fewer number of days were taken to 80 per cent maturity under full sunlight both during 2010-11 and 2011-12, respectively, which increased significantly with each successive increase in degree of shade during both the growing seasons, with no significant difference between 2/3 and 1/3 of full sunlight availability in 2010-12.

The wheat varieties significantly differed in their duration taken to 80 per cent maturity during both the years i.e. 2010-11 and 2011-12 and the variety PDW 233 took more days for 80 per cent maturity than other varieties, except UP 2113 during both the years. Whereas, the varieties UP 2684, UP 2526 and UP 2565 took statistically same duration to maturity both during 2010-11 and 2011-12.

Table 4.1.11 **Days taken to 50 % heading and 80 % maturity by different wheat varieties and under varying degree of shades during both the growing seasons**

Treatment	50% heading		80% maturity	
	2010-11	2011-12	2010-11	2011-12
A. Degree of shades				
L0 – Full sun light	94	96	124	127
L1 – Mild shade	97	99	132	131
L2 – Severe shade	103	101	133	133
SEm±	0.3	0.3	0.4	0.4
CD at 5 %	1.1	1.0	1.3	1.4
B. Wheat varieties				
UP 2684	96	96	128	129
UP 2526	98	97	129	129
UP 2565	97	94	128	127
UP 2113	99	102	132	133
PDW 233	100	104	132	134
SEm±	1.0	0.9	0.9	0.9
CD at 5 %	2.1	2.6	2.7	2.8
CV (%)	2.2	2.7	2.1	2.2
Interaction (A x B)	NS	NS	NS	NS

S - Significant NS - Non-significant

Likewise, the total crop duration i.e. number of days taken to 80 per cent maturity was also affected significantly during both the years. There was a small increase in number of days taken to 80 per cent maturity under severe shade (i.e. shading) as compared to both the mild shade and full sunlight but only in 2011-12. Whereas, no significantly difference observed between mild and severe shade during 2010-11. Perusal of data (Table 4.1.11) indicated that wheat crop grown under shade took more number of days to physiological maturity as compared to full sunlight (i.e. control) and under severe shade significantly more number of days were taken by crop for maturity than mild shade and full sunlight during both the years. The reason for this increase may be primarily due to shading effects and better micro climate, lower temperature more conducive for the growth of wheat crop which avoided forced maturity and resulted in delayed maturity. Puri and Bangarwa (1992), Bhakuni (1998) and Kumar (1999) also observed increase in number of days to maturity in wheat under trees. Among the varieties PDW 233 and UP 2113 took longer to mature than all other varieties, as it might be genetically controlled character.

4.2 Growth studies

4.2.1 Dry matter accumulation (g m^{-2})

4.2.1.1 Leaves

The dry matter accumulation in leaves (g m^{-2}) in wheat was significantly influenced by degree of shades at 40, 60 80, 100 and 120 DAS, by wheat varieties at all the stages and the interaction between them only 60 and 80 DAS during both the years and also the interaction 40 DAS in 2010-12 and 100 DAS in 2011-12 (Table 4.2.1.1 and Appendix XIV).

The maximum (34.22, 99.70, 130.34. 167.46 and 139.90 g m^{-2} in 2010-11 and 35.33, 98.90, 129.94, 168.13 and 141.24 g m^{-2} in 2011-12) and significantly more dry matter was accumulated in leaves under full sunlight (i.e. control) at 40, 60, 80 100 and 120 DAS, respectively, which reduced significantly with each successive increase in degree of shade at all these stages during both the years.

The wheat varieties differed significantly in their leaf dry matter (g m^{-2}) accumulation at 20, 40, 60, 80, 100 and 120 DAS during both the years i.e. 2010-11 and 2011-12 and variety PDW 233 accumulated the maximum (6.19, 31.86 and 102.86 g m^{-2} in 2010-11 and 6.17, 34.20 and 103.17 g m^{-2} in 2011-12) and significantly higher leaf dry matter at 20, 40 and 60 DAS, respectively, than of variety UP 2113 at 40 and 60 DAS during both the years and also UP 2565 at 20 DAS during 2010-11. However, the varieties UP 2526 at 80 DAS and UP 2113 at 100 DAS accumulated maximum leaf dry matter during both the years than other varieties, except UP 2113 at par with PDW 233 at 120 DAS both during 2010-11 and 2011-12. Whereas, the minimum and significantly lower leaf dry matter was produced by the varieties UP 2526 at 20 and 40 DAS; UP 2684 at 60 and 120 DAS and UP 2565 at 80 and 100 DAS during both the years.

The interaction between degree of shade and different wheat varieties was found to be significant at 60 and 80 DAS during both the years and at 40 DAS in 2011-12 and at 100 DAS in 2010-11 (Table 4.2.1.1a). The variety PDW found to have higher leaf dry matter accumulation not only under full sunlight but also under mild and severe shaded treatments at 60 and 100 DAS in 2010-11 and 40 and 60 DAS in 2011-12, except under severe shade at 40 DAS in 2011-12, being on par with UP 2113 under all the shaded treatments i.e. full sunlight, 2/3 and 1/3 light availability, at 100 DAS in 2010-11, than other combinations. But the variety UP 2526 accumulated more leaf dry matter under all the shaded treatments at 80 DAS both during 2010-11 and 2011-12.

During 2011-12, the minimum leaf dry matter was obtained in UP 2684 at 60 DAS; UP 2565 at 80 and 100 DAS all under full sunlight (82.4, 11.6 and 142.7 g m^{-2}, respectively), 2/3 (69.9, 99.6 and 132.0 g m^{-2}, respectively) and 1/3 (60.0, 86.0 and 119.6 g m^{-2}, respectively) of light availability than all the other varieties under corresponding light availability. Whereas, PDW 233 recorded higher dry matter accumulation at 40 and 60 DAS under full sunlight as well as under different degree of shades than all other varieties and also UP 2526 at 80 DAS except PDW 233 under severe shade at 40 DAS. The minimum and significantly lower leaf dry matter accumulated in UP 2526 at 40 DAS; UP 2684 at 60 DAS and UP 2113 at 80 DAS under full sunlight, mild and severe shaded treatments, respectively (Table 4.2.1.1b).

Table 4.2.1.1 Dry matter accumulation in leaves (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	5.56	5.95	34.22	35.33	99.70	98.90	130.34	129.94	167.46	168.13	139.90	141.24
L1 – Mild shade	5.61	6.07	29.73	31.33	86.48	89.40	111.49	112.00	150.17	150.83	118.30	119.04
L2 – Severe shade	5.32	5.77	24.97	26.08	72.56	78.64	102.28	98.08	135.89	136.56	101.41	102.15
SEm±	0.12	0.11	0.27	0.08	0.41	0.26	0.33	0.34	0.9	1.33	0.78	0.97
CD at 5 %	NS	NS	1.04	0.32	1.59	1.03	1.31	1.34	3.53	5.19	3.05	3.81
B. Wheat varieties												
UP 2684	5.33	6.41	28.84	34.67	70.66	76.53	116.72	116.06	156.09	156.76	113.12	114.45
UP 2526	5.07	5.77	29.73	29.63	76.13	81.07	127.64	126.98	135.12	135.78	117.78	118.45
UP 2565	5.66	5.50	30.11	30.92	84.84	86.97	99.07	91.73	131.43	132.09	120.18	121.07
UP 2113	5.22	5.81	27.67	31.80	96.74	97.77	111.43	112.09	169.55	170.22	125.27	126.15
PDW 233	6.19	6.17	31.86	34.20	102.86	103.17	118.65	118.99	163.67	164.33	123.01	123.90
SEm±	0.16	0.19	0.71	0.24	0.71	0.65	0.84	0.83	1.13	1.39	1.49	1.58
CD at 5 %	0.47	0.56	2.07	0.69	2.08	1.91	2.46	2.42	3.31	4.05	4.36	4.61
CV (%)	8.9	9.7	7.2	2.1	2.5	2.2	2.2	2.3	2.3	2.7	3.7	3.9
Interaction (A x B)	NS	NS	NS	S	S	S	S	S	S	NS	NS	NS

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

Table 4.2.1.1a Dry matter accumulation in leaves (g m^{-2}) in different wheat varieties as influenced by varying degree of shades 60, 80 and 100 DAS during 2010-11

Wheat varieties (B)	Degree of shades (A)								
	60 DAS			80 DAS			100 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	82.4	69.6	60.0	134.2	112.0	104.0	172.8	153.4	142.0
UP 2526	89.8	76.2	62.4	141.7	123.4	117.8	152.8	130.6	122.0
UP 2565	100.3	85.8	68.4	111.6	99.6	86.0	142.7	132.0	119.6
UP 2113	110.0	98.2	82.0	129.0	105.2	100.0	187.2	170.2	151.3
PDW 233	116.0	102.6	90.0	135.2	117.2	103.6	181.8	164.6	144.6
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		1.2	3.6		1.5	4.3		0.9	5.7
To compare means of two 'A' at the same or different 'B'		1.2	3.6		1.4	4.0		0.9	6.2

Table 4.2.1.1b Dry matter accumulation in leaves (g m^{-2}) in different wheat varieties as influenced by varying degree of shades 40, 60 and 80 DAS during 2011-12

Wheat varieties (A)	Degree of shades (A)								
	40 DAS			60 DAS			80 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	36.5	30.1	37.4	88.4	75.6	65.6	135.2	110.0	103.0
UP 2526	33.5	29.3	26.1	91.8	80.2	71.2	140.7	124.4	115.8
UP 2565	34.1	31.3	27.4	98.3	88.2	74.4	112.6	97.6	65.0
UP 2113	35.4	31.6	28.4	106.0	99.0	86.5	128.0	107.3	101.0
PDW 233	37.1	34.4	31.1	110.0	104.0	95.5	133.2	118.2	105.6
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		0.4	1.2		1.1	3.3		1.4	4.2
To compare means of two 'A' at the same or different 'B'		0.4	1.1		1.1	3.1		1.3	3.9

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

The variety PDW 233 under full sunlight showed its superiority in leaf dry matter accumulation over all other combination of degree of shades and varieties. Whereas, the variety UP 2565 and UP 2526 under severe shaded treatment have been significantly inferior than all other combinations of degree of shades and varieties

4.2.1.2 Stem

The stem dry matter (g m^{-2}) accumulation in stems of wheat was significantly influenced by varying degree of shades and wheat varieties at 20, 40, 60 80, 100 and 120 DAS during both the years i.e. 2010-11 and 2011-12 (Table 4.2.1.2 and Appendix XV). Whereas, the interaction between different magnitude of shade and wheat varieties was influenced significantly at all these stages too, except at 40 DAS in 2011-12 and at 100 DAS in 2010-11.

The maximum (4.9, 29.7, 99.3, 501.8, 504.7 and 525.8 g m^{-2} in 2010-11 and 5.6, 42.2, 100.1, 537.8, 544.7 and 560.8 g m^{-2} in 2011-12) and significantly more stem dry matter was observed under full sunlight (i.e. control) at all the stages i.e. 20,40, 60, 80 100 and 120 DAS, respectively, which reduced significantly with each successive increase in shade both during 2010-11 and 2011-12, with no significant difference between full, 2/3 and 1/3 of full sunlight availability at 20 DAS in 2010-11 and also 2/3 and 1/3 of full sunlight at 20 DAS in2011-12.

The wheat varieties differed significantly in their stem dry matter accumulation at 20, 40, 60, 80, 100 and 120 DAS during both the years i.e. 2010-11 and 2011-12 and the variety UP 2113 produced maximum (5.2, 479.1, 457.9 and 465.7 g m^{-2} in 2010-11 and 5.8, 519.497.8 and 501.7 g m^{-2} in 2011-12) and significantly more stem dry matter was accumulated at 20, 80 100 and 120 DAS, respectively. Whereas, the maximum stem dry matter was produced from the variety PDW 233 40 DAS in both the years and 80 DAS in 2010-11and UP 2526 60 DAS in 2010-11 and UP 2113 at 60 DAS in 2011-12. However, the variety UP 2113 was at par with UP 2684 and UP 2526 at 20 DAS and also PDW 233 at 120 DAS during both the years i.e. 2010-11 and 2011-12.

Table 4.2.1.2 Dry matter accumulation in stems (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	4.9	5.6	29.7	42.2	99.3	100.1	501.8	537.8	504.7	544.7	525.8	560.8
L1 – Mild shade	4.7	5.3	26.4	37.7	87.8	76.7	431.1	471.1	425.7	465.7	439.5	475.5
L2 – Severe shade	4.8	5.4	22.3	32.4	77.3	72.6	373.6	413.6	354.7	394.7	343.4	379.4
SEm±	0.1	0.1	0.1	0.2	0.2	0.5	1.1	1.4	4.1	1.4	3.0	1.8
CD at 5 %	0.1	0.1	0.3	0.8	0.9	2.1	4.3	5.3	15.9	5.3	11.7	7.1
B. Wheat varieties												
UP 2684	5.1	5.7	25.9	36.9	87.6	84.3	375.7	409.0	397.1	437.1	406.4	442.4
UP 2526	5.0	5.6	25.2	37.7	98.7	85.8	415.6	455.6	438.1	478.1	426.7	462.7
UP 2565	4.2	4.8	26.8	38.1	92.2	75.0	439.0	479.0	412.3	452.3	426.4	462.4
UP 2113	5.2	5.8	25.8	35.7	80.1	89.7	479.1	519.1	457.9	497.8	465.7	501.7
PDW 233	4.5	5.2	27.0	40.5	82.2	80.7	468.0	508.0	436.6	476.6	454.4	490.4
SEm±	0.1	0.1	0.2	0.4	0.7	0.9	3.9	3.8	5.4	4.0	4.8	4.1
CD at 5 %	0.2	0.2	0.6	1.3	1.9	2.7	11.2	11.0	15.8	11.6	14.1	12.0
CV (%)	4.7	4.1	2.2	3.5	2.2	3.4	2.7	2.4	3.8	2.5	3.3	2.6
Interaction (A x B)	S	S	S	NS	S	S	S	S	NS	S	S	S

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

Table 4.2.1.2a Dry matter accumulation in stems (g m^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)														
	20 DAS			40 DAS			60 DAS			80 DAS			120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	5.2	4.8	5.4	20.1	25.8	22.8	99.4	86.4	77.0	425.8	368.6	332.6	485.0	405.6	328.6
UP 2526	5.0	5.4	4.5	29.7	24.0	22.0	112.6	99.6	84.0	479.4	409.0	358.4	526.2	422.4	331.4
UP 2565	4.2	4.6	3.8	30.2	26.6	23.4	104.6	93.0	79.0	507.4	435.8	373.8	515.8	428.5	334.7
UP 2113	5.6	4.8	5.2	28.5	27.4	21.4	93.0	78.2	69.0	576.1	475.4	385.9	557.0	462.2	377.8
PDW 233	4.6	4.0	5.0	30.9	28.2	22.0	87.0	82.0	77.6	520.2	466.6	417.1	539.8	478.7	344.6

	20 DAS SEm±	20 DAS CD at 5%	40 DAS SEm±	40 DAS CD at 5%	60 DAS SEm±	60 DAS CD at 5%	80 DAS SEm±	80 DAS CD at 5%	120 DAS SEm±	120 DAS CD at 5%
To compare means of two B at the same 'A'	0.1	0.4	0.3	1.0	1.1	3.3	6.7	19.5	8.4	24.5
To compare means of two 'A' at the same or different 'B'	0.1	0.3	0.3	0.9	1.0	3.1	6.1	17.9	8.1	24.8

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

Table 4.2.1.2b Dry matter accumulation in stems (g m^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)														
	20 DAS			60 DAS			80 DAS			100 DAS			120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	5.8	5.4	6.0	107.9	77.6	67.4	445.8	408.6	372.6	494.8	439.0	377.4	521.0	441.6	364.6
UP 2526	5.6	6.0	5.2	107.9	75.7	73.8	519.4	449.0	398.4	552.4	472.2	409.7	562.2	458.4	367.4
UP 2565	4.8	5.2	4.4	88.3	66.9	69.9	547.4	475.8	413.8	528.4	445.8	382.6	551.8	464.5	370.7
UP 2113	6.2	5.4	5.8	105.5	85.9	77.7	616.2	515.4	425.8	588.3	499.0	406.2	593.0	498.2	413.8
PDW 233	5.4	4.6	5.6	90.8	77.2	74.1	560.2	506.6	457.2	559.8	472.6	397.4	575.8	514.7	380.6

	20 DAS SEm±	20 DAS CD at 5%	60 DAS SEm±	60 DAS CD at 5%	80 DAS SEm±	80 DAS CD at 5%	100 DAS SEm±	100 DAS CD at 5%	120 DAS SEm±	120 DAS CD at 5%
To compare means of two B at the same 'A'	0.1	0.4	1.6	4.7	6.5	18.9	6.9	20.0	7.1	20.8
To compare means of two 'A' at the same or different 'B'	0.1	0.4	1.5	4.7	5.9	17.7	6.3	18.6	6.6	19.8

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

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The significantly poorer stem dry matter was recorded in variety UP 2684 at 80, 100 and 120 DAS during both the growing seasons i.e. 2010-11 and 2011-12. Whereas, at 20, 40 and 60 DAS, the varieties UP 2565, UP 2526 and UP 2113 were recorded lower stem dry matter accumulations, respectively in 2010-11, and also UP 2565 and UP 2113 at 20 and 60 and at 40 DAS, respectively in 2011-12.

During 2010-11, the interaction between degree of shades and different wheat varieties was found to be significant all at 20, 40, 60, 80, 100 and 120 DAS (Table 4.2.1.2a). The variety UP 2113 found to have higher stem dry matter accumulation not only under full sunlight but also under mild shades treatment at 20, 80 and 120 DAS in 2010-11 than other combinations, except under mild shade at 20 DAS and also severe shade at 80 DAS. Whereas, at 40 and 60 DAS the variety PDW 233 and UP 2526, respectively were recorded higher stem dry matter under full sunlight, mild and severe shaded treatment than other combinations, except PDW 233 under severe shade at 40 DAS. The lowest stem dry matter was accumulated in the variety UP 2684 at 80 and 120 DAS under full sunlight as well as 2/3 and 1/3 light available conditions during 2010-11 than other combinations of light conditions and varieties. Whereas, in 2011-12 the variety UP 2113 recorded more stem dry matter accumulated at 20, 60, 80, 100 and 120 DAS under all the light availability conditions i.e. full, 2/3 and 1/3 availability of full sunlight than others combinations, except at 20 DAS under mild shade by UP 2526 and UP 2684 under severe shade. The minimum and significantly lower stem dry matter was recorded in UP 2684 at 80, 100 and 120 DAS under severe shade than other combinations, except UP 2565 and PDW 233 under severe shade during 2011-12 (Table 4.2.1.2b).

The variety UP 2113 under full sunlight was at par with UP 2526 under mild shade and UP 2684 under severe shade at 20 DAS during both the years. Variety UP 2113 showed its superiority in stem dry matter accumulation at 80 and 120 DAS during both the years and at 100 DAS in 2011-12 than all other combinations of degree of shades and varieties. Whereas, UP 2684 under severe shade showed its inferior than all other combinations of degree of shades and varieties at 80 and 120 DAS during both the years and at 100 DAS in 2011-12.

4.2.1.3 Spike

The dry matter (g m^{-2}) accumulation in spikes of wheat was influenced significantly by varying degree of shades, wheat varieties and the interaction between them both during 2010-11 and 2011-12 (Table 4.2.1.3 and Appendix XVI).

The maximum (158.5 and 405.9 g m^{-2} in 2010-11 and 165.3 and 414.3 g m^{-2} in 2011-12) and significantly higher spike dry matter was recorded under full sunlight (i.e. control) both at 100 and 120 DAS, respectively, which reduced significantly with each successive increase in magnitude of shade during both the years.

The spike dry matter accumulation in wheat varieties significantly varied both at 100 and 120 DAS both during 2010-11 and 2011-12. The variety PDW 233 recorded maximum (113.7 and 388.7 g m^{-2} in 2010-11 and 383.9 and 392.3 g m^{-2} in 2011-12) and significantly more spike dry matter at 100 and 120 DAS, respectively than other varieties, except UP 2565 at 120 DAS during both the years i.e. 2010-11 and 2011-12. The variety UP 2113 produced minimum (74.5 and 81.3 g m^{-2} in 2010-11 and 354.5 and 362.9 g m^{-2} in 2011-12) and significantly lower spike dry matter at 100 and 120 DAS, respectively than others, except UP 2684 at 100 and 120 DAS and also UP 2526 at 120 DAS during both the growing season i.e. 2010-11 and 2011-12

The interaction for spike dry matter accumulation between degree of shades and wheat varieties appeared to be significant (Table 4.2.1.3a). While, the variety PDW 233 under all the light availability conditions was found to be superior both at 100 and 120 DAS during both the years over other varieties and light conditions, except variety UP 2565 under full sunlight which outer performed PDW 233 at 120 DAS both during 2010-11 and 2011-12 and was at par with variety UP 2565 under full sunlight and severe shaded treatment at 100 DAS during both the years and also at 120 DAS with the varieties UP 2113, UP2565 and UP2526 under mild shaded treatments during 2010-11. The significantly lower spike dry matter was recorded from UP 2113 at 100 DAS during both the years. Whereas, at 120 DAS UP 2113 recorded minimum spike dry matter under severe shade treatment being on par with UP 2565, UP 2526 and UP 2684 during both the years i.e. 2010-11 and 2011-12.

Table 4.2.1.3 Dry matter accumulation in spikes (g m^{-2}) of different wheat varieties and under varying degree of shades 100 and 120 DAS during both the growing seasons

Treatment	100 DAS		120 DAS	
	2010-11	2011-12	2010-11	2011-12
A. Degree of shades				
L0 – Full sun light	158.5	165.3	405.9	414.3
L1 – Mild shade	78.4	85.2	364.1	372.5
L2 – Severe shade	44.7	51.5	338.0	346.4
SEm±	0.5	0.4	1.6	0.8
CD at 5 %	1.9	1.5	6.3	3.0
B. Wheat varieties				
UP 2684	78.3	85.1	356.8	365.2
UP 2526	96.9	103.7	362.9	371.3
UP 2565	105.8	112.6	388.7	397.1
UP 2113	74.5	81.3	354.5	362.9
PDW 233	113.7	120.5	383.9	392.3
SEm±	1.8	2.7	4.4	4.3
CD at 5 %	5.3	7.8	12.8	12.6
CV (%)	5.8	7.9	3.6	3.4
Interaction (A x B)	S	S	S	S

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

Table 4.2.1.3a Dry matter accumulation in spikes (g m^{-2}) of different wheat varieties as influenced by varying degree of shades 100 and 120 DAS during both the growing seasons

Wheat varieties (B)	Degree of shades (A)											
	100 DAS						120 DAS					
	2010-11			2011-12			2010-11			2011-12		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	126.0	71.3	37.7	132.8	78.1	44.5	386.9	356.0	327.4	395.3	364.4	335.8
UP 2526	173.0	72.7	44.9	179.8	79.5	51.7	398.7	359.9	330.2	407.1	368.3	338.6
UP 2565	184.6	82.3	50.6	191.4	89.1	57.4	448.2	366.1	351.7	456.6	374.5	360.1
UP 2113	119.8	68.4	35.3	126.6	75.2	42.1	352.6	360.8	320.0	391.0	369.2	328.4
PDW 233	188.9	97.2	55.0	195.7	104.0	61.8	413.1	377.9	360.8	421.5	386.3	369.2
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		3.1	9.2		4.6	13.5		7.6	22.1		7.5	21.8
To compare means of two 'A' at the same or different 'B'		2.9	8.4		4.1	12.1		7.0	20.7		6.7	19.7

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

The variety PDW 233 under full sunlight showed its superiority at 100 DAS in spike dry matter production over all other combinations of degree of shades and varieties. Whereas, at 120 DAS UP 2565 showed it's superiority under full sunlight during both the years. While the variety UP 2113 under severe shaded treatment has been significantly inferior than all other combinations of degree of shades and varieties.

4.2.1.4 Total plant dry matter accumulation

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 4.2.1.4, Fig 4.3 and Appendix XVII). The interaction between magnitude of shade and wheat varieties was influenced significantly 20 and 60 DAS in 2010-11 and 40 and 100 DAS in 2011-12, but it was significantly influenced during both the years at 80 DAS.

The maximum (63.9, 199.0, 632.2, 725.0 and 1070.6 g m^{-2} in 2010-11 and 77.6, 199.0, 667.8, 878.1 and 1117.6 g m^{-2} in 2011-12) and significantly higher total plant dry matter was accumulated under full sunlight (i.e. control) at 40, 60, 80 100 and 120 DAS, respectively, except at 20 DAS during 2011-12, which reduced significantly with each successive increase in degree of shades at all these stages during both the years.

The total plant dry matter accumulation in wheat varieties significantly varied at 20, 40, 60, 80, 100 and 120 DAS during both the years i.e. 2010-11 and 2011-12. The variety PDW 233 accumulated the maximum (10.8, 58.9, 185.1, 575.7, 638.2 and 961.2 g m^{-2} in 2010-11 and 11.4, 74.7, 183.9, 627.0, 761.4 and 1006.6 g m^{-2} in 2011-12) and significantly more total dry matter at 20, 40, 60, 80, 100 and 120 DAS, respectively, being at par with the variety UP 2113 at 80 and 100 DAS during both the years i.e. 2010-11 and 2011-12, and at 60 and 120 DAS in 2011-12. Whereas, at 20 DAS varieties UP 2684, UP 2526, UP 2113 and PDW 233 were not found to significant in 2011-12. The minimum (158.3, 492.4, 579.3 and 876.3 g m^{-2} in 2010-11 and 160.8, 525.1, 678.9 and 924.3 g m^{-2} in 2011-12) and significantly less total plant dry matter was accumulated in UP 2684 60, 80, 100 and 120 DAS, respectively. While, the varieties UP 2565 and UP 2113 were recorded at 20 and 40 DAS, respectively during both the years.

Table 4.2.1.4 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

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

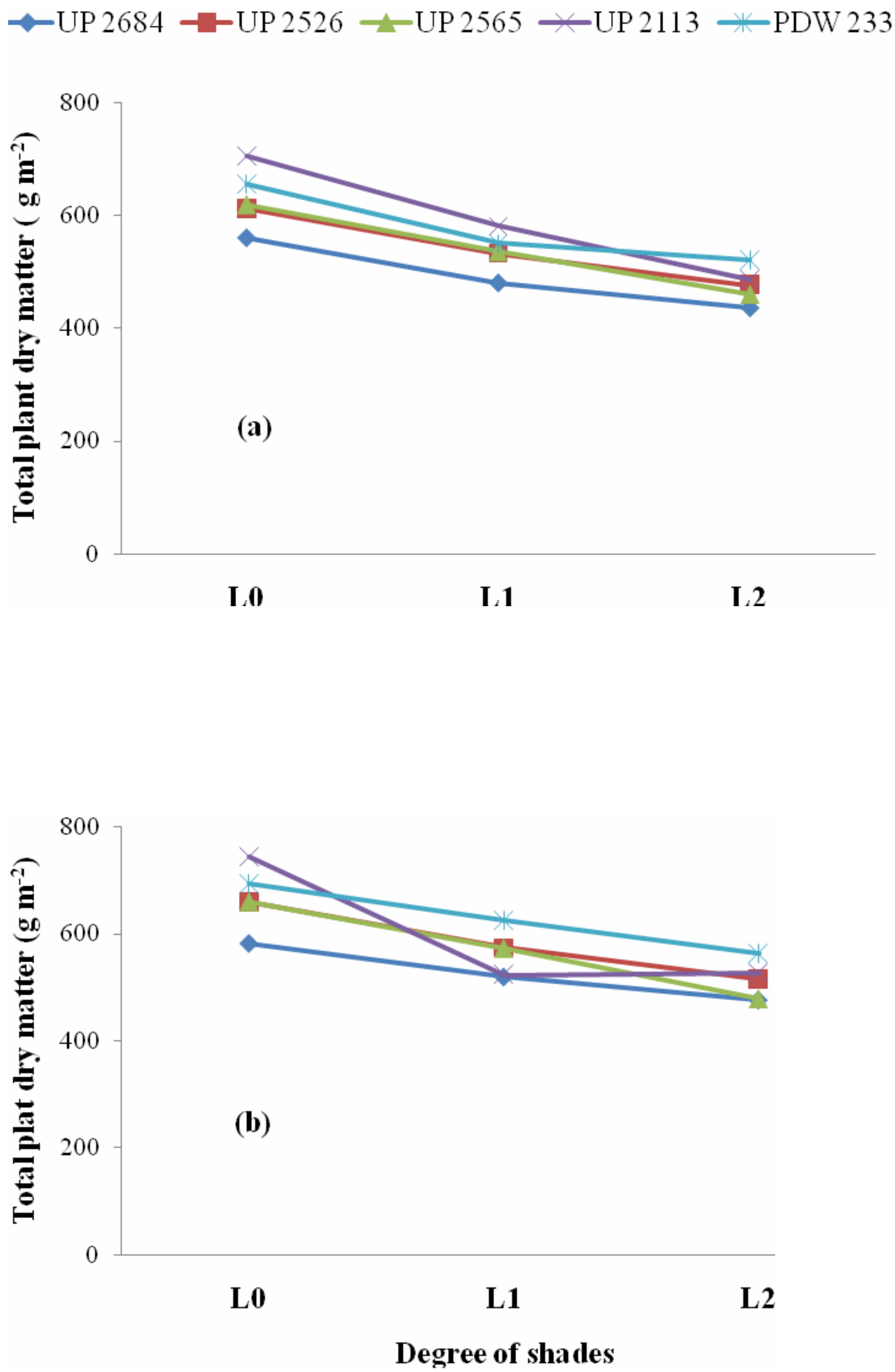
Table 4.2.1.4a Total plant dry matter accumulation (g m^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)								
	20 DAS			60 DAS			80 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	10.6	10.4	10.4	181.8	156.0	137.0	559.9	480.6	436.6
UP 2526	9.8	9.8	10.6	202.4	175.8	146.4	612.1	532.4	476.2
UP 2565	9.8	10.8	9.0	205.0	178.8	147.4	619.0	535.4	459.8
UP 2113	11.4	10.2	9.6	203.0	176.4	151.0	705.2	580.6	485.8
PDW 233	10.8	10.4	11.0	203.0	184.6	167.6	655.5	550.5	521.2
		SEm±	**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		0.2	0.6	2.2		6.5	9.9		28.9
To compare means of two 'A' at the same or different 'B'		0.2	0.6	2.0		6.1	10.0		31.4

Table 4.2.1.4b Total plant dry matter accumulation (g m^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	40 DAS			80 DAS			100 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	77.5	66.3	70.8	580.9	518.6	475.6	801.1	671.2	564.6
UP 2526	76.1	67.5	58.5	660.1	573.4	514.2	885.7	682.9	584.1
UP 2565	77.1	69.5	60.4	660.0	573.4	478.8	863.1	667.6	560.3
UP 2113	75.8	67.2	59.4	744.2	522.7	526.8	902.7	745.1	600.2
PDW 233	81.3	74.8	68.1	693.4	624.8	562.8	937.9	741.9	604.4
		SEm±	**CD at5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		1.7	5.1	10.0		29.2	11.5		33.7
To compare means of two 'A' at the same or different 'B'		1.6	4.6	9.7		29.6	10.8		32.7

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



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.3 Total plant dry matter accumulation (g m^{-2}) of wheat varieties as influenced by varying degree of shades at 80 DAS during 2010-11(a) and 2011-12(b)

The interaction between magnitude of shade and different wheat varieties was found to be significant at 20, 60 and 80 DAS during 2010-11 (Table 4.2.1.4a). The variety PDW 233 accumulated better under all the light availability conditions (i.e. full, 2/3 and 1/3 available light) at 20 and 60 DAS in 2010-11, being at par with UP 2113 full sunlight and mild shade UP 2565 under mild shade; UP 2526 under severe shade and UP 2684 under mild and severe shade treatment at 20 DAS during 2010-11. Whereas, at 60 DAS it was at par with UP 2113 under full sunlight; UP 2565 under full sunlight and mild shade and also UP 2526 and UP 2565 under full sunlight in 2010-11. However, at 80 DAS the variety UP 2113 recorded higher total plant dry matter than all other varieties under full sunlight and mild shaded treatments. The minimum and significantly poorest total plant dry matter was accumulated in UP 2684 at 60 and 80 DAS under all the light availability condition except at 20 DAS in 2010-11.

The total plant dry matter between degree of shade and wheat varieties appeared to be significant at 40, 80 and 100 DAS during 2011-12 (Table 4.2.1.4b). While, PDW 233 found to be superior over other varieties at 40, 80 and 100 DAS under all the light availability conditions except under full sunlight at 80 DAS in 2011-12.

The variety UP 2684 remained significantly poorer in its total plant dry matter than other varieties 80 and 100 DAS under all the light availability condition only during 2011-12 and also 40 DAS UP 2113 under full sunlight, mild and severe shaded treatments, being at par with UP 2565 and UP 2526 under all the light availability conditions and also UP 2684 under full sunlight and mild shaded treatments in 2011-12.

The variety UP 2113 under full sunlight showed its superiority in total plant dry matter accumulation 20 and 80 DAS in 2010-11, except UP 2526 at 60 DAS under full sunlight the variety UP 2684 under severe shaded treatment has been significantly inferior than all other combinations of degree of shades and varieties at 60 and 80 DAS during both the years i.e. 2010-11 and 2011-12. Whereas, 2011-12, variety PDW 233 and UP 2113 under full sunlight showed its superiority in total plant dry matter at 40 and 100 DAS at 80 DAS, respectively, over all other combinations of degree of shades and varieties.

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 4.2.1.4) 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 dry matter accumulation in stem was 33.2 and 30.2 per cent of total under full sunlight compare to 1/3 light availability at 40 DAS both during 2010-11 and 2011-12, respectively, which increased with age of crop plant to reach maximum at 80 days. Thereafter, it declined sharply during 100 to 120 days period. This indicates that for photosynthate allocation, the leaves remained the priority sink during early growth stage i.e. up to 80 days and once the sufficient photosynthetic area (i.e. leaf area) is developed, more photosynthesis is allocated to stems (as on 100th day). And after the development of economic sink (heading), almost entire current photosynthate is allocated to it to become priority sink as at 120th day. The wheat varieties differed in their stem biomass also at all growth stages. However, trend in proportion of photosynthate allocation to stems was almost similar under various degree of shade (from full sunlight to 1/3 of full sunlight).

Among the wheat varieties PDW 233 had maximum proportion of total biomass in spikes followed by UP 2565, UP 2526, and UP 2684 at 100 day during both the years (i.e. 2010-11 and 2011-12) but it was on par with UP 2565 at 120 day which indicates that the vegetative period in these three varieties (UP 2684, UP 2113 and UP 2526) prolonged up to 100 days after sowing. However, spike dry matter was maximum under full sunlight (i.e. control) in PDW 233 during 2010-11 and in UP 2565 during 2011-12.

4.2.2 Leaf area index

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 both the growing season i.e. 2010-11 and 2011-12. The interaction between varying degree of shade and wheat varieties was influenced significantly at all the stages, except at 20 DAS during both the years (Table 4.2.2 and Appendix XVIII).

The maximum (0.45, 1.47, 3.78, 4.90, 5.04 and 0.99 in 2010-11 and 0.48, 1.49, 3.90, 4.87, 4.96 and 1.01 in 2011-12) and significantly higher leaf area index was observed under severe shade (i.e. 2/3 shading) 20, 40, 60, 80, 100 and 120 DAS, respectively, which reduced significantly with each reduction in shade at all the stages during both the years i.e. 2010-11 and 2011-12.

The leaf area index in wheat varieties differed significantly at 20, 40, 60, 80, 100 and 120 DAS both during 2010-11 and 2011-12. The variety UP 2113 recorded maximum (0.33, 0.94, 1.77, 2.94, 3.45 and 0.44 in 2010-11 and 0.34, 0.97, 1.85, 2.89, 3.40 and 0.45 in 2011-12) and significantly higher leaf area index at 20, 40, 60, 80, 100 and 120 DAS, respectively, being at par with UP 2526, and UP 2684 at 20 and 100 DAS in 2011-12; UP 2526 at 60 DAS in 2011-12; UP 2526 at 80 DAS both during 2010-11 and 2011-12 and also PDW 233 at 20 DAS in 2011-12. The minimum and significantly lowest leaf area index was observed in UP 2565 at 20, 40, 100 and 120 DAS during both the growing seasons i.e. 2010-11 and 2011-12. Whereas, the UP 2565 recorded lowest leaf area index at 60 and 80 DAS in 2010-11 and at 100 and 120 DAS during both the years i.e. 2010-11 and 2011-12.

The interaction between varying degree of shades and different wheat varieties was found to be significant (Table 4.2.2a). The variety UP 2113 significantly higher leaf area index under full sunlight (1.01, 2.36, 3.24, 3.80 and 0.50), mild (1.30, 3.18, 4.56, 4.48 and 0.89) and severe (1.73, 4.27, 5.02, 5.53 and 1.17) shaded treatments, respectively, at 40, 60, 80, 100 and 120 DAS in 2010-11. Whereas, 80 DAS variety UP 2113 was at par with all other varieties under severe shade in 2010-11. However, the variety UP 2565 observed significantly lower leaf area index at 40, 60, 100 and 120 DAS under all the combinations of degree of shades and varieties in 2010-11.

Table 4.2.2 Leaf area index (LAI) 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	0.33	0.34	0.94	0.97	1.77	1.85	2.94	2.89	3.45	3.40	0.44	0.45
L1 – Mild shade	0.38	0.41	1.13	1.10	2.76	3.11	4.35	4.08	4.14	3.86	0.79	0.79
L2 – Severe shade	0.45	0.48	1.47	1.49	3.78	3.90	4.90	4.87	5.04	4.96	0.99	1.01
SEm±	0.01	0.01	0.01	0.01	0.04	0.04	0.02	0.02	0.03	0.04	0.01	0.01
CD at 5 %	0.01	0.02	0.04	0.05	0.14	0.14	0.08	0.07	0.12	0.15	0.01	0.03
B. Wheat varieties												
UP 2684	0.37	0.40	1.12	1.14	2.48	2.69	3.79	3.77	4.14	4.18	0.72	0.75
UP 2526	0.40	0.43	1.19	1.22	3.07	3.35	4.35	4.32	4.39	4.39	0.79	0.81
UP 2565	0.36	0.39	1.06	1.09	2.26	2.96	3.96	3.93	3.60	3.63	0.65	0.68
UP 2113	0.42	0.40	1.35	1.35	3.27	3.23	4.27	4.21	4.61	4.39	0.85	0.87
PDW 233	0.38	0.42	1.17	1.13	2.77	2.54	3.94	3.52	4.32	3.79	0.67	0.65
SEm±	0.01	0.01	0.01	0.02	0.04	0.05	0.06	0.04	0.07	0.08	0.01	0.01
CD at 5 %	0.01	0.03	0.04	0.05	0.11	0.15	0.17	0.12	0.19	0.22	0.03	0.03
CV (%)	3.30	6.60	3.60	4.20	4.20	5.40	4.30	3.00	4.80	5.70	3.90	4.10
Interaction (A x B)	NS	NS	S	S	S	S	S	S	S	S	S	S

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

Table 4.2.2a Leaf area index of different wheat varieties as influenced by varying degree of shades at various growth stages during 2010-11

Wheat varieties (B)	Degree of shades (A)														
	40 DAS			60 DAS			80 DAS			100 DAS			120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	0.90	1.08	1.37	1.44	2.50	3.49	2.40	4.15	4.84	3.66	4.11	4.66	0.43	0.74	1.00
UP 2526	0.98	1.12	1.47	2.01	3.11	4.09	3.26	4.81	4.97	3.64	4.32	5.19	0.46	0.87	1.04
UP 2565	0.83	1.04	1.32	1.16	2.42	3.19	2.86	4.18	4.84	2.51	3.67	4.61	0.37	0.67	0.91
UP 2113	1.01	1.30	1.73	2.36	3.18	4.27	3.24	4.56	5.02	3.80	4.48	5.53	0.50	0.89	1.17
PDW 233	0.97	1.09	1.46	1.91	2.56	3.84	2.96	4.02	4.83	3.66	4.13	5.17	0.43	0.76	0.80
		SEm±	**CD at 5%**	**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'		0.02	0.07	0.06	0.19		0.10	0.29		0.12	0.34		0.02	0.05	
To compare means of two 'A' at the same or different 'B'		0.02	0.07	0.07	0.22		0.09	0.27		0.10	0.32		0.01	0.04	

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

Table 4.2.2b Leaf area index of different wheat varieties as influenced by varying degree of shades at various growth stages during 2011-12

Wheat varieties (B)	Degree of shades (A)														
	40 DAS			60 DAS			80 DAS			100 DAS			120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	0.92	1.11	1.39	1.07	3.15	3.84	2.38	4.13	4.82	3.69	4.14	4.96	0.45	0.77	1.02
UP 2526	1.01	1.14	1.50	2.26	3.81	3.97	3.24	1.79	4.94	3.68	4.35	5.13	0.48	0.89	1.06
UP 2565	0.86	1.06	1.34	1.86	3.18	3.84	2.84	4.16	4.81	2.54	3.71	4.64	0.40	0.69	0.94
UP 2113	0.98	1.33	1.75	2.11	3.56	4.02	3.09	4.54	4.99	3.41	4.51	5.25	0.48	0.91	1.20
PDW 233	1.02	0.88	1.49	1.96	1.83	3.83	2.84	2.91	4.81	2.60	3.69	5.10	0.45	0.66	0.82
		SEm±	**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		0.03	0.08	0.09		0.26	0.07		0.20	0.13		0.39	0.02		0.05
To compare means of two 'A' at the same or different 'B'		0.03	0.09	0.09		0.27	0.06		0.19	0.12		0.37	0.02		0.06

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

The interaction between magnitude of shade and wheat varieties was found to be significant (Table 4.2.2b). Though, the variety UP 2113 found to be highest leaf area index under all the light available conditions i.e. full sunlight, mild and severe shade, at 40, 60, 80 100 and 120 DAS in 2011-12, being at par with UP 2526 at 40 DAS under full sunlight; 60 and 100 DAS under all the light availability conditions i.e. full, 2/3 and 1/3 available light; 80 DAS under full and severe shade and also 120 DAS under full and mild shade treatment in only during 2011-12. The minimum and significantly lowest leaf area index was observed in UP 2565 40 DAS under full sunlight and severe shaded treatment; 60 and 80 DAS UP 2684 and PDW 233 under full sunlight and mild shaded treatment, respectively; at 100 DAS UP 2565 and PDW 233 under full sunlight and 2/3 light available condition, respectively and also at 120 DAS variety PDW 233 under 2/3 and 1/3 available light in 2011-12.

The variety UP 2113 under severe shade showed its superiority in leaf area index over all other combinations of degree of shade and varieties at 40, 60, 80, 100 and 120 DAS. Whereas, the variety UP 2565 under full sunlight has been significantly inferior than all other combinations of degree of shades and varieties at 40, 100 and 120 during both the years.

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 4.2.2). 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).

The differential behavior of wheat varieties in their leaf area development under varying degree of shades it's noticeable. Although, lowest leaf area index in all the varieties was observed under full sunlight, which increased with increasing intensity of shade but the magnitude of variation among varieties has been different. For instance, the per cent increase in leaf area index (45.5 and 54.0) under severe shade as compare to full sunlight was in UP 2113 at 100 DAS during 2010-11 and 2011-12, respectively.

4.2.3 Crop growth rate

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 both the years i.e. 2010-11 and 2011-12 (Table 4.2.3 Fig 4.4 and Appendix XIX). The interaction between magnitude of shades and wheat varieties was found to be significant at 40-60, 60-80, 80-100 (only 2010-11) and 100-120 DAS except at 20-40 DAS during both the growing seasons i.e. 2010-11 and 2011-12.

The maximum (2.90, 12.16, 23.53, 18.79 and 5.05 g m^{-2} day^{-1} in 2010-11 and 2.94, 12.19, 23.51, 18.46 and 5.20 g m^{-2} day^{-1} in 2011-12)and significantly higher CGR was obtained under full sunlight at 20-40, 40-60, 60-80, 80-100 and 100-120 DAS, respectively, which reduced significantly with each increase in shade at all the crop growth stages during both the years i.e. 2010-11 and 2011-12.

The CGR in wheat varieties varied significantly at 20-40, 40-60, 60-80, 80-100 and 100-120 DAS during both the years i.e. 2010-11 and 2011-12. Variety PDW 233 obtained maximum (2.62 and 21.83 g m^{-2} day^{-1} in 2010-11 and 2.65 and 21.85 g m^{-2} day^{-1} in 2011-12) and significantly higher CGR 20-40 and 60-80 DAS, respectively, being at par with the variety UP 2113 (22.48 and 22.50 g m^{-2} day^{-1}) at 60-80 DAS and also UP 2565 (2.55 and 2.58 g m^{-2} day^{-1}) at 20-40 DAS both during 2010-11 and 2011-12, respectively. 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 15.84 g m^{-2} day^{-1} in 2011-12)and significantly lowest CGR was obtained in UP 2113 at 20-40, 40-60 and 80-100 DAS, respectively, being at par with UP 2684 and UP 2526 at 20-40 and 80-100 DAS both during 2010-11 and 2011-12. However, UP 2684 and UP 2565 recorded poorest CGR at 60-80 and at 100-120 DAS during both the years, respectively.

The interaction between varying degree of shades and wheat varieties was found to be significant at 40-60, 60-80, 80-100 and 100-120 DAS only during 2010-11 (Table 4.2.3a). The maximum and significantly higher CGR was obtained in UP 2526 (13.58,

Table 4.2.3 Crop growth rate (g m^{-2} day^{-1}) of different wheat varieties and under varying degree of shades at various growth stages during both the growing seasons

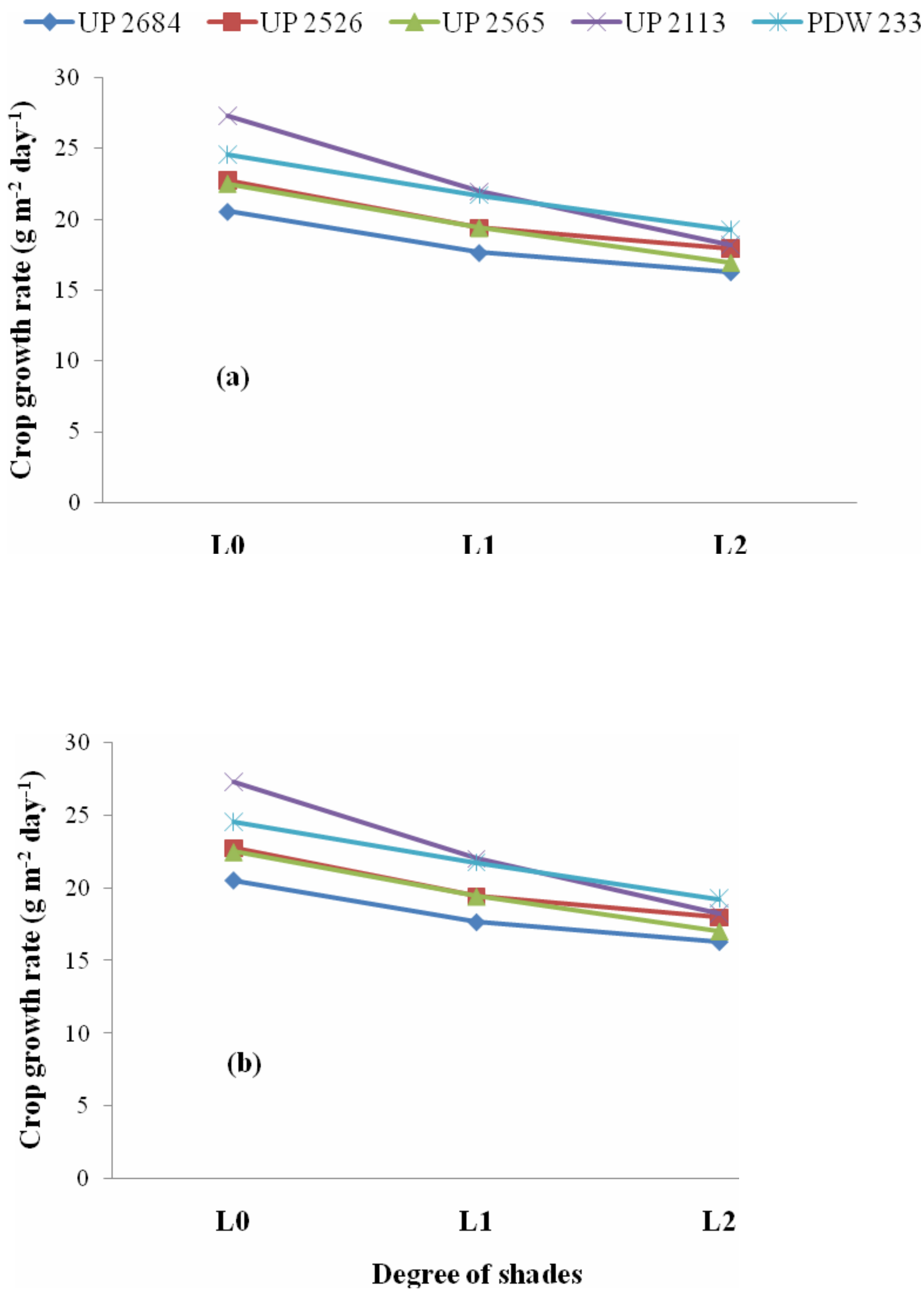
Treatment	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades										
L0 – Full sun light	2.90	2.94	12.16	12.19	23.53	23.51	18.79	18.46	5.05	5.20
L1 – Mild shade	2.48	2.52	7.89	7.91	20.01	20.04	17.38	17.40	3.23	3.39
L2 – Severe shade	2.02	2.05	6.78	6.80	17.72	17.76	15.09	15.12	1.82	1.97
SEm±	0.03	0.02	0.11	0.03	0.19	0.24	0.17	0.05	0.11	0.09
CD at 5 %	0.12	0.08	0.42	0.11	0.77	0.93	0.66	0.02	0.42	0.38
B. Wheat varieties										
UP 2684	2.41	2.44	8.25	8.28	19.15	18.18	16.15	16.05	4.72	4.87
UP 2526	2.44	2.47	10.29	10.31	20.02	20.04	16.39	16.31	3.39	3.54
UP 2565	2.55	2.58	9.02	9.05	19.62	19.64	19.38	19.29	2.22	2.38
UP 2113	2.34	2.37	7.78	7.81	22.48	22.50	15.93	15.84	3.35	3.50
PDW 233	2.62	2.65	9.37	9.39	21.83	21.85	17.56	17.47	3.15	3.30
SEm±	0.04	0.05	0.17	0.09	0.26	0.34	0.26	0.39	0.12	0.18
CD at 5 %	0.12	0.13	0.51	0.26	0.75	0.99	0.75	1.13	0.34	0.53
CV (%)	4.9	5.4	5.8	3.0	3.8	5.0	4.5	6.8	10.3	15.5
Interaction (A x B)	NS	NS	S	S	S	S	S	NS	S	S

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

Table 4.2.3a Crop growth rate (g m^{-2} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)											
	40-60 DAS			60-80 DAS			80-100 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	11.37	5.54	7.84	20.55	17.64	16.28	18.31	15.97	14.15	5.96	5.19	3.01
UP 2526	13.58	8.88	8.41	22.75	19.38	17.92	18.33	16.96	13.89	5.53	2.97	1.66
UP 2565	12.61	9.08	5.38	22.50	19.38	16.92	22.17	19.02	16.95	4.00	1.62	1.05
UP 2113	10.96	6.59	5.79	27.29	21.96	18.19	17.02	16.07	14.70	3.82	3.88	2.36
PDW 233	12.32	9.34	6.44	24.58	21.69	19.22	18.05	18.88	15.74	5.93	2.49	1.02
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		0.30	0.87		0.44	1.29		0.45	1.31		0.20	0.58
To compare means of two 'A' at the same or different 'B'		0.28	0.88		0.44	1.38		0.43	1.33		0.21	0.66

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



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.4 Crop growth rate (g m^{-2} day^{-1}) of wheat varieties as influenced by varying degree of shades 60-80 DAS during 2010-11(a) and 2011-12(b)

8.88 and 8.41 g m^{-2} day^{-1}), UP2113 (27.29, 21.96 and 18.19 g m^{-2} day^{-1}), UP 2565 (22.17, 19.02 and 16.95 g m^{-2} day^{-1}) and UP 2684 (5.96, 5.19 and 3.01 g m^{-2} day^{-1}) under full, 2/3 and 1/3 of sunlight availability at 40-60, 60-80, 80-100 and 100-120 DAS, respectively, only during 2010-11. However, UP 2113 and UP 2565 were at par with PDW 233 under mild and severe shaded treatment at 60-80 and 80-100 DAS in 2010-11.

Table 4.2.3b Crop growth rate (g m^{-2} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	40-60 DAS			60-80 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	11.39	5.57	7.86	20.53	17.67	16.32	6.11	5.35	3.16
UP 2526	13.60	8.90	8.44	22.73	19.41	17.97	5.68	3.12	1.81
UP 2565	12.63	9.10	5.40	22.48	19.41	17.02	4.15	1.78	1.20
UP 2113	10.98	6.62	5.82	27.27	22.00	18.24	3.97	4.03	2.51
PDW 233	12.34	9.37	6.47	24.56	21.73	19.25	6.09	2.64	1.18
		SEm±	**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		0.15	0.44	0.59		1.72	0.32		0.92
To compare means of two 'A' at the same or different 'B'		0.13	0.41	0.58		1.78	0.29		0.90

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

The minimum and significantly lowest CGR was observed from UP 2684 under all the shaded treatments at 60-80 and 80-100 DAS and also UP 2565 at 100-120 DAS only during 2010-11.

During 2011-12, the varieties UP 2113 and UP 2684 were found to be higher crop growth rate under all the light available conditions (i.e. full sunlight, 2/3 and 1/3 of full sunlight) at 60-80 DAS(27.27, 22.00 and 18.24 g m^{-2} day^{-1}) and 100-120 DAS (6.11, 5.35 and 3.16 g m^{-2} day^{-1}), respectively. Whereas, UP 2526 obtained highest under full sunlight and severe shade treatment than all other varieties at 40-60 DAS. The minimum and significantly lower crop growth rate was observed in UP 2684 and UP 2565 under full sunlight, mild and severe shaded treatment at 60-80 DAS (20.53, 17.67 and 16.32 g m^{-2} day^{-1}) and 100-120 (4.15, 1.78 and 1.20 g m^{-2} day^{-1}), respectively (Table 4.2.3b).

The varieties UP 2526, UP 2113 and UP 2684 under full sunlight at 40-60, 60-80 and 100-120 DAS showed its superiority over all other combinations of degree of shades and varieties. The variety UP 2565 and PDW 233 under severe shade, has been significantly inferior than all other combinations of degree of shades and varieties at 40-60 and 100-120 during both the years.

In general, the mean crop growth rate (i.e. the biomass produced per unit area and time), increased rapidly upto the period of 80^{th} 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 4.2.3). 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.

The mean CGR during all the growth periods i.e. 20-40 to 100-120 DAS was maximum under full sunlight (i.e. control) in all the varieties, which decreased with each successive increased in shades and became lowest under 1/3 light availability (i.e. 2/3 shading). However, the degree of reduction varied among the varieties, for instance significant reduction was observed in mean CGR from control (i.e. full sunlight) to 2/3 light availability (i.e. mild shade) but than not to 1/3 light availability (severe shade) in all the wheat varieties during 40-60 DAS period, whereas, each successive increase in shade caused significant reduction in mean CGR in all the varieties at all other growth stages.

4.2.4 Relative growth rate

The relative growth rate (RGR) in wheat was significantly influenced by varying degree of shades and wheat varieties at all the crop growth stages both during 2010-11 and 2011-12. The interaction between degree of shades and wheat varieties was influenced significantly at all the stages of crop growth, except 80-100 DAS during both the seasons and 20-40 DAS only during 2011-12 (Table 4.2.4 and Appendix XX).

The maximum (21.90, 57.59, 90.48, 58.18 and 6.92 mg g^{-1} day^{-1} in 2010-11 and 21.98, 57.83, 91.38, 59.30 and 7.77 mg g^{-1} day^{-1} in 2011-12) and significantly higher RGR was obtained under full sunlight (i.e. control) at all the crop growth stages, respectively, which reduced significantly with each successive increase in shades during both the years i.e. 2010-11 and 2011-12, with no significant difference between 2/3 and 1/3 of full sunlight availability at 40-60 and 80-100 DAS both during 2010-11 and 2011-12 and also full sunlight and 2/3 of full sunlight condition at 20-40 DAS in 2011-12.

The wheat varieties showed significantly difference in their RGR at all the stages during both the years i.e. 2010-11 and 2011-12. The variety UP 2565 recorded significantly higher RGR at 20-40 (24.11 and 24.6 mg g^{-1} day^{-1}) and 60-80 DAS (87.34 and 88.47 mg g^{-1} day^{-1}); UP 2113 measured at 40-60 (59.88 and 60.11 mg g^{-1} day^{-1}) and 80-100 DAS (59.88 and 61.00 mg g^{-1} day^{-1}) and also UP 2684 at 100-120 DAS (7.99 and 8.54 mg g^{-1} day^{-1}) both during 2010-11 and 2011-12, respectively. 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 both the years.

During, 2010-11, the interaction between varying degree of shades and wheat varieties found to be significant (Table 4.2.4a). The variety UP 2565 obtained significantly higher RGR under full sunlight, mild and severe shade treatments at 20-40 and 60-80 DAS, except under mild shade 60-80 DAS in 2010-11. Whereas, UP 2113 and UP 2684 performed better under all the shaded treatment i.e. full, 2/3 and 1/3 light availability, at 40-60 and 100-120 DAS, respectively. The minimum and significantly lowest RGR was observed in UP 2113 (20.65, 18.70 and 16.96 mg g^{-1} day^{-1}), UP 2684 (52.23, 53.73 and 53.10 mg g^{-1} day^{-1}) and UP 2565 (5.62, 2.71 and 2.05 mg g^{-1} day^{-1})

Table 4.2.4 Relative growth rate (mg g^{-1} day^{-1}) of different wheat varieties and under varying degree of shades at various growth stages during both the growing seasons

Treatment	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	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	21.90	21.98	57.59	57.83	90.48	91.38	58.18	59.30	6.92	7.77
L1 – Mild shade	21.34	21.35	56.77	57.00	84.66	84.89	56.32	57.44	5.23	5.81
L2 – Severe shade	19.54	19.78	56.62	56.85	77.19	77.01	55.49	56.61	3.74	3.97
SEm±	0.10	0.24	0.16	0.15	0.18	0.25	0.39	0.41	0.02	0.14
CD at 5 %	0.39	0.95	0.60	0.60	0.69	0.96	1.56	1.59	0.07	0.53
B. Wheat varieties										
UP 2684	20.74	20.97	53.02	53.25	82.47	83.27	51.36	52.47	7.99	8.54
UP 2526	20.29	20.38	57.87	58.09	84.47	84.71	57.86	58.99	5.19	5.74
UP 2565	24.11	24.16	56.72	56.95	87.34	88.47	56.72	57.84	3.46	4.01
UP 2113	18.77	18.89	59.88	60.11	81.54	80.24	59.88	61.00	4.94	5.49
PDW 233	20.71	20.82	57.49	57.72	84.73	85.43	57.49	58.62	4.92	5.47
SEm±	0.23	0.38	0.42	0.42	0.84	0.92	0.57	0.74	0.04	0.19
CD at 5 %	0.68	1.09	1.22	1.22	2.46	2.68	1.67	2.16	0.12	0.55
CV (%)	3.3	5.4	2.2	2.1	3.0	3.3	3.0	3.8	2.3	9.6
Interaction (A x B)	S	NS	S	S	S	S	NS	NS	S	S

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

Table 4.2.4a Relative growth rate (mg g^{-1} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)											
	20-40 DAS			40-60 DAS			60-80 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	21.24	20.60	20.38	52.23	53.73	53.10	88.44	82.29	76.67	8.94	9.07	5.96
UP 2526	20.42	21.32	19.15	57.45	57.38	58.77	94.01	85.57	73.82	7.58	4.88	3.11
UP 2565	25.07	24.09	23.16	55.68	57.19	57.27	94.83	83.06	84.11	5.62	2.71	2.05
UP 2113	20.65	18.70	16.96	61.20	60.17	58.27	83.80	84.24	76.57	4.74	5.79	4.27
PDW 233	22.13	21.97	18.04	61.42	55.37	55.69	91.30	88.12	74.76	7.70	3.77	3.28
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	0.40	1.17		0.72	2.11		1.46	4.26		0.07	0.21	
To compare means of two 'A' at the same or different 'B'	0.37	1.11		0.66	1.97		1.32	3.87		0.06	0.19	

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

Table 4.2.4b Relative growth rate (mg g^{-1} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	40-60 DAS			60-80 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	52.46	53.96	53.34	89.47	84.33	76.00	9.78	9.63	6.20
UP 2526	57.68	57.61	59.00	94.04	86.61	73.50	8.44	5.45	3.34
UP 2565	55.91	57.43	57.51	96.20	85.06	84.14	6.47	3.27	2.28
UP 2113	61.43	60.40	58.50	84.84	80.28	75.61	5.60	6.35	4.51
PDW 233	61.65	55.60	55.92	92.34	88.15	75.80	8.56	4.34	3.51
		SEm±	**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		0.72	2.11	1.59		4.64	0.32		0.94
To compare means of two 'A' at the same or different 'B'		0.66	1.97	1.44		4.25	0.32		0.99

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

under all the shaded treatments at 20-40, 40-60 and 100-120 DAS, respectively. Whereas, 60-80 DAS variety UP 2684 recorded lowest RGR under mild and severe shade, being at par with all other varieties, except PDW 233 under mild shade and UP 2565 under severe shade in 2010-11.

Whereas, 2011-12, the varieties UP 2113, UP 2565 and UP 2684 recorded significantly higher RGR under all the shaded treatments at 40-60, 60-80 and 100-120, respectively. However, the variety UP 2565 was at par with UP 2526 and PDW 233 under full sunlight and 2/3 light availability condition at 60-80 DAS. The lowest RGR was obtained in UP 2684; UP 2113 and UP 2565 under all the light availability condition i.e. full sunlight, 2/3 and 1/3 available light, at 40-60, 60-80 and 100-120

DAS, respectively. While, variety UP 2113 was not found to be significant with all other varieties under severe shade at 60-80 DAS, except UP 2565 (Table 4.2.4b).

The variety PDW 233 at par with UP 2113 under full sunlight showed its superiority in RGR over all other combinations of degree of shade and varieties at 40-60 DAS in 2011-12, whereas, PDW 233 under full sunlight proved its superiority at 40-60 DAS in 2010-11. However, the variety UP 2565 under full sunlight at 60-80 DAS and UP 2684 under full sunlight at 100-120 DAS was proved to be superior over other combinations of degree of shades and varieties during both the years. The variety UP 2684 at 40-60 DAS under full sunlight; UP 2526 at 60-80 DAS under severe shade and UP 2565 under severe shade at 100-120 DAS has been observed significantly inferior than all other combinations of degree of shades and varieties both during 2010-11 and 2011-12.

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 4.2.4). 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.

The mean RGR was influenced by varying degree of shades during all the crop growth stages. The mean RGR was recorded maximum under full sunlight which increased upto 60-80 DAS, and thereafter declined slowly during 80-100 and sharply from 100 to 120 day's period. Whereas, each successive increase in shade caused significant reduction in mean RGR. Varieties showed significant variations in their mean RGR during 20-40 and 60-80 DAS periods with significant and consistent superiority of UP 2565 and during 40-60 and 80-100 DAS periods with significant and consistent superiority of UP 2113. The wheat varieties also behaved differently under varying degree of shade during all the growth periods. During 60-80 DAS period, when variety PDW 233, UP 2113 and UP 2526 did not differ in their mean RGR under mild shade in 2010-11, whereas, in 2011-12 variety PDW 233, UP 2565 and UP 2526 did not differ in their mean RGR.

4.2.5 Net assimilation rate

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 both during 2010-11 and 2011-12 (Table 4.2.5 and Appendix XXI). 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 both the seasons, and at 20-40 DAS and 100-120 DAS in 2011-12.

The wheat NAR was maximum (0.115, 0.189. 0.313 and 0.120 mg cm^{-2} day^{-1} in 2010-11 and (0.207, 0.211, 0.327 and 0.150 mg cm^{-2} day^{-1} in 2011-12) and significantly higher under full sunlight at 40-60, 60-80, 80-100 and 100-120 DAS, respectively, which reduced significantly with each successive increase in shade during both the years, except 20-40 DAS in 2011-12 with no significant difference between 2/3 and 1/3 of full sunlight availability at 40-60 DAS in 2010-11 and at 100-120 DAS in 2011-12.

The wheat varieties differed significantly in their net assimilation rate at all the crop growth stage during both the years. The maximum and significantly higher NAR was recorded varieties UP 2565 at 20-40 (0.160 and 0.126 mg cm^{-2} day^{-1}) and 100-120 DAS (0.142 and 0.143 mg cm^{-2} day^{-1}), respectively; varieties UP 2113 at 60-80 DAS (0.198 and 0.220 mg cm^{-2} day^{-1}) and also UP 2684 at 80-100 DAS (0.316 and 0.339 mg cm^{-2} day^{-1}) during both the years, respectively. 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 during both the years; UP 2565 at 80-100 DAS and also UP 2113 at 100-120 DAS during both the years.

The interaction between degree of shades and different wheat varieties was found to be significant at 20-40, 40-60, 80-100 and 100-120 DAS during 2010-11. Though, the variety UP 2526 recorded highest NAR under all the shaded treatments at 20-40 and 40-60 DAS in 2010-11, except under sever shade at 20-40 DAS. Whereas, at 80-100 and 100-120 DAS the variety UP 2684 and UP 2565 recorded highest NAR under all the light availability conditions i.e. full sunlight, 2/3 and 1/3 available light only during 2010-11, except UP 2684 under severe shade at 80-100 DAS. The

Table 4.2.5 Net assimilation rate (mg cm^{-2} day^{-1}) of different wheat varieties and under varying degree of shades at various growth stages during both the growing seasons

Treatment	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	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	0.170	0.128	0.115	0.207	0.189	0.211	0.313	0.327	0.120	0.150
L1 – Mild shade	0.159	0.123	0.112	0.179	0.178	0.199	0.227	0.250	0.118	0.108
L2 – Severe shade	0.147	0.122	0.111	0.168	0.168	0.189	0.124	0.183	0.114	0.105
SEm±	0.001	0.001	0.001	0.002	0.001	0.002	0.001	0.006	0.001	0.005
CD at 5 %	0.001	NS	0.001	0.009	0.003	0.009	0.002	0.002	0.001	0.019
B. Wheat varieties										
UP 2684	0.159	0.123	0.111	0.208	0.165	0.186	0.316	0.339	0.111	0.112
UP 2526	0.161	0.133	0.122	0.182	0.177	0.198	0.229	0.252	0.120	0.120
UP 2565	0.160	0.126	0.114	0.181	0.186	0.207	0.172	0.195	0.142	0.143
UP 2113	0.160	0.123	0.112	0.180	0.198	0.220	0.221	0.244	0.101	0.116
PDW 233	0.153	0.117	0.105	0.173	0.165	0.187	0.169	0.236	0.114	0.115
SEm±	0.001	0.003	0.001	0.006	0.003	0.004	0.002	0.008	0.001	0.006
CD at 5 %	0.003	0.008	0.002	0.016	0.007	0.012	0.005	0.023	0.003	0.018
CV (%)	2.2	7.0	2.2	9.1	3.8	6.1	2.4	9.5	2.3	15.5
Interaction (A x B)	S	NS	S	S	NS	NS	S	S	S	NS

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

Table 4.2.5a Net assimilation ratio (mg cm^{-2} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)											
	20-40 DAS			40-60 DAS			80-100 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	0.169	0.156	0.151	0.110	0.111	0.111	0.359	0.363	0.227	0.113	0.111	0.110
UP 2526	0.181	0.166	0.136	0.124	0.122	0.119	0.346	0.215	0.127	0.126	0.115	0.117
UP 2565	0.173	0.152	0.156	0.115	0.114	0.112	0.291	0.130	0.950	0.139	0.140	0.146
UP 2113	0.160	0.165	0.155	0.115	0.109	0.112	0.225	0.264	0.175	0.101	0.108	0.094
PDW 233	0.166	0.157	0.136	0.113	0.102	0.099	0.347	0.164	0.140	0.123	0.117	0.102

	20-40 DAS SEm±	20-40 DAS CD at 5%	40-60 DAS SEm±	40-60 DAS CD at 5%	80-100 DAS SEm±	80-100 DAS CD at 5%	100-120 DAS SEm±	100-120 DAS CD at 5%
To compare means of two B at the same 'A'	0.002	0.006	0.001	0.004	0.003	0.009	0.002	0.005
To compare means of two 'A' at the same or different 'B'	0.002	0.006	0.001	0.004	0.003	0.008	0.001	0.004

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

Table 4.2.5b Net assimilation ratio (mg cm^{-2} day^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)					
	40-60 DAS			80-100 DAS		
	L0	L1	L2	L0	L1	L2
UP 2684	0.273	0.176	0.173	0.382	0.386	0.250
UP 2526	0.203	0.186	0.156	0.368	0.238	0.150
UP 2565	0.193	0.173	0.176	0.314	0.153	0.117
UP 2113	0.180	0.183	0.177	0.248	0.287	0.196
PDW 233	0.186	0.176	0.156	0.321	0.187	0.201
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	0.009	0.028		0.013	0.040	
To compare means of two 'A' at the same or different 'B'	0.008	0.026		0.014	0.043	

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

minimum and significantly lowest NAR was observed from UP 2113 under all the shaded treatments (i.e. full, 2/3 and 1/3 light availability) at 100-120 DAS, being at par with UP 2684 under mild shade condition. Whereas, at 40-60 DAS the variety PDW 233 obtained lowest NAR under full sunlight, mild and severe shaded treatment, it was on par with UP 2113 and UP 2565 under full sunlight during 2010-11 (Table 4.2.5a).

During, 2011-12 the interaction between varying degree of shades and different wheat varieties was significant at 40-60 and 80-100 DAS (Table 4.2.5b). The variety UP 2684 recorded significantly higher NAR under all the shaded treatments 40-60 and 80-100 DAS in 2011-12. It was at par with all other varieties under mild and severe shaded treatments at 40-60 DAS. The minimum and significantly lowest NAR was obtained in UP 2113 under full sunlight at 40-60 and also 80-100 DAS in 2011-12, being at par with PDW 233, UP 2565 and UP 2526 under full sunlight at 40-60 DAS.

Whereas, the variety UP 2565 recorded lowest NAR under mild and severe shaded treatments 80-100 DAS in 2011-12, being at par with PDW 233 under mild shade and also UP 2526 under severe shade at 80-100 DAS (Table 18b).

The variety UP 2684 under full sunlight showed its superiority at all the stages in NAR over all other combination of degree of shade and varieties in 2011-12, whereas, in 2010-11 it was superior under full sunlight at 20-40 and 80-100 DAS. The variety PDW 233 under severe shade proved to be inferior most than all the other combinations of light and varieties at 40-60 DAS during both the years.

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 4.2.5). 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. The mean NAR decreased with increased in shade but it was not significant during 20-40 DAS in 2011-12. 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.

Varieties showed significantly variation in their mean NAR during all the crop growth stages during both the years i.e. 2010-11 and 2011-12. As the variety UP 2113 during 60-80 DAS; UP 2684 during 80-100 DAS and UP 2565 during 100-120 DAS have had maximum and PDW 233, UP 2565 and UP 2113 lowest mean NAR during all these three periods during both the years, respectively. Wheat varieties showed differential behavior for their mean NAR under varying degree of shades. The highest mean NAR during 40-60 DAS was observed in all the shaded treatments with UP 2526 in 2010-11 and UP 2684 in 2011-12, whereas, UP 2684 was not found to be significant with other varieties under mild and severe shade during 40-60 DAS in 2011-12 (Table 4.2.5b). The magnitude of reduction among varieties has also been different.

4.2.6 Leaf area ratio

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 both the growing season, except 100-120 DAS in 2011-12 (Table 4.2.6 Fig 4.5 and Appendix XXII).

The maximum (415.1, 287.8, 232.4, 92.3 and 91.5 cm^2 g^{-1} in 2010-11 and (414.1, 286.4, 233.4, 90.0 and 89.4 cm^2 g^{-1} in 2011-12) 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 both during 2010-11 and 2011-12.

The leaf area ratio of wheat varieties significantly varied at all the stages during both the years. 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 380.8, 241.1, 178.8, 76.8 and 66.0 cm^2 g^{-1} in 2011-12) and significantly higher leaf area ratio at all the crop growth stages, respectively, being at par with UP 2684 and UP 2526 at 80-100 and 100-120 DAS both during 2010-11 and 2011-12. 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 and 2011-12. Whereas, UP 2684 obtained significantly lowest leaf area ratio at 20-40 DAS being at par with PDW 233 both during 2010-11 and 2011-12.

The interaction between degree of shades and different wheat varieties was found to be significant at all the crop growth stages during both the years i.e. 2010-11 and 2011-12 (Table 4.2.6a & b). The variety UP 2113 maximum and significantly highest leaf area ratio under all the shaded treatments 20-40, 40-60 and 60-80 DAS in 2010-11. Whereas, 80-100 and 100-120 DAS variety UP 2526 obtained highest leaf area ratio under full sunlight, mild and severe shaded treatment, being at par with UP 2684 under full sunlight and mild shaded treatment; UP 2113 under full sunlight and severe shade and also PDW 233 under full sunlight at 80-100 DAS in 2010-11. However, the variety UP 2565 obtained significantly lowest leaf area ratio under all the shaded treatments at 40-60, 60-80, 80-100 and 100-120 DAS during 2010-11.

During 2011-12, variety UP 2113 showed its superiority under all the shaded treatments 20-40, 40-60, 60-80 and 80-100 DAS, being at par with UP 2526 under full sunlight and mild at 20-40 DAS; UP 2684, UP 2526 and PDW 233 under full sunlight at 40-60 DAS; UP 2526 under mild and severe shade at 60-80 DAS and also UP 2684,

Table 4.2.6 Leaf area ratio ($cm^2 g^{-1}$) of different wheat varieties and under varying degree of shades at various growth stages during both the growing seasons

Treatment	20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
	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	286.1	288.6	135.8	133.4	82.0	85.0	50.8	54.1	43.9	41.7
L1 – Mild shade	338.6	339.8	185.5	183.2	145.8	144.5	75.2	78.5	63.3	61.2
L2 – Severe shade	415.1	414.1	287.8	286.4	232.4	233.4	92.3	90.0	91.5	89.4
SEm±	1.3	1.8	0.9	1.6	2.3	0.9	0.4	1.1	0.6	0.5
CD at 5 %	5.1	6.8	3.6	6.2	8.9	3.6	1.6	4.3	2.2	1.8
B. Wheat varieties										
UP 2684	323.0	323.7	193.4	191.0	151.4	152.4	77.2	77.1	67.7	65.6
UP 2526	363.1	363.8	208.1	205.8	170.5	171.4	77.6	77.5	69.5	67.2
UP 2565	337.4	338.2	178.9	176.6	125.4	126.4	65.0	68.3	60.6	58.4
UP 2113	380.0	380.8	243.4	241.1	178.0	178.8	76.2	76.8	68.1	66.0
PDW 233	329.6	331.0	191.3	188.9	141.7	142.6	67.9	71.3	65.3	63.3
SEm±	3.4	4.6	3.1	4.0	2.7	1.8	1.0	1.3	0.8	1.4
CD at 5 %	9.9	13.3	9.1	11.7	7.9	5.2	2.8	3.9	2.3	4.2
CV (%)	2.9	3.9	4.6	5.9	5.3	3.5	3.9	5.4	3.5	6.7
Interaction (A x B)	S	S	S	S	S	S	S	S	S	NS

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

Table 4.2.6a Leaf area ratio (cm^2 g^{-1}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)														
	20-40 DAS			40-60 DAS			60-80 DAS			80-100 DAS			100-120 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	257.4	319.5	391.8	133.0	185.0	261.9	72.7	147.3	234.0	55.8	81.3	94.4	50.2	65.6	87.2
UP 2526	322.8	364.4	402.0	141.6	190.2	292.4	91.3	162.7	257.3	56.8	77.9	97.9	46.4	67.6	94.3
UP 2565	268.4	305.2	438.3	117.7	168.1	250.8	52.3	124.7	199.1	36.3	71.9	86.7	33.3	59.8	88.5
UP 2113	307.4	366.7	465.9	152.9	218.7	358.6	106.9	166.2	260.6	52.5	75.4	100.6	45.1	63.1	96.0
PDW 233	274.5	336.8	377.4	133.5	165.4	274.8	86.6	127.7	210.7	52.4	69.5	81.7	44.1	60.3	91.4
		SEm±	**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		5.8	17.1	5.4		15.7	4.7		13.7	1.6		4.8	1.3		3.9
To compare means of two 'A' at the same or different 'B'		5.4	16.1	4.9		14.5	4.8		15.0	1.5		4.6	1.3		4.1

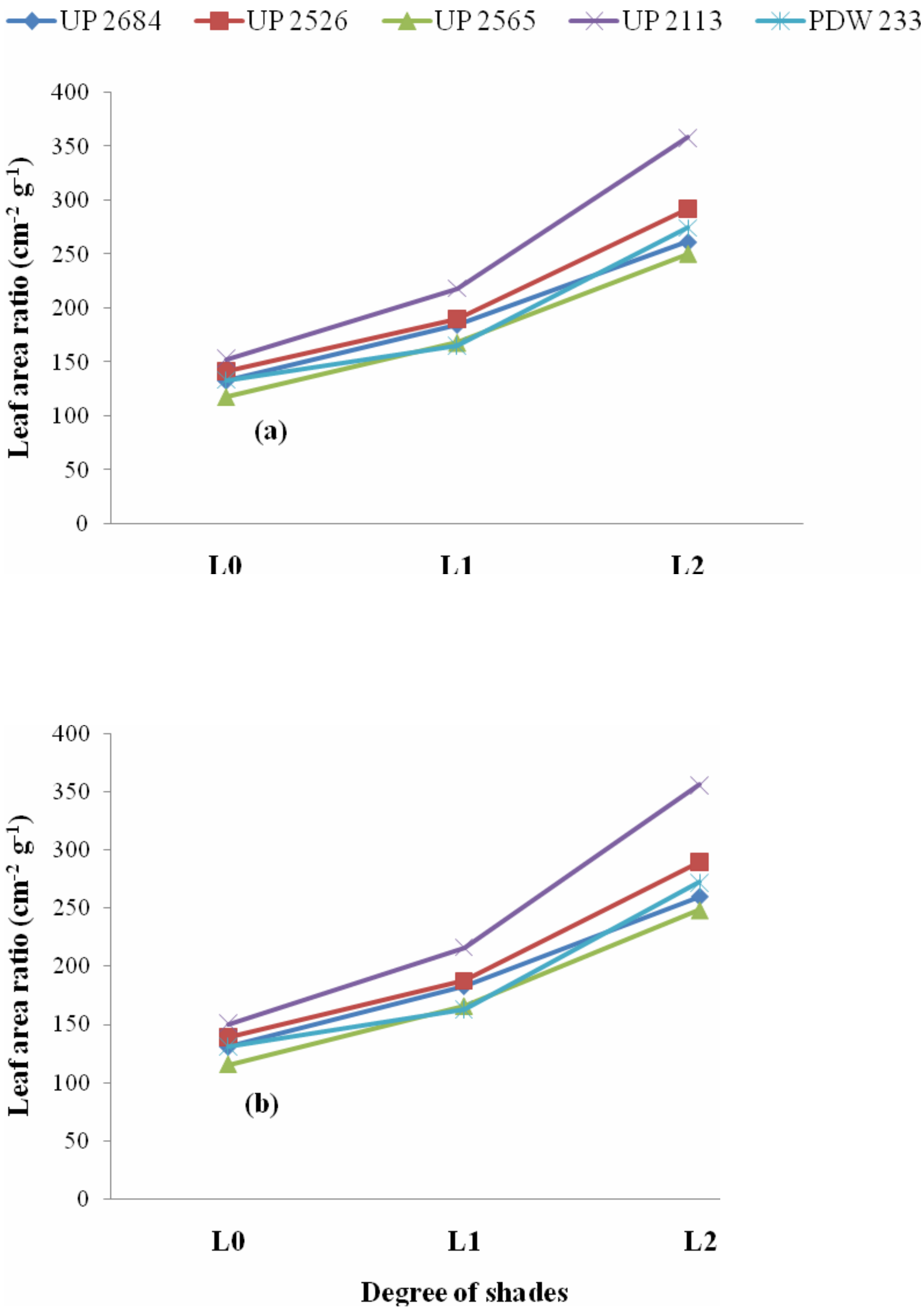
DAS – Days after sowing **L0** –Full sun light **L1** – Mild shade **L2** – Severe shade

Table 4.2.6b Leaf area ratio ($cm^2\ g^{-1}$) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)											
	20-40 DAS			40-60 DAS			60-80 DAS			80-100 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	259.6	320.8	390.7	130.7	182.7	259.5	76.0	146.1	235.1	59.1	84.5	87.6
UP 2526	324.9	365.6	400.9	139.3	187.8	290.1	94.2	161.5	258.3	60.1	81.2	91.2
UP 2565	270.6	306.5	437.3	115.4	165.7	248.4	55.5	123.5	200.2	39.6	75.2	90.0
UP 2113	309.5	367.9	464.9	150.5	216.3	356.2	109.8	164.9	261.6	55.7	78.6	95.9
PDW 233	278.5	338.1	376.4	131.1	163.1	272.4	89.5	129.4	211.7	56.0	72.8	85.0

	20-40 DAS SEm±	20-40 DAS CD at 5%	40-60 DAS SEm±	40-60 DAS CD at 5%	60-80 DAS SEm±	60-80 DAS CD at 5%	80-100 DAS SEm±	80-100 DAS CD at 5%
To compare means of two B at the same 'A'	7.8	23.0	6.9	20.2	3.1	9.0	2.3	6.7
To compare means of two 'A' at the same or different 'B'	7.2	21.6	6.4	19.0	2.9	8.7	2.3	7.3

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



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.5 Leaf area ratio (cm^2 g^{-1}) of wheat varieties as influenced by varying degree of shades 40-60 DAS during 2010-11(a) and 2011-12(b)

UP 2526, PDW 233 under full sunlight (i.e. control). However, the variety UP 2565 at 40-60 and 60-80 DAS obtained significantly lowest leaf area ratio under all the light available condition i.e. full, 2/3 and 1/3 available light (Table 4.2.6b). The variety UP 2113 under severe shade showed its superiority in leaf area ratio over all other combinations of degree of shades and varieties at all the stages during both years. Whereas, the variety UP 2565 under full sunlight has been significantly inferior to all other combinations of degree of shades and varieties, except 20-40 DAS during both the years.

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 both the years i.e. 2010-11 and 2011-12 (Table 4.2.6). Although during all the crop growth periods, severe shades favoured 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). Wheat variety UP 2113 had significantly more mean LAR than other varieties during all the crop growth periods during both the growing seasons, but it was not found to be significant with UP 2526 and UP 2684 at 80-100 and 100-120 DAS during both years and PDW 233 at 100-120 DAS in 2011-12. This variation clearly indicates the adoptability of a variety to shady condition. Like many other growth parameters, the wheat varieties also exhibited significant variations in their mean LAR with varying degree of shades during 40-60 and 60-80 DAS, when, variety UP 2113 had higher mean LAR under severe shades (i.e. 2/3 shading) it showed their superiority during 20-40, 40-60, 60-80 and 80-100 DAS. The magnitude of decrease in LAR among varieties differed a lot under varying degree of shades. For instance, the percent decrease in LAR (50.3, 40.4 and 23.0 % reduction in LAR) in UP 2113 under full sunlight compare to severe shade at 40-60 DAS over 20-40 DAS during both the years, respectively.

4.2.7 Specific leaf weight

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 both during 2010-11 and 2011-12, except 20 DAS in 2011-12 (Table 4.2.7 Fig 4.6 and Appendix XXIII). The interaction between degree of shades and wheat varieties was influenced significantly at 40, 60, 80 and 100 DAS, except at 120 DAS during both the years.

The significantly higher (3.97, 6.42, 4.14, 5.32 and 3.42 mg cm^{-2} in 2010-11 and 4.01, 6.54, 4.46, 5.56 and 3.09 mg cm^{-2} in 2011-12) specific leaf weight was obtained under full sunlight (i.e. control) at 40, 60, 80, 100 and 120 DAS, respectively, which reduced significantly with each successive increase in shade during both the years i.e. 2010-11 and 2011-12, except at 20 DAS in 2011-12.

The specific leaf weight of wheat varieties significantly varied at all the crop growth stages during both the years i.e. 2010-11 and 2011-12. 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 2.02, 3.32, 5.30, 3.56, 4.54 and 2.04 mg cm^{-2} in 2011-12) and significantly highest specific leaf weight at all the crop growth stages, respectively, 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 both during 2010-11 and 2011-12. 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 both the years i.e. 2010-11 and 2011-12.

The interaction between magnitude of shades and different wheat varieties was found to be significant at all the stages, except at 120 DAS in 2010-11. Though, the variety PDW 233 obtained highest specific leaf weight under all the shaded treatments at 20 DAS but it was highest under mild and severe shaded treatments at 40, 60 and 80 DAS in 2010-11, being at par with UP 2565 under mild and severe shades at 40 DAS; UP 2526 and UP 2684 under mild and severe shade at 80 DAS in 2010-11. Whereas, at 100 DAS variety PDW 233 performed best under mild shade, being at par with UP 2684 and UP 2113 in 2010-11. The minimum and significantly lowest specific leaf weight was obtained in UP 2526 under full sunlight and mild shade at 20 and 60 DAS and also under all the light available condition at 100 DAS in 2010-11. Whereas, at 40 and 80 DAS the variety UP 2113 significantly lowest specific leaf weight was obtained under full sunlight and mild shade (Table 4.2.7a).

Table 4.2.7 Specific leaf weight (mg cm^{-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	1.88	1.90	3.97	4.01	6.42	6.54	4.14	4.46	5.32	5.56	3.42	3.09
L1 – Mild shade	1.61	1.84	2.89	2.94	3.45	3.57	2.74	3.06	3.94	4.18	1.64	1.32
L2 – Severe shade	1.28	1.85	1.86	1.92	2.10	2.22	2.33	2.66	2.93	3.17	1.14	0.82
SEm±	0.01	0.07	0.04	0.03	0.02	0.02	0.02	0.04	0.06	0.05	0.05	0.05
CD at 5 %	0.03	NS	0.15	0.09	0.08	0.83	0.06	0.16	0.22	0.19	0.18	0.18
B. Wheat varieties												
UP 2684	1.63	1.96	2.94	2.99	3.71	3.83	3.23	3.55	4.17	4.41	2.02	1.69
UP 2526	1.38	1.65	2.84	2.89	3.07	3.19	3.17	3.49	3.46	3.69	1.91	1.58
UP 2565	1.78	2.02	3.26	3.32	5.18	5.30	3.23	3.56	4.30	4.54	2.36	2.04
UP 2113	1.36	1.55	2.41	2.44	3.50	3.62	2.65	2.97	4.14	4.37	1.90	1.80
PDW 233	1.79	2.13	3.09	3.14	4.49	4.62	3.08	3.41	4.25	4.49	2.15	1.82
SEm±	0.02	0.08	0.05	0.06	0.07	0.07	0.07	0.09	0.08	0.07	0.11	0.01
CD at 5 %	0.06	0.25	0.16	0.17	0.19	0.21	0.19	0.25	0.22	0.21	0.31	0.31
CV (%)	3.80	13.50	5.60	5.80	4.90	5.10	6.50	7.70	5.60	5.00	15.50	18.40
Interaction (A x B)	S	NS	S	S	S	S	S	S	S	S	NS	NS

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

Table 4.2.7a Specific leaf weight (mg cm^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2010-11

Wheat varieties (B)	Degree of shades (A)														
	20 DAS			40 DAS			60 DAS			80 DAS			100 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	1.98	1.68	1.23	4.00	2.82	2.01	6.23	3.03	1.87	4.29	2.87	2.52	5.13	4.06	3.31
UP 2526	1.52	1.23	1.41	3.79	2.93	1.79	4.85	2.66	1.68	4.01	2.97	2.52	4.55	3.28	2.55
UP 2565	2.13	1.88	1.32	4.56	3.17	2.06	6.36	3.85	2.33	4.95	2.57	2.16	6.17	3.90	3.82
UP 2113	1.66	1.44	0.98	3.48	2.29	1.44	5.07	3.35	2.08	3.49	2.40	2.04	5.35	4.13	2.95
PDW 233	2.09	1.83	1.44	4.04	3.23	2.01	6.59	4.35	2.55	3.94	2.89	2.43	5.38	4.33	3.04
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	0.04	0.10		0.09	0.27		0.11	0.33		0.12	0.34		0.13	0.38	
To compare means of two 'A' at the same or different 'B'	0.03	0.09		0.09	0.28		0.10	0.31		0.10	0.31		0.13	0.40	

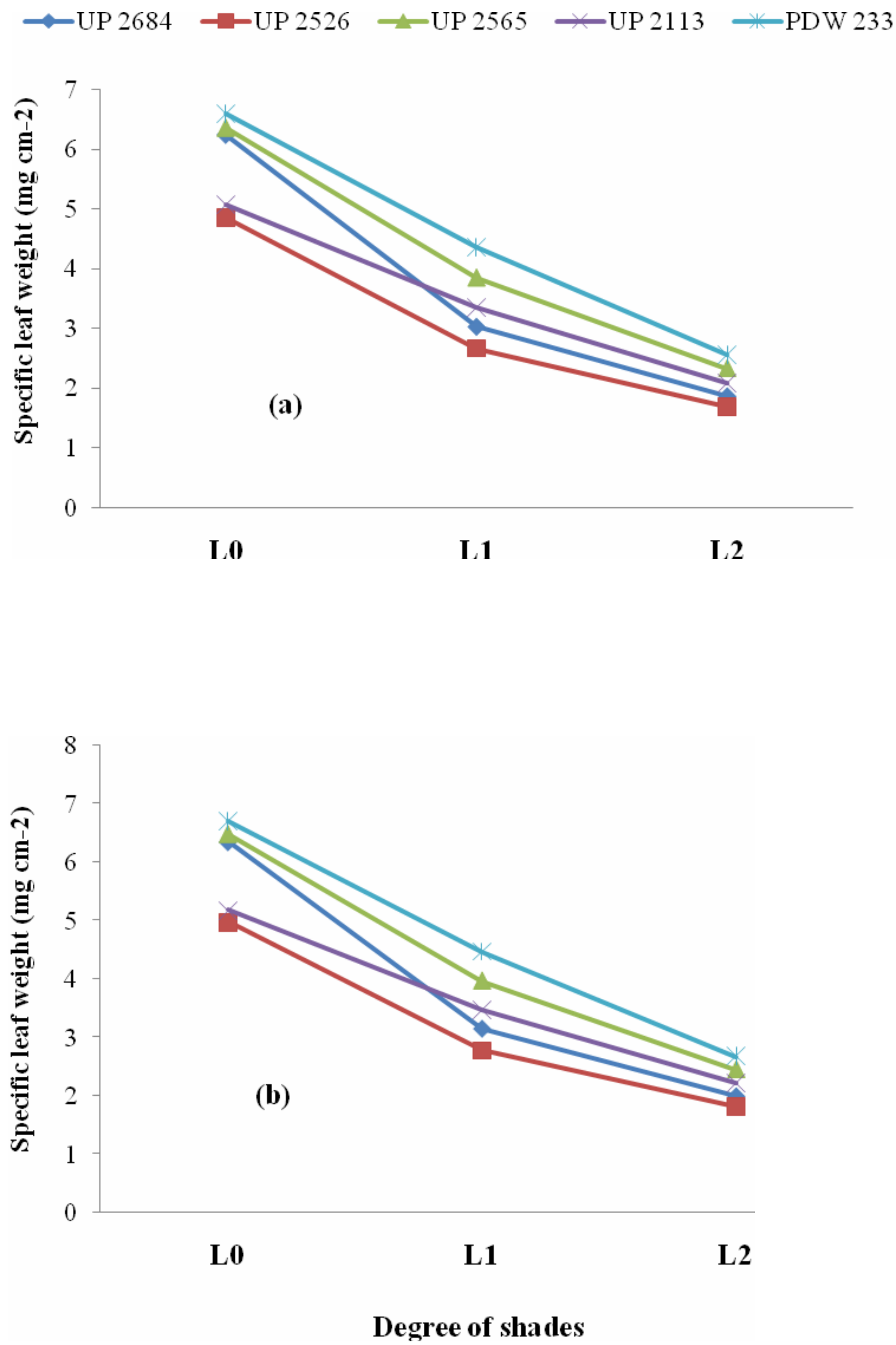
S - Significant NS - Non-significant DAS - Days after sowing

Table 4.2.7b Specific leaf weight (mg cm^{-2}) of different wheat varieties as influenced by varying degree of shades at various stages during 2011-12

Wheat varieties (B)	Degree of shades (A)											
	40 DAS			60 DAS			80 DAS			100 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	4.05	2.87	2.07	6.35	3.15	1.99	4.62	3.19	2.84	5.37	4.29	3.55
UP 2526	3.85	2.99	1.85	4.98	2.78	1.81	4.33	3.29	2.85	4.78	3.52	2.78
UP 2565	4.61	3.22	2.11	6.48	3.97	2.45	5.28	2.91	2.48	6.42	4.14	3.06
UP 2113	3.46	2.35	1.50	5.18	3.47	2.21	3.81	2.73	2.37	5.58	4.37	3.18
PDW 233	4.09	3.28	2.06	6.71	4.47	2.67	4.26	3.21	2.75	5.63	4.57	3.28

	40 DAS SEm±	40 DAS CD at 5%	60 DAS SEm±	60 DAS CD at 5%	80 DAS SEm±	80 DAS CD at 5%	100 DAS SEm±	100 DAS CD at 5%
To compare means of two B at the same 'A'	0.09	0.29	0.12	0.36	0.15	0.44	0.12	0.36
To compare means of two 'A' at the same or different 'B'	0.09	0.27	0.11	0.33	0.14	0.42	0.12	0.37

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



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.6 Specific leaf weight (mg cm^{-2}) of wheat varieties as influenced by varying degree of shades at 60 DAS during 2010-11(a) and 2011-12(b)

During 2011-12, the variety UP 2565 significantly highest specific leaf weight was obtained under all the shaded treatments at 40, and 80 DAS, being at par with UP 2526 and PDW 233 under mild and severe shades at 40 and 80 DAS and also UP 2684 at 80 DAS. Whereas, at 60 and 100 DAS variety PDW 233 performed best under all the treatment, except under full sunlight at 100 DAS in 2011-12. It was at par with UP 2113 under mild shade and also UP 2684 under mild and severe shade at 100 DAS. However, the variety UP 2113 and UP 2526 obtained significantly lowest specific leaf weight at 40 and 80 and 60 and 100 DAS, respectively (Table 4.2.7b).

The variety UP 2565 under full sunlight was obtained higher specific leaf weight than other varieties under any other light condition during both the years except 60 DAS. It was proved to be superior over other combinations of degree of shades and varieties. The variety UP 2113 under severe shade showed its inferior most than all the other combinations of degree of shades and varieties at 40 and 80 DAS during both the years. Whereas, at 60 and 100 DAS UP 2526 showed its inferiority than all other combinations of degree of shades and varieties.

The specific leaf weight (SLW), a measure of leaf thickness, was relatively higher at 60th day which slightly decreased at 80th day and again increased to the maximum at 100th day, indicating the maximum leaf area development/expansion during tillering and early jointing stage of crop i.e. around 80 days stage (Table 4.2.7) during both the years i.e. 2010-11 and 2011-12. 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 both the years, except 20th day in 2011-12. 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 both during 2010-11 and 2011-12. Shyam (1986) also reported slight increase in SLW after anthesis with significant varietal differences.

Wheat varieties behaved differently for SLW under varying degree of shades at all the crop growth periods both during 2010-11 and 2011-12, except at 120 DAS in 2010-11 and 2011-12 and vat 20 in 2011-12. The SLW decreased with increase in shade from full sunlight to severe shade (i.e. 2/3 shading) at all the crop growth periods. The highest SLW was obtained under full sunlight by UP 2565 at 40, 80 and 100 DAS both during 2010-11 and 2011-12 but PDW 233, had maximum SLW under mild shade (i.e. 1/3 shading) at 40, 60, 80 and 100 DAS. The magnitude of variation in SLW of different wheat varieties has also been different under varying degree of shades. For instance, the per cent reduction in SLW (61.3 and 60.2) in PDW 233 under severe shade compare to full sunlight at 60 DAS during 2010-11 and 2011-12 respectively.

4.3 Intercellular CO_2 concentration

The CO_2 concentration (ppm) inside leaves of wheat was significantly influenced by degree of shades on boot stage and anthesis in 2011-12 and also 10 days after anthesis during both the years i.e. 2010-11 and 2011-12 (Table 4.3.1 and 4.3.2 and Appendix XXIV and XXV). The wheat varieties and their interaction with degree of shades were not significantly influenced at either of these stages i.e. boot stage and anthesis during 2011-12 and also 10 days after anthesis during either growing seasons i.e. 2010-11 or 2011-12.

The maximum (358.6 and 363.6 ppm) and significantly higher intercellular CO_2 concentration was recorded under higher degree of shade both at boot stage and anthesis in 2011-12 and 10 days after anthesis (323.7 and 324.6 ppm) during both the years i.e. 2010-11 and 2011-12, respectively, which reduced significantly with each successive reduction in shade at all these stages of crop growth through full sunlight.

Diffusion of CO_2 into the leaves is mainly driven through the stomatal aperture and linearly correlates with photosynthetic capacity (Wong *et al*. 1979). It plays an important role in the physiological process of plant modulated by environmental regime (Korner *et al*., 1979). Intercellular CO_2 concentration varied by magnitude of shades during different growth periods (Table 4.3.1 and 4.3.2). The CO_2 concentration was higher under severe shade (i.e. 2/3 shading) as compared to mild shade and full sunlight condition both during booting, and anthesis in 2011-12 and at 10 days after anthesis (DAA) during both the years. The per cent increase was 9.5 in booting and 11.7 at anthesis in 2011-12 and 10.9 and 12.5 per cent of 10 DAA during both the years, respectively, as compared to full sunlight. The direct effects of increased carbon dioxide (CO2) concentration on plant growth refers to the change in plant grow with the levels of temperature, precipitation, evaporation and growing season at their present values.

Table 4.3.1 Intercellular CO_2 concentration, Photosynthetic rate, Stomatal conductance and Transpiration rate at 10 days after anthesis in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	10 days after anthesis							
	CO_2 concentration (ppm)		Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})		Stomatal conductance (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
CV (%)	3.5	2.5	11.4	11.0	7.9	6.1	26.4	10.4
Interaction (A x B)	NS	NS	NS	NS	S	S	NS	NS

S - Significant   NS - Non-significant

Table 4.3.2 Intercellular CO_2 concentration, Photosynthetic rate, Stomatal conductance and Transpiration rate at boot and anthesis stages of crop growth in different wheat varieties and under varying degree of shades during 2011-12

Treatment	CO_2 concentration (ppm)		Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})		Stomatal conductance (mmol CO_2 m^{-2} s^{-1})		Transpiration rate (mmol H_2Om^{-2} s^{-1})	
	Boot	**Anthesis**	**Boot**	**Anthesis**	**Boot**	**Anthesis**	**Boot**	**Anthesis**
A. Degree of shades								
L0 – Full sun light	324.5	321.2	20.0	20.1	193.7	210.1	1.50	1.42
L1 – Mild shade	343.4	339.8	13.5	12.2	160.5	151.9	0.91	0.86
L2 – Severe shade	358.6	363.6	9.6	10.7	121.9	110.0	0.43	0.49
SEm±	3.0	3.7	0.5	0.3	4.5	4.3	0.07	0.02
CD at 5 %	11.9	14.7	2.1	1.3	17.5	16.9	0.28	0.09
B. Wheat varieties								
UP 2684	345.7	346.0	13.7	13.8	159.5	160.7	0.94	0.95
UP 2526	343.6	341.6	13.9	14.1	157.0	149.4	1.02	0.94
UP 2565	337.6	341.5	13.6	14.4	160.7	153.0	0.91	0.96
UP 2113	341.1	340.8	14.1	13.2	144.4	151.8	0.88	0.83
PDW 233	342.7	337.6	16.5	16.0	171.9	171.7	0.97	0.92
SEm±	3.4	2.9	0.7	0.7	4.6	6.0	0.05	0.04
CD at 5 %	NS	NS	2.0	NS	13.5	NS	NS	NS
CV (%)	3.0	2.6	14.2	15.2	8.7	11.5	16.4	12.8
Interaction (A x B)	NS	NS	NS	NS	NS	NS	NS	NS

S - Significant NS - Non-significant

The effect of enhanced intercellular CO_2 concentration is even greater for plants grown under low light conditions as lower rates of CO_2 reduction at mesophyll site decrease the concentration gradient. The enhance growth is greater than 100 percent for a 100 percent increase in CO_2 concentration under shaded/reduce light, this compares to less than 50 percent for plants grown in normal light conditions (Poorter, 1993). Loreto et al. (1994) envisaged that the rate of photosynthesis declined as leaf sensed which could be attributed in part to increase of mesophyll conductance of CO_2. Among the wheat varieties it did not vary significantly during all the growth stages (i.e. booting and at anthesis in 2011-12) and at 10 DAA during both the years.

4.4 Physiological studies

4.4.1 Leaf photosynthetic rate

The photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) in wheat was significantly influenced by degree of shades at both the stages viz. boot and anthesis in 2011-12 and 10 days after anthesis during both the years i.e. 2010-11 and 2011-12, whereas, the wheat varieties varied significantly in their photosynthetic rates at booting in 2011-12 and 10 days after anthesis during both the growing seasons i.e. 2010-11 and 2011-12 (Table 4.3.1 and 4.3.2 and Appendix XXIV and XXV). However, the interaction between varying degree of shades and wheat varieties was not influenced significantly at either of the growth stages i.e. booting and at anthesis in 2011-12 and at 10 days after anthesis both during 2010-11 and 2011-12.

The significantly higher photosynthetic rate (µmol CO_2 m^{-2} s^{-1}) was recorded under full sunlight both at booting and anthesis stage in 2011-12 and also 10 days after anthesis during both the years i.e. 2010-11 and 2011-12, which reduced significantly with each successive increase in degree of shade.

The wheat varieties differed significantly in their photosynthetic rate at booting in only during 2011-12 and during both years 10 days after anthesis. The maximum and significantly higher photosynthetic rate was recorded in variety PDW 233 at boot stage in 2011-12 then all other varieties. Whereas, the differences in photosynthetic rate of UP 2113, UP 2526, UP 2684 and UP 2565 exhibited significantly were not found significant in 2011-12 (Table 21). However, at 10 days after anthesis, the variety PDW 233 exhibited significantly higher photosynthetic rate than other varieties during both the years, except UP 2684 and UP 2526 only during 2011-12. The minimum and significantly lower photosynthetic rate was recorded UP 2113 at 10 days after anthesis during than others both the years i.e. 2010-11 and 2011-12, except UP 2565 both during 2010-11 and 2011-12 and also UP 2526 and UP 2684 in 2010-11 (Table 4.1.4).

The response of net photosynthetic rate (Pn) to shading differed with leaf positions and amongst the cultivars (Li *et al*., 2010). The data revealed that the photosynthetic rate was higher under full sunlight and it was significantly reduced with each successive increase in shade on booting and at anthesis in 2011-12 and at 10 DAA during both the years. The per cent reduction (52.0 and 46.7) was recorded under severe shade as compared to full sunlight (i.e. control) on booting and at anthesis in 2011-12, respectively. Whereas at 10 DAA, 47.9 and 52.9 per cent reduction was exhibited during both the years, respectively. The Pn decrease could be explained by reduction in stomatal conductance, which reduced diffusion into the leaves (Condon *et al.,* 2002). Mu *et al*. (2010) also reported that small reduction in radiation showed marked reduction in Pn of wheat flag leaf. The wheat varieties differed significantly in their photosynthetic rate on booting in 2011-12 and at 10 DAA during both the years. Among the varieties PDW 233 showed higher Pn at booting in 2011-12 and at 10 DAA during both the years but it was not significantly different than of UP 2684 and UP 2526 at 10 DAA in 2011-12. The reduction in photosynthesis was attributed to high starch accumulation in leaves, suggesting that photosynthetic production (i.e. source activity) was greater than photosynthate utilization (i.e. sink activity) which must have caused the “bottle neck” effect and reduced Pn. The higher source activity relative than sink activity may have initiated the down regulated of photosynthesis at the protein or transcriptional level, thereby lowering the amount and/or activity of Rubisco (Marina *et al.,* 2010).

4.4.2 Stomatal conductance for CO_2

The stomatal conductance (mmol CO_2 m^{-2} s^{-1}) in wheat was significantly influenced by degree of shades both at booting and anthesis stages in 2011-12 and also 10 days after anthesis during both the years i.e. 2010-11 and 2011-12 (Table 4.3.1 and 4.3.2 and Appendix XXIV and XXV). The wheat varieties significantly differed in their stomatal conductance at booting in 2011-12 and 10 days after anthesis 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 10 day after anthesis only during both the years i.e. 2010-11 and 2011-12.

The maximum (193.7 and 210.1 mmol CO_2 m^{-2} s^{-1}) and significantly higher stomatal conductance was recorded under full sunlight both during booting and anthesis stages in 2011-12 and also at 10 days after anthesis (257.4 and 222.7 mmol CO_2 m^{-2} s^{-1}) during both the years i.e. 2010-11 and 2011-12, respectively, which reduced significantly with each successive increase in magnitude of shade during all these stages and seasons.

The wheat varieties significantly differed in their stomatal conductance (mmol m^{-2} s^{-1}) booting in 2011-12 and 10 days after anthesis during both the years i.e. 2010-11 and 2011-12. The variety PDW 233 recorded higher (171.9) stomatal conductance on booting in 2011-12 and 10 days after anthesis (218.6 and 181.9) during both the growing season i.e. 2010-11 and 2011-12, respectively, than other varieties, except UP 2565, UP 2526 and UP 2684 on booting in 2011-12 and also UP 2684 at 10 days after anthesis in 2011-12. The minimum (144.4) and significantly lower stomatal conductance was obtained in variety UP 2113 at booting in 2011-12 and at 10 days after anthesis (153.6 and 138.2) during both the years i.e. 2010-11 and 2011-12, respectively, than others, except UP 2684 at boot stage in 2010-11.

The interaction between varying degree of shade and different wheat varieties was found to be significant (Table 4.3.2a). The variety PDW 233 exhibited significantly higher stomatal conductance not only under full sunlight but also under mild and severe shades than all other combinations of shades and varieties, at 10 days after anthesis during both the years i.e. 2010-11 and 2011-1, except varieties UP 2565 and UP 2526 under mild shade and also UP 2565 under mild and severe shade in 2010-11, while, variety PDW 233 was at par with UP 2684 under full sunlight and mild shade; UP 2526 under mild and severe shades and also UP 2565 under severe shaded treatment in only during 2011-12. The minimum and significantly lower stomatal conductance was obtained in UP 2113 at 10 days after anthesis than other combinations during both the years i.e. 2010-11 and 2011-12 under all light conditions, except UP 2684 under full sunlight in 2010-11; UP 2526 and UP 2565 both under mild and severe shade during both the years and also UP 2684 in 2010-11.

The variety PDW 233 under full sunlight, exhibited maximum and significantly higher stomatal conductance over all other combination of degree of shades and varieties except UP 2684 and UP 2565 under full sunlight in 2011-12. The variety UP 2113 showed minimum (93.3 and 106.6 mmol CO_2 m^{-2} s^{-1}) and significantly lower stomatal conductance 10 days after under severe shaded treatment anthesis during 2010-11 and 2011-12, respectively than all other combination of degree of shades and varieties, except UP 2684 and UP 2526 in 2010-11 and all the other varieties in 2011-12.

Table 4.3.2a Stomatal conductance (mmol CO_2 m^{-2} s^{-1}) of different wheat varieties as influenced by varying degree of shades 10 days after anthesis during both the growing seasons

Wheat varieties (B)	Degree of shades (A)					
	2010-11			2011-12		
	L0	L1	L2	L0	L1	L2
UP 2684	209.0	155.3	109.0	243.0	166.3	109.0
UP 2526	245.0	171.0	114.3	221.3	155.3	114.0
UP 2565	280.0	173.0	119.6	228.0	147.3	118.0
UP 2113	220.4	147.0	93.3	173.7	134.3	106.6
PDW 233	332.6	181.6	141.6	247.3	171.7	126.7
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	8.2	23.9		5.7	16.8	
To compare means of two 'A' at the same or different 'B'	7.9	24.4		6.2	20.2	

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

Stomatal conductance (Gs) is a measure of the maximum rate of passage of carbon dioxide into the leaf. The data on stomatal conductance showed significant influence of varying degree of shades (Table 4.3.1 and 4.3.2). The maximum and significantly higher Gs was observed under full sunlight (i.e. control) which reduced significantly with each successive increase in shade both at booting and at anthesis in 2011-12 and at 10 DAA during both the years. The per cent reduction (37.1 and 47.6) was recorded on booting and at anthesis in 2011-12, respectively, and 55.2 and 48.4 per cent was obtained at 10 DAA during 2010-11 and 2011-12, respectively, as compared to full sunlight (i.e. control). Condon *et al*. (2002) reported that the decrease in Pn could be explained by reduction in stomatal conductance under shading. The wheat varieties differed significantly in their stomatal conductance. Among the varieties, PDW 233 recorded higher stomatal conductance than all other varieties at booting in 2011-12 and at 10 DAA during both the years. Camilo *et al*. (2002) reported that the Stomatal conductance and assimilation rates were higher in control plants, which indicated PAR limitation for photosynthesis in shaded citrus plants.

4.4.3 Transpiration rate

The transpiration rate (mmol H_2O m^{-2} s^{-1}) in wheat was influenced significantly by varying degree of shades both at booting and anthesis stages in 2011-12 and also 10 days after anthesis during both the year's i.e. 2010-11 and 2011-12 (Table 4.3.1 and 4.3.2 and Appendix XXIV and XXV). However, the wheat varieties and interaction between degree of shade and wheat variety were found to be non-significantly at all the above stages of crop growth and seasons.

The transpiration rate (mmol H_2O m^{-2} s^{-1}) was maximum and significantly higher under full sunlight both at booting (1.50) and anthesis (1.42) stages in 2010-11 and also 10 days after anthesis (1.94 and 1.72) both during 2010-11 and 2011-12, respectively, than other light conditions, which reduced significantly with each successive increase in intensity of shade during all these crop growth stages and seasons.

Perusal of data (Table 4.3.1 and 4.3.2) revealed that under full sunlight transpiration rate was higher as compared to mild and severe shade both at booting and anthesis in 2011-12 and at 10 DAA during both the years. The per cent reduction (71.0 and 65.5) was observed under severe shade as compared to full sunlight at booting and anthesis in 2011-12, respectively. Whereas, at 10 DAA per cent reduction (67.0 and 65.7) was observed during both the years, respectively. This slight increase in transpiration rates under shade was due to the lower leaf and air temperatures that brought about a lower leaf-to-air vapor pressure gradient, and hence lower evaporative demand. In control plants, the observed stomatal closure did not largely restrain transpiration rates. In this case, higher temperatures may have led to a high vapor pressure gradient and higher stomatal conductance facilitating and causing the water loss from plants. In fact, similar leaf transpiration has been observed for citrus under different environmental conditions (Sinclair and Allen, 1982), and it is possible that the direct effect of leaf-to-air vapor pressure gradient had a central role in this response. Due to the greater influence of shading on CO_2 assimilation rather than on transpiration. The wheat varieties were not significantly influenced in the transpiration rate on booting and at anthesis in 2011-12 and at 10 DAA during both the years.

4.4.4 Chlorophyll ‘a’ content

The chlorophyll a (mg g^{-1} F.wt) content in leaves of wheat was significantly influenced by varying degree of shades at all the stages i.e. 75, 91 and 111 DAS during both the years i.e. 2010-11 and 2011-12, however, the wheat varieties differed in their chlorophyll a content only at 75 and 91 DAS in 2011-12 and the interaction between these two appeared to be significant at 75 DAS in 2010-11 and at 111 DAS in 2011-12 only (Table 4.4.4 and Appendix XXVI).

The maximum (1.18, 1.19 and 1.04 and 1.14, 1.38 and 1.11 mg g^{-1} F.wt.) and significant higher chlorophyll a content was observed under full sunlight at 75, 91 and 111 DAS, respectively, both during 2010-11 and 2011-12, which reduced significantly with each successive increase in degree of shades with no significant differences between 2/3 and 1/3 of full sunlight availability at 111 DAS during both the years i.e. 2010-11 and 2011-12; at 75 DAS in 2010-11 and also at 91 DAS in 2011-12.

Interaction between magnitude of shades and different wheat varieties was found to be significant at 75 DAS in 2010-11 and at 111 DAS in 2011-12 (Table 4.4.4a). While, the variety UP 2565 retained more chlorophyll a content in leaves under mild and severe shade both at 75 DAS in 2010-11 and at 111 DAS in 2011-12 it was at par with all the other varieties under mild and severe shades, except variety PDW 233 under mild shade both during 2010-11 and 2011-12. The minimum and significantly lower chlorophyll a was recorded in PDW 233 under mild shade, being at par with UP 2113 and UP 2526 both at 75 DAS and at 111 DAS during both the years.

Table 4.4.4 Chlorophyll ‘a’ and Chlorophyll ‘b’ (mg g^{-1} F.wt.) contents in leaves of different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Chlorophyll a (mg g^{-1} F.wt.)						Chlorophyll b (mg g^{-1} F.wt.)					
	75 DAS		91 DAS		111 DAS		75 DAS		91 DAS		111 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	1.18	1.41	1.19	1.38	1.04	1.11	0.63	0.69	0.68	0.65	0.63	0.69
L1 – Mild shade	0.86	1.09	0.81	0.99	0.78	0.85	1.08	1.12	1.19	1.16	1.17	1.23
L2 – Severe shade	0.78	0.96	0.77	0.95	0.75	0.83	1.39	1.43	1.49	1.47	1.49	1.55
SEm±	0.03	0.02	0.02	0.04	0.03	0.01	0.03	0.01	0.03	0.01	0.04	0.02
CD at 5 %	0.10	0.06	0.09	0.16	0.11	0.04	0.12	0.05	0.14	0.04	0.14	0.09
B. Wheat varieties												
UP 2684	1.00	1.24	0.92	1.11	0.81	0.88	1.04	1.09	1.15	1.12	1.14	1.2
UP 2526	0.89	1.12	0.92	1.10	0.86	0.96	1.08	1.12	1.12	1.19	1.13	1.19
UP 2565	0.96	1.19	0.96	1.14	0.83	0.91	1.01	1.08	1.16	1.14	1.09	1.15
UP 2113	0.93	1.16	0.97	1.15	0.89	0.96	1.10	1.15	1.09	1.07	1.11	1.18
PDW 233	0.92	1.15	0.85	1.04	0.88	0.95	0.93	0.97	0.98	0.96	0.99	1.05
SEm±	0.03	0.05	0.03	0.03	0.03	0.08	0.04	0.03	0.04	0.05	0.04	0.04
CD at 5 %	NS	NS	NS	NS	NS	NS	0.12	0.09	0.13	0.14	NS	NS
CV (%)	11.0	11.8	9.5	8.4	12.0	8.4	11.9	8.6	12.6	13.6	13.1	10.8
Interaction (A x B)	S	NS	NS	NS	NS	S	NS	S	NS	NS	NS	NS

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

Table 4.4.4a Chlorophyll 'a' and Chlorophyll 'b' (mg g^{-1} F.wt.) content in leaves different wheat varieties as influenced by varying degree of shades during both the growing season

Wheat varieties (B)	Degree of shades (A)								
	Chlorophyll a						Chlorophyll b		
	75 DAS			111 DAS			75 DAS		
	2010-11			2011-12			2011-12		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	1.25	0.94	0.81	0.99	0.84	0.81	0.62	1.17	1.47
UP 2526	1.08	0.86	0.73	1.17	0.86	0.85	0.74	1.21	1.42
UP 2565	1.13	0.94	0.82	1.00	0.91	0.81	0.60	1.16	1.37
UP 2113	1.12	0.83	0.83	1.16	0.88	0.84	0.69	1.24	1.50
PDW 233	1.32	0.71	0.72	1.27	0.76	0.86	0.69	0.83	1.39

	SEm±	CD at 5%	SEm±	CD at 5%	SEm±	CD at 5%
To compare means of two B at the same 'A'	0.06	0.17	0.05	0.13	0.05	0.16
To compare means of two 'A' at the same or different 'B'	0.05	0.18	0.04	0.12	0.04	0.14

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

The variety PDW 233 under full sunlight which showed its superiority in chlorophyll a content over all other combination of degree of shades and varieties, retained minimum chlorophyll a content under mild shade treatment being at par with all the other varieties under severe shade and UP 2526 and UP 2113 in 2010-11 both 75 and 111 DAS and also UP 2684 in 2011-12 at 111 DAS.

4.4.5 Chlorophyll 'b' content

The chlorophyll b (mg g^{-1} F.wt.) content in leaves of wheat was significantly influenced by varying degree of shades all at 75, 91 and 111 DAS and by wheat varieties at 75 and 91 DAS during both the years i.e. 2010-11 and 2011-12 (Table 4.4.4 and Appendix XXVI). However, the interaction between varying degree of shades and different wheat varieties was not found to be significant at any of the stages during either season, except at 75 DAS in 2011-12.

The maximum (1.39, 1.49 and 1.49 and 1.43, 1.47 and 1.55 mg g^{-1} F.wt.) and significantly higher chlorophyll b (mg g^{-1} F.wt.) content in leaves was observed under higher degree of shade at all the stages i.e. 75, 91 and 111 DAS both during 2010-11 and 2011-12, respectively, which reduced significantly with each successive reduction in shade at all these growth stages and both the seasons.

The wheat varieties differed significantly in their chlorophyll b (mg g^{-1} F.wt.) content at 75 and 91 DAS during both the years i.e. 2010-11 and 2011-12. The variety UP 2113 recorded higher chlorophyll b content both at 75 and 91 DAS than others, except UP 2684, UP 2526 and UP 2565 during both the years i.e. 2010-11 and 2011-12. The minimum and significantly lower chlorophyll b content was observed in PDW 233 both at 75 and 91 DAS during both the years than others varieties, except UP 2113 at 91 DAS both during 2010-11 and 2011-12 and also UP 2684 and UP 2565 at 75 DAS in 2010-11.

The interaction between varying degree of shades and wheat varieties was found to be significant at 75 DAS during 2011-12 (Table 4.4.4a). The wheat varieties did not differ in chlorophyll b contents of their leaves both under full sun light and severe shade, however, under mild shade, variety PDW 233 had significantly lower chlorophyll b content than others with no significant difference among others. While, the variety UP 2113 under full sunlight had highest (1.50 mg g^{-1} F.wt.) chlorophyll b content in leaves, which was significantly higher than all wheat varieties under full sunlight and mild shade but was on par with all the varieties under severe shade condition. Whereas, UP 2565 under no shade proved to be inferior most than all the other combinations of light and varieties, except any variety under full sunlight.

Chlorophyll pigments play vital role in crop productivity, since these pigments are primarily the receptor of radiation for photosynthesis but has no linear relation above the critical level of chlorophyll in plants. The chlorophyll content in leaves has a relationship with leaf age the rate of decrease in chlorophyll contact could denote the duration of functional period of leaf which is closely related to accumulation of photosynthates. Chlorophyll content is also found to be closely related to leaf area, leaf dry weight, net assimilation rate and dry matter accumulation (Wong *et al.*, 1979).

Perusal of data (Table 4.4.4) revealed that chlorophyll a content is significantly higher under control (i.e. full sunlight) condition than under any degree of shade but it was reverse incase of chlorophyll b content at all the different stages during both the years (i.e. 2010-11 and 2011-12). A wheat variety was not significantly differed in chlorophyll a content but differed in chlorophyll b content at 75 and 91 DAS during both years. The contents of chlorophyll a generally declined with increase in shade. The reduction in chlorophyll a content was phenomenal with shades. Similar reduction in chlorophyll content of rice was observed under stress (i.e. light and moisture) by several workers (Deka and Baruah, 2000; Meghanatha Reddy *et al*., 2007). As opined by Garica *et al*. (1987), the reduction in chlorophyll a content under stress (i.e. light) might be due to enhanced activity of chlorophyllase enzyme which was sensitive to light and water deficit and highly deleterious to crop productivity. Surprisingly, the content of chlorophyll b was found to be increasing especially under severe shade (i.e. 2/3 shading). The chlorophyll b is considered to be the primary light harvesting pigment for photosystem II and hence largely responsible for the oxidation of cytochrome and water (Boardman and Anderson, 1964). Besides, it enlarges photosystem II for better harnessing of the entire machinery (Phrosene and Karlander, 1973) and thus plays a dominant role under light and water stress situations in higher production of assimilatory powers (such as ATP, $NADPH_2$ etc.) which are required for survival of plants under stress (Pieters and El Souki, 2005). Thus, the increase in chlorophyll 'b' content under water stress might gear the metabolic systems for efficient functioning for fixing more CO_2 to the extent possible.

4.4.6 Chlorophyll a/b ratio

The chl a/b ratio in wheat was significantly influenced by varying degree of shades, different wheat varieties and the interaction between them at all stages i.e. 75, 91 and 111 DAS during both the years i.e. 2010-11 and 2011-12 (Table 4.4.6 and Appendix XXVII).

The maximum and significantly higher chlorophyll a/b ratio was recorded at 75 DAS (1.89 and 2.12), 91 DAS (1.76 and 2.12) and 111 DAS (1.66 and 1.62) under full sunlight during both the years i.e. 2010-11 and 2011-12, respectively, which reduced significantly with each successive increase in shade during both the growing seasons i.e. 2010-11 and 2011-12.

Table 4.4.6 Chlorophyll a/b ratio and Total chlorophyll content (mg g^{-1} F.wt.) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Chlorophyll a/b ratio						Total chlorophyll content (mg g^{-1} F.wt.)					
	75 DAS		91 DAS		111 DAS		75 DAS		91 DAS		111 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	1.89	2.12	1.76	2.12	1.66	1.62	1.79	2.08	1.88	2.03	1.67	1.80
L1 – Mild shade	0.75	0.98	0.65	0.86	0.63	0.70	1.92	2.21	1.99	2.16	1.93	2.08
L2 – Severe shade	0.56	0.71	0.52	0.65	0.50	0.53	2.18	2.45	2.27	2.42	2.24	2.39
SEm±	0.02	0.02	0.02	0.02	0.03	0.02	0.07	0.03	0.07	0.05	0.07	0.04
CD at 5 %	0.09	0.08	0.07	0.09	0.09	0.08	0.26	0.10	0.27	0.19	0.29	0.02
B. Wheat varieties												
UP 2684	1.18	1.37	0.98	1.20	0.81	0.83	2.05	2.32	2.08	2.23	1.95	2.08
UP 2526	0.93	1.12	0.88	1.07	0.94	0.95	1.98	2.25	2.14	2.29	2.00	2.15
UP 2565	1.15	1.34	1.00	1.22	0.91	0.92	1.97	2.24	2.12	2.28	1.93	2.06
UP 2113	0.99	1.17	1.05	1.28	0.97	0.98	2.03	2.30	2.07	2.23	2.01	2.15
PDW 233	1.10	1.36	0.96	1.27	1.01	1.06	1.79	2.12	1.81	1.99	1.84	2.01
SEm±	0.04	0.03	0.02	0.02	0.02	0.03	0.08	0.06	0.09	0.07	0.09	0.06
CD at 5 %	0.11	0.08	0.06	0.07	0.08	0.08	NS	NS	NS	NS	NS	NS
CV (%)	10.9	6.6	7.0	5.6	9.6	8.3	13.3	7.5	13.1	9.2	14.4	8.8
Interaction (A x B)	S	S	S	S	S	S	NS	S	NS	NS	NS	NS

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

Table 4.4.6a Chlorophyll a/b ratio of different wheat varieties as influenced by varying degree of shades during 2010-11

Wheat varieties (B)	Degree of shades (A)								
	75 DAS			91 DAS			111 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	2.16	0.83	0.57	1.78	0.65	0.51	1.32	0.62	0.49
UP 2526	1.54	0.73	0.53	1.56	0.58	0.52	1.75	0.61	0.48
UP 2565	2.00	0.83	0.61	1.80	0.68	0.52	1.56	0.69	0.50
UP 2113	1.72	0.69	0.57	1.83	0.80	0.52	1.76	0.65	0.51
PDW 233	2.03	0.68	0.54	1.82	0.55	0.52	1.90	0.59	0.54
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	0.06	0.19		0.04	0.11		0.05	0.15	
To compare means of two 'A' at the same or different 'B'	0.06	0.19		0.03	0.12		0.05	0.16	

Table 4.4.6b Chlorophyll a/b ratio of different wheat varieties as influenced by varying degree of shades during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	75 DAS			91 DAS			111 DAS		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	2.41	1.00	0.71	2.16	0.81	0.64	1.31	0.65	0.52
UP 2526	1.77	0.91	0.67	1.86	0.72	0.65	1.70	0.64	0.51
UP 2565	2.25	1.01	0.76	2.17	0.84	0.65	1.53	0.71	0.52
UP 2113	1.94	0.85	0.71	2.19	0.99	0.65	1.71	0.68	0.54
PDW 233	2.25	1.13	0.67	2.19	0.95	0.66	1.84	0.79	0.56
	SEm±	**CD at 5%**		**SEm±**	**CD at 5%**		**SEm±**	**CD at 5%**	
To compare means of two B at the same 'A'	0.05	0.14		0.04	0.11		0.05	0.13	
To compare means of two 'A' at the same or different 'B'	0.05	0.15		0.04	0.14		0.05	0.14	

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

The wheat varieties differed significantly in their chlorophyll a/b ratio at 75, 91 and 111 DAS during both the years i.e. 2010-11 and 2011-12. The maximum and significantly higher chlorophyll a/b was produced by UP 2684 at 75 DAS (1.18 and 1.37) and by UP 2113 both at 91 DAS (1.05 and 1.28) and 111 DAS (0.97 and 0.98) both during 2010-11 and 2011-12, respectively. However, UP 2113 was at par with UP 2565 at 91 DAS and PDW 233 at 111 DAS during both the years and also PDW 233 at 91 DAS in 2011-12. While, UP 2684 at par with UP 2565 and PDW 233 at 75 DAS during both the years. The minimum and significantly lower chlorophyll a/b ratio was observed in UP 2526 both at 75 DAS (0.93 and 1.12) and 91 DAS (0.88 and 1.07) and UP 2684 at 111 DAS (0.81 and 0.83) during both the years i.e. 2010-11 and 2011-12.

The interaction between varying degree of shade and different wheat varieties was also found to be significant in 2010-11 (Table 4.4.6a & b). Though, the variety UP 2684 exhibited higher chlorophyll a/b ratio under full sunlight than of UP 2526 and UP 2113, but under both the shaded (mild and severe) treatments, all the varieties were statistically on par for chlorophyll a/b ratio at 75 DAS in 2010-11. Whereas, at 91 DAS, the chlorophyll a/b ratio was higher in variety UP 2113 both under full sunlight and both mild shade than other varieties, except UP 2684, UP 2565 and PDW 233 under full sunlight. At 111 days stage, variety PDW 233 exhibited higher chlorophyll a/b ratio than UP 2684, UP 2565 and UP 2113 under full sunlight, while varietal differences disappeared under both mild and severe shades.

During, 2011-12, (Table 4.4.6b) the variety up 2684 exhibited higher chl a/b ratio under full sunlight than other varieties and PDW 233 under mild shade than UP 2526 and UP 2113 at 75 DAS; PDW 233 under full sunlight than UP 2526 and UP 2113 under mild shade than UP 2684, UP 2526 and UP 2565 at 91 DAS and PDW 233 than other varieties, except UP 2113 under full sunlight and UP 2113 and UP 2565 under mild shade at 111 DAS. However, varietal differences were not significant at any stage under severely shaded conditions in both the years. The minimum and significantly lowest chlorophyll a/b ratio was observed for UP 2526 under full sunlight and mild shade at 75 and 91DAS and also UP 2684 under full sunlight and mild at 111 DAS in only during 2011-12.

The variety UP 2684 under full sunlight showed its superiority over all the other combinations of degree of shades varieties at 75 DAS during both the years. Whereas, UP 2113 under full sunlight retained maximum chlorophyll a/b ratio at 91 and 111 DAS than all other combination of degree of shades and varieties during both the years. While, UP 2526 under severe shade at 75 and 111 DAS and also UP 2684 under severe shade at 91 DAS showed its inferiority over all other combination of degree of shades and varieties during both the years.

4.4.7 Total chlorophyll content

The total chlorophyll content (mg g^{-1} F.wt.) in wheat was significantly influenced by varying degree of shade at 75, 91 and 111 DAS both during 2010-11 and 2011-12 (Table 4.4.6 and Appendix XXVII). However, the varietal differences and the interaction between shade levels and wheat varieties were not significant at various growth stages during both the growing seasons, except at 75 DAS in 2011-12.

Table 4.4.6c Total chlorophyll content (mg g^{-1} F.wt.) in leaves of different wheat varieties as influenced by varying degree of shades during 2011-12 at 75 days

Degree of shades (A)	Wheat varieties (B)				
	UP 2684	**UP 2526**	**UP 2565**	**UP 2113**	**PDW 233**
L0 – Full sun light	2.09	2.06	1.96	2.04	2.25
L1 – Mild shade	2.35	2.29	2.34	2.31	1.77
L2 – Severe shade	2.52	2.39	2.43	2.56	2.35
				SEm±	**CD at 5%**
To compare means of two B at the same 'A'				0.10	0.29
To compare means of two 'A' at the same or different 'B'				0.09	0.25

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

The maximum (2.18, 2.27 and 2.24 and 2.45, 2.42 and 2.39 mg g^{-1} fresh weight) and significantly higher total chlorophyll content (mg g^{-1} F.wt.) was observed under highest degree of shade at all the stages i.e.75, 91 and 111 DAS both during 2010-11 and 2011-12, respectively, which reduced significantly with each successive reduction in shade, with no significant difference between full sunlight and 2/3 of full sunlight availability at 91 DAS both during 2010-11 and 2011-12 and at 71 and 111 DAS in 2010-11.

During 2011-12, the interaction between the varying degree of shade and wheat variety was found to be significant at 75 DAS during 2011- 12. Wheat varieties did not differ in their total chlorophyll content in leaves both under full sunlight and severe shade. However, mild shade caused significantly lower amount of total chlorophyll in leaves of variety PDW 233 than others.

The variety UP 2113 under severe shade had significantly highest total chlorophyll content in leaves than other combinations, except UP 2565 and UP 2684 under mild and severe shade; UP 2526 and PDW 233 under severe shade and also itself under mild shade conditions. The variety PDW 233 under mild shade at par with UP 2565 under full sunlight, has been significantly lower total chlorophyll content than all other combinations of degree of shades and varieties (Table 4.4.6c).

The data presented in (Table 4.4.6) indicated that chl a/b ratio and total chlorophyll content had inverse relationship i.e. that chl a/b ratio recorded to be higher under full sunlight as compared to mild and severe shade while total chlorophyll content increased with degree of shade during all the different crop growth stages in both the years (i.e. 2010-11 and 2011-12). Total chlorophyll content was higher under severe shade due to higher magnitude of increase in chlorophyll b than relative decrease in chlorophyll a under severe shade. The total chlorophyll content per cent increase under severe shade (20.7 and 19.2 per cent) as compared to full sunlight at 91 DAS during both the years, respectively. Mishra *et al*. (2010) reported the total chlorophyll accumulation under shade might be due to more accountability of chlorophyll b, which indicates shade adaptation ability of grass species (*Cenchrus ciliaris* L). Similar trend was also observed at other stages, the total chlorophyll content continued to increase upto 91 days stage but later on it started decline during both years, however, rate of decline was much faster under full sunlight than shade. Chlorophyll content used to estimate photosynthetic carbon dioxide assimilation as well as it indicates the health of PSII (Krause and Weiss, 1991).

4.5 Light transmission (%) in crop canopy

(a) Top of the canopy

The light transmission per cent at top of the canopy in wheat was significantly influenced by varying degree of shades at 81 DAS during both the years i.e. 2010-11 and 2011-12 (Table 4.5.1 and Appendix XXVIII). The interaction between shading treatments and wheat verities was not significantly influenced at this stage during both the growing seasons i.e. 2010-11 and 2011-12.

The maximum (100%) light transmission was observed under full sunlight at 81 DAS during both the years i.e. 2010-11 and 2011-12, which reduced significantly with each successive increase in intensity of shade and has been as envisaged (approx. 63-64 and approx. 32 % of full sunlight) while formulating treatments, at all the stages during both the growing seasons i.e. 2010-11 and 2011-12.

(b) Middle of the canopy

At middle of the canopy in wheat, the amount of light transmitted was significantly influenced by varying degree of shades at 81 DAS during both the growing seasons i.e. 2010-11 and 2011-12, however, the different wheat varieties and the interaction between varying degree of shades and wheat varieties did not affect it significantly both during 2010-11 and 211-12 (Table 4.5.1 Appendix XXVIII).

Under full sunlight, the maximum and significantly higher (100%) light transmission was observed under no shade treatment at 81 DAS both during 2010-11 (46.8%) and 2011-12 (44.8%), respectively, which reduced significantly with each successive increase in degree of shade during both the years i.e. 2010-11 and 2011-12 and at all the stages.

(c) Bottom of the canopy

A like top and middle the bottom of the canopy in wheat light transmission was significantly influenced by varying magnitude of shades at 81 DAS during both the growing seasons i.e. 2010-11 and 2011-12, while the different wheat varieties and the interaction between varying degree of shades and wheat varieties did not influences it significantly during either of growing stage or the year (Table 4.5.1 and Appendix XXVIII).

Table 4.5.1 Light transmission (% of full sunlight) at top, middle and bottom of the canopy in different wheat varieties and under varying degree of shades at 81 DAS during both the seasons

Treatment	Above canopy (below the cloths in treatment)		Middle of the canopy		Bottom of the canopy	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades						
L0 – Full sun light	100.0 (1200)*	100.0 (1350)*	46.8 (562)*	44.8 (603)*	30.1 (361)*	29.9 (403)*
L1 – Mild shade	63.0 (755)*	63.9 (865)*	38.9 (295)*	34.8 (301)*	20.2 (153)*	18.9 (164)*
L2 – Severe shade	31.7 (380)*	32.1 (433)*	28.0 (105)*	25.8 (112)*	10.5 (40)*	10.9 (47)*
SEm±	2.52	0.5	0.08	0.1	0.72	0.4
CD at 5 %	9.87	2.1	0.31	0.6	0.81	1.1
B. Wheat varieties						
UP 2684	64.6 (775)*	65.1 (879)*	38.2 (289)*	33.9 (293)*	19.9 (76)*	19.7 (85)*
UP 2526	64.8 (778)*	64.9 (876)*	37.8 (286)*	34.7 (300)*	20.0 (76)*	19.3 (83)*
UP 2565	64.9 (780)*	65.2 (880)*	38.2 (289)*	35.3 (306)*	20.0 (76)*	20.1 (87)*
UP 2113	65.2 (783)*	65.6 (885)*	37.7 (285)*	36.4 (315)*	19.7 (75)*	20.4 (88)*
PDW 233	58.7 (705)*	65.8 (888)*	37.7 (285)*	35.4 (307)*	22.0 (83)*	20.2 (87)*
SEm±	3.3	0.4	0.3	0.5	0.9	0.4
CD at 5 %	NS	NS	NS	NS	NS	NS
CV (%)	15.4	4.7	2.2	4.5	13.9	5.8
Interaction (A x B)	NS	NS	NS	NS	NS	NS

*The figures in parentheses are the light intensity (lux cm^{-2} s^{-1}), S - Significant NS - Non-significant DAS - Days after sowing

The maximum and significantly higher amount of light transmitted to bottom of the crop canopy was observed under full sunlight all at 81 DAS both during 2010-11 (30.1%) and 2011-12 (29.9%), respectively, which reduced significantly with each successive increased intensity of shade at this stage both during 2010-11 and 2011-12.

Light availability transmission to wheat crop averaged 63.0 and 63.9 per cent of 100 per cent in full sunlight under mild shade and to 31.7 and 32.1 per cent of full sunlight under severe shade 81 DAS at top of the wheat canopy both during 2010-11 and 2011-12, respectively (Table 4.5.1). This reduction in the available light to crop canopy was in accordance with the frame work of planned treatments and within the range generally observed in many agroforestry systems depending on tree species (Phenology), age, arrangement (spatial and/or temporal) and their density. Newaj *et al* (2003) also reported that the light interception in crop was gradually increased with increasing distance from tree base in mustard and blackgram under trees canopy. The significant reduction in light availability for the underneath crop with each successive increase in degree of shade. But the wheat varieties did not show significant difference in light interception above and below half canopy under varying degree of shades during different dates during both the years.

4.6 Yield and Yield attributes

4.6.1 Yields

4.6.1.1 Grain yield

A like biological yield, the grain yield of wheat was significantly influenced by varying magnitude of shades, different wheat varieties and the interaction between them during both the growing seasons i.e. 2010-11 and 2011-12 (Table 4.6.1 Fig 4.7 and Appendix XXIX).

The wheat grain yield (42.9 and 43.6 q ha^{-1}) was significantly higher under full sunlight, which reduced significantly with each successive increase in shade during both the growing seasons i.e. 2010-11 and 2011-12, respectively.

The grain yield of wheat varieties significantly varied during both the years i.e. 2010-11 and 2011-12. Variety PDW 233 recorded maximum (34.3 and 33.8 q ha^{-1}) grain yield both during 2010-11 and 2011-12, respectively, which was significantly higher than the grain yield of varieties UP 2526, UP 2684 and UP 2113 both during 2010-11 and 2011-12 and also UP 2565 during 2011-12. However, the difference between UP 2565 and UP 2526 during 2010-11 and amongst UP 2565 and UP 2526 and UP 2684 during 2011- 12 were not significant. The variety UP 2113 produced the minimum (25.7 and 26.8 q ha^{-1}) and significantly lowest grain than all other varieties during both the years i.e. 2010-11 and 2011-12, respectively.

The interaction between magnitude of shading and wheat varieties was found to be significant. Though, the variety PDW 233 was found to be higher (48.0, 32.6 and 23.0 q ha^{-1} in 2010-11 and 46.7, 32.8 and 22.0 q ha^{-1} in 2011-12) grain yield or not only under full sunlight but also under both the mild and severe shaded treatments, respectively, than others, but remained at par with variety UP 2565 under all the light availability conditions i.e. full, 2/3 and 1/3 available light both in 2010-11 and 2011-12 and also variety UP 2526 and UP 2684 under severe (2/3) shade during 2011-12 (Table 4.6.1a). The lowest (33.3, 28.2 and 15.5 q ha^{-1} in 2010-11 and 39.1, 23.0 and 18.3 q ha^{-1} in 2011-12) and significantly poorest grain yield was obtained in variety UP 2113 than other varieties under all the light condition i.e. full sunlight, mild and severe shades, respectively than other varieties, except UP 2684 under mild shade both in 2010-11 and 2011-12 and also variety UP 2565 under full sunlight. The variety UP 2113 under severe shade remained significantly poorer in its grain yield than all other combinations of light conditions and varieties, except UP 2526 and UP 2565 under severe shade treatment (Table 4.6.1b).

The variety PDW 233 both under full sunlight and mild shade out yielded other varieties, except UP 2565 under full sunlight. However, UP 2684 under severe shade in 2011-12 proved to be superior over other combinations of light conditions and varieties except, PDW 233. Whereas, UP 2113 under severe shade proved to be inferior most than all other combinations of light and varieties during both the years.

4.6.1.2 Straw yield

The straw yield in wheat was also significantly influenced by varying degree of shades, different wheat varieties and the interaction between them during both the growing seasons i.e. 2010-11 and 2011-12 (Table 4.6.1 Fig 4.8 and Appendix XXIX).

The maximum (61.2 and 58.3 q ha^{-1}) and significantly higher straw yield was recorded under full sunlight which reduced significantly with each successive reduction in light availability during both the years i.e. 2010-11 and 2011-12.

The wheat varieties differed significantly in their straw yield during both the years i.e. 2011-11 and 2011-12. The variety PDW 233 and UP 2565 produced maximum (53.5 q ha^{-1} each) straw yield during 2010-11, which was significantly higher than the straw yield of varieties UP 2684 and UP 2113. However, the variety UP 2113 (51.0 q ha^{-1}) recorded higher straw yield during 2011-12 which was significantly higher than all the other varieties. The variety UP 2113 produced the minimum (42.2 q ha^{-1}) straw during 2010-11, while UP 2684 (45.7 q ha^{-1}) during 2011-12, which were significantly lower than all other varieties in 2010-11 and UP 2113 and UP 2526 during 2011-12.

Interaction between magnitude of shading and wheat varieties was found to be significant (Table 4.6.1a & b). During 2010-11, UP 2565 at par with the variety UP 2526 yielded maximum (65.6 q ha^{-1}) straw and was significantly better than all other varieties under full sunlight. While, variety PDW 233 performed better under both the shaded treatments, being at par with varieties UP 2565 and UP 2526 both under mild and severe shades and also UP 2684 with severe shade. The minimum (59.3, 40.1 and 27.1 q ha^{-1}) and significantly poorer straw yield was recorded from UP 2113 under mild and severe shaded treatment, respectively, than all other varieties, but PDW 233 proved to be the poorest amongst all varieties under full sunlight. During 2011-12, the straw yield of variety UP 2113 was found to be maximum and significantly higher than other varieties under full sunlight and mild shade, except UP 2684, UP 2526 and UP 2565 under mild shade. But PDW 233 proved to be better than UP 2113 and UP 2684 under severe shade. The minimum (53.9 and 49.0 q ha^{-1}) straws yield was obtained in variety PDW 233 on par with UP 2565 and UP 2684 under full sunlight and mild shade, respectively, but straw yield was minimum (30.2 q ha^{-1}) in UP 2113 which was significantly poorer than UP 2526 and PDW 233 with severe shade.

The variety UP 2113 both under full sunlight and mild shade out yielded other varieties under any light condition. However, PDW 233 under severe shade proved to be superior over other combinations of light conditions and varieties. The variety UP 2113 at par with UP 2565 and UP 2526 under severe shaded treatment has been significantly inferior than all other combinations of degree of shades and varieties.

4.6.1.3 Biological yield

The biological yield in wheat was significantly influenced by the varying degree of shades, different wheat varieties and the interaction between them during both the growing seasons, i.e. 2010-11 and 2011-12 (Table 4.6.1 Fig 4.9 and Appendix XXIX).

The maximum (104.1 and 101.9 q ha^{-1}) and significantly higher biological yield was recorded under full sunlight which reduced significantly with each successive increase in shade during both the years i.e. 2010-11 and 2011-12.

The wheat varieties differed significantly in their biological yield during both the years i.e. 2010-11 and 2011-12 and variety PDW 233 produced maximum (87.9 and 80.9 q ha^{-1}) total biological yield during 2010-11 and 2011-12, respectively, which was significantly higher than the biological yield of varieties UP 2684 in both the years and also UP 2113 in 2010-11. While, the minimum (67.9 and 76.2 q ha^{-1}) biological yield was produced by the variety UP 2113 in 2010-11 and UP 2684 in 2011-12, respectively. However in 2011-12, the differences in biological yield of variety UP 2684 and UP 2113 were not found to be significant.

The interaction between degree of shades and wheat varieties was found to be significant. While, the variety UP 2565 at par with variety UP 2526 was found best under full sunlight and significantly superior than all other combination of various degree of shades and varieties but the variety PDW 233 performed better under both the shaded treatments being at par with varieties UP 2526 and UP 2565 both under mild and severe shades during 2010-11 (Table 4.6.1a). The minimum (92.6, 68.4 and 42.6 q ha^{-1}) and significantly poorer biological yield was obtained from UP 2113 in full sunlight as well as under different degree of shades, respectively, than all the other varieties under corresponding light conditions. Whereas in 2011-12, the biological yield of variety UP 2113 at par with variety UP 2526 and UP 2565 was found to be superior than other varieties under full sunlight but variety PDW 233 proved to be the better than UP 2113 under mild shade and UP 2684, UP 2565 and UP 2113 under severe shade.

Table 4.6.1 Biological, Grain and Straw yield (q ha^{-1}) and Harvest index (%) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Biological yield		Grain yield		Straw yield		Harvest Index	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades								
L0 – Full sun light	104.1	101.9	42.9	43.6	61.2	58.3	41.1	42.8
L1 – Mild shade	78.8	79.1	29.9	28.0	48.9	51.1	38.1	38.1
L2 – Severe shade	60.2	54.6	20.6	20.8	39.6	33.8	34.4	35.3
SEm±	0.4	0.3	0.1	0.2	0.1	0.2	0.3	0.2
CD at 5 %	1.7	1.0	0.6	0.7	0.5	0.9	1.0	0.8
B. Wheat varieties								
UP 2684	79.4	76.2	29.4	30.5	49.9	45.7	36.4	40.1
UP 2526	85.8	79.3	32.5	31.2	53.3	48.1	37.2	38.8
UP 2565	87.1	78.8	33.6	31.5	53.5	47.3	37.9	39.1
UP 2113	67.9	77.8	25.7	26.8	42.2	51.0	37.9	34.2
PDW 233	87.9	80.5	34.3	33.8	53.5	46.7	39.7	41.2
SEm±	0.8	0.9	0.4	0.5	0.5	0.6	0.4	0.5
CD at 5 %	2.2	2.7	1.1	1.4	1.6	1.8	1.2	1.4
CV (%)	2.8	3.6	3.5	4.6	3.3	4.0	3.1	3.7
Interaction (A x B)	S	S	S	S	S	S	S	S

S - Significant NS - Non-significant

Table 4.6.1a Biological, Grain and Straw yield (q ha^{-1}) and Harvest index (%) in different wheat varieties as influenced by varying degree of shades during 2010-11

Wheat varieties (B)	Degree of shades (A)											
	Biological yield (q ha^{-1})			Grain yield (q ha^{-1})			Straw yield (q ha^{-1})			Harvest Index (%)		
	L0	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**
UP 2684	101.4	75.6	61.1	40.9	27.3	20.2	60.5	48.3	41.0	40.2	36.1	33.0
UP 2526	110.5	81.6	65.3	45.4	30.3	21.9	65.1	51.3	43.4	41.1	37.2	33.7
UP 2565	112.4	82.9	65.9	47.1	31.2	22.5	65.6	51.8	43.5	41.8	37.8	34.1
UP 2113	92.6	68.4	42.6	33.3	28.2	15.5	59.3	40.1	27.1	36.0	41.3	36.4
PDW 233	103.8	85.4	66.1	48.0	32.6	23.0	55.8	52.8	43.1	46.2	38.2	34.8

	Biological yield SEm±	Biological yield CD at 5%	Grain yield SEm±	Grain yield CD at 5%	Straw yield SEm±	Straw yield CD at 5%	Harvest Index SEm±	Harvest Index CD at 5%
To compare means of two B at the same 'A'	1.3	3.9	0.6	1.8	0.9	2.8	0.7	2.0
To compare means of two 'A' at the same or different 'B'	1.3	3.8	0.6	1.7	0.9	2.5	0.6	2.1

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

Table 4.6.1b Biological, Grain and Straw yield (q ha^{-1}) and Harvest index (%) in different wheat varieties as influenced by varying degree of shades during 2011-12

Wheat varieties (B)	Degree of shades (A)											
	Biological yield (q ha^{-1})			Grain yield (q ha^{-1})			Straw yield (q ha^{-1})			Harvest Index (%)		
	L0	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**
UP 2684	97.2	77.9	53.5	42.0	26.3	23.3	55.2	51.6	30.2	43.2	43.5	33.7
UP 2526	102.0	80.4	55.6	43.7	29.4	20.7	58.3	51.0	35.0	42.9	37.1	36.5
UP 2565	103.0	79.5	53.8	46.3	28.5	19.8	56.7	51.1	34.1	44.9	36.7	35.8
UP 2113	106.5	75.8	51.0	39.1	23.0	18.3	68.0	52.8	32.8	36.5	35.8	30.4
PDW 233	100.7	81.8	59.2	46.7	32.8	22.0	53.9	49.0	37.2	46.4	37.1	40.1

	Biological yield SEm±	Biological yield CD at 5%	Grain yield SEm±	Grain yield CD at 5%	Straw yield SEm±	Straw yield CD at 5%	Harvest Index SEm±	Harvest Index CD at 5%
To compare means of two B at the same 'A'	1.61	4.70	0.8	2.4	1.1	3.2	0.8	2.4
To compare means of two 'A' at the same or different 'B'	1.46	4.31	0.8	2.2	1.0	3.0	0.8	2.3

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

The minimum (97.2 q ha^{-1}) biological yield was obtained in variety UP 2684 on par with UP 2526 and PDW 233 under full sunlight, and in UP 2113 on par with all other varieties both under mild and severe shaded treatments (Table 4.6.1b). While, the variety UP 2113 (106.5 q ha^{-1}) at par with UP 2565 and UP 2526 under full sunlight showed its superiority in biological production over all other combination of degree of shades and varieties, the variety UP 2113 (51.0 q ha^{-1}) at par with UP 2684 and UP 2565 under severe shaded treatment has been significantly inferior than all other combinations of degree of shades and varieties.

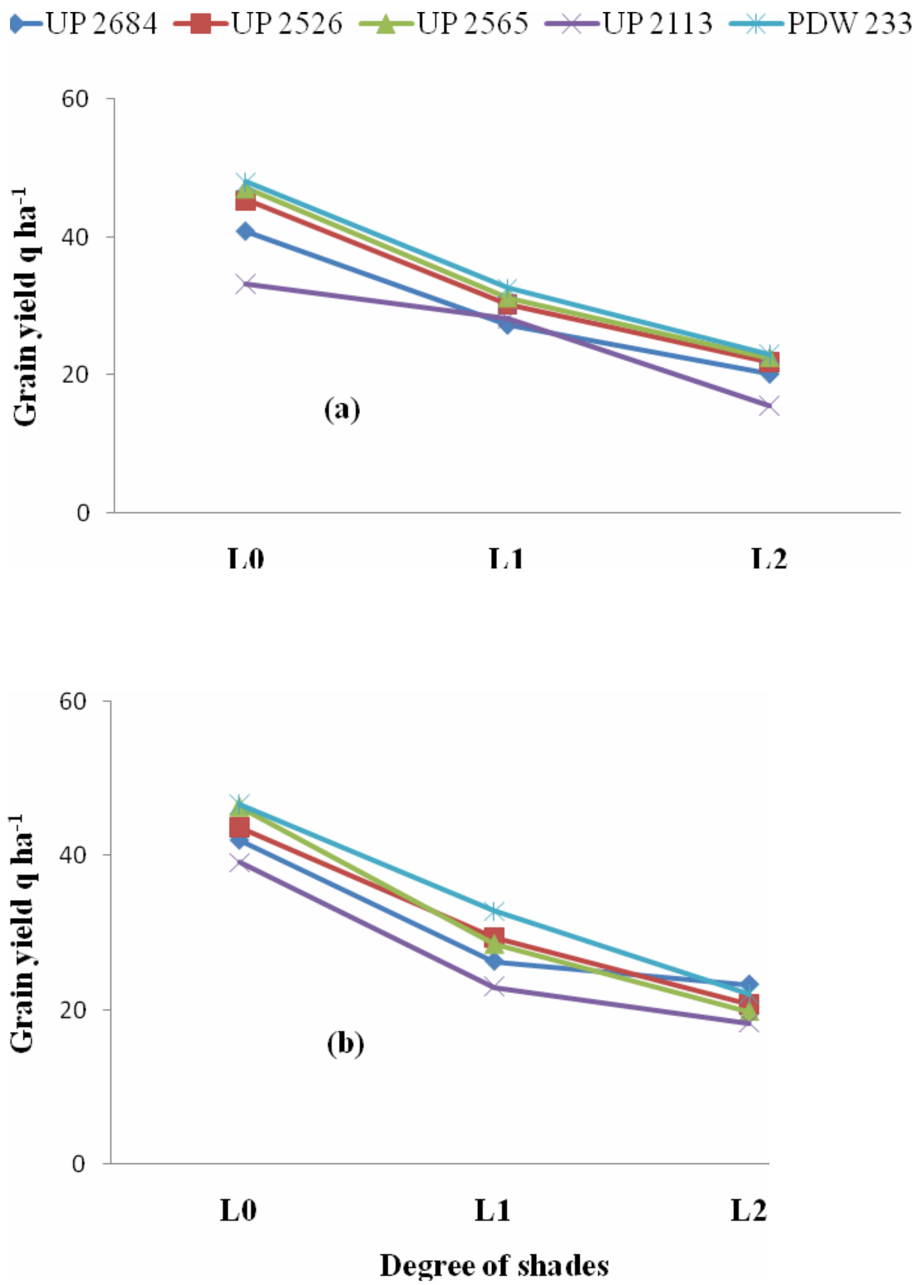
4.6.1.4 Harvest index

The harvest index in wheat was also significantly influenced by varying degree of shades, different wheat varieties and the interaction between them during both the growing seasons i.e. 2010-11 and 2011-12 (Table 4.6.1, Fig 4.10 and Appendix XXIX).

The wheat harvest index (41.1 and 42.8%) was significantly higher under full sunlight, which reduced significantly with each successive increase in shades during both the growing seasons i.e. 2010-11 and 2011-12, respectively.

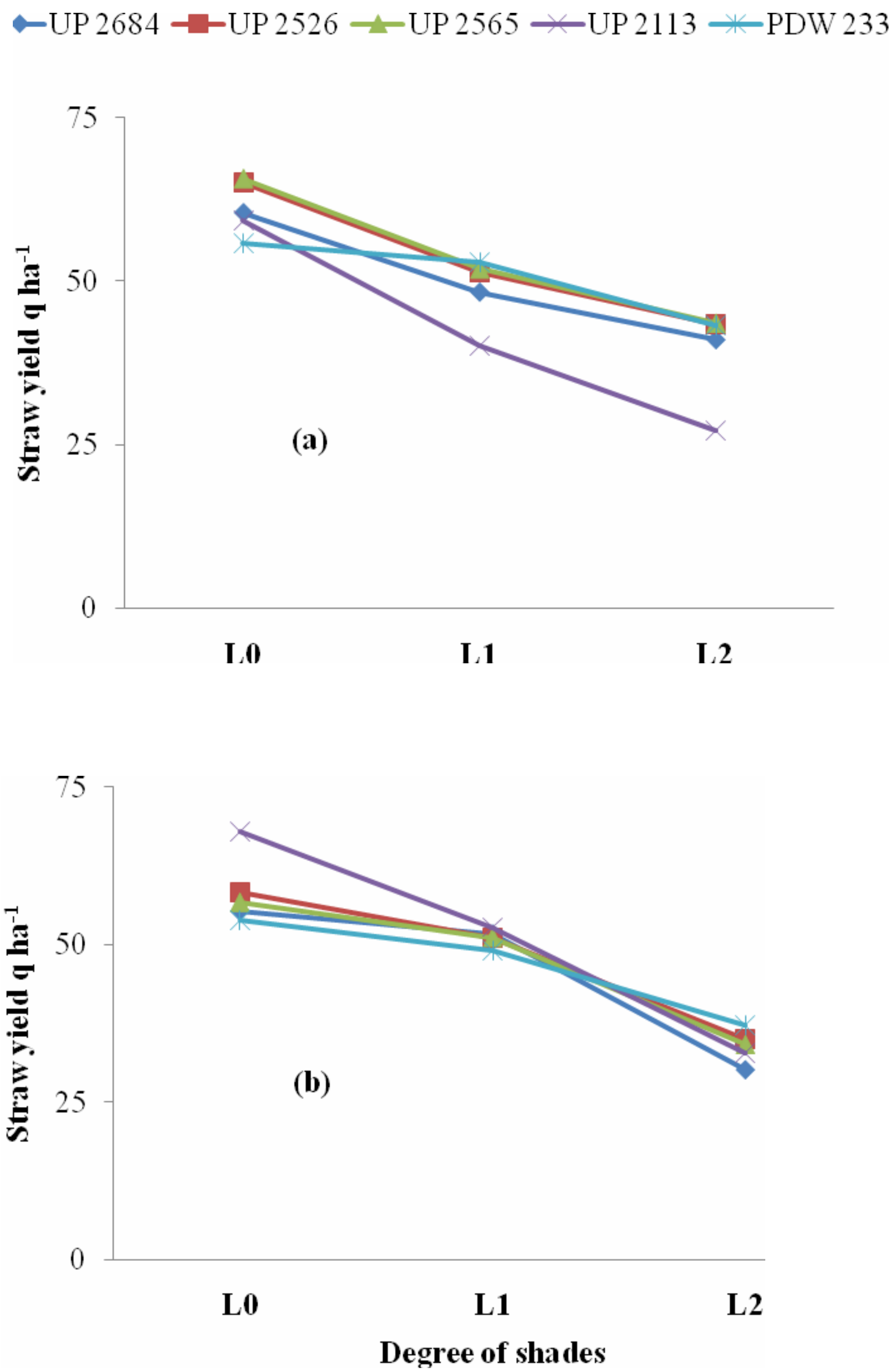
Harvest index in wheat varieties significantly varied during both the years i.e. 2010-11 and 2011-12. Variety PDW 233 exhibited maximum (39.7 and 41.2%) harvest index during 2010-11 and 2011-12, respectively which was significantly higher than the harvest index of varieties UP 2565 and UP 2113 both in 2010-11 and 2011-12 and also UP 2684 during 2010-11. However, the difference amongst the variety PDW 233 and UP 2684 during 2011-12 and amongst UP 2113, UP 2565 and UP 2526 during 2010-11 were not significant. The variety UP 2684 (36.4%) and UP 2113 (34.2 %) recorded the minimum harvest index during 2010-11 and 2011-12, respectively.

The interaction between degree of shades and wheat varieties was found to be significant. While, the variety PDW 233 and UP 2113 were found to have higher harvest index under full sunlight and both (mild and severe) the shaded treatments, respectively. The minimum (36.1 and 33.0) and significantly poorer harvest index was recorded in variety UP 2684 than other varieties under mild and severe shade condition being at par with variety UP 2526, UP 2565 and PDW 233 during 2010-11. However, under full sunlight, variety UP 2113 significantly lower harvest index than other varieties during 2010-11 (Table 4.6.1a).



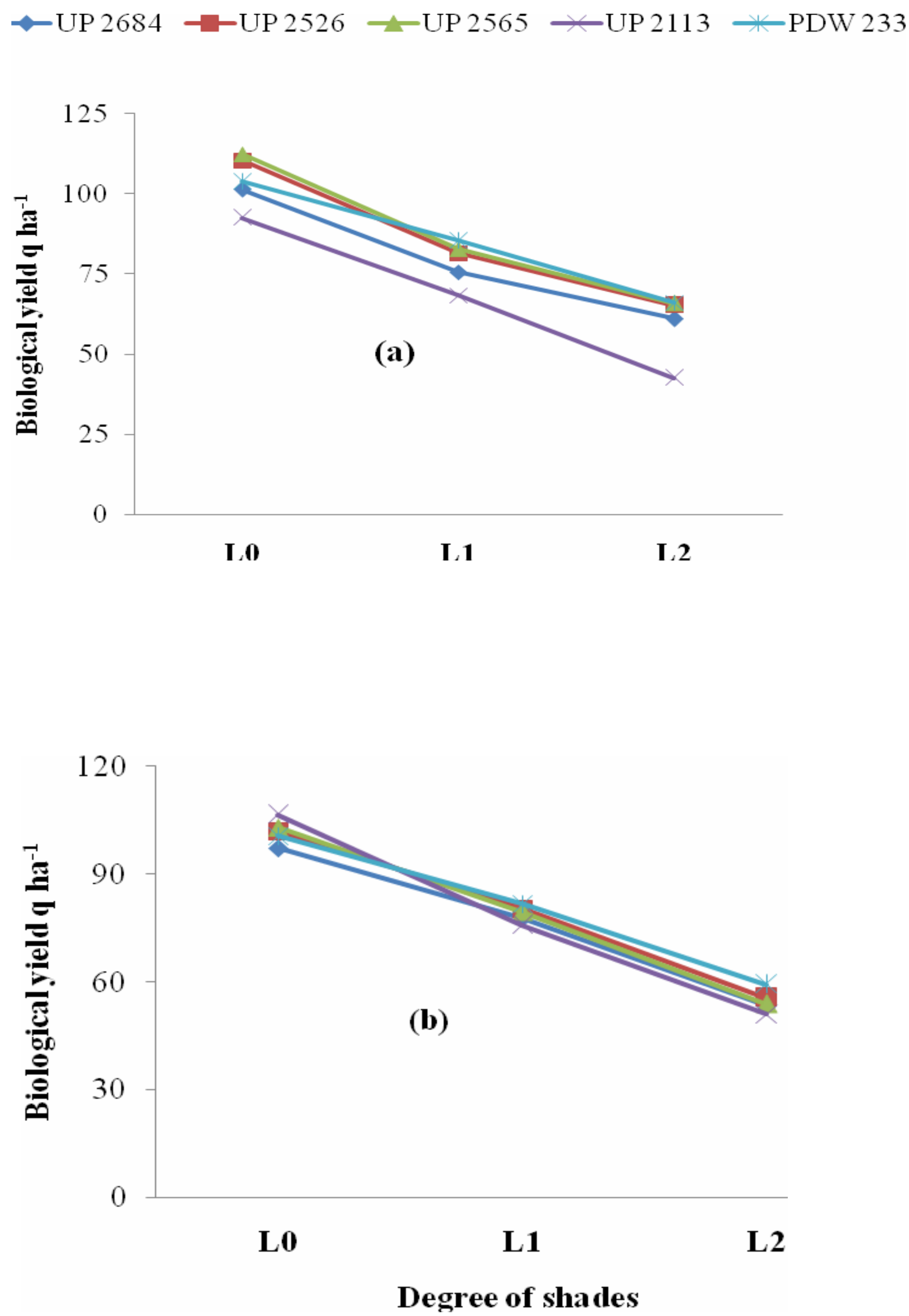
L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.7 Grain yield (q ha^{-1}) of wheat varieties as influenced by varying degree of shades during 2010-11(a) and 2011-12(b)



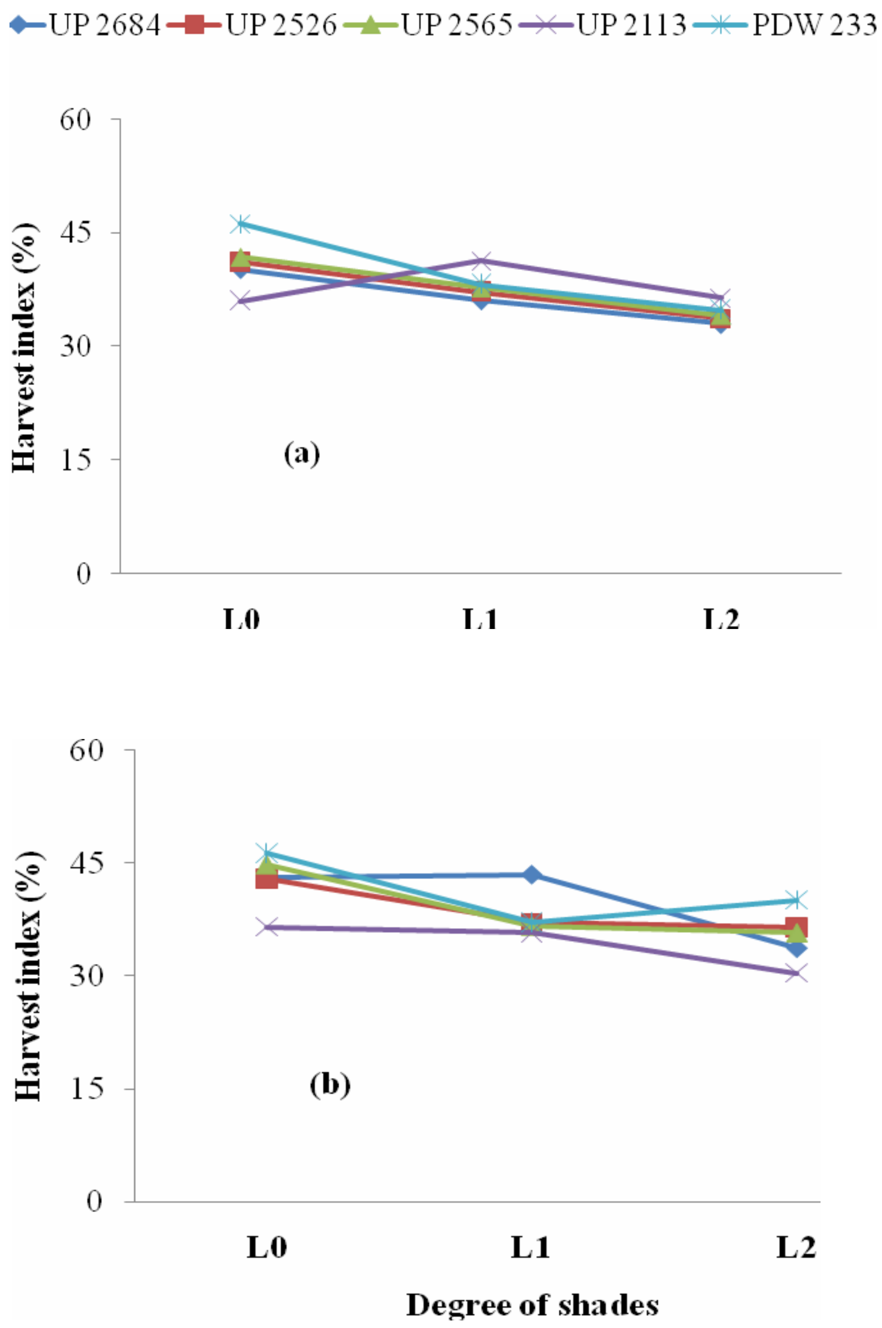
L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.8 Straw yield (q ha^{-1}) and Harvest index (%) of wheat varieties as influenced by varying degree of shades during 2010-11(a) and 2011-12(b)



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.9 Biological yield (q ha^{-1}) of wheat varieties as influenced by varying degree of shades during 2010-11(a) and 2011-12(b)



L0 – Full sunlight L1 – Mild shade L2 – Severe shade

Fig 4.10 Harvest index (%) of wheat varieties as influenced by varying degree of shades during 2010-11(a) and 2011-12(b)

While during 2011.12, the variety PDW 233 was found to be superior over other varieties, except variety UP 2684 under mild shades. The variety UP 2113 remained significantly poorer in its harvest index than other varieties (Table 4.6.1b).

The variety PDW 233 under full sunlight during both the years and severe shade in 2011-12, was recorded higher harvest index than other varieties under any other light conditions, except UP 2565 under mild shade in 2011-12. During 2010-11, UP 2113 performed better under mild and severe shades than all other combinations of light conditions and varieties. Whereas, UP 2684 and UP 2113 under severe shade proved to be inferior most than all the other combinations of light and varieties both during 2010-11 and 2011-12, respectively.

The capacity of plant to produce economic yield depends not only on growth and developmental parameters such as the size of photosynthetic system, its efficiency and duration for which it is active but also the portioning of photosynthate i.e. translocation of photosynthate to the economic sink under the given set of environmental conditions. In cereals, the final build up of ultimate yield (grain yield per unit area) is the additive function of two main yield contributing traits namely, number of spikes per unit area and grain weight per spike. The later itself is a product of the number of grains per spike and the individual grain weight. The development of grain components occurs in a sequential manner and that the negative correlation among the components is due to the competition between two or more components (partitioning) for a common limiting factor (may be photosynthate). There are some growth characters which do not have a direct and substantial effect on yield, but contribute indirectly to a component responsible for yield. These characters such as morphological and physiological processes which remain under the influence of environmental conditions partly that are modified by various cultural practices, to affect the plant growth, development, physiological processes.

The maximum total grain, straw and biological yields were obtained under full sunlight (control) which was significantly higher than under mild and severe shaded treatment during both the years i.e. 2010-11 and 2011-12 (Table 4.6.1). The present investigation revealed that the lowest yield was recorded under 1/3 light available condition in biological yield, grain yield and straw yield which increased significantly with each successive reduction in magnitude of shade both during 2010-11 and 2011-12. The yields (i.e. biological, grain and straw) were observed and the per cent reduction was recorded higher in severe shaded treatment in biological (42.0 and 46.4), grain (52.0 and 52.3) and straw (35.3 and 42.0) both during 2010-11 and 2011-12, respectively over full sunlight condition. Number of studies has shown reduced in grain, straw and/or biological yield under shade (or) trees (Kausik and Singh, 2001; Puri *et al*., 2001; Verma *et al*., 2002 and Kaushik *et al*., 2001). However, the magnitude of reduction may depend and vary with the tree species and density, plantation geometry and the tree management practices. The wider spacement of trees in mixed agroforestry system has been advocated by Li *et al*. (1999) for best yields of intercrops. Variety PDW 233 yielded significantly higher biological and grain yield than other varieties during both the years i.e. 2010-11 and 2011-12, while, straw yield was higher in UP 2565 and PDW 233 in 2010-11 and UP 2113 in 2011-12. The lowest biological and grain yield was obtained in UP 2113 both during 2010-11 and 2011-12, while, straw yield was lower in UP 2113 in 2010-11 and UP 2684 in 2011-12.

All the wheat varieties produced maximum grain under full sunlight (control) which decreased with increased degree of shades during both the years. However, the magnitude of reduction varied and ranged from 33 per cent in UP 2684, UP 2526 and UP 2565 to 15 per cent in UP 2113 in 2010-11 and 41 per cent in UP 2113 to 29 per cent in PDW 233 during 2011-12 under mild shade compared to full sunlight. However, under severe shade, UP 2684 reduced lower magnitude (50.6 and 44.52 per cent) reduction in grain yield than the variety UP 2565 (52.2 and 57.2 per cent) both during 2010-11 and 2011-12, respectively compared to full sunlight. Jain (1998) also reported significant varietal differences in wheat for biological, grain and straw yields. The significant effects of tree spacing on the performance (grain and straw yields) of wheat varieties has also been reported by Puri *et al.* (2001). Mu *et al*. (2010) reported that the wheat grain yield losses were proportionately less than the reduction in solar radiation under shading by trees in agroforestry.

Harvest index and grain to straw ratio were influenced by varying degree of shades. It was higher under full sunlight compared to mild and severe shade. However, variety UP 2113 under mild and severe shade being at par with PDW 2113 under severe shades in 2010-11. Whereas, in 2011-12 UP 2684 recorded highest harvest index under mild shade and also PDW 233 under full sunlight and severe shaded treatment, which indicates the marginal improvement in translocation of photosynthate from leaves and/or stem to grain under shade of varying degree. Almost similar pattern is exhibited by grain to straw ratio. The translocation of photosynthate under shade must have been facilitated due to milder temperature under shade during grain development stage compared to control (full sunlight). Jhale and Jadon (1989) also observed that certain degree of shade is desirable for better growth of crop and it reduce adverse effect of increased temperature (i.e. forced maturity) in wheat particularly during grain development stage.

4.6.2 Yield attributes

4.6.2.1 Potential shoots/m^2

The potential (ear bearing) shoots m^{-2} in wheat were significantly influenced by magnitude of shades, different wheat varieties and the interaction between them both during 2010-11 and 2011-12 (Table 4.6.2 and Appendix XXX).

Significantly higher (505 and 512 m^{-2}) potential shoots were obtained under full sunlight, which reduced with each successive reduction in light availability (i.e. full sunlight through severe shade) during both the growing seasons i.e. 2010-11 and 2011-12.

The wheat varieties significantly differed in their potential shoots m^{-2} during both the years i.e. 2010-11 and 2011-12. The variety PDW 233 produced maximum (420 and 427 m^{-2}) and significantly more number of potential shoots m^{-2} than the others, except UP 2113 in both the seasons. Whereas, UP 2526 had minimum (356 and 362 m^{-2}) and significantly fewer number of potential shoots than other varieties during the both years i.e. 2010-11 and 2011-12, except UP 2565 in 2010-11.

Variety PDW 233 having maximum number of potential shoots m^{-2} under full sunlight and severely shaded conditions showed superiority over UP 2526, UP 2684 and UP 2565 under full sunlight and UP 2565 under severe shade in 2010-11 and over all other varieties under full sunlight and also UP 2684 and UP 2565 under severe shade in 2011-12. While, under the mild shade all varieties had no significant differences in their potential shoots m^{-2} in 2010-11, while in 2011-12, variety UP 2684 had significantly more number of potential shoots than UP 2526 and PDW 233 (Table 4.6.2a).

The variety PDW 233 in both the years under full sunlight showed its superiority in potential shoots m^{-2} over all other combinations of degree of shades and varieties, except UP 2113 under full sunlight in 2010-11. Whereas, UP 2565 under severe shade proved to be significantly poorer than all the other combinations of degree of shades and varieties during both the seasons.

4.6.2.2 Spike length

The spike length (cm) in wheat was influenced significantly both by varying degree of shades and different wheat varieties, however, the interaction between varying degree of shades and wheat varieties did not appear to be significant during both the years i.e. 2010-11 and 2011-12 (Table 4.6.2 and Appendix XXX).

The maximum (11.4 and 10.5 cm) and significantly longer mean spike length was recorded under full sunlight, which reduced significantly with each successive increase in degree of shade during both the years i.e. 2010-11 and 2011-12 with no significant difference between full and 2/3 light availability and 2/3 and 1/3 of full sunlight availability only during 2011-12.

The wheat varieties differed significantly in their mean spike length (cm) during both the years i.e. 2010-11 and 2011-12 and variety PDW 233 (10.8 cm) in 2010-11 and UP 2113 and UP 2526 (1101 cm) in 2011-12 recorded maximum and significantly longer spike length than others, except UP 2565 during 2010-11. The minimum spike length was recorded in UP 2113 being at par with UP 2565, UP 2526 and UP 2684 during 2010-11 and in PDW 233 during 2011-12.

4.6.2.3 Fertile spikelets/spike

The average number of fertile spikelets per spike was significantly influenced by varying degree of shades, wheat varieties and also the interaction between them during both the growing seasons i.e. 2010-2011 and 2011-12 (Table 4.6.2 and Appendix XXX).

An average number of fertile spikelets per spike were decreased significantly with each successive increase in shade being the maximum (16.9 and 16.6) and significantly higher under full sunlight during both the crop seasons i.e. 2010-11 and 2011-12, respectively.

The wheat varieties differed significantly in their fertile spikelets per spike during both the years i.e. 2010-11 and 2011-12. The varieties UP 2565 produced significantly more fertile spikelets per spike during 2010-11 than others, except PDW 233, while UP 2113 recorded higher fertile spikelets spike^{-1} than all the others in 2011-12. The minimum and significantly fewer fertile spikelets per spike were found in variety UP 2113 (13.32) and UP 2526 (14.16) during 2010-11 and 2011-12, respectively, than rest of the varieties.

Table 4.6.2 Potential shoots m^{-2}, Spike length (cm) and Average number of fertile and sterile spikelets spike^{-1} in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Potential shoots m^{-2}		Spike length(cm)		Spikelets spike^{-1}			
					Fertile		Sterile	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades								
L0 - Full sun light	505	512	11.4	10.5	16.88	16.63	1.87	1.35
L1 - Mild shade	373	379	10.1	10.0	14.34	15.13	1.94	1.63
L2 - Severe shade	292	298	8.0	9.6	12.27	14.55	3.61	1.77
SEm±	4.2	3.0	0.1	0.2	0.04	0.04	0.01	0.01
CD at 5 %	16.3	13.0	0.5	0.6	0.15	0.17	0.05	0.02
B. Wheat varieties								
UP 2684	383	390	9.5	10.3	14.02	15.44	2.52	1.71
UP 2526	356	362	9.7	11.1	14.50	14.16	2.43	1.64
UP 2565	374	381	10.3	9.6	15.94	14.99	2.41	1.57
UP 2113	416	423	9.0	11.1	13.32	17.37	2.69	1.99
PDW 233	420	427	10.8	8.0	15.71	15.25	2.31	0.99
SEm±	8.0	5.0	0.3	0.3	0.11	0.11	0.01	0.04
CD at 5 %	23.0	14.0	0.8	0.7	0.31	0.33	0.05	0.12
CV (%)	6.0	3.6	8.6	7.6	2.2	2.2	3.7	7.8
Interaction (A x B)	S	S	NS	NS	S	S	NS	NS

S - Significant NS - Non-significant

Table 4.6.2a Potential shoots m^{-2} and Number of fertile spikelets spike^{-1} in different wheat varieties as influenced by varying degree of shades during both the growing seasons

Wheat varieties (B)	**Degree of shades (A)**											
	Potential shoots m^{-2}						**Fertile spikelets spike^{-1}**					
	2010-11			**2011-12**			**2010-11**			**2011-12**		
	L0	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**	**L0**	**L1**	**L2**
UP 2684	480.3	388.0	281.3	486.8	394.7	288.0	16.21	14.07	11.79	17.33	14.80	14.20
UP 2526	402.0	350.0	314.7	408.7	356.7	321.3	17.03	14.40	12.07	15.70	13.97	13.70
UP 2565	497.0	386.7	239.0	503.3	393.3	245.3	17.67	14.63	12.52	16.47	14.60	13.90
UP 2113	560.0	382.7	305.3	566.7	389.3	312.0	15.42	13.47	11.07	18.63	17.10	16.40
PDW 233	588.0	356.0	317.3	594.7	362.6	324.0	18.09	15.13	13.90	16.00	15.20	14.57

	SEm±	**CD at 5%**	**SEm±**	**CD at 5%**	**SEm±**	**CD at 5%**	**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'	13.6	39.7	8.3	24.1	0.18	0.54	0.19	0.57
To compare means of two 'A' at the same or different 'B'	12.9	38.9	8.1	24.9	0.16	0.50	0.18	0.53

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

The interaction between varying magnitude of shades and wheat varieties was found to be significant (Table 4.6.2a) in both the seasons. While, the variety PDW 233 at par with variety UP 2565 was found to be superior in fertile spikelets spike^{-1} under full sunlight and mild shade than other varieties with corresponding light availability conditions and than all the other varieties under severe shade during 2010-11. The minimum (15.42, 13.47 and 11.07) and significantly fewer fertile spikelets/spike were recorded in UP 2113 with full sunlight, mild and severe shade conditions, respectively, than all the other varieties with corresponding light availability. Whereas, in 2011-12, the maximum (18.6, 17.1 and 16.4) and significantly more number of fertile spikelets per spike were observed in variety UP 2113 all under full sunlight, mild and severe shaded treatments, respectively, than rest of the varieties with corresponding light availability conditions. The minimum (15.70, 13.97 and 13.70) and significantly fewer number of fertile spikelets per spike were recorded in variety UP 2526 under full sunlight, mild and severe shade conditions, respectively, than other varieties, except PDW 233 with full sunlight and UP 2684 and UP 2565 with severe shade. The variety PDW 233 and UP 2113 showed superiority in fertile spikelets production per spike over all other combination of shades and varieties during 2010-11 and 2011-12, respectively. Whereas, UP 2113 and UP 2526 showed significantly inferiority over other combinations during 2010-11 and 2011-12, respectively.

4.6.2.4 Sterile spikelets/spike

A like spike length, the average number of sterile spikelets per spike of wheat were also significantly influenced by varying degree of shades and by different wheat varieties both during 2010-11- and 2011-12 (Table 4.6.2 and Appendix XXX). However, the interaction between degree of shades and wheat varieties was not found to be significant either season i.e. 2010-11 or 2011-12.

In general, the sterility of spikelets was more in first year (2010-11) compared to second (2011-12) year, due to lodging particularly in varieties like UP 2113 and UP 2684. The average number of sterile spikelets per spike increased significantly with each successive increase in shade both during 2010-11 and 2011-12. The maximum (3.61 and 1.77 spike^{-1}) and significantly higher number of sterile spikelets were obtained under severely shaded treatment both during 2010-11 and 2011-12.

The average number of sterile spikelets per spike in wheat varieties varied significantly both during 2010-11 and 2011-12. Variety UP 2113 recorded maximum (2.69 and 1.99) and significantly more number of sterile spikelets per spike than other varieties during both the years i.e. 2010-11 and 2011-12, respectively. The minimum (2.31 and 0.99) and significantly lower sterile spikelets per spike were observed in PDW 233 than others both during 2010-11 and 2011-12, respectively.

4.6.2.5 Grains/spikes

The number of grains spike^{-1} in wheat was significantly influenced by varying degree of shades, different wheat varieties and the interaction between them during both the growing season i.e. 2010-11 and 2011-12 (Table 4.6.3 Appendix XXXI).

The maximum (42.7 and 42.7) and significantly more grains spike^{-1} were produced under full sunlight, which reduced significantly with each successive reduction light intensity during both the years i.e. 2010-11 and 2011-12, respectively.

Wheat varieties differed significantly in their grains spike^{-1} both during 2010-11 and 2011-12. The variety UP 2565 (37.2 and 39.8) produced more grains per spike both during 2010-11 and 2011-12, respectively, than others, except PDW 233 in 2010-11. The minimum and significantly fewer (33.5 and 35.3) grains per spike were observed in UP 2113 and UP 2684 during 2010-11 and 2011-12, respectively. However, the variety UP 2684 was at par with PDW 233 during 2011-12.

The interaction between varying degree of shade and wheat varieties was found to be significant during both the seasons. While, the variety PDW 233 had maximum grains spike^{-1} but was at par with all other varieties under mild and severe shaded treatments, except UP 2113 under severe shade during 2010-11. The minimum (40.9 and 24.7) and significantly fewer number of grain spike^{-1} were observed in UP 2113 both under full sunlight and severe shade during 2010-11 compared to PDW 233 with full sunlight and all the other varieties under severe shade but none under mild shade condition (Table 4.6.3a).

However, 2011-12, the significantly more (49.0, 40.0 and 34.8) grains per spike were recorded in UP 2565 under full sunlight; UP 2113 under mild shade and PDW 233 under severe shade, respectively than other varieties under corresponding light conditions, except UP 2113 and UP 2565 under severe shade. The minimum (36.7, 34.4 and 29.2) and significantly fewer grains per spike were recorded in variety PDW 233 under full sunlight and UP 2684 both under mild and severe shade, respectively, but being at par with UP 2526 and PDW 233 under 2/3 of full sunlight availability (Table 4.6.3b). The variety UP 2565 under full sunlight showed its superiority in grains spike^{-1} over all other combination of degree of shades and varieties. Whereas, UP 2684 under severe shade proved to be inferior most than all the other combinations of light conditions and varieties during 2011-12.

4.6.2.6 Grain weight/ spike

The grain weight spike^{-1} (g) in wheat was significantly influenced by varying degree of shades and wheat varieties both during 2010-11 and 2011-12 (Table 4.6.3 and Appendix XXXI). However, the interaction between shade treatments and wheat varieties was significantly influenced only during 2011-12.

During both the years i.e. 2010-11 and 2011-12 the grain weight per spike was significantly reduced with each successive increase in magnitude of shade. The maximum (1.74 and 1.57 g) and significantly higher grain weight spike^{-1} was obtained under full sunlight both during 2010-11 and 2011-12, respectively.

The wheat varieties differed significantly in their grain weight/spike during both the years i.e. 2010-11 and 2011-12 and variety PDW 233 recorded maximum (1.62 and 1.43 g) of total grain weight per spike both during 2010-11 and 2011-12, respectively, than other varieties, except UP 2565 in 2011-12. The minimum and significantly lower grain weight per spike was produced by UP 2113 during both the years than other varieties, except UP 2684 and UP 2526 in 2010-11 and also UP 2684 during 2011-12.

The interaction between varying degree of shades and wheat varieties was found to be significant during 2011-12. Though, the variety UP 2565 under full sunlight; UP 2526 and PDW 233 under mild shade and PDW 233 under severe shade had higher grain weight per spike but were UP 2565 and UP 2526 both under mild and severely shaded conditions. The minimum (1.41, 1.12 and 0.98 g) and significantly lower grain weight per spike was recorded from variety UP 2113 than other varieties, except UP 2684 under all the light condition i.e. full sunlight, mild and severe shade, respectively (Table 4.6.3b).

4.6.2.7 1000 grain weight

The 1000 grain weight (g) in wheat was significantly influenced by varying degree of shades, different wheat varieties and the interaction between them during both the years i.e. 2010-11 and 2011-12 (Table 4.6.3 and Appendix XXXI).

The maximum (43.37 and 43.72 g) and significantly higher 1000 grain weight was recorded under full sunlight, which reduced significantly with each successive increase in degree of shade both during 2010-11 and 2011-12.

The 1000 grain weight of wheat varieties significantly varied during both the years i.e. 2010-11 and 2011-12. Variety PDW 233 recorded maximum (40.41 and 41.44 g) and significantly higher 1000 grain weight both during 2010-11 and 2011-12, respectively, than all the other varieties. Whereas, variety UP 2113 recorded minimum (35.60 and 35.95 g) and significantly lower 1000 grain weight during both the years i.e. 2010-11 and 2011-12 than other varieties, except UP 2684 during 2010-11.

The interaction between varying degree of shades and different wheat varieties was found to be significant in both the years (Table 4.6.3a& b). While, the variety PDW 233 at par with variety UP 2565 and UP 2526 was found to be best and significantly superior under full sunlight as well as with mild and severe shade in 2010-11. The minimum (38.93, 36.73 and 31.14 g) and significantly smaller 1000 grain weight was recorded in UP 2113 under all full sunlight, mild and severe shaded conditions, respectively, than all other varieties, except all other than PDW 233 under mild shade and UP 2684 under severe shade in 2010-11. Whereas, in 2011-12, variety PDW 233 at par with variety UP 2565 all under full sunlight, mild and severe shade and also UP 2526 under sever shaded treatment, was found to be superior to other varieties. The minimum (39.27, 37.09 and 31.49 g) and significantly lower 1000 grain weight was recorded from UP 2113 under all light treatments including full sun light during 2011-12. While, the variety PDW 233 under full sunlight showed its superiority in 1000 grain weight production over all other combinations of degree of shade and varieties. The variety UP 2113 under severely shaded treatment has been significantly inferior then all other combinations of degree of shades and varieties.

Table 4.6.3 Number of grains spike^{-1}, Grain weight spike^{-1} (g) and 1000 grain weight (g) in different wheat varieties and under varying degree of shades during both the growing seasons

Treatment	Grains spike^{-1}		Grain weight spike^{-1} (g)		1000 grain weight (g)	
	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
A. Degree of shades						
L0 – Full sun light	42.7	42.7	1.74	1.57	43.37	43.72
L1 – Mild shade	35.7	36.5	1.37	1.28	37.41	39.16
L2 – Severe shade	30.8	32.7	1.07	1.14	33.54	34.29
SEm±	0.4	0.2	0.07	0.02	0.15	0.10
CD at 5 %	1.4	0.8	0.27	0.08	0.59	0.41
B. Wheat varieties						
UP 2684	35.8	35.3	1.28	1.19	36.74	37.76
UP 2526	36.8	36.9	1.39	1.35	38.57	39.56
UP 2565	37.2	39.8	1.44	1.51	39.23	40.56
UP 2113	33.5	38.5	1.25	1.17	35.60	35.95
PDW 233	38.7	35.9	1.62	1.42	40.41	41.44
SEm±	0.6	0.4	0.04	0.03	0.40	0.03
CD at 5 %	1.7	1.2	0.13	0.08	1.17	0.08
CV (%)	5.0	3.4	10.2	6.5	3.2	2.2
Interaction (A x B)	S	S	NS	S	S	S

S - Significant NS - Non-significant

Table 4.6.2a Number of grains spike^{-1} and 1000 grain weight (g) in different wheat varieties as influenced by varying degree of shades during 2010-11

Wheat varieties (B)	Degree of shades (A)					
	Grains spike^{-1}			1000 grain weight (g)		
	L0	L1	L2	L0	L1	L2
UP 2684	40.2	35.3	31.8	42.80	35.88	31.53
UP 2526	42.5	35.4	32.4	44.21	37.37	34.14
UP 2565	43.1	36.1	32.5	45.02	37.83	34.83
UP 2113	40.9	35.0	24.7	38.93	36.73	31.14
PDW 233	46.9	36.8	32.6	45.90	39.26	36.07
		SEm±	**CD at 5%**		**SEm±**	**CD at 5%**
To compare means of two B at the same 'A'		1.05	3.07		0.69	2.02
To compare means of two 'A' at the same or different 'B'		1.01	3.09		0.63	1.89

Table 4.6.2b Number of grains spike^{-1}, Grain weight spike^{-1} (g) and 1000 grain weight (g) in different wheat varieties as influenced by varying degree of shades during 2011-12

Wheat varieties (B)	Degree of shades (A)								
	Grains spike^{-1}			Grain weight spike^{-1} (g)			1000 grain weight (g)		
	L0	L1	L2	L0	L1	L2	L0	L1	L2
UP 2684	42.2	34.4	29.2	1.43	1.14	1.01	43.16	38.23	31.88
UP 2526	43.0	35.8	32.0	1.51	1.39	1.15	44.55	38.72	35.49
UP 2565	49.0	36.6	33.9	1.89	1.38	1.26	45.35	40.16	36.17
UP 2113	42.6	39.7	33.3	1.41	1.12	0.98	39.27	37.09	31.49
PDW 233	36.7	36.1	34.8	1.59	1.39	1.27	46.25	41.61	36.44
		SEm±	**CD at5%**	**SEm±**		**CD at 5%**	**SEm±**		**CD at 5%**
To compare means of two B at the same 'A'		0.72	2.11	0.05		0.14	0.49		1.45
To compare means of two 'A' at the same or different 'B'		0.68	2.05	0.05		0.15	0.45		1.35

L0 –Full sun light **L1** – Mild shade **L2** – Severe shade

Grain yield is the function of number of plants per unit area and yield/plant, whereas, the number of plants in wheat means potential/ear bearing shoots and the yield/plant than is the function of gains spike^{-1} and individual grain weight.

The number of potential shoots m^{-2} was influenced significantly by varying degree of shades, wheat varieties and interaction between them (Table 4.6.2). However, the maximum values were obtained under full sunlight compared to mild and severe shade. Under higher degree of shade potential shoots m^{-2} reduced significantly compared to mild (21.7 and 21.4 per cent) and full sunlight (41.8 and 42.0 per cent) both during 2010-11 and 2011-12, respectively. The higher number of potential shoots m^{-2} observed in PDW 233, at par with UP 2113, has been the result of lowest shoot mortality per cent compared to other varieties both during 2010-11 and 2011-12. The highest shoot mortality per cent was observed from UP 2565 during both the years. Thome and Wood (1987) postulated that because of their position in the canopy, tillers are often shaded by taller shoots, and tiller might, therefore, be expected to be more affected by shading than the main shoot and higher rate of mortality be observed.

The fertile spikelets spike^{-1} were found to be maximum under control (full sunlight) which decreased with increased in varying degree of shade during both the years. However, reverse was true for sterile spikelets spike^{-1}, probably due to limiting photosynthate supply for grain development under shades. Varietal differences both for fertile and sterile spikelets spike^{-1} were observed to be significant to the grain yields of these varieties. Nazir *et al.* (1993) also noticed that increased duration of shading decreased number of fertile tillers in wheat crop.

The more number of grains spike^{-1} were observed under full sunlight (i.e. control), which reduced significantly with increase in degree of shade. The highest yielding variety PDW 233 and UP 2565 also had maximum number of grains spike^{-1}. It appears that shade of low intensity (2/3 of full sunlight) has helped the spike fertility and grains spike^{-1} over control. However, increased shade by more number of trees and/or increased intensity of shade had adversely affected the number of grains spike^{-1}. Variety PDW 233 had significantly higher number of grains spike^{-1} than other varieties under full sunlight but reduction was not significant under mild and severe shade in 2010-11. Whereas, in 2011-12, UP 2565 observed higher grains/spike under full sunlight and severe shade and was at par with UP 2113 and PDW 233 in only under severe shades. It is visualized that higher potential shoots and more number of grains spike^{-1} have basically been responsible for higher grain yield in PDW 233 and UP 2565 and thus exhibited better tolerance to shade. Puri *et al*. (2001) also found the number of effective tillers and seeds per spike in wheat to be influenced significantly in agri-silviculture system with significant varietal differences.

The grain size (1000 grain weight) has been maximum in control (i.e. full sunlight) which reduced under shades with significant differences between 2/3 to 1/3 of full sunlight. The per cent reduction under severe shade was 22.7 and 21.6 per cent compared to full sunlight both during 2010-11 and 2011-12, respectively. The heavier grains were obtained under full sunlight in all the varieties with reduction with varying degree under shades, particularly under severe shade (1/3 of full sunlight). The significant reduction in test weight and pods/plant of lentil and mungbean under varying degree of shades casted by different tree spacings in *Dalbergia sissoo* compared to open have also been reported by Nandal and Singh (2001).

In grain yield spike^{-1}, which is the function of grains spike^{-1} and individual grain weight, has been maximum and significantly more under lower degree of shade compared to higher degree of shade both during 2010-11 and 2011-12. The grain weight spike^{-1} under severe shade decreased by 21.9 and 10.9 per cent compared to mild shade both during 2010-11 and 2011-12, respectively. Although, highest grain weight spike^{-1} was found to be in PDW 233 which made it a higher grain yielder in combination with more number of potential shoots/unit area. Jain (1998) also observed reported that grain weight spike^{-1} vary significantly among wheat varieties under poplar plantation and was a major yield attribute.

4.7 Character Association

The correlation coefficients between yields and its different attributes both during 2010-11 and 2011-12 are presented in Table 4.7.1 and 4.7.2.

In the present study, grain yield exhibited a highly significant positive correlation with fertile spikelets spike^{-1} (0.9545) in 2010-11, but exhibited a significant negative correlation (-0.7398) in 2011-12. A significant positive correlation also occurred between grain yield and 1000 grain weight both during 2010-11(0.8923) and 2011-12 (0.7273).

The significant positive correlation occurred between grain yield and grain weight spike^{-1} (0.6157 and 0.7089) both during 2010-11 and 2011-12, respectively. A significant positive correlation also occurred between grain yield and spike length (0.5440) in 2010-11, but it was an exhibited a significant negative correlation (-0.7123) in 2011-12. Potential shoots m^{-2} (0.5310) exhibited significant positive correlation in 2010-11, but it was not significant in 2011-12.

Fertile spikelets spike^{-1} had a significant positive (0.6173 and 0.5506) correlation with potential shoots m^{-2} both during 2010-11 and 2011-12. The thousand grain weight exhibited a significant positive correlation (0.8984) with fertile spikelets spike^{-1} in 2010-11 and it was significant negative correlation (-0.6231) in 2011-12. Thousand grain weight, 50 per cent heading and number of grain spike^{-1} exhibited a significant positive correlation with potential shoots (0.7306, 0.5955 and 0.6251, respectively) in only during 2010-11.

4.8 Path Analysis

Path analysis offers the measure of direct and indirect influence of one independent variable upon the other dependent one. The value assigned to a path is termed as path coefficient and is defined as the ratio of standard deviation in the independent variable and the present study carried out by taking grain yield as the dependent variable and rest of the characters (yield attributes) as independent variable. The results are presented in Table 4.8.1 and 4.8.2.

a) Direct effects

Table 4.8.1 revealed that fertile spikelets spike^{-1} (0.9075) exerted high order of positive direct effect towards grain yield followed by sterile spikelet spike^{-1} (0.2219), grain weight spike^{-1} (0.1337) and number of grains spike^{-1} (0.0324). However, potential shoots m^{-2} (-0.0142), 50 per cent heading (-0.0360), spike length (-0.0662), 1000 grain weight (-0.1437) and 80 per cent maturity (-0.5121) exerted direct negative effect towards grain yields in only during 2010-11.

Whereas, in 2011-12 the table 4.8.2 revealed that 1000 grain weight (1.0907) exerted high order of positive direct effect towards grain yield followed by sterile spikelets spike^{-1} (0.6651), grain weight spike^{-1} (0.5958), fertile spikelets spike^{-1} (0.4020) and days to 50 per cent heading (0.1696). However, potential shoots m^{-2} (-0.3440), spike length (-0.5292), number of grains spike^{-1} (-0.8685) and days to 80 per cent maturity (-1.0043) exerted direct negative effect towards grain yield in 2011-12.

b) Indirect effects

Potential shoots m^{-2} showed positive contribution towards grain yield via fertile spikelets spike^{-1} (0.5602), sterile spikelets spike^{-1} (0.0693), grain weight spike^{-1} (0.0516) and number of grains spike^{-1} (0.0203). However, it exerted negative indirect effect via 1000 grain weight (-0.1050), spike length (-0.0267), days to 50 per cent heading (-0.0214) and days to 80 per cent maturity (-0.0029) on grain yield in only during 2010-11. Whereas, in 2011-12, potential shoots m^{-2} showed positive contribution towards grain yield via fertile spikelets spike^{-1} (0.2214), number of grains spike^{-1} (0.0886), days to 50 per cent heading (0.0739) and sterile spikelets spike^{-1} (0.0654). However, it exerted negative indirect effect via days to 80 per cent maturity (-0.2985), grains weight spike^{-1} (-0.1173), 1000 grain weight (-0.0390) and spike length (-0.0325) on grain yield. During 2010-11, spike length contributed its positive indirect effect towards grain yield via fertile spikelets spike^{-1} (0.5311), sterile spikelets spike^{-1} (0.0718), grain weight spike^{-1} (0.0705), days to 80 per cent maturity (0.0172) and number of grains spike^{-1} (0.0123). However, negative indirect effect of spike length on grain yield was contributed via 1000 grain weight (-0.0736), days to 50 per cent heading (-0.0133) and potential shoots m^{-2} (-0.0058). Whereas, in 2011-12 spike length contributed its positive indirect effect towards grain yield via days to 80 per cent maturity (0.5567, sterile spikelets spike^{-1} (0.5399) and fertile spikelets spike^{-1} (0.1685). However, negative indirect effect of spike length on grain yield was contributed via 1000 grain weight (-0.8756), grain weight spike^{-1} (-0.2849), number of grains spike^{-1} (-0.2635) and potential shoots m^{-2} (-0.0211).

Table 4.7.1 Correlation coefficients between different yield attributes in wheat during 2010-11

Characters	Potential shoots m^{-2}	Spike length (cm)	Fertile spikelets $spike^{-1}$	Sterile spikelets $spike^{-1}$	Number of grains $spike^{-1}$	Grain weight $spike^{-1}$ (g)	1000 grain weight (g)	50% Heading	80 % Maturity	Grain yield q ha^{-1}
Potential shoots m^{-2}	1.0000	0.4042	0.6173*	0.3121	0.6251*	0.3863	0.7306**	0.5955*	0.0057	0.5310*
Spike length (cm)		1.0000	0.5851*	0.3236	0.3807	0.5274*	0.5122	0.3692	-0.0336	0.5440*
Fertile spikelets $spike^{-1}$			1.0000	0.3288	0.7711**	0.6667**	0.8984**	0.4538	-0.1033	0.9545**
Sterile spikelets $spike^{-1}$				1.0000	0.6464**	0.5507*	0.2304	0.4801	0.8210**	0.1182
Number of grains $spike^{-1}$					1.0000	0.7115**	0.7110**	0.5273*	0.3559	0.6333*
Grain weight $spike^{-1}$ (g)						1.0000	0.5104	0.0723	0.2969	0.6157*
1000 grain weight (g)							1.0000	0.4672	-0.2722	0.8923**
50% Heading								1.0000	0.3066	0.2560
80 % Maturity									1.0000	-0.3421
Grain yield q ha^{-1}										1.0000

Table 4.7.2 Correlation coefficients between different yield attributes in wheat during 2011-12

Characters	Potential shoots m^{-2}	Spike length (cm)	Fertile spikelets $spike^{-1}$	Sterile spikelets $spike^{-1}$	Number of grains $spike^{-1}$	Grain weight $spike^{-1}$ (g)	1000 grain weight (g)	50% Heading	80 % Maturity	Grain yield q ha^{-1}
Potential shoots m^{-2}	1.0000	0.0614	0.5506*	0.0984	-0.1021	-0.1969	-0.0357	0.4358	0.2972	-0.3818
Spike length (cm)		1.0000	0.4191	0.8117**	0.3035	-0.4782	-0.8029**	-0.0174	-0.5543*	-0.7123**
Fertile spikelets $spike^{-1}$			1.0000	0.6742**	0.1480	-0.3855	-0.6231	0.3486	0.1996	-0.7398**
Sterile spikelets $spike^{-1}$				1.0000	0.3375	-0.3557	-0.9223**	0.0313	-0.3068	-0.7246**
Number of grains $spike^{-1}$					1.0000	0.4634	-0.2513	-0.4986	-0.6955**	-0.0940
Grain weight $spike^{-1}$ (g)						1.0000	0.3366	-0.5199*	-0.3061	0.7089**
1000 grain weight (g)							1.0000	0.0335	0.3594	0.7273**
50% Heading								1.0000	0.7255**	-0.3790
80 % Maturity									1.0000	-0.0003
Grain yield q ha^{-1}										1.0000

Fertile spikelets spike^{-1} made positive contribution towards grain yield via fertile spikelets spike^{-1} (0.5310), grain weight spike^{-1} (0.0892), sterile spikelets spike^{-1} (0.0729), days to 80 per cent maturity (0.0528) and number of grains spike^{-1} (0.0249) in 2010-11 and sterile spikelets spike^{-1} (0.4484), fertile spikelets spike^{-1} (0.1685) and days to 50 per cent heading (0.0591) in 2011-12. However, fertile spikelets spike^{-1} exerted negative indirect effect via 1000 grain weight (-0.1291), spike length (-0.0387) and potential shoots m^{-2} (-0.0088) in 2010-11 and via 1000 grain weight (-0.6795), grain weight spike^{-1} (-0.2296), spike length (-0.2217), 80 per cent maturity (-0.2004), potential shoots m^{-2} (-0.1894) and number of grains spike^{-1} (-0.1285) in 2011-12.

Sterile spikelets spike^{-1} contributed its positive indirect effect towards grain yield via fertile spikelets spike^{-1} (0.2983), grain weight spike^{-1} (0.0736) and number of grains spike^{-1} (0.0209) but has negative indirect effect towards grain yield via days to 80 per cent maturity (-0.4285), 1000 grain weight (-0.0331), spike length (-0.0214), days to 50 per cent heading (-0.0173) and potential shoots m^{-2} (-0.0045) in 2010-11. Whereas, in 2011-12 sterile spikelets spike^{-1} contributed its positive indirect effect towards grain yield via days to 80 per cent maturity (0.3081), fertile spikelets spike^{-1} (0.0271) and days to 50 per cent heading (0.0053). However, it exerted negative indirect effect via 1000 grain weight (-1.0059), spike length (-0.4295), number of grains spike^{-1} (-0.2931), grain weight spike^{-1} (-0.2119) and potential shoots m^{-2} (-0.0338) on grain yield.

Number of grains spike^{-1} exhibited positive indirect effect on grain yield via fertile spikelets spike^{-1} (0.6998), sterile spikelets spike^{-1} (0.2983) and grain weight spike^{-1} (0.0952), but exerted its negative effect on grain yield via days to 80 per cent maturity (-0.1822), 1000 grain weight (-0.1022), spike length (-0.0252), days to 50 per cent heading (-0.0189) and potential shoots m^{-2} (-0.0089) in 2010-11. Whereas, in 2011-12, the number of grains spike^{-1} exerted positive indirect effect on grain yield via days to 80 per cent maturity (0.6985), grain weight spike^{-1} (0.2761), sterile spikelets spike^{-1} (0.2245), fertile spikelets spike^{-1} (0.0595) and potential shoots m^{-2} (0.0351) but it exhibited negative indirect effect on grain yield via number of grains spike^{-1} (-0.2931), 1000 grain weight (-0.2741), spike length (-0.1606) and days to 50 per cent heading (-0.0845).

Table 4.8.1 Path coefficient analysis-Direct and indirect effects during 2010-11

Characters	Correlation with yield	Direct effect	Indirect effect								
			Potential shoots m^{-2}	Spike length (cm)	Fertile spikelets $spike^{-1}$	Sterile spikelets $spike^{-1}$	Number of grains $spike^{-1}$	Grain weight $spike^{-1}$ (g)	1000 grain weight (g)	50% Heading	80 % Maturity
Potential shoots m^{-2}	0.5310*	-0.0142	**-0.0143**	-0.0267	0.5602	0.0693	0.0203	0.0516	-0.1050	-0.0214	-0.0029
Spike length (cm)	0.5440*	-0.0662	-0.0058	**-0.0268**	0.5311	0.0718	0.0123	0.0705	-0.0736	-0.0133	0.0172
Fertile spikelets $spike^{-1}$	0.9550*	0.9075	-0.0088	-0.0387	**0.5310**	0.0729	0.0249	0.0892	-0.1291	-0.0163	0.0528
Sterile spikelets $spike^{-1}$	0.1180	0.2219	-0.0045	-0.0214	0.2983	**0.0729**	0.0209	0.0736	-0.0331	-0.0173	-0.4285
Number of grains $spike^{-1}$	0.6330*	0.0324	-0.0089	-0.0252	0.6998	0.1435	**0.0209**	0.0952	-0.1022	-0.0189	-0.1822
Grain weight spike-1 (g)	0.6160*	0.1337	-0.0055	-0.0349	0.6051	0.1222	0.0230	**0.0952**	-0.0734	-0.0026	-0.1520
1000 grain weight (g)	0.892**	-0.1437	-0.0104	-0.0339	0.8153	0.0511	0.0230	0.0682	**-0.0734**	-0.0168	0.1394
50% Heading	0.2520	-0.0360	-0.0085	-0.0245	0.4118	0.1066	0.0170	0.0096	-0.0672	**-0.0168**	-0.1570
80 % Maturity	-0.3420	-0.5121	-0.0001	0.0022	-0.0937	0.1822	0.0115	0.0397	0.0391	-0.0110	**-0.1570**

Residual factor 0.0104

Table 4.8.2 Path coefficient analysis-Direct and indirect effects during 2011-12

Characters	Correlation with yield	Direct effect	Indirect effect								
			Potential shoots m^{-2}	Spike length (cm)	Fertile spikelets $spike^{-1}$	Sterile spikelets $spike^{-1}$	Number of grains $spike^{-1}$	Grain weight $spike^{-1}$ (g)	1000 grain weight (g)	50% Heading	80 % Maturity
Potential shoots m^{-2}	-0.3818	-0.3440	**-0.3440**	-0.0325	0.2214	0.0654	0.0886	-0.1173	-0.0390	0.0739	-0.2985
Spike length (cm)	-0.7123**	-0.5292	-0.0211	**-0.0324**	0.1685	0.5399	-0.2635	-0.2849	-0.8756	-0.0029	0.5567
Fertile spikelets $spike^{-1}$	-0.7398**	0.4020	-0.1894	-0.2217	**0.1685**	0.4484	-0.1285	-0.2296	-0.6795	0.0591	-0.2004
Sterile spikelets $spike^{-1}$	-0.7246**	0.6651	-0.0338	-0.4295	0.0271	**0.4484**	-0.2931	-0.2119	-1.0059	0.0053	0.3081
Number of grains $spike^{-1}$	-0.0940	-0.8685	0.0351	-0.1606	0.0595	0.2245	**-0.2931**	0.2761	-0.2741	-0.0845	0.6985
Grain weight $spike^{-1}$ (g)	0.7089**	0.5958	0.0677	0.2531	-0.1549	-0.2366	-0.4024	**0.2761**	0.3671	-0.0881	0.3074
1000 grain weight (g)	0.7273**	1.0907	0.0122	0.4248	-0.2505	-0.6135	0.2183	0.2006	**0.3671**	0.0056	-0.3609
50% Heading	-0.0370	0.1696	-0.1499	0.0092	0.1401	0.0208	0.4331	-0.3097	0.0365	**-0.0056**	-0.7286
80 % Maturity	-0.0003	-1.0043	-0.1022	0.2933	0.0802	-0.2041	0.6041	-0.1823	0.3921	0.1230	**-0.7286**

Residual factor 0.0378

Grain weight spike^{-1} contributed its positive effect on grain yield via fertile spikelets spike^{-1} (0.6051), sterile spikelets spike^{-1} (0.1222) and number of grains spike^{-1} (0.0230) in 2010-11. However, it exerted its negative effect on grain yield via days to 80 per cent maturity (-0.1520), 1000 grain weight (-0.0734), spike length (-0.0349), potential shoots m^{-2} (-0.0055) and days to 50 per cent (-0.0026) in 2010-11. Grain weight spike^{-1} exhibited positive indirect effect on grain yield via 1000 grain weight (0.3671), days to 80 per cent maturity (0.3074), spike length (0.2531) and potential shoots m^{-2} (0.0677) but it contributed negative effect on grain yield via number of grains spike^{-1} (-0.4024), sterile spikelets spike^{-1} (-0.2366), fertile spikelets spike^{-1} (-0.1549) and days to 50 per cent heading (-0.0881) in 2011-12.

Thousand grain weight exhibited negative indirect effect on grain yield via spike length (-0.0339), days to 50 per cent heading (-0.0168) and potential shoots m^{-2} (-0.0339) in 2010-11. Whereas, in 2011-12, it contributed negative indirect effect on grain yield via sterile spikelets spike^{-1} (-0.6135), days to 80 per cent maturity (-0.3609) and fertile spikelets spike^{-1} (-0.2505).

Days to 50 per cent heading exhibited positive indirect effect on grain yield via fertile spikelets spike^{-1} (0.4118), sterile spikelets spike^{-1} (0.1066), number of grains spike^{-1} (0.0170) and grain weight spike^{-1} (0.0096) in 2010-11. However, it exerted its negative effect on grain yield via days to 80 per cent maturity (-0.1570), 1000 grain weight (-0.0672), spike length (-0.0245) and potential shoots m^{-2} (-0.0085) in 2010-11. Whereas, in 2011-12 it has contributed positive indirect effect on grain yield via number of grains spike^{-1} (0.4331), fertile spikelets spike^{-1} (0.1401), 1000 grain weight (0.0365) sterile spikelets spike^{-1} (0.0208) and spike length (0.0092) but contributed negative indirect effect on grain yield via days to 80 per cent maturity (-0.7286), grain weight spike^{-1} (-0.3097) and potential shoots m^{-2} (-0.1499).

Days to 80 per cent maturity exhibited positive indirect effect on grain yield via sterile spikelets spike^{-1} (0.1822), grain weight spike^{-1} (0.0397), 1000 grain weight (0.0391), number of grains spike^{-1} (0.0115) and spike length (0.0022) but contributed negative indirect effect on grain yield via fertile spikelets spike^{-1} (-0.0937), days to 50 per cent heading (-0.0110) and potential shoots m^{-2} (-0.0001) in 2010-11. Whereas, in 2011-12, days to 80 per cent maturity made positive indirect effect on grain yield via number of grains spike^{-1}

(0.6041), 1000 grain weight (0.3921), spike length (0.2933), days to 50 per cent heading (0.1230) and fertile spikelets spike^{-1} (0.0802). However, it exerted its negative effect on grain yield via sterile spikelets spike^{-1} (-0.2041), grain weight spike^{-1} (-0.1823) and potential shoots m^{-2} (-0.1022) in 2011-12.

Character Association and Path Coefficient Analysis

Grain yield is a complex character resulting from multiplicative interaction of yield components. Improvement in this trait by selection based on component characters appears to be more useful as compared to selection of yield *per se,* as has also been advocated by Grafffius (1956). Since all these characters are correlated, the change in one of the character brings about a series of changes in other characters. Thus, to bring a change in yield or other characters to a desired level, proper understanding of association among the yield and yield attributing characters is must.

Grain yield exhibited a highly significant positive correlation with number of grains spike^{-1} in 2010-11. These results are in accordance with the findings of Tiwari and Rawat (1993) and Subhani (2000). A significant positive correlation also occurred between grain yield and 1000 grain weight both during 2010-11 and 2011-12.

Grain yield had a significant positive correlation with grain weight spike^{-1} during both the years i.e. 2010-11 and 2011-12. Fertile spikelets spike^{-1} had a significant positive (0.617 and 0.551) correlation with potential shoots m^{-2} during both the years i.e. 2010-11 and 2011-12 and significant positive correlation also occurred between fertile spikelets spike^{-1} and spike length but only during 2010-11.

The correlation coefficient simply indicates the degree of association among the characters contributing towards economic (grain) yield. It helps in evaluating the relative influence of yield attributes on grain yield and permits the separation of correlation coefficient into the measure of direct and indirect effect. In the present study, path coefficient analysis was carried out taking grain yield as dependent variable and rest of the yield attributing characters as independent variables.

Days to heading exerted positive direct effect on grain yield in 2011-12 as supported by Nirmala and Jha (1997) and also exerted its positive indirect effect on grain yield via fertile spikelets spike^{-1}, sterile spikelets spike^{-1}, number of grains spike^{-1} and grain weight spike^{-1} in 2010-11 and also fertile spikelets spike^{-1}, sterile spikelets spike^{-1}, grain weight spike^{-1} and 1000 grain weight in 2011-12. Fertile and sterile spikelets spike^{-1} exerted positive direct effect on grain yield, where as spike length exerted negative direct on grain yield both during 2010-11 and 2011-12. Grain weight spike^{-1} exerted positive direct effect on grain yield and it showed parity with the findings of Paroda and Joshi (1970).

Spike length exerted direct negative effect on grain yield. While, it had indirect negative effect via potential shoots m^{-2}, number of grains spike^{-1}, grain weight spike^{-1} in 2010-11 and also 1000 grain weight and 50 per cent heading in both the years. 1000 grain weight exerted high order of positive direct effect on grain yield via potential shoots m^{-2}, spike length, number of grains spike^{-1}, grain weight spike^{-1} and 50 per cent heading. It exerted negative indirect effect on grain yield via rest of the characters in 2011-12. These findings were in conformity with Jaimini *et al*. (1974).

Thousand grain weight exerted high order of positive direct effect towards grain yield indicates that it had the highest correlation with yield, as also reported earlier by Paroda and Joshi (1970), Jaimini *et al.* (1974), Deswal *et al*. (1997) and Tammam *et al*. (2000).

Summary and Conclusion

The field experiment was conducted during *Rabi* season of 2010-11 and 2011-12 in D3 wheat Agronomy block, at Norman E. Borlaug Crop Research Centre, G. B Pant University of Agriculture and Technology, Pantnagar, district Udham Singh Nagar (Uttarkhand) entitled "Morpho-physiological bases of shade tolerance in wheat varieties". The field experiments were conducted to study the growth and development, physiological processes *viz.* Chlorophyll contents, photosynthetic rate (Pn), stomatal conductance (Gs), transpiration rate, intercellular CO_2 concentration, light availability at various heights in crop canopy and yield and yield attributing characters of wheat varieties under varying degree of shades. The experiments were laid out in split-plot design with three main plot consisting three levels of light exposures i.e. full sunlight, 2/3 and 1/3 of full sunlight and five sub-plot treatment i.e. wheat varieties *viz.* UP 2684, UP 2526, UP 2565, UP 2113 and PDW 233. The salient findings of the investigation are summarized below.

I. Crop emergence (germinants m^{-2}) was not influenced by varying degree of shades and interaction between levels of shade and varieties but varied significantly amongst wheat varieties both during 2010-11 and 2011-12 (Table 4.1.1).

II. The shoot height (cm) in wheat was significantly influenced by varying degree of shades at 60, 90 and 120 DAS during both the years, except 30 DAS in 2011-12 (Table 4.1.2). The interaction between magnitude of shades and wheat varieties was not found to be significant at all the stages, except 120 days during both the years. The varieties UP 2113 and PDW 233 attained maximum and minimum shoot heights under all the shaded treatment (i.e. full, 2/3 and 1/3 of full sunlight), respectively, at 120 DAS. The result might be combined effect of genetic variations between these varieties and their differential response to shade in increasing and decreasing their internode length.

III. The mean leaf length (cm) was significantly influenced by varying degree of shades at 60, 90 and 120 DAS but not at 30 DAS. The variety UP 2113 produced lengthier leaf at all the growth stages under all the light availability condition (i.e. full, 2/3 and 1/3 of full sunlight) compared to other varieties (Table 4.1.3).

IV. The mean leaf width in wheat was significantly influenced by the varying degree of shades and wheat varieties at 30, 60 90 and 120 DAS both during 2010-11 and 2011-12. However, the interaction between degree of shades and wheat varieties was influenced significantly only 30 and 60 DAS during both the years (Table 4.1.4). Among the wheat varieties, UP 2684 had higher leaf width under mild and severe shade both at 30 and 60 days after sowing during both the years except at 60 DAS in 2011-12.

V. The average length (Table 4.1.5) 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 4.1.6) 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. 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. The significant increase in internode length of wheat varieties might be combined effect of genetic variations between these varieties and their differential response to shade in increasing in their lengths.

VI. The 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. The significant reduction in dry weight of stems with increasing shade in wheat and the longer stems exhibited lower specific internode weight. 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 to 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 for PDW 233, UP 2113 and UP 2684 at 90 DAS in 2010-11 and UP 2565 at 128 DAS in 2011-12 (Table 4.1.7 and 4.1.8). 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. This indicated that shading promoted remobilization of the stored dry matter in the lower internodes as a plastic response to light.

VII. The flag leaf area (cm^2 $leaf^{-1}$) in wheat was influenced significantly by degree of shade, wheat varieties and interaction between them at 10 days after anthesis during both the years (Table 4.1.9). The variety UP 2684 at par with UO 2113 in both the seasons and also UP 2526 and PDW 233 in 2011-12, produced significantly higher flag leaf area during both the years than all the other varieties.

VIII. Days taken to 50 per cent heading in wheat were influenced significantly by magnitude of shade and wheat varieties. The interaction between shaded treatment and wheat varieties was not found to be significant during both the years (Table 4.1.11). Alike day taken to 50 per cent heading the days taken 80 per cent maturity in wheat were also influenced significantly by degree of shade and wheat varieties both during both the years. The interaction between varying degree of shade and wheat variety was not found to be significant during the both the years. Among the variety PDW 233 took more days for 50 per cent heading as well for 80 per cent maturity followed by UP 2113 during both the years.

IX. The dry matter accumulation as a function of time followed the sigmoid path. There was a "initial lag" phase upto 40th day, followed by "log" phase from 41 to 100 day and a phase of decreasing growth rate upto 120th days. Thus, the maximum dry matter was accumulated at 120th days. The dry matter accumulated at 120th day was maximum for variety PDW 233 during both the years and lowest for variety UP 2113 in 2010-11 and UP 2684 in 2011-12. It might be due to increasing and decreasing of spike dry weight at 120 DAS during both the years. On the basis of dry matter accumulation pattern in stem and leaves from 100 to 120th days, varieties UP 2113 and PDW 233 can be said higher biomass producting varieties, because they continued increasing their stem and leaf weight even after spike emergence under all the shaded treatment. The 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 of total upto 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. The varying degree of reduction in dry matter produced was related with increased magnitude of shade. 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. The significant differences in total dry matter accumulation per unit area 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).

X. The wheat varieties differed significantly in all the growth parameters at most of the stages under all the shaded treatments. The CGR was found to follow leaf area development whereas, RGR followed exactly the NAR, both of which peaked at 61-80 days during both the years. However, LAR in all the varieties peaked at 21-40 days period and started decreasing as the dry matter accumulation was rapid in non-leaf tissue. The CGR, RGR and NAR had positive and LAR negative association with grain yield but associations were usually non-significant.

XI. The intercellular CO_2 concentration (Ci) (ppm) in wheat leaves was significantly influenced by degree of shades at boot stage and anthesis in 2011-12 and at 10 days after anthesis during both the years (Table 4.3.1 and 4.3.2). The intercellular CO_2 concentration was higher under severe shade (i.e. 2/3 shading) as compared to mild shade and full sunlight condition both during booting, and anthesis in 2011-12 and at 10 days after anthesis (DAA) during both the years. The direct effect of increased carbon dioxide (CO_2) concentration on plant growth refers to the change in plant growth under given set of environment. The effect of enhanced intercellular CO_2 concentration is even greater for plants grown under low light conditions. The enhance growth is greater than 100 percent for a 100 percent increase in CO_2 concentration under shaded reduce light, this compares to less than 50 percent for plants grown in normal light conditions.

XII. The photosynthetic rate (Pn) and stomatal conductance (Gs) were significantly influenced by varying degree of shades both at boot stage and at anthesis in 2011-12 and 10 days after anthesis during both the years (Table 4.3.1 and 4.3.2). The photosynthetic rate was higher under full sunlight which significantly reduced with each successive increase in shades both at boot stage and at anthesis in 2011-12 and at 10 DAA during both the years. The decrease in Pn could be explained by reduction in stomatal conductance, which reduced diffusion into the leaves. The wheat varieties differed significantly in their photosynthetic rate on booting in 2011-12 and at 10 DAA during both the years. Among the varieties PDW 233 showed higher Pn at booting in 2011-12 and at 10 DAA during both the years but it was not significantly different from UP 2684 and UP 2526 at 10 DAA in 2011-12. The reduction in photosynthesis was attributed to high starch accumulation in leaves, suggesting that photosynthesis production (i.e. source activity) was greater than photosynthate utilization (i.e. sink activity). Therefore, higher source activity relative than sink activity may have initiated the down regulated of photosynthesis at the protein or transcriptional level, thereby lowering the amount and/or activity of Rubisco. Stomatal conductance (Gs) is a measure of the maximum rate of passage of carbon dioxide into the leaf. The maximum and significantly higher Gs was observed under full sunlight (i.e. control) which reduced significantly with each successive increase in shade both at booting and at anthesis in 2011-12 and at 10 DAA during both the years. Among the varieties, PDW 233 recorded higher stomatal conductance than all other varieties at booting in 2011-12 and at 10 DAA during both the years. The Stomatal conductance and assimilation rates were higher in control plants, which indicated PAR limitation for photosynthesis in shaded plants.

XIII. The total chlorophyll content in wheat was significantly influenced by varying degree of shade at 75, 91 and 111 DAS during both years (Table 4.4.6). The total chlorophyll content per cent increase under severe shade (20.7 and 19.2 per cent) as compared to full sunlight at 91 DAS during both the years, respectively. The total chlorophyll accumulation under shade might be due to more accountability of chlorophyll b, which indicates shade adaptation ability of species. The total chlorophyll content continued to increase upto 91 days stage but later on it started decline during both years, however, rate of decline was much faster under full sunlight than shade. Chlorophyll content used to estimate photosynthetic carbon dioxide assimilation as well as it indicates the health of PSII.

XIV. Light availability transmission to wheat crop averaged 63.0 and 63.9 per cent of 100 per cent in full sunlight under mild shade and to 31.7 and 32.1 per cent of full sunlight under severe shade 81 DAS at top of the wheat canopy both during 2010-11 and 2011-12, respectively (Table 4.5.1). The significant reduction in light availability for crop underneath cloth could be envisaged with each successive increase in shade. The per cent of light availability (after interception under varying degree of shades) by the wheat varieties did not differ either by upper half of the canopy or the lower half of the canopy.

XV. The grain, straw and biological yield were significantly influenced by varying degree of shades, wheat varieties and interaction between them (Table 4.6.1). The maximum grain, straw and biological yields were obtained under full sunlight (i.e. control) than mild and severe shaded treatments. Among the varieties, PDW 233 yielded maximum grain, biological and straw yields it was at par with UP 2526 and UP 2565 in biological yields during both the years and straw yields with UP 2526 and UP 2565 in 2010-11 and also UP 2113 in 2011-12. Grain yield was adversely affected by increasing in shade and same pattern was also observed for straw and biological yields. The higher grain yield was mainly attributed by more photosynthetic rate, stomatal conductance, number of grains/spike and higher potential shoots. The harvest index was influenced significantly by varying degree of shades, wheat varieties and the interaction between them. Variety PDW 233 and UP 2113 gained maximum harvest index under severe shade (i.e. 2/3 shading).

XVI. The character association analysis revealed that grain weight/spike and 1000 grain weight had strong positive and significant correlation with gain yield during both the growing season (Table 4.7.1 and 4.7.2). Fertile spikelets had a significant positive correlation with potential shoots m^{-2} during both years. Number of grains $spike^{-1}$ was positively associated with grain weight $spike^{-1}$, 1000 grain weight and days to 50 per cent heading in 2010-11 but it was negatively correlated with days to 80 per cent maturity in 2011-12.

XVII. Path coefficient analysis showed high positive direct effects of fertile spikelets $spike^{-1}$ and grain weight $spike^{-1}$ during both years and 1000 grain weight 2011-12 and moderate direct effect of sterile spikelets $spike^{-1}$ during both the years and number grains $spike^{-1}$ in 2010-11 (Table 4.8.1 and 4.8.2).

In the light of the results summarized above, it may be concluded that, the wheat variety, PDW 233 is superior over others (UP 2684, UP 2526, UP 2565 and UP 2113) in its grain yield, not only in open but also under all the intensities of shade, however, the choice can be made between UP 2684 and PDW 233 for severe shade conditions. The higher yields in PDW 233was basically due to better dry matter accumulation, lower shoot mortality rate (higher potential shoots m^{-2}), higher photosynthetic rate, higher stomatal conductance even under shade, better harvest index and grain filling (number grains spike^{-1}). The yield advantage of PDW 233 over other varieties, irrespective of shades suggests its genotypic superiority and better adaptability under sub-optimal conditions (Particularly light) for agroforestry like situations. However, under severe shade UP 2684 can also be preferred over UP 2526, UP 2565 and UP 2113.

It is, therefore, suggested that even under higher degree of shade (i.e. approximately 33 per cent light availability condition) or tree based agroforestry system, variety PDW 233 could be preferred over others. These results are based on two season's testing of five wheat varieties under artificial shade in pure culture/sole crop system only. It is therefore, wisely suggested that the performance of this variety along with more varieties (including local/wild types) with wider genetic make-up be tested under real agroforestry situations to confirm the findings, get reproducible results, foolproof recommendations and to provide wider choice of wheat varieties for agroforestry land-uses.

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Appendices

APPENDIX I

Weekly average weather parameters during experimentation at Pantnagar (November to April, 2010-11)

Months	Standard Weeks	Sunshine hours	Temperature		Relative humidity		Rainfall/week (mm)
			Max	Min	At 7 AM	At 2 PM	
Nov., 10	45	8.2	29.8	15.1	88	41	00.0
	46	6.8	28.7	14.5	84	42	00.0
	47	4.3	25.0	13.1	89	48	0.4
	48	6.0	24.0	10.6	91	54	00.0
Dec., 10	49	8.8	25.9	8.0	89	37	00.0
	50	5.9	22.6	7.3	92	45	00.0
	51	7.4	21.7	4.4	96	45	00.0
	52	6.3	21.9	6.7	93	51	14.8
Jan., 11	1	1.0	14.1	7.1	92	81	22.0
	2	1.3	12.4	4.5	95	77	00.0
	3	4.6	18.1	5.6	92	55	2.4
	4	7.2	21.6	5.3	89	48	00.0
	5	6.6	22.5	6.4	94	46	00.0
Feb., 11	6	6.9	24.8	8.9	90	48	10.8
	7	5.4	22.8	11.2	88	58	19.4
	8	7.6	22.7	8.7	91	47	00.0
	9	6.0	23.3	9.6	89	49	4.8
March, 11	10	9.3	27.5	9.1	89	37	2.4
	11	8.2	29.3	13.1	88	35	00.0
	12	8.2	32.4	13.4	83	27	00.0
	13	8.9	31.9	15.6	83	33	9.2
April, 11	14	9.5	33.4	14.1	78	27	00.0
	15	8.0	34.3	16.6	70	22	3.4
	16	9.6	35.4	16.5	71	26	2.4
	17	8.9	35.9	20.3	65	29	00.0

APPENDIX II

Weekly average weather parameters during experimentation at Pantnagar

(November to April, 2011-12)

Months	Standard Weeks	Sunshine hours	Temperature		Relative humidity		Rainfall/week (mm)
			Max	Min	At 7 AM	At 2 PM	
Nov., 11	45	3.6	27.2	13.9	88	54	00.0
	46	2.1	26.7	14.1	90	57	00.0
	47	4.8	27.1	11.9	91	49	00.0
	48	6.8	26.1	9.3	91	48	00.0
Dec., 11	49	4.9	25.7	10.6	93	53	00.0
	50	1.0	20.3	9.6	94	70	00.0
	51	3.1	18.1	6.6	94	65	00.0
	52	7.7	22.6	5.5	92	42	00.0
Jan., 12	1	2.0	18.8	11.0	91	72	19.4
	2	3.8	19.3	7.1	91	61	1.0
	3	3.5	17.9	7.1	90	66	4.8
	4	5.8	20.8	3.7	92	55	00.0
	5	7.1	21.5	4.4	92	45	00.0
Feb., 12	6	6.7	22.0	6.8	91	46	0.6
	7	5.5	23.3	9.1	89	44	00.0
	8	8.2	27.1	9.5	90	33	00.0
	9	8.0	26.0	7.4	90	36	00.0
March, 12	10	5.5	27.4	11.8	88	45	0.6
	11	8.9	27.5	11.0	90	40	3.2
	12	7.0	30.4	13.5	88	39	00.0
	13	7.1	32.9	15.5	88	38	00.0
April, 12	14	8.5	35.7	18.7	77	31	00.0
	15	4.9	32.1	17.7	83	49	1.1
	16	10.0	35.0	18.2	72	30	00.0
	17	11.2	36.4	19.4	60	22	00.0

APPENDIX III

Analysis of variance for Crop emergence (Germinants m^{-2}) during 2010-11 and 2011-12

Source of variance	**df**	**Germinants/m^2**	
		2010-11	**2011-12**
Replication	2	154.85	193.39
Degree of shade (A)	2	184.05	92.59
Error (a)	4	39.17	380.02
Wheat varieties (B)	4	548.12**	848.89**
A x B	8	285.48	106.48
Error (b)	24	126.65	235.07

**Significant at 5% level of probability

APPENDIX IV

Analysis of variance for shoot height (cm shoot^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square							
		30 DAS		60 DAS		90 DAS		120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.0117	0.519	0.0494	0.0627	0.587	0.138	0.345	0.185
Degree of shade (A)	2	52.47**	4.352	150.32**	23.366**	555.77**	96.87**	647.04**	227.43**
Error (a)	4	0.0635	1.019	0.369	0.591	2.152	0.83	1.872	1.061
Wheat varieties (B)	4	2.496**	31.446**	9.4327**	44.258**	46.413**	119.09**	58.27**	312.58**
A x B	8	0.151	0.0849	0.5251	0.683	5.483	3.065	12.70**	18.738**
Error (b)	24	0.1604	0.565	0.9274	2.132	4.015	3.845	5.107	5.014

**Significant at 5% level of probability

APPENDIX V

Analysis of variance for leaf length (cm leaf^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square							
		30 DAS		60 DAS		90 DAS		120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.53	1.31	0.79	1.35	0.35	1.08	0.16	0.1
Degree of shade (A)	2	1.02	2.73	12.77**	16.28**	75.10**	75.78**	52.71**	52.72**
Error (a)	4	0.23	0.56	0.56	0.93	1.27	2.07	0.35	0.41
Wheat varieties (B)	4	0.89**	9.41**	10.11**	97.36**	28.08**	22.82**	33.66**	33.64**
A x B	8	0.58	1.43	3.34	3.38	2.89**	9.97	5.49**	5.49**
Error (b)	24	0.23	2.21	1.39	1.78	1.07	0.87	1.39	2.28

**Significant at 5% level of probability

APPENDIX VI

Analysis of variance for leaf width (cm leaf^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square							
		30 DAS		60 DAS		90 DAS		120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.0007	0.002	0.0009	0.00004	0.00044	0.00253	0.00011	0.00173
Degree of shade (A)	2	.0214**	0.0214**	0.0343**	0.0343**	0.0265**	0.02830**	0.2081**	0.2264**
Error (a)	4	0.00008	0.002	0.0005	0.001	0.000213	0.00347	0.00037	0.00048
Wheat varieties (B)	4	0.0631**	0.0631**	0.0630**	0.0633**	0.04407**	0.04454**	0.01529**	0.01522**
A x B	8	0.0059**	0.0060**	0.0174**	0.0174**	0.00062	0.000617	0.0025	0.002412
Error (b)	24	0.0006	0.002	0.0015	0.0038	0.00153	0.00355	0.00154	0.00315

**Significant at 5% level of probability

APPENDIX VII

Analysis of variance for internode length (cm) of different internode from top downwards in wheat crop on 90 DAS during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		First		Second		Third		Fourth		Fifth	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.057	1.187	0.2059	0.509	0.00441	0.535	0.0992	5.67	0.133	0.429
Degree of shade (A)	2	25.93**	24.67**	22.55**	22.553**	5.8265**	5.891**	3.549**	3.549**	0.5309	0.488
Error (a)	4	0.0946	0.106	0.0212	0.0958	0.1181	0.251	0.1563	0.156	0.1016	0.1542
Wheat varieties (B)	4	50.76**	50.87**	50.89**	50.895**	23.86**	23.848**	14.514**	14.515**	8.790**	7.973**
A x B	8	0.573**	0.724**	0.8187**	0.818**	0.3668	0.3791	0.3036	0.3035	3.0911	3.085
Error (b)	24	0.166	0.171	0.289	0.3065	0.3107	0.3299	0.1422	0.1416	0.1469	0.1701

**Significant at 5% level of probability

APPENDIX VIII

Analysis of variance for internode length (cm) of different internode from top downwards in wheat crop on 128 DAS during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		First		Second		Third		Fourth		Fifth	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.475	0.876	0.21	0.369	0.0154	0.695	0.0789	0.526	0.393	1.196
Degree of shade (A)	2	78.25**	78.25**	40.109**	40.286**	24.07**	24.06**	8.539**	10.596**	7.806**	22.698**
Error (a)	4	0.431	0.993	0.244	0.2609	0.0437	0.402	0.0651	0.3209	0.321	1.241
Wheat varieties (B)	4	27.05**	27.04**	74.59**	74.408**	23.23**	23.22**	2.306**	23.05**	11.187**	28.58**
A x B	8	0.364	0.365	0.414	0.4231	0.0651	0.6506	0.1051	0.1015	0.426	0.84
Error (b)	24	2.04	2.563	1.503	1.585	0.775	0.8137	0.3161	0.603	0.405	0.935

**Significant at 5% level of probability

APPENDIX IX

Analysis of variance for internode dry weight (mg) from top downwards in wheat varieties on 90 DAS during 2010-11 and 2011-12

		Mean sum of square									
Source of variance	**df**	**First**		**Second**		**Third**		**Fourth**		**Fifth**	
		2010-11	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**
Replication	2	5.958	573.09	347.2	575	407.66	74.47	95.2	396.8	307.86	1576.36
Degree of shade (A)	2	20781.0**	21123.89**	316318.4**	321596.9**	311119.1**	330571.5**	112980.5**	110082.1**	110718.5**	109981.7**
Error (a)	4	7.32	489.47	302.79	1132.76	378.3	316.5	355.33	842.93	210.6	1813.41
Wheat varieties (B)	4	8717.97**	8627.924**	73183.5**	73261.28**	108720.3**	110747.3**	104366.0**	105357.8**	256639.9**	249135.5**
A x B	8	379.91**	355.30**	5872.78**	5847.39**	22515.99**	22557.23**	297.53	315.24	1298.08	1552.96
Error (b)	24	24.022	66.92	1055.37	1893.79	1357.83	1894.21	730.28	1086.05	934.56	1162.4

**Significant at 5% level of probability

APPENDIX X

Analysis of variance for internode dry weight (mg) from top downwards in wheat varieties on 128 DAS during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		First		Second		Third		Fourth		Fifth	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	855.73	280	49.73	4880.26	747.9	1143.6	191.2	45.73	310.43	6193.6
Degree of shade (A)	2	404414.1**	412877.3**	197897.2**	197895.7**	125163.4**	123543.1**	56263.77**	59233.46**	63724.8**	63792.54**
Error (a)	4	819.07	2246.12	403.93	2344.39	1025.11	3566.06	109.05	562.6	458.71	459.73
Wheat varieties (B)	4	136840.7**	139079.6**	353362.6**	353318.9**	58461.8**	562576.7**	86154.4**	86730.78**	83192.64**	83209.34**
A x B	8	9698.46**	10738.2**	12481.2**	12484.63**	2352.1	2264.06	938.39	769.74	3807.93**	3805.44**
Error (b)	24	1485.39	1594	1370.33	2240.91	1255.8	1287	1260.79	1394.67	673.35	672.36

**Significant at 5% level of probability

APPENDIX XI

Analysis of variance for flag leaf area (cm^2 $leaf^{-1}$) 10 days after anthesis during 2010-11 and 2011-12

Source of variance	df	Mean sum of square	
		2010-11	2011-12
Replication	2	0.715	0.793
Degree of shade (A)	2	728.16**	639.92**
Error (a)	4	1.424	0.213
Wheat varieties (B)	4	79.79**	39.18**
A x B	8	18.68**	15.63**
Error (b)	24	1.654	2.29

**Significant at 5% level of probability

APPENDIX XII

Analysis of variance for maximum number of shoots m^{-2} and Shoot mortality (%) of crop during 2010-11 and 2011-12

Source of variance	df	Mean sum of square			
		Maximum shoots m^{-2}		Shoot mortality (%)	
		2010-11	2011-12	2010-11	2011-12
Replication	2	52.66	20.6	0.352	2.705
Degree of shade (A)	2	25075.07**	24990.73**	2919.60**	2841.15**
Error (a)	4	134.73	111.43	1.819	1.0678
Wheat varieties (B)	4	15317.00**	15272.6**	26.88**	25.654**
A x B	8	2194.4**	2199.76**	158.95**	155.98**
Error (b)	24	537.39	422.62	3.787	1.225

**Significant at 5% level of probability

APPENDIX XIII

Analysis of variance for Days taken to 50% heading and 80% maturity during 2010-11 and 2011-12

Source of variance	df	Mean sum of square			
		Days taken to 50% heading		Days taken to 80% maturity	
		2010-11	2011-12	2010-11	2011-12
Replication	2	0.236	0.284	0.075	0.431
Degree of shade (A)	2	307.00**	85.43**	380.94**	147.73**
Error (a)	4	1.219	0.932	0.229	1.959
Wheat varieties (B)	4	30.96**	191.7**	28.159**	72.26**
A x B	8	3.669	1.893	3.236	4.817
Error (b)	24	4.605	6.96	0.177	8.166

**Significant at 5% level of probability

APPENDIX XIV

Analysis of variance for leaf dry matter (g m^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		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
Replication	2	0.0263	0.0573	3.232	0.0837	2.811	0.318	0.468	0.512	14.12	24.11	50.87	33.13
Degree of shade (A)	2	0.3519	0.386	321.13**	112.57**	2763.57**	1541.80**	3070.36**	3839.8**	3748.09**	3747.35**	5583.47**	5765.5**
Error (a)	4	0.216	0.197	1.066	0.1018	2.481	1.0489	1.678	1.7562	12.24	26.46	9.152	14.266
Wheat varieties (B)	4	1.800**	1.145**	21.868**	41.627**	1650.28**	1102.14**	995.49**	1560.40**	2622.3**	2622.6**	200.65**	189.26**
A x B	8	1.085	0.386	1.391	18.51**	11.191**	13.625**	24.10**	112.63**	36.71**	36.75	30.91	32.66**
Error (b)	24	0.242	0.332	4.569	0.5019	4.552	3.844	6.373	6.236	11.59	17.36	20.09	22.48

**Significant at 5% level of probability

APPENDIX XV

Analysis of variance for stem dry matter (g m^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		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
Replication	2	0.089	0.0132	0.0259	0.8684	0.112	3.618	20.93	16.16	10.58	39.1	110.3	45.033
Degree of shade (A)	2	0.1725**	02239**	204.79**	295.73**	1816.12**	3301.63**	61880.6**	57990.0**	84540.72**	84543.1**	123443.7**	12344.9**
Error (a)	4	0.00338	0.0191	0.0701	0.6037	0.7104	4.357	17.99	27.44	249.37	27.64	134.7	49.284
Wheat varieties (B)	4	1.599**	1.5920**	4.944**	29.17**	516.26**	277.15**	15632.78**	17508.7**	5109.73**	5108.52**	5114.72**	5114.02**
A x B	8	0.620**	0.5839**	3.686**	1.837	44.436**	95.406**	1098.2**	1424.49**	470.26	469.66**	5.038**	504.05**
Error (b)	24	0.0515	0.0489	0.332	1.768	3.826	7.914	133.51	126.66	262.88	141.23	211	151.97

**Significant at 5% level of probability

APPENDIX XVI

Analysis of variance for spike dry matter (g m^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square			
		100 DAS		120 DAS	
		2010-11	2011-12	2010-11	2011-12
Replication	2	1.914	60.81	168.3	42.88
Degree of shade (A)	2	51217.5**	51217.5**	17578.18**	17579.42**
Error (a)	4	3.687	2.1166	39.016	8.525
Wheat varieties (B)	4	2615.77**	2615.72**	2266.08**	2265.8**
A x B	8	642.42**	642.45	475.51**	475.42**
Error (b)	24	29.68	63.847	172.2	168.02

**Significant at 5% level of probability

APPENDIX XVII

Analysis of variance for total plant dry matter (g m^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		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
Replication	2	0.114	0.392	0.359	11.87	0.841	58.3	5.2	103.66	157.2	76	30.4	43.6
Degree of shade (A)	2	0.478**	0.459	1037.5**	758.83**	9062.6**	8964.3**	93197.7**	91643.4**	181712.9**	331345.3**	309946.1**	314676.1**
Error (a)	4	0.064	1.976	2.378	0.819	3.17	34.13	325.93	201.76	197.13	169.32	87.73	125.937
Wheat varieties (B)	4	1.104**	4.004**	40.86**	88.12**	871.3**	1379.8**	13030.78**	17270.05**	10107.6**	10785.1**	10187.1**	9526.33**
A x B	8	1.358**	1.005	5.32	27.76**	67.98**	143.01	1218.17**	1503.54**	715.43	1339.7	725.24	649.968
Error (b)	24	0.108	0.898	4.255	9.109	14.84	66.62	294.2	301.17	433.79	399.05	418.56	683.82

**Significant at 5% level of probability

APPENDIX XVIII

Analysis of variance for leaf area index (g m^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		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
Replication	2	0.0000006	0.00016	0.00004	0.004	0.0029	0.0265	0.015	0.004	0.011	0.079	0.00002	0.00023
Degree of shade (A)	2	.0625**	0.0777**	1.0818**	1.1625**	15.01**	15.99**	15.24**	14.91**	9.383**	9.668**	1.147**	1.181**
Error (a)	4	0.000058	0.00051	0.00123	0.00291	0.01	1.84	0.0058	0.0047	0.014	0.0216	0.00014	0.0011
Wheat varieties (B)	4	0.0063**	0.00245**	0.1039**	0.099**	1.55**	1.067**	0.498**	0.956**	1.29**	1.081**	0.0647**	0.075**
A x B	8	0.00034	0.00053	0.00979**	0.0342**	0.048**	0.678**	0.108**	0.57**	0.14**	0.826**	0.012**	0.0135**
Error (b)	24	0.00015	0.00073	0.00183	0.0025	0.013	0.025	0.0307	0.014	0.041	0.053	0.00081	0.00094

**Significant at 5% level of probability

APPENDIX XIX

Analysis of variance for mean CGR (g m^{-2} day^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.0017	0.0011	0.259	0.012	0.021	0.322	0.049	0.37	0.055	0.016
Degree of shade (A)	2	2.935**	2.934**	121.5**	121.5**	128.8**	125.9**	52.01**	43.62**	39.29**	39.29**
Error (a)	4	0.014	0.0064	0.17	0.011	0.579	0.85	0.428	0.036	0.174	0.146
Wheat varieties (B)	4	0.114**	0.1139**	8.62**	8.62**	27.42**	27.39**	18.43**	18.45**	7.184**	7.17**
A x B	8	0.023	0.024	4.257**	4.25**	2.80**	1.28**	2.318**	2.318	2.003**	2.003**
Error (b)	24	0.014	0.018	0.27	0.069	0.58	1.047	0.601	1.344	0.12	0.298

**Significant at 5% level of probability

APPENDIX XX

Analysis of variance for mean RGR (mg g^{-1} day^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.137	0.305	0.066	0.08	0.246	3.007	0.418	0.57	0.0011	0.184
Degree of shade (A)	2	22.90**	19.26**	4.132**	4.147**	665.71**	776.55**	28.50**	28.48**	37.97**	54.30**
Error (a)	4	0.15	0.88	0.363	0.35	0.48	0.9	2.37	2.49	0.005	0.27
Wheat varieties (B)	4	0.34**	33.37**	56.68**	56.69**	45.44**	81.65**	91.47**	91.49**	24.57**	24.57**
A x B	8	2.59**	2.44	10.79**	10.78**	40.18**	26.89**	4.73	4.73	4.18**	4.17**
Error (b)	24	0.48	1.27	1.563	1.57	6.411	7.58	2.94	4.93	0.015	0.314

**Significant at 5% level of probability

APPENDIX XXI

Analysis of variance for mean NAR (mg cm^{-2} day^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	0.0000006	0.000028	0.00000016	0.00011	0.000012	0.00018	0.0000007	0.00047	0.00000041	0.00034
Degree of shade (A)	2	0.0019**	0.00014	0.000089**	0.0061**	0.0016**	0.0018**	0.1348**	0.077**	0.00017**	0.00931**
Error (a)	4	0.0000022	0.000028	0.0000009	0.00008	0.00001	0.000079	0.0000051	0.0003	0.0000012	0.00034
Wheat varieties (B)	4	0.000097**	0.00032**	0.00034**	0.00158**	0.0018**	0.0018**	0.03206**	0.025**	0.00205**	0.0013**
A x B	8	0.00024**	0.00004	0.000030**	0.0015**	0.000031	0.000042	0.0126**	0.0080**	0.00012**	0.00038
Error (b)	24	0.000012	0.000076	0.0000061	0.00028	0.000045	0.00014	0.000028	0.00057	0.000007	0.00035

**Significant at 5% level of probability

APPENDIX XXII

Analysis of variance for LAR (cm^{-2} g^{-1}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square									
		20-40 DAS		40-60 DAS		60-80 DAS		80-100 DAS		100-120 DAS	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	24.61	69.2	52.25	61.31	18.18	1.241	2.63	5.02	0.129	9.87
Degree of shade (A)	2	63106.48**	59670.8**	90019.39**	90018.2**	85425.9**	83616.11**	6538.05	5030.7**	8615.4**	8607.39**
Error (a)	4	25.02	45.79	12.48	38.02	77.21	12.46	2.627	17.87	4.53	3.094
Wheat varieties (B)	4	5221.26**	5175.1**	5562.67**	5562.1**	4092.2**	4077.46**	310.13**	156.25**	110.8**	108.28**
A x B	8	1609.68**	1617.5**	871.7**	871.8**	269.16**	266.89**	73.95**	83.41**	42.53**	42.95
Error (b)	24	103.98	186.9	87.56	143.5	66.39	28.42	8.26	16.11	5.41	18.66

**Significant at 5% level of probability

APPENDIX XXIII

Analysis of variance for SLW (mg cm^{-2}) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		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
Replication	2	0.001	0.0088	0.00003	0.009	0.00008	0.016	0.00013	0.0024	0.00038	0.0152	0.000068	0.04
Degree of shade (A)	2	0.013**	0.017	0.148**	16.44**	0.742**	73.22**	0.135**	13.37**	0.214**	21.56**	0.2296**	21.56**
Error (a)	4	0.00008	0.069	0.00003	0.009	0.00013	0.0067	0.00027	0.025	0.0003	0.035	0.00014	0.0323
Wheat varieties (B)	4	0.0036**	0.558**	0.021**	0.98**	0.063**	6.38**	0.0053	0.542**	0.0102**	1.067**	0.0036**	0.33**
A x B	8	0.0008**	0.95	0.0015**	0.07**	0.024	2.51**	0.0035**	0.325**	0.0034**	0.342**	0.00036	0.064
Error (b)	24	0.00008	0.063	0.00011	0.029	0.0003	0.044	0.00034	0.0675	0.00034	0.0467	0.00031	0.103

**Significant at 5% level of probability

APPENDIX XXIV

Analysis of variance for intercellular CO_2 concentration, Photosynthetic rate, Stomatal conductance and Transpiration rate on booting and at anthesis during 2011-12

Source of variance	df	Mean sum of square							
		CO2 concentration (ppm)		Photosynthetic rate (µ mol m^{-2} sec^{-1})		Stomatal conductance (m mol CO_2 m^{-2} sec^{-1})		Transpiration rate (m mol H_2O m^{-2} sec^{-1})	
		boot	Anthesis	boot	Anthesis	boot	Anthesis	boot	Anthesis
Replication	2	944.06	8.966	0.4813	0.266	33.69	417.67	0.094	0.054
Degree of shade (A)	2	4385.13**	6773.76**	414.96**	388.4**	19405.4**	37883.45**	4.388**	3.266**
Error (a)	4	138.1	214.38	4.328	1.722	301.15	280.34	0.077	0.0082
Wheat varieties (B)	4	83.16	79.41	13.209**	9.994	865.47**	738.96	0.0253	0.0257
A x B	8	232.5	125.97	2.387	3.452	326.47	345.36	0.013	0.0307
Error (b)	24	106.31	79.6	4.224	4.74	192.44	328.21	0.024	0.0141

**Significant at 5% level of probability

APPENDIX XXV

Analysis of variance for intercellular CO_2 concentration, Photosynthetic rate, Stomatal conductance and Transpiration rate at 10 days after anthesis during 2010-11 and 2011-12

Source of variance	**df**	**Mean sum of square**							
		CO2 concentration (ppm)		**Photosynthetic rate (µmol m^{-2} sec^{-1})**		**Stomatal conductance (mmol CO_2 m^{-2} sec^{-1})**		**Transpiration rate (mmol H_2O m^{-2} sec^{-1})**	
		2010-11	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**	**2010-11**	**2011-12**
Replication	2	30.01	61.7	0.358	1.75	160.11	323.1	0.05	0.037
Degree of shade (A)	2	5971.3**	8232.10**	339.26**	541.8**	77612.1**	44525.7**	6.79**	4.92**
Error (a)	4	73.79	81.75	1.607	3.67	143.6	187.4	0.03	0.003
Wheat varieties (B)	4	95.54	35.58	12.80**	19.97**	6331.9**	2389.04**	0.03	0.0008
A x B	8	63.95	31.39	0.455	3.53	1359.6**	529.27**	0.02	0.022
Error (b)	24	14.51	77.12	2.82	3.08	202.2	98.78	0.1	0.012

**Significant at 5% level of probability

APPENDIX XXVI

Analysis of variance for Chl a and Chl b (mg g^{-1} F.wt.) content at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		Chl a content						Chl b content					
		75 DAS		91 DAS		111 DAS		75 DAS		91 DAS		111 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
Replication	2	0.0101	0.012	0.0064	0.0173	0.0075	0.005	0.012	0.0005	0.02	0.005	0.018	0.002
Degree of shade (A)	2	0.6609**	0.6609**	0.8209**	0.824**	0.390**	0.37**	2.208**	2.212**	2.54**	2.53**	2.83**	2.84
Error (a)	4	0.0101	0.0036	0.0081	0.026	0.013	0.0013	0.015	0.0027	0.021	0.0018	0.02	0.0071
Wheat varieties (B)	4	0.017	0.0172	0.0201	0.019	0.01	0.0127	0.0422**	0.043**	0.07**	0.07**	0.034	0.034
A x B	8	0.025**	0.0253	0.0099	0.01	0.02	0.019**	0.029	0.029**	0.029	0.029	0.023	0.023
Error (b)	24	0.0107	0.0192	0.0077	0.008	0.01	0.006	0.015	0.008	0.02	0.02	0.02	0.015

**Significant at 5% level of probability

APPENDIX XXVII

Analysis of variance for Chl. a/b ratio and Total chlorophyll (mg g^{-1} F.wt.) at various stages of crop growth during 2010-11 and 2011-12

Source of variance	df	Mean sum of square											
		Chl. a/ b ratio						Total chlorophyll content					
		75 DAS		91 DAS		111 DAS		75 DAS		91 DAS		111 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
Replication	2	0.017	0.00017	0.0041	0.003	0.004	0.00039	0.0637	0.011	0.065	0.041	0.066	0.0336
Degree of shade (A)	2	7.71**	8.46**	6.988**	9.40**	6.02**	5.187**	0.577**	0.52**	0.605**	0587**	1.206**	1.265**
Error (a)	4	0.009	0.006	0.0048	0.0086	0.009	0.0069	0.0705	0.01	0.072	0.035	0.083	0.0258
Wheat varieties (B)	4	0.100**	0.13**	0.033**	0.056**	0.051	0.0669**	0.0965	0.053	0.162	0.133**	0.0406	0.0339
A x B	8	0.05**	0.057**	0.018**	0.019**	0.05	0.0356**	0.0939	0.093**	0.0809	0.063	0.0921	0.068
Error (b)	24	0.013	0.0071	0.0047	0.004	0.007	0.0061	0.0689	0.028	0.072	0.041	0.0792	0.033

**Significant at 5% level of probability

APPENDIX XXVIII

Analysis of variance for light transmission (%) at 81 DAS during 2010-11 and 2011-12

Source of variance	df	Mean sum of square					
		Light transmission (%)					
		Above canopy		Middle of the canopy		Bottom of the canopy	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	95.68	0.665	0.075	2.919	7.932	0.144
Degree of shade (A)	2	17685.40**	17290.7**	1338.8**	1357.2**	1443.55**	1369.6**
Error (a)	4	95.6	4.319	0.0985	0.32	7.756	2.328
Wheat varieties (B)	4	69.65	1.206	0.555	7.335**	8.064	1.706
A x B	8	77.15	0.794	0.326	2.883	8.648	1.043
Error (b)	24	96.4	1.352	0.724	2.491	7.985	1.356

**Significant at 5% level of probability

APPENDIX XXIX

Analysis of variance for biological, grain and straw yield (q ha^{-1}) and harvest index of crop during 2010-11 and 2011-12

Source of variance	df	Mean sum of square							
		Biological yield		Grain yield		Straw yield		Harvest index (%)	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	5358.9	2756.2	1248	1254.4	7522.1	5973.3	1.314	0.408
Degree of shade (A)	2	72961670.0**	83746700.0**	18831980.0**	20332760.0**	17758730.0**	23909990.0**	166.72**	213.85**
Error (a)	4	27562.9	9493.8	3365.6	4821	2946.5	7816.7	1.021	0.6481
Wheat varieties (B)	4	5662692.0**	241358.2**	1169997.0**	583900.4**	1910717.0**	393301.3**	13.129**	64.30**
A x B	8	316908.3**	27029.29**	168455.8**	111334.9**	442937.4**	405851.8**	21.68**	22.90**
Error (b)	24	52623.6	77814.6	11812.4	19672.4	27038.52	35831.4	1.41	2.062

**Significant at 5% level of probability

APPENDIX XXX

Analysis of variance for Potential shoots m^{-2}, Spike length (cm) and Average number of fertile and sterile spikelets spike^{-1} of crop during 2010-11 and 2011-12

Source of variance	df	Mean sum of square							
		Potential shoots m^{-2}		Spike length (cm)		Fertile spikelets spike^{-1}		Sterile spikelets spike^{-1}	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	204.81	76.53	0.583	0.558	0.0087	0.005	0.0008	0.005
Degree of shade (A)	2	174964.8**	174909.3**	43.58**	2.834**	80.18**	20.92**	14.51**	0.659**
Error (a)	4	260.46	162.66	0.272	0.357	0.0216	0.029	0.0023	0.00019
Wheat varieties (B)	4	6939.20**	6955.88**	4.39**	14.74**	7.372**	11.10**	0.183**	1.226**
A x B	8	6569.96**	6582.4**	0.244	0.135	0.3213**	0.413**	0.514**	0.0269
Error (b)	24	555.03	205.21	0.72	0.582	0.1028	0.115	0.008	0.015

**Significant at 5% level of probability

APPENDIX XXXI

Analysis of variance for Grains spike^{-1}, Grain weight spike^{-1} and 1000 grain weight (g) of crop during 2010-11 and 2011-12

Source of variance	df	Mean sum of square					
		Grains spike^{-1}		Grain weight spike^{-1}		1000 grain weight (g)	
		2010-11	2011-12	2010-11	2011-12	2010-11	2011-12
Replication	2	1.271	0.367	0.0328	0.00009	0.0825	0.05
Degree of shade (A)	2	538.4**	384.18**	1.6807**	0.7191**	367.95**	333.3**
Error (a)	4	2.064	0.677	0.0719	0.0068	0.34	0.165
Wheat varieties (B)	4	33.57**	31.91**	0.2038**	0.194**	33.606**	43.92**
A x B	8	11.8**	25.28**	0.0239	0.019**	3.636**	2.577**
Error (b)	24	1.331	1.575	0.0201	0.0075	1.443	0.74

**Significant at 5% level of probability

VITA

The author was born on April 6, 1985 at Kadathikollumedu village, Mallapuram Post, Palacode Taluk, District Dharmapuri (Tamil Nadu). He passed his High School in 2000 in first and Intermediate in 2002 in first class from GBHS School, Marandahalli, Dharmapuri (Tamil Nadu). He passed his B.Sc. (Agri) degree in 2006 and then M.Sc Ag. (Agronomy) in 2008 from Tamilnadu Agriculture University (TNAU), Coimbatore, Tamil Nadu. Then he joined as a Senior Surveillance Inspector in the Department of Agronomy at the same institute in August, 2008. In 2009, he was admitted as regular student to the college of post graduate studies of Govind Ballabh Pant University of Agriculture & Technology, Pantnagar (U.K) for his Ph.D. degree with major in Agronomy and minor in Plant Physiology.

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Thesis Title	:	"Morpho-physiological bases of shade tolerance in wheat varieties"			
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The present investigation was carried out during *rabi* seasons of 2010-11 and 2011-12 at Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, entitled "Morpho-physiological bases of shade tolerance in wheat varieties". The experiment was laid out in split-plot design with three main-plot treatments *viz,* three degree of shades (full, 2/3 and 1/3 of full sunlight availability) and five sub-plots i.e. wheat varieties (*viz,* UP 2684, UP 2526, UP 2565, UP 2113 and PDW 233) with three replications. The observations were recorded on morphological (i.e. tillering, shoot height, leaf length, leaf width, internodal length and dry weights etc.), physiological (i.e. chlorophyll content, intercellular CO_2 concentration, photosynthetic rate, stomatal conductance and transpiration rate), growth & development and yield and yield attributes of wheat varieties under varying degree of shades. Average grain and straw yield of wheat varieties showed a slightly (51.9 and 35.3 per cent in 2010-11 and 52.3 and 42.0 per cent in 2011-12) reduction under severe shaded treatment, respectively, compare to full sunlight (control). 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. Crop growth rate, relative growth rate, net assimilation rate, leaf area ratio, leaf area index and specific leaf weight varied amongst varieties but was also influenced by varying degree of shades. Among the wheat varieties, PDW 233 yielded maximum grain than other varieties under all the shaded treatments, however, under severe shade choice can be made between PDW 233 and UP 2684. Number of grains/spike, number of fertile spikes/m^2 and 1000 grain weight (g) appeared to be most important yield attributes. Path coefficient analysis revealed that fertile spikelets/spike, grain weight/spike and 1000 grain weight exerted high positive direct effect on grain yield.

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शोध शीर्षक : 'गेहूँ की किरूमसें में छाया सहनशीलता का रूपतामक शारीरिक आधार''
सलाहकार : डा० ओ०पी०एस० बाना

वर्तमान शोध २०१०-११ और २०११-१२ में रबी मौसम के दौरान नॉर्मन ई० बोरलॉग फसल अनुसंधान केन्द्र, गो०ब० पन्त कृषि एवं प्रौद्योगिकी विश्वविद्यालय, पन्तनगर में गेहूँ की किस्मों में छाया सहनषीलता का रूपतामक शारीरिक अधार शीर्षक के अंतर्गत किया गया। यह प्रयोग तीन मुख्य प्लाट उपचार अर्थात तीन स्तर तक छाया करण (पूर्ण, २/३ और १/३ धूप की उपलब्धता) और पॉच उप-प्लाटों अर्थात गेहूँ किस्मों (यूपी २६८४, यूपी २५२६, यूपी २५६५, यूपी २११३ एवं पीडीडब्ल्यू २३३) के तीन प्रतिकृतियों के साथ किया गया। इस प्रयोग में गेहूँ की किस्मों के रूपतामक (अर्थात कल्ले निकलना, अंकुर ऊँचाई, पत्ती की लम्बाई-चौड़ाई, पर्वान्तर की लम्बाई व शुष्क भार इत्यादि), शारीरिक (अर्थात क्लोरोफिल मात्रा, अंतरकोशिकीय कार्बनडाइ-ऑक्साइड सांद्रता, प्रकाश संश्लेषण दर, रन्ध्र संचरण और जलवाष्प दर), वृद्धि व विकास और पैदावार एवं उपज गुणों को बदलते छाया स्तर के अन्तर्गत मापा गया। गेहूँ की किस्मों ने औसत अनाज एवं भूसे की पैदावार में पूर्ण धूप (नियंत्रित) की तुलना में गंभीर छाया उपचार के अंतर्गत अल्प कमी (५१.६ व ३५.३ प्रतिशत २०१०-११ में तथा ५२.३ व ४२.० प्रतिशत २०११-१२ में) दर्शायी। छाया उपचार का गेहूँ की किस्मों की अंकुर ऊँाई, कल्ले निकलना और पर्वान्तर गुणों पर महत्वपूर्ण प्रभाव देखा गया। पूर्ण धूप की तुलना में छाया के बदलते स्तर के अंतर्गत पत्तियों, तने एवम् बाली में शुष्क पदार्थ के संचय होने में कमी देखी गयी। किस्मों के साथ-साथ बदलते छाया के स्तर से भी फसल विकास दर, सापेक्ष वृद्धि दर, कुल आत्मसात दर, पत्ती क्षेत्र अनुपात, पत्ती क्षेत्र सूचकांक और विशिष्ट पत्ती भार प्रभावित होते देखे गये। सभी छाया उपचारों के अंतर्गत पीडीडब्ल्यू २३३ से अन्य किस्मों की तुलना में सबसे अधिक अनाज की पैदावार हुई। अनाज प्रति बाली, उपजाऊ बाली प्रति वर्ग मीटर एवम् १००० अनाज भार सबसे महत्वपूर्ण पैदावार गुण प्रतीत हुये। पथ गुणांक विश्लेषण ने दर्शाया कि उपजाऊ बाली पत्र प्रति बाली, अनाज भार प्रति बाली और १००० अनाज भार का उपज पैदावार पर सीधा उच्च्य सकारात्मक प्रभाव था।

(ओ०पी०एस० बाना)
परामर्शदाता

(पी. लक्ष्मनकुमार)
लेखक