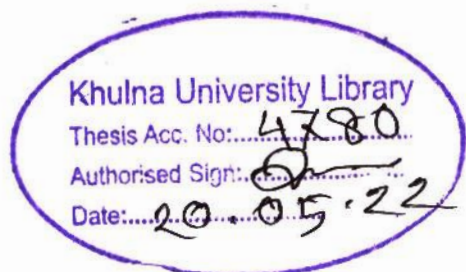


**EFFECT OF RADIATION LEVELS AND PLANT POPULATION
ON GROWTH AND YIELD OF WHEAT (*Triticum aestivum* L.)**



A Thesis

By

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KHULNA UNIVERSITY
KHULNA-9208**

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**DEDICATED TO MY
BELOVED PARENTS**

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ABSTRACT

A field experiment was conducted to study the effect of radiation levels and plant population on growth and yield of wheat at Professor Purnendu Gain Field Laboratory, Agrotechnology Discipline, Khulna University, Khulna during the period from November 2018 to March 2019. The study included four radiation levels viz. S_1 = Full sunlight, S_2 = 75% light (25% reduction of light), S_3 = 55% light (45% reduction of light), S_4 = 25% light (75 % reduction of light) and three plant population density viz. P_1 = 160 plant m^{-2} , P_2 = 200 plant m^{-2} , P_3 = 230 plant m^{-2} . The two factors experiment was laid out in the Randomized Complete Block Design (RCBD) with three replications. The results showed the both radiation levels and plant population exerted significant influence on most of the plant characters studied. The highest grain yield (3.82 t ha^{-1}), highest number of grains (50.27), highest 1000-grain weight (51.88 g), maximum straw yield (4.81 t ha^{-1}) were found in S_1 treatment. In most of the cases the S_2 treatment had almost the similar effect on the plant characters as S_1 treatment. The lowest grain yield (1.88 t ha^{-1}), minimum number of grains per spike (36.04), lowest 1000-grain weight (42.81 g), minimum straw yield (2.85 t ha^{-1}) were found in S_4 treatment. At harvest, the tallest plants were found in S_3 (93.76 cm) treatment. The present study revealed that 230 plant m^{-2} produced the highest grain yield (3.15 t ha^{-1}) which did not differ significantly with 200 plants m^{-2} (2.96 t ha^{-1}). The highest 1000-grain weight (49.03 g) was obtained from 160 plant m^{-2} . Whereas, 160 plant m^{-2} resulted in the lowest grain yield (2.73 t ha^{-1}) and comparatively lower grain number per spike were produced from 230 plant m^{-2} . The plants grown under full sunlight with 230 plant m^{-2} showed the best performance and produced the highest grain yield (3.94 t ha^{-1}). The highest number of grain per spike (52.40) and 1000-grain weight (53.53 g) were observed in P_2S_1 treatment where 200 plant m^{-2} grown under full sunlight. Poor performance showed by plants grown under 25 % of available light at all plant densities and produced the lowest grain yield. The lowest number of grain per spike (34.93), the lowest 1000-grains weight (39.11 g) obtained from P_3S_4 and lowest grain yield was obtained from P_1S_4 where number of plant was 230 per square meter under 25% of full ambient light.

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CHAPTER I

INTRODUCTION

Wheat is a grass widely cultivated for its seed, a cereal grain which is staple food worldwide. Wheat is grown on more land area than any other food crop and the most widely common wheat is *Triticum aestivum*. Extensive extent and high adaptation of this plant as well as its diverse consumptions in the human nutrition lead to present as the most important cereal in the world, especially in developing countries and it can provide 20 percent food resources of the world people (Farzi *et al.*, 2010). In 2016, world production of wheat was 749 million tonnes, making it the most produced cereal after maize. In Bangladesh, wheat is the second most cultivated cereal crop after rice. Farmers in Bangladesh grow wheat fitting the crop in their intensive rice-based cropping system. The acreage of wheat production was 4.29 lakh hectares in fiscal year 2013-2014, according to BBS. As the developing world's appetite for the cereal is growing swiftly, driven in part by rapid urbanization, rising incomes, and more female family members joining the workforce outside of their homes, the demand for wheat-made foods will continue to grow in Bangladesh. Researchers have determined that wheat consumption in Bangladesh will increase dramatically by 2030, with demand growing fastest in urban areas.

Solar radiation is an important climatic factor directly influenced the growth and yield of plants. Light plays a key role in plant life, determining their photo-morphogenesis and photosynthesis rate (Avercheva *et al.*, 2009). The sun emits most of its radiation in the visible range, it covers the range of wavelength from 400-700 nm (Li, *et al.*, 2012). The integration, quality, duration and intensity of red, far-red, blue, UV-A (320–500 nm) and UV-B (280–320 nm) light have a profound influence on plants by triggering physiological reactions to control their growth and development (Briggs *et al.*, 2001; Briggs and Olney, 2001; Clouse, 2001). Because of the potential to be implemented in dynamic lighting strategies to control plant growth, development, physiological responses and production, it is important to learn more about the influence of light quality on these processes (Folta and Childers, 2008; Lefsrud *et al.*, 2008; Massa *et al.*, 2008)

Variation in light intensity affect physiological activity and growth of plants especially the photosynthesis (Drew, 1978). Plants have an optimal intensity of light. This is the point at which the process of photosynthesis is maximized and plant growth is greatest (Lichtenthaler, 1996). Morphological and physiological adaptations tend to take place in response to variations in solar radiation in order to maintain maximum photosynthetic efficiency of leaves. Deficient light intensities tend to reduce plant growth, development and yield (Strain *et al.*, 1985). This is because low amount of solar energy restricts the rate of photosynthesis. Likewise, excessive light intensity should be avoided, it can scorch the leaves and reduce crop yield (Hasanuzzaman *et al.*, 2012).

Receiving sunlight by the plants and using that in plant biomass indicates the fundamental processes which control the crop yield (Purcell *et al.*, 2002). Studying the growth and various crops biomass density has shown that biomass production is dependent on received light during the growth (Wolf *et al.*, 2002; Yano *et al.*, 2007; Asseng *et al.*, 2004).

As a consequence of increases 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). Studies have shown that between 25°N and 45°N, global radiation has been reduced by as much as 1.4–2.7% per decade (Stanhill and Cohen, 2001; Forster *et al.*, 2007). However, continuous cloudy days or rainfall during critical stages of growth, such as panicle differentiation or grain-filling stages, often induce great loss of grain yield and poor grain quality (Liu *et al.*, 2014). Stress caused by low light often creates severe meteorological disasters in some wheat-growing regions worldwide (Liu *et al.*, 2014).

Plant density defines the number of plants per square meter, which in turn determines the area available to each individual plant. Plant density is an important agronomic factor that manipulates micro environment of the field and affect growth, development, and yield formation of crops. Within certain limits, increase of plant population density (PPD) decreases the growth and yield per plant but the reverse occurs for yield per unit area (Rahman *et al.*, 2011). Optimal PPD allows interception of all ($\geq 95\%$) of the available Photosynthetically Active Radiation (PAR) to give the highest yield. No further yield

CHAPTER II

REVIEW OF LITERATURE

2.1 Effect of light on plant characters

Light is an important environmental factor influencing plant growth, development, and secondary metabolism. Under high light conditions, certain plant species, such as bayberry trees, do not grow because light irradiance decreases photosynthetic rates. Plants are dependent on light to generate food, induce the growing cycle and allow for healthy development. Without light (natural or artificial), most plants would not be able to grow or reproduce, photosynthesis would not occur without the energy absorbed from sunlight and there would not be enough oxygen to support life. Deficient light intensities tend to reduce plant growth, development and yield (Abbate *et al.*, 1997). This is because low amount of solar energy restricts the rate of photosynthesis. Below a minimum intensity, the plant falls below the 'compensation point'. Photosynthesis significantly slows down or ceases while respiration continues (Lichtenthaler *et al.*, 1981). Therefore, all plants have their own optimal light intensity ranges for growth. Light intensity that is too high or too low impacts morphology, photosynthetic physiology, and secondary metabolite production.

2.1.1. Effect of light on plant growth characters

Plant biomass, plant height changes under different light conditions. Steinger *et al.* (2003) reported that low radiation intensity can lead to increase of plant height. These adaptations aimed to maximize available light absorption for photosynthesis. Other researches indicated that the response of plants (growth, flowering time and secondary metabolites) to light quality was not the same in different species (Johkan *et al.*, 2012).

Both the plant dry mass (leaf, shoot, root and whole plant) and the number of the leaves responded similarly to light intensity. They were the highest at FAL (Full ambient light) and decreased as much as the plants were shaded. The decrement was 30-50% for the plants which were grown under 25% of FAL. The above results indicated that high-light grown *S. officinalis* plants yielded greater productivity than low-light grown ones just like was shown for several other plants (Zervoudakis *et al.*, 2012; Adamson *et al.*, 1991). However, it has been reported that the intermediate light conditions (about 50% of FAL)

Mitchell (1958), Wassinck *et al.*, (1956) and Dengler (1980) reported that light intensity during the development of a leaf can modify its anatomy and morphology including the number and dimensions of mesophyll cells.

The adaptive traits have also been reported in previous studies for *Datura stramonium* (Qin *et al.* 2014) and *Brassica napus* L. (Yao *et al.*, 2017). Plant leaf structure is influenced by environmental factors. Many researches showed that there is a flexible change before the change of external conditions, especially under the influence of light. The parameters such as thickness of the leaf, palisade tissue, and spongy tissue and the PT/ST in *Radix bupleuri* were reduced under shade conditions.

Longer and thinner plants, increased area of leaf blades, and increased shoot to root ratios have been observed under shading (Li *et al.*, 2010). In addition, light fractions distribute 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).

Liphan and Detpiratmongkol (2017) reported that number of branches plant⁻¹ varied significantly among the varieties at harvest. The highest number of branches plant⁻¹ (25.33) was recorded in the variety Prachinburi and the lowest number of branches plant⁻¹ (19.73) was recorded from the variety Phisanulok 5-4. Kalmegh grown at 0% shading had significantly ($P < 0.05$) higher number of branches plant⁻¹ when compared to those shaded at 40%, 50% and 80% levels, respectively. Shivashankara *et al.*, (2000) reported that 10-60% light curtailment produced higher internodal length, increase in number of branches, leaf number in betel vine (*Piper betle*).

Ren *et al.* (2013) and Liu *et al.* 2009) reported that a lack of adequate light strongly influences not only the duration of growth but also some agronomic traits of rice. For example, low light results in a prolonged period of growth and also increases plant height and leaf area.

Low light results in a reduction in the amount of dry matter produced in shoots and roots, as well as a lower overall dry matter weight for rice plants (Liu *et al.*, 2014). The rate of dry matter weight in shoots to the total (shoots + roots) in rice plants increases under low light conditions, suggesting that dry matter weight in roots decreases more than that of shoots. Similarly, an increased rate of dry matter weight in culm to the total

Rice grown in shaded plots have a higher percentage of missing hills than those grown in un-shaded plots. As a result, shaded plots give lower yield than the un-shaded plots (Moula and Golam, 2009). Although the shade effect on yield of agricultural crops are reported elsewhere (Willeng and Holiday, 1971; Quddus and Pendleton, 1991), there is no available report on the same in Bangladesh.

Mu *et al.* (2010) found that grain yield losses and leaf area index (LAI) reduction were less than the reduction in solar radiation under both shading treatment in two cultivars of wheat in China. Compared with the control (S_0), grain yield only reduced 6.4 % and 9.9 % under 22 % shading treatment (S_1), while 16.2 % and 25.8 % under 33 % shading (S_2) in two cultivars namely Yangmai 158 and Yangmai 11 respectively.

Jenner *et al.* (1979), for instance, showed that the reduction in grain weight per ear resulting from a period of dim lighting soon after anthesis was due to both components being reduced by about the same extent. Despite the fact that accumulation of dry matter in the endosperm does not begin until a few days (3-5) after anthesis, and requires several more days to achieve its maximum rate, grain weight is nevertheless responsive to the level of irradiance during the period immediately following anthesis (Ford and Thorne 1975). Conceivably such a response could arise in a number of different ways. Shading, even for brief periods, might, for example, result later in a reduction in the provision of assimilates for grain-filling. Alternatively, shading could influence other processes, such as those involved in the early stages of the growth of the grain, and in turn result in the deposition of less dry matter.

Before the heading stage, low light gives rise to a pronounced decrease in fertile panicles of rice plants. After the heading stage, shading causes impairment of the net photosynthetic rate as well as lower dry matter accumulation and sink capacity in rice plants, and this significantly reduces the number of filled grains and 1000-grain weight, thereby leading to decreased grain yield (Brewster, 1986; Wang *et al.*, 2015; Liu *et al.*, 2009). Low light after the heading stage also results in poor appearances of rice grain and milling qualities, including a high percentage of chalky grains and also a reduced head yield. This may be primarily attributed to an insufficient supply of assimilates and decrease activity of a soluble starch branching enzyme involved in starch synthesis in grains (Liu *et al.*, 2014; Miizuno *et al.*, 1992; Li *et al.*, 1997; Ren *et al.*, 2003).

Light penetration into soybean canopy leads into later lower canopy leaves fall and increase the seed yield (Shafiq *et al.*, 2006). Leaf area index increases the soybean yield during procreation and especially during grain filling stage (Kaushal *et al.*, 2006).

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 (Abbate *et al.*, 1997). Spike growth period was defined as the interval during which spikes achieved from 5% to 100% of the dry weight they accumulated by day 7 after anthesis excluding grain weight. Radiation level during this period affected yield mainly through variation in number of grains m^{-2} (Abbate *et al.*, 1997). The adequacy of supply was quantified by means of dry weight of spikes 7 days after anthesis, excluding grain weight. Grain number m^{-2} was related to such dry weight of spikes. Shading well-watered crops has made it possible to identify the development stages when radiation is most critical for grain yield. Willey and Holliday (1971) and Fischer (1975) found that applying shade to spring wheat during 30 days preceding anthesis (during the spike growth period), caused an appreciable decrease in yield by reducing number of grains m^{-2} . Shading during the grain-filling period also depresses yield by decreasing weight per grain, but the response varies substantially according to environment.

The major effect of shading was to reduce number of grains m^{-2} without any effect on weight per grain. Green area index and intercepted PAR at the beginning of grain filling were alike with and without shading, except for the 85% shade treatment. Pre-anthesis shading could have reduced the reserves of assimilates by the beginning 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 per grain in shading treatments did not increase. This stability in weight per grain under changes in radiation during the spike growth period can be attributed to yield being limited by number of sinks, both in shaded and un-shaded treatments, for the sink range obtained in the experiments reported. Grain number m^{-2} related much more strongly to crop growth during the spike growth period ($r=0.96$, $df=7$) than to crop dry weight at the beginning ($r=0.38$) or the end of the period ($r=0.85$). As incident radiation was the main factor determining crop growth, grain number m^{-2} was linearly related to intercepted PAR during the spike growth period.

Under adequate supply of water and nutrients, wheat yield has been shown to be closely related to the amount of radiation intercepted during the growing season. Gallagher and Biscoe (1978) found that 3 g dry matter of wheat was produced by each mega joule (MJ) of photosynthetically active radiation (PAR) absorbed until the emergence of ear.

Studies revealed that rice plants grown under low light from the transplanting to the booting stages exhibit a 34.51% reduction in grain yield partly caused by a considerable decrease in the numbers of fertile panicles and grains per panicle produced (Liu *et al.*, 2009). When exposed to low light for 10 d (starting from the heading stage), rice grain yield decreases by 14.99% because the seed-setting rate is significantly reduced. When grown under low light from the initial heading to maturity stages, rice grain yield decreases markedly (by 55.45%), which is directly ascribed to significant decreases in the seed setting rate and 1000-grain weight.

Similar data was published by Matsushima *et al.* (1953), Janardhan *et al.* (1980), Nayak and Minor (1980) and Voleti and Singh (1996). These results confirm that low light conditions during the panicle differentiation or grain-filling stages exert a greater adverse effect on rice grain yield than that during other growth stages, which better explains the greater loss in grain yield caused by low light during the reproductive stage (Matsushima *et al.*, 1953).

Under low light conditions, rice plants mainly receive diffused light including higher amounts of blue-purple light but lower amount of red light, and this may be associated with impaired photosynthesis and reduced photosynthetic production (Cooperative Group, 1995). Additionally, low light inhibits the translocation of assimilates from source organs to sink organs (grains) (Ota *et al.*, 1959; Nayak and Minor, 1980). Other researchers found the responses of grain yield to low light differ for various varieties (Janardhan and Murty, 1980; Nayak and Minor, 1980; Voleti and Singh, 2007). In spite of detrimental effects on carbohydrate accumulation and transportation caused by low light, tolerant varieties maintain their carbohydrate production levels, due to higher chlorophyll content and efficiency in photosynthesis, and stronger antioxidant ability, which makes them more adaptable to low light conditions (Nayak *et al.*, 2008; Nayak and Minor, 1980; Liu *et al.*, 2012).

Heavy shading treatments were found to reduce grain yield. In contrast, low-intensity shading increased grain yield.

2.2 Effect of plant population on plant characters

The plant density and plant distribution have a key role in maximizing dry matter production by internal and external plant competition (Ferreira and Abreu, 2001). They noticed that light absorption and grain yield of crops increased significantly under uniform plant distribution. Adjustment of seeding schemes is one of the crop management techniques that most influences grain yield components. This work aimed to characterize the potential grain yield and its components in wheat (*Triticum aestivum* L.) genotypes with contrasting tillering ability under different seeding densities and environments. Seeding density is important for the wheat (*Triticum aestivum* L.) crop, since it directly affects the number of ears per unit area. As a consequence, other yield components such as the number of grains per ear and individual grain weight (Davidson and Chevalier, 1990; Lloveras *et al.*, 2004; Ozturk *et al.*, 2006). The ability of wheat and other cold-season cereals to compensate the lack or excess of a yield component through changes in the other components is essential for their best performance (Freeze and Bacon, 1990). Such compensation can maximize the yield potential of the species per unit area, depending on the genotype, the environment and their interaction. Currently, the seeding density used for the wheat ranges from 250 to 400 viable seeds per square meter. This is based on the cultivar cycle, as well as its dual ability as a forage and grain crop (Comissão Brasileira de Pesquisa de Trigo, 2007).

2.2.1 Effect of plant population on plant growth characters

Optimum plant population is the prerequisite for obtaining maximum yield (Trenton *et al.*, 2006; Gustavo *et al.*, 2006). In dense population most plants remain barren, ear and ear size remain smaller, crop become susceptible to lodging, disease and pest; while plant population at suboptimum level resulted lower yield per unit area (Nasir, 2000). In case of low plant density, yield per unit area is reduced because of lesser than optimum plants (Cardwell, 1982).

Sharma and Adamu (1984) reported that plant height was maximum at highest population. Yadav and Warsi (1986) also confirmed these results who reported that plant height decreased with low planting density and vice versa. Height of the crop is mainly controlled by the genetic makeup of a genotype and it can also be affected by the environmental factors (Shahzad *et al.*, 2007). In case of seeding rates, the maximum plant

height (103.3 cm) was observed with seed rate of 150 kg ha⁻¹ followed by 175 kg seed ha⁻¹ which produced plants of 93.2 cm (Baloch *et al.*, 2010).

The economic yield of most of the cereals is determined by the number of tillers. It has the great agronomic importance as this may compensate the difference in number of plants, partially or totally after crop establishment and may allow crop recovery from early frost (Acevedo *et al.*, 1998). Different seed rates significantly increased the number of tillers wherein, the use of 200 kg seed ha⁻¹ produced higher number of tillers (311.8 m⁻²) closely followed by 150 kg seed ha⁻¹ with 306 number of tillers m⁻² (Baloch *et al.*, 2010).

The proper leaf area index (LAI) and consequently a maximum light absorption can be obtained in an optimal plant density (Agele *et al.*, 2007). Increasing plant density enhanced the LAI of per unit area but the LAI of individual plant declined might be due to competition between plants in unit area. Similar results were also reported by (Raja, 2001; Khayam *et al.*, 2002 and Fathi, 2005). Diepenbrok *et al.*, (2001) in their studies on sweet corn, sugarbeet and sunflower found that increasing plant density per unit area enhanced the LAI per unit area, thereby decreasing competition between plants for light absorption. Yoshida (1991) also reported that dense planting maximizes the leaf area index (LAI), ensuring that plant photosynthesis meets the high yield requirements.

In wheat, the number of spikelets per spike changes under different planting densities. Qu *et al.* reported that grain yield was improved with increasing plant density as a result of the increased spikelets number.

2.2.2 Effect of plant population on radiation absorption

There was significant difference among different cultivars in terms of light absorption under various plant densities. The higher level of light absorption was recorded under the plant density of 12 plants m⁻², whereas minimum light absorption was observed under the plant density of 6 plants m⁻². All this shows that increasing number of plants in each row contributes to more photosynthesis per unit area and finally higher light absorption. Similar results were also reported by Riahinia and Dehdashti (2008). During reproductive stage, higher radiation was absorbed by top leaves under higher plant densities. Thereafter when senescence of leaves began the radiation absorption also declined. At this stage,

factors such as rate of gross photosynthesis and respiration determine the accumulation of dry matter in plants (Asseng *et al.*, 2004).

2.2.3 Effect of plant population on dry matter and yield

The levels of plant density significantly affected the dry matter production at flowering stage. Ferreira and Souza (2001) in maize and Sedghi *et al.* (2008) in sunflower also reported that both LAI and dry matter accumulation increased with increasing plant density. Rao *et al.* (1991) in oilseed rape found that with increasing plant density the value of LAI and dry matter also increase.

Agele *et al.* (2007) showed that there was a significant relation between plant density and yield of sunflower hybrid Cms-26×R103. However, light extinction coefficient (K) though depends on the plant genotypes due to their physiological, morphological habits and their stage of growth but plant density has the main role (Maddoni *et al.*, 2001).

Increased plant population could lead to increased yields of maize under optimal climatic and management conditions due to greater number of smaller cobs per unit area (Bavec and Bavec, 2002). Zaffaroni and Schneiter (1991) reported that with increasing plant density in rapeseed, the light absorption and dry matter production maximized in a short time in comparison to low plant density. Nakano *et al.* (2012) also reported that dense planting might increase the grain yield, the percentage of filled spikelets, and the 1000-grain weight in forage rice (*Oryza sativa* L.). However, some studies have reported that dense planting does not necessarily increase the grain yield. At low plant population the reproductive sink capacity of individual plant are greater as compared to high plant population. Significant differences among plant population have been reported by Das and Kashyapi (1984).

Shafi *et al.*, (2012) reported that highest plant population had a negative impact on ear length. This may be due to the fact that available nutrients, moisture, space and light become limited in high plant population due to high competition of soil resources between plants. Ultimately plants produced relatively small ears. Similar results were reported by Chakor and Awasthi (1983); Esechie (1992) and Hassan (2000). They observed that ear length decreased with increase in plant population.

Number of grains ear⁻¹ contributes to the economic yield as well as represent the productive efficiency of any cereal crop or crop variety. Grains ear⁻¹ was significantly

($p < 0.05$) affected by planting density and varieties while their interactions were non-significant ($p > 0.05$). Highest plant density negatively affected number of grains ear⁻¹. With increasing plant population, number of grains ear⁻¹ decreased in a linear manner reported by Mohammad shafi *et al.*, (2012). This could be due to the fact that in high planting density, photosynthetic capability of plants was reduced due to the low light interception that negatively affected number of grains ear⁻¹. These results are in line with Esechie (1992) and Zada (1998) who found that the number of grains ear⁻¹ decreased with increasing plant density.

The maximum 1000-grain weight (38.7 g) of wheat was obtained when normal seed rate of 100 kg ha⁻¹ was used. Further increase in seed rate did not show any positive effect on grain weight (Baloch *et al.*, 2010). This might be due to bulk planting density on account of higher seed rates used that eventually declined the seed weight. Sharma & Adamu (1984) also reported that grain weight ear⁻¹ was highest at lowest plant population. The results are in accordance with the findings of Shahzad *et al.* (2007) who also observed that earlier sowing resulted in better development of the grain due to longer growing period.

The use of 150 kg wheat seed ha⁻¹ produced higher grain yield of 5103.3 kg ha⁻¹ than other seeding rates used (Baloch *et al.*, 2010). Further increase in seed rate did not improve grain yield because the dense wheat population creates keen competition between plants for nutrients, moisture etc. which leads to the decrease in grain yield (Ragasits, 1998).

Biological yield is a major contributor to total output of any crop and dependent upon crop management, type of variety and various other factors. Akbar *et al.*, (2002) reported that biological yield of wheat was significantly ($p < 0.05$) increased at 180000 plants ha⁻¹. These results are consistent with the findings of Plensicar & Kustori (2005) who reported that maximum biological yield was found at higher planting density.

Harvest index is the partitioning of dry matter by plant among biological and economic yield. Planting density had a significant effect ($p < 0.05$) on harvest index. Highest harvest index was observed in the treatment of 65000 plants ha⁻¹ and lowest in 45000 plants ha⁻¹ reported by Mohammad shafi *et al.* (2012). The reasons for such results could be better utilization of available nutrients by maize plants in highest plant population as compared to lowest plant population. In lowest plant population, weeds also compete with crop for

nutrients. Highest plant population produced more grain and thus resulted in maximum harvest index. Ahmad & Khan (2002) reported that increase in plant density significantly increased harvest index.

It has been noted that the increase of seeding rate at early and optimal sowing time is unfavourable, but the negative effect of late sowing could be compensated by the increase of seed quantity (Pan *et al.*, 1994) up to a certain stage of plant growth. Hiltbrunner *et al.* (2007) advocated that a rationale increase of the seeding density with that of sowing time is an effective mean to increase the grain yield.

2.3 Interactive effects of light and planting density on the growth and yield

Davidson and Donald (1958) and Watson (1958) have observed that percent of light interception in crops were dependent on planting pattern, plant density, leaf arrangement and leaf shape.

An experiment was conducted to investigate the effect of different planting density and light intensities on the growth and yield of soybean. This was with the view to provide appropriate information on planting densities and actual light intensities required for the growth and yield. A screen house was constructed to maintain the radiations emitted to the plant. The intensity of light was also determined using a digital luxmeter LX 1000. The intensities of average light determined were 5764 (100%) and 3517 (61%). The four treatments of light regimes are $L_1 = 100\%$ light, $L_2 = 61\%$ light, $L_{10} = 5$ weeks in 100% light, thereafter in 61% light and $L_{20} = 5$ weeks in 61% light, thereafter in 100% light. The seeds of the soybean were sown at the rate of five seeds (P_5), three seeds (P_3) and one seed (P_1). They were watered daily with 200 ml of tap water in the morning and 200 ml of tap water in the evening until they were fully established. The results obtained showed shoot height, number of leaves and leaf area of soybeans were more enhanced under 61% light or partial light intensity and when sown at the rate three seeds (P_3). The yield components of soybean were more enhanced when placed in 5 weeks in 100% light, thereafter in 61% light and when sown at the rate three seeds (P_3). This study concluded that better growth and yield were obtained with partial light (L_2) with three planting density (P_3) reported by Olowolaju *et al.* (2017)

In another experiment, the relationship between dry matter production and intercepted photosynthetically active radiation (PAR) was highly significant and linear throughout the

growing season. Yield variation among treatments caused by affecting both the amount of intercepted PAR and radiation use efficiency reported by Muhammad Rafiq *et al.* (2004). The fraction of radiation intercepted by crops increase hyperbolically with LAI, interception of radiation increase when LAI increase reported by (Scott and Jaggard, 1978; Milford *et al.*, 1980). The relationship has been used as a basis for theoretical investigations into tropical crop productivity and the importance of light as a limiting factor in crop performance reported by (Monteith, 1972, 1973, 1981).

Francescangeli *et al.*, (2006) reported that plant density affected the intercepted PAR. There were no effects on vegetative reproductive periods, the total and final leaves and fresh diameter of broccoli. The magnitude and evolution of leaf area (LA) was independent of plant density up to 70 days after transplanting (DAT). Since then on, LA increased linearly with plant density. As plant density increase, degree of shading increased, net assimilation rate decreased and leaf area ratio increased.

Increased population density of wheat per unit area and closer row spacing increase the percentage of light intercepted. Light interception and dry matter production were closely associated to the number of seeds planted per unit area. Dry matter production was proportionally higher with increased light interception. The number of tillers increased as the light interception increased until 30-40% reported by Mapangada Chengappa Ganapathy (1968). By increasing plant population per acre and reducing the row spacing in corn, Pendleton *et al.*, (1966) and Aubertin and Peters (1961) observed less light reached the ground.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with materials and methods that were used in carrying out the experiment. It consists of a short description of locations of the experimental site, characteristics of soil, climate, materials used for the experiment, raising of seedlings, treatments of the investigation, layout and design, raising of seedlings, treatments of the investigation, layout and design, raising of crop, harvesting, data collection procedure and statistical analysis of collected data which have been described under the following subheads:

3.1 Experimental site

The field experiment was carried out at Professor Purnendu Gain Field Laboratory, Agrotechnology Discipline, Khulna University, Khulna during the period from November 2018 to March 2019 to study the effect of radiation levels and plant population on growth and yield of wheat. Soil was clay loam in texture having a pH of 7.5.

3.2 Climate and weather

Experimental area was under the sub-tropical monsoon climate, which is characterized by high temperature, heavy rainfall, high humidity and relatively long day during the months April to September (Kharif season) and low rainfall, associated with low temperature, low humidity and short day during the rest of the year. Plenty of sunshine and moderately low temperature prevails during Rabi season (October to March), which are suitable for growing wheat in Bangladesh.

3.3 Materials used for the experiment

The variety of wheat used in the experiment is BARI Gom 25 collected from Bangladesh Agricultural Research Institute (BARI), Joydebpur, Gazipur 1701. The following are the characteristics of BARI Gom 25 (BARI 2012):

The variety is semi-dwarf, early maturing and high yielding variety, suitable for the southern region of the country and low and medium salt tolerant variety ($8-10 \text{ dsm}^{-1}$). Panicle initiation time 57-61 days, spike long, grain/panicle 45/50, grain color is white,

glossy and large size, 1000-grain weight 54-58 g. Crop duration is 102-110 days and yield 3800-5000kg/ha optimum condition.

3.4 Design of Experiment

The two factor experiment was laid out in Randomized Complete Block Design (RCBD) with three replications.

3.5 Treatments

The study comprised of two factors as follows:

Factor A: Solar radiation levels -04

S_1 = Full sunlight

S_2 = 75% light (25% reduction of light)

S_3 = 55% light (45% reduction of light)

S_4 = 25% light (75 %reduction of light)

Factor B: Plant population -03

P_1 = 160 plant m^{-2}

P_2 = 200 plant m^{-2}

P_3 = 230 plant m^{-2}

3.6 Layout and design of the experiment

The experiment was laid out in the two factor randomized complete block design (RCBD) with three replications. The size of a unit plot was 3.0 m x 2.0 m. The distance between two plots was 1m and between two blocks was 1m.

3.7 Land preparation

The land where experiment was conducted ploughed and cross ploughed three times followed by breaking clods and laddering to obtain desirable tilth. The corners of the land were trimmed with a spad and all the weeds and stubbles were removed from the field. Finally the land was leveled and divided into blocks and plots maintaining the recommended distances.

3.8 Seed sowing

The seeds were sown directly on the plots on November 16, 2018. The amount of seed for each plot was measured according to the plant population maintained in the treatment section. The seeds were sown in the plots by continuous seed sowing maintaining 20 cm line spacing. Soil of the plots was well prepared and converted into loose friable. To inhibit the infestation of damping off disease, the seed beds were dried in the sun. Cow dung was applied to the prepared seed beds @ 7 t/ha. After sowing seeds were covered with fine light soil to protect the young seedlings from scorching sunshine and heavy rainfall. Weeding and light irrigation were done from time to time for maintaining favorable environmental condition for raising healthy seedlings.

3.9 Plant population density

In this experiment three different plant population rate were used to observe the effect of different plant population density on growth and yield of wheat. During the period of sowing the optimum seed rate was taken for P_2 treatment, the optimum seed rate was reduced and increased in P_1 and P_3 treatment respectively. Then, before tillering stage the plant population was maintained to get the desired plant population density in each treatment.

The three plant population rate used were: 160, 200 and 230 plant m^{-2}

3.10 Process of maintaining radiation levels

For making different levels of light intensity in the experimental field, net and clothe were used one layer or two layers. The screens were set over the plant for reducing light intensity on the plants. In the experiment the radiation levels were maintained as follows:

S_1 = No screen (Full sunlight)

S_2 = One layer of net (75% light)

S_3 = Two layer of net (55% light)

S_4 = Two layer of markin cloth (25% light)

The screens were set at 35 DAS.

3.11 Measurement of light intensity

The light intensity of the field area where the experiment was done measured by using luxmeter when first the screens were set then later after 15 days interval at noon usually. The light intensity of the open field, upper canopy and in the lower canopy was measured to observe the radiation interception of the plant population.

3.12 Fertilizer Application

Inorganic fertilizers and cow dung were applied at the doses mentioned in the table below:

Table 1: Fertilizer doses

Crop Name	Amount (kg/ha)				
	Urea	TSP	MoP	Gypsum	CD
Wheat	220	160	45	115	7000

In the wheat crop, full cow dung, TSP, MoP and gypsum were broadcasted and incorporated during final land preparation. Remaining urea was applied in two equal installments at 20 and 40 days after sowing.

3.13 Intercultural operations

3.13.1 Gap filling

Seedlings were kept under careful observation after sowing. Some seedlings were damaged and those were replaced. Replacement was done with healthy seedlings. Gap filling was done as and when necessary to maintain the optimum plant population.

3.13.2 Irrigation

In case of Wheat: Irrigation was done on the regular basis until the plants were fully established then irrigation was done when the soil moisture content reduced as per water requirement of the crop.

3.13.3 Weed Control

In order to keep the crop weed free two manual weeding was done through hand pulling, nirani and khurpi as and when necessary.

3.13.4 Insect control

During the experiment insect infestation was occurred in the wheat field. The insects attacked the wheat field were field cricket, mole cricket and aphid and to control the insects insecticides namely carbofuran and malathion were used.

3.14 Harvesting and processing

The experimental crop was harvested plot wise (1m^2) at maturity when leaf and spikelets became yellow and the grain is in hard dough stage in 9 March 2019. Five plants were randomly selected from 1m^2 of each plot prior to harvest for data collection on plant characteristics, grain yield and its components. The harvested crop from 1m^2 of each plot were bundled separately, tagged and taken to the threshing floor. These were dried in bright sunshine. Threshing was done manually and drying the grains. The grains were cleaned properly. Grains and straw were thoroughly dried before their weights were recorded.

3.15 Parameter studied

3.15.1 Growth studies

3.15.1.1 Plant height (cm)

Five plants were randomly selected from 1m^2 of each plot. The height of these plants was measured at 45 DAS, 60 DAS, 75 DAS, 90 DAS and at harvesting from the base of plant to the tip of upper most leaf. Average value of five plants expressed as mean plant height in centimeters

3.15.1.2 Number of leaves per plant

The total number of leaves of five randomly selected plants from 1m^2 of each plot was counted at 45 DAS, 60 DAS, 75 DAS and 90 DAS and the mean number of leaf per plant were worked out by dividing the total number of leaves by five.



3.15.1.3 Number of tillers per plant

The total number of tillers of five randomly selected plants from 1m^2 of each plot was counted at 45 DAS, 60 DAS, 75 DAS and 90 DAS and the mean number of tillers per plant was calculated by dividing the total number of tillers by five.

3.15.1.4 Total dry matter per plant

The total dry matter of five randomly selected plants from 1m^2 of each plot was taken at 45 DAS, 60 DAS, 75 DAS and 90 DAS and the mean weight of dry matter was calculated by dividing the total dry matter weight.

3.15.1.5 Spike length

Five plants were randomly selected from 1m^2 of each plot. The length of the spike was measured at harvest. Average value of spike length of five plants expressed as mean plant spike length in centimeters.

3.15.1.6 Number of spikelet per spike

The total number of spikelet per spike of five randomly selected plants from 1m^2 of each plot was counted and the mean number of spikelet per spike per plant at 45 DAS, 60 DAS, 75 DAS and 90 DAS was calculated by dividing the total number of spikelet per spike by five.

3.15.2. Yield contributing characters and yield

3.15.2.1 Number of grains per spike

Five randomly selected plants from each net plot were taken and threshed. The grains were cleaned and counted. The mean value of five plants was given as grains per plant.

3.15.2.2 1000-grain weight

Grain samples from 1m^2 of each plot were collected at random from the grain yield of each plot and 1000 grains were counted. The samples were thoroughly dried and weighted to record 1000-grain weight in grams.

3.15.2.3 Grain yield

The wheat crop each plot was harvested with the help of sickles and sun dried in respective plots. The produce was threshed manually, winnowed, dried in sun and clean grains were separated. The grain weight thus obtained was taken and calculated by converting the weight of grain of a plot in hectare and was expressed in t/ha. Grain yield was measured by the following formula:

Weight of grains of all the plants (crops) in a plot was taken and grain yield per hectare was calculated

3.15.2.3 Straw yield

Straw yield was worked out by subtracting the grain yield from biological yield and expressed in kilograms per hectare by converting the weight of grains of a plot into hectare and was expressed in t/ha.

3.15.2.3 Biological yield

The crop from the net plot area was harvested and dried in sun for 2-3 days in respective plots. It was weighted to record the biological yield and expressed in ton per hectare

3.15.2.4 Harvest index

Harvest index of crop was determined by working out the ratio of grain to biological yield of individual plot and was expressed in per cent. The following standard formula was employed for the calculation of harvest index.

$$\text{Harvest index} = \frac{\text{Grain Yield}}{\text{Biological yield}} \times 100$$

3.16 Statistical analysis

The collected data on various parameters under study were statistically analyzed using Statistix 10 statistical programme to find out the significance of differences between treatment and treatment combination. Means for all the treatments were calculated and analyses of variances (ANOVA) for all the characters under consideration were performed by F-test. Significance of differences between pairs of treatment means were evaluated by Duncan's Multiple Range Test (Gomez and Gomez, 198

CHAPTER IV

RESULT AND DISCUSSION

Growth and yield of wheat depends on various environmental factors like light, temperature, moisture etc. and also on different agronomic practices among which maintaining the plant population number is a very important. The presented research was conducted to study the effect of radiation levels and plant population on the growth and yield of wheat. Results of the analysis of variance in respect of all parameters obtained from the present investigation have been presented and discussed in this chapter. The data have been presented in the table for ease of discussion and understanding.

4. Effect on growth parameters

4.1 Plant height

It was evident from the results of the experiment that plant height significantly varied with the radiation levels (Fig. 1 and Appendix 2). The maximum plant height was recorded from the crop grown in open sunlight S_1 (65.02 cm) followed by S_2 (60.08 cm) where 75% light and S_3 treatment (59.53 cm) where 55% light was available to the plant. The lowest plant height was recorded in the S_4 treatment (53.07 cm) where 25% light was available to the plant at 45 DAS. At 60 DAS the maximum plant height was recorded from the crop grown in open sunlight S_1 (87.71 cm) and the lowest plant height was recorded from S_4 (70.71 cm). At 75 DAS, maximum plant height obtained from S_1 (93.26 cm) which is similar to S_3 (91.556 cm) treatment followed by S_2 (87.49 cm) treatment and the lowest plant height was recorded from S_4 treatment (85.87 cm). At 90 DAS, maximum plant height obtained from S_1 (95.04 cm) which is statistically similar to S_2 (93.79 cm) and S_3 (94.44 cm) and the minimum height was obtained from S_4 (87.41 cm). At harvest the tallest plant was recorded in S_3 (93.76 cm) which was statistically similar to the S_1 (91.66 cm) and S_2 (90.89 cm) treatment and the shortest plant was recorded from S_4 (89.50 cm) treatment.

In this study plants grow under full sunlight was shown to have the highest height from the beginning to the maturity. Plants grow in 75% of light and 55% of sunlight attain higher height and had statistically similar height from 60 DAS to harvest but the plant grown in 25% of light had the lowest height at all stages. The reason may be at later

stage plants grown at 55% of light adapt themselves to this level of light and they grow tall. These findings were in agreement with studies by different scientists on other plants (Yang *et al.*, 2007; Wang *et al.*, 2009) and resembled to etiolated grown plants which have unusually tall appearance (Taiz and Zeiger 2002). The lowest height observed in the S₄ where only 25% light was available to the plant which might be due to more reduction of light, which was not sufficient for normal growth of plant.

The effect of plant population on plant height was significantly varied (Fig. 2 and Appendix 2). The highest plant height was recorded in P₂ (62.95 cm) where number of plant were 200 plant m⁻² which is statistically similar to P₃ (60.75 cm) where number of plant were 230 plant m⁻² and the lowest plant height was recorded in P₁ (54.58 cm) treatment where number of plant was 160 plant m⁻² at 45 DAS. At 60 DAS maximum plant height was obtained from P₃ (84.20 cm) which was statistically similar to the P₂ (83.08 cm) treatment and the lowest plant height was obtained from the P₁ (75.15 cm) treatment. At 75 DAS the highest plant height recorded in P₃ (91.55 cm) treatment which is similar to the P₂ (90.97 cm) treatment and the lowest plant height was obtained from P₁ (86.84 cm) treatment. At 90 DAS maximum plant height was obtained from P₃ (94.03 cm) treatment which is statistically similar to P₂ (93.34 cm) treatment and the lowest plant height was obtained from P₁ (91.23 cm) treatment. At harvest plant population had no significant effect on plant height. However, numerically the highest plant height was recorded in P₃ (92.37 cm) and the lowest from P₁ (89.30 cm) treatment. This might be due to plant density, because plant density influences the plant height. Competition between plants in P₃ treatment was more, which influence the plant height. At the earlier stages, plant height was lower in treatment with lower plant populations. But at the later stages plants in lower population recover their height using higher space, light and other growth factors. Finally, plant height was statically similar at harvest. Sharma & Adamu (1984) reported that plant height was maximum at highest population. Yadav & Warsi (1986) also confirmed these results who reported that plant height decreased with low planting density and vice versa.

The combined effect of radiation levels and plant population showed significant variation on plant height (Table 2 and Appendix 2). At 45 DAS, 75 DAS, 90 DAS and at harvest the highest plant height was recorded from the treatment P_3S_3 but at 60 DAS, the highest plant height was obtained from the treatment P_2S_1 (91.40 cm) which is statistically similar to P_3S_3 (90.07 cm) combination. At 60 DAS, 75 DAS, 90 DAS and at harvest the lowest plant height was recorded from the treatment combination P_1S_4 while at 45 DAS the lowest plant height was recorded from the treatment combination P_3S_4 (44.73 cm) which is statistically similar to P_1S_4 (49.33 cm). At low level of radiation (25%), all plant densities had low plant height because of deficiency of adequate light for normal growth of plants. In general, full sunlight (S_1) enhances higher plant height in all plant densities.

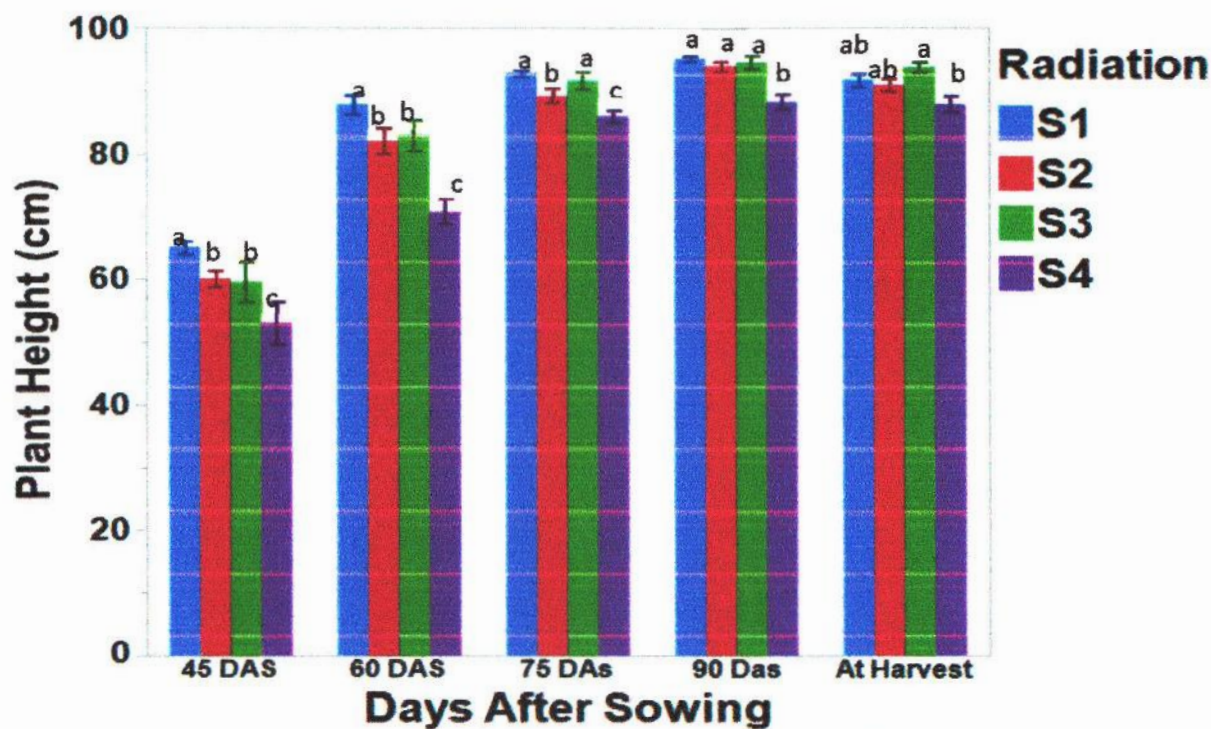


Fig. 1: Effect of radiation levels on plant height (cm) of wheat at different DAS

[S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

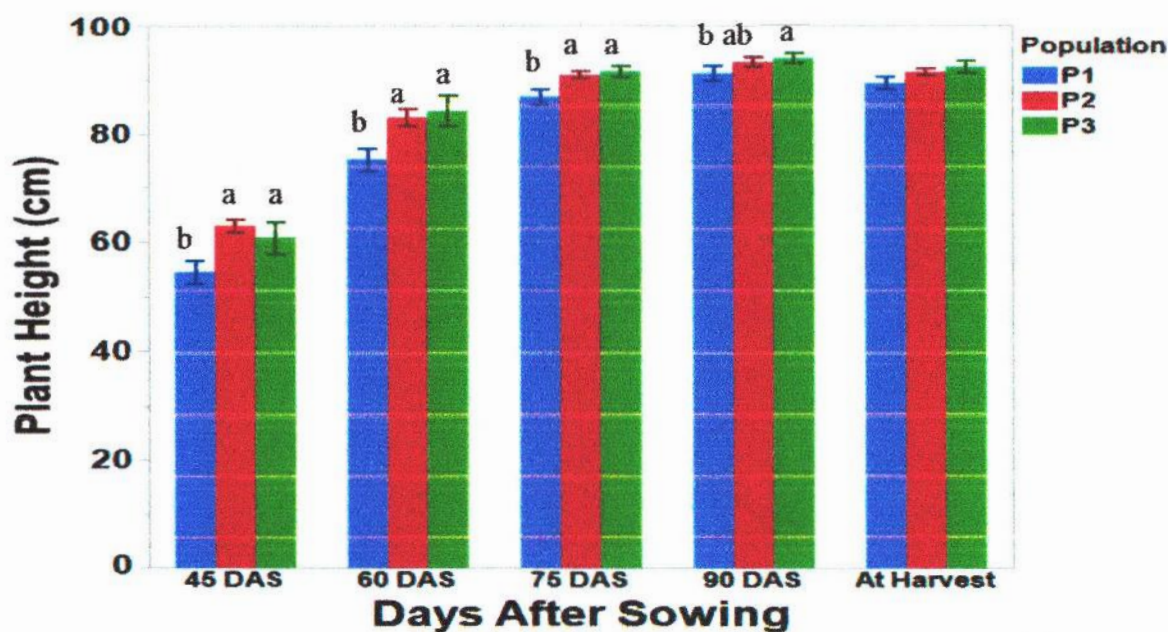


Fig.2: Effect of plant population on plant height (cm) of wheat at different DAS

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻²]

Table 2. Interaction effect of radiation levels and plant population on plant height of wheat at different DAS

Treatment Combination	Plant height (cm)				
	45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
P ₁ S ₁	62.33a	82.67abc	92.13ab	95.33a	91.27 ab
P ₂ S ₁	65.33a	91.40a	93.33ab	94.60ab	91.30 ab
P ₃ S ₁	67.40a	89.07ab	92.67ab	95.20a	92.40 ab
P ₁ S ₂	58.40abc	76.53cd	84.77cd	92.20ab	89.72 ab
P ₂ S ₂	59.65ab	81.67bc	90.87abc	95.67a	90.50 ab
P ₃ S ₂	62.19a	87.93ab	91.62abc	93.50ab	92.47 ab
P ₁ S ₃	48.27cd	76.20cd	87.87bcd	92.70ab	92.17 ab
P ₂ S ₃	61.67a	82.07abc	91.32abc	93.73a	93.08 ab
P ₃ S ₃	68.67a	90.07ab	95.27a	96.90a	96.04 a
P ₁ S ₄	49.33bcd	65.20e	82.59d	84.70c	84.07 b
P ₂ S ₄	65.13a	77.20c	88.37a-d	89.36bc	90.87 ab
P ₃ S ₄	44.73d	69.73de	86.67bcd	90.51abc	88.57 ab
Level of significance	0.01	0.01	0.05	0.05	0.05
CV (%)	6.02	3.97	2.70	2.52	3.36

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly. [P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻², S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

4.2 Leaf number

The number of leaves varied significantly at 45 DAS (Table 3 and Appendix 3) with the variation of radiation levels. The highest number of leaves were recorded from S_1 (8.02) treatment which is statistically similar to the treatment S_2 (6.73) and S_3 (5.22) and the lowest number of leaves were observed in S_4 (4.48) treatment. At 60 DAS, 75 DAS, 90 DAS and at harvest the leaf number variation was non-significant. Numerically, the highest leaves were recorded from S_2 treatment and the lowest from S_4 treatment. George Zervoudakis *et al.* (2012) found that number of leaves higher at full ambient light. However, it has been reported that the intermediate light conditions (about 50% of FAL) were more adequate for some species to reach higher levels of biomass productivity (De Carvalho Gonçalves *et al.*, 2005).

Significant difference was observed among the plant populations at 45 DAS and 75 DAS in leaf number but it had no variation at 60 DAS and 90 DAS (Table 4 and Appendix 3). At 45 DAS and 75 DAS the leaf number was the highest in P_1 followed by P_2 treatment and the lowest number of leaf was recorded from P_3 treatment. At 45 DAS and 60 DAS the leaf number was the highest in P_1 which might at early stage plants with low density bear more leaves but at the later stage due to tillering occurred so leaf number became similar to the P_3 and P_2 treatments.

There was significant combined effect of radiation levels and plant population on leaf numbers at 45 DAS and 75 DAS (Table 5 and Appendix 3). The highest number of leaf was observed in P_1S_1 (10.41) treatment combination and the lowest number of leaf was observed in P_3S_4 (4.05) treatment combination at 45 DAS. At 75 DAS the highest number of leaf was recorded from P_1S_1 (17.97) and the lowest number of leaf was observed from P_3S_1 (11.20) treatment. When the plant population number decreased the leaf number increased under full sunlight condition and increasing the plant population decreased the number of leaves specially when plants grown under low light condition.

4.3 Tiller number

Radiation levels had significant effect on tiller number of wheat (Table 3 and Appendix 3). The highest number of tillers were obtained from S₂ (3.83) which was statistically similar to S₁ (3.35) treatment and the lowest number of tillers were recorded from S₄ (2.26) treatment which was statistically similar to S₃ (2.70) treatment at 45 DAS. At 75 DAS the highest number of tillers were obtained from S₁ (5.24) which was statistically similar to S₂ (4.90) and minimum number of tillers were recorded from S₄ (4.21) treatment which was statistically similar to S₃ (4.44) treatment. At 60 DAS and 90 DAS the highest number of tiller were observed in S₂ treatment which was statistically similar to S₁ treatment. At 60 DAS the lowest number of tiller was obtained from S₃ (3.67) treatment which was statistically similar to S₄ (3.76). At 90 DAS the lowest number of tiller was found in S₄ (4.70) treatment which was statistically similar to S₃ (4.95). At all the growth stages S₁ (Full sunlight) and S₂ (75% light) produced significantly higher tiller number whereas, S₃ (55% light) and S₄ (25% light) produced lower tillers. Numerically higher tillers were found in S₂ treatment in most of the cases, it indicates that little diffused light induce tiller production in wheat. Tiller production significantly reduced when around 50% light was curtailed (S₃ and S₄ treatments). Abeledo *et al.* (2004) found that light environment can modify tiller appearance in cereal crops, mainly if canopy plants compete for light. Self-shading of plants within a dense canopy is associated with reduction of tillering.

There was no significant variation in tiller number among the plant population (Table 4 and Appendix 3). However numerically the highest number of tillers were obtained from P₃ (3.16) and the lowest number of tillers were obtained from P₁ (2.91) treatment at 45 DAS. At 60 DAS, 75 DAS and 90 DAS the highest number of tillers were recorded from P₂ treatment and the lowest number of tiller were found in P₁ treatment.

The interaction effect of radiation levels and plant population was found significant on the tiller per plant of wheat at all growth stages (Table 5 and Appendix 3). At 45 DAS, 60 DAS and 90 DAS the highest number of tillers were found in P₃S₂ treatment combination which was statistically similar to the treatment combination P₁S₁, P₂S₁, P₃S₁, P₁S₂ and P₂S₂. At 45 DAS, the lowest number of tiller found in P₁S₄ (1.53) and at 60 DAS, 75 DAS and 90 DAS the lowest number of tiller was observed in P₃S₄ treatment. Results revealed that tillers were similar for all plant population densities with full and 75% of full radiation but it varied significantly if light is reduced to 50% or less.

Table 3. Effect of radiation levels on leaf number and tiller number of wheat at different DAS

Radiation Level	Leaf Number/ Plant				Tiller Number/ Plant			
	45 DAS	60 DAS	75 DAS	90 DAS	45 DAS	60 DAS	75 DAS	90 DAS
S ₁	8.02a	11.54	15.07	14.49	3.35 a	4.05ab	5.24a	5.68a
S ₂	6.73 ab	12.13	15.58	15.52	3.83 a	4.38a	4.90ab	5.81a
S ₃	5.22bc	11.78	14.86	14.30	2.70 b	3.67b	4.44 b	4.95ab
S ₄	4.48c	12.70	13.94	13.14	2.26 b	3.76ab	4.21 b	4.70b
Level of significance	0.01	NS	NS	NS	0.01	0.05	0.01	0.05
CV (%)	21.19	16.51	13.34	15.77	15.74	12.25	12.94	13.79

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly. [S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

Table 4. Effect of plant population on leaf number and tiller number of wheat at different DAS

Plant Population	Leaf Number/ Plant				Tiller Number/ Plant			
	45 DAS	60 DAS	75 DAS	90 DAS	45 DAS	60 DAS	75 DAS	90 DAS
P ₁	7.41a	12.08	16.30a	14.16	2.91	3.90	4.79	5.16
P ₂	5.25b	12.45	14.88ab	14.46	3.04	4.18	4.75	5.41
P ₃	5.66b	11.58	13.40b	14.46	3.16	3.82	4.55	5.30
Level of significance	0.01	NS	0.01	NS	NS	NS	NS	NS
CV (%)	21.19	16.51	13.34	15.77	15.74	12.25	12.94	13.79

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly.

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻².

Table 5. Interaction effect of radiation levels and plant population on leaf number and tiller number of wheat at different DAS

Treatment Combination	Leaf Number/ Plant				Tiller Number/ Plant			
	45 DAS	60 DAS	75 DAS	90 DAS	45 DAS	60 DAS	75 DAS	90 DAS
P ₁ S ₁	10.41a	12.29	17.97a	15.61	3.53a	4.10abc	5.20ab	5.60
P ₂ S ₁	6.88abc	12.53	16.05ab	14.80	3.23a	4.60ab	5.67a	6.07
P ₃ S ₁	6.78abc	9.80	11.20b	13.05	3.30a	3.47bc	4.86ab	5.40
P ₁ S ₂	8.57ab	11.59	15.25ab	12.83	3.86a	4.10abc	4.43ab	5.17
P ₂ S ₂	4.27c	9.77	14.84ab	16.40	3.70a	3.87abc	4.67ab	6.00
P ₃ S ₂	7.34abc	15.03	16.64ab	17.32	3.93a	5.20a	5.60a	6.27
P ₁ S ₃	6.42bc	11.37	16.61ab	14.92	2.71ab	3.53bc	5.00ab	5.07
P ₂ S ₃	4.74bc	12.48	15.23ab	13.12	2.63ab	3.87abc	4.33ab	4.80
P ₃ S ₃	4.49c	11.51	12.73ab	14.87	2.76ab	3.60bc	4.00ab	5.00
P ₁ S ₄	4.24c	13.08	15.37ab	13.29	1.53b	3.86abc	4.53ab	4.80
P ₂ S ₄	5.15bc	15.03	13.43ab	13.54	2.60ab	4.40abc	4.36ab	4.76
P ₃ S ₄	4.05c	10.00	13.03ab	12.58	2.67ab	3.03 c	3.73 b	4.53
Level of significance	0.05	NS	0.05	NS	0.05	0.01	0.05	NS
CV (%)	21.19	16.51	13.34	15.77	15.74	12.25	12.94	13.79

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly. [P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻², S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

4.4 Dry matter

Radiation levels had significant effect on dry matter of wheat (Fig. 3 and Appendix 4). The highest weight of dry matter was obtained from S₁ (6.24 g) which was statistically similar to S₂ (5.39 g) and S₃ (5.12 g) treatment and the lowest weight of dry matter was recorded from S₄ (3.51 g) treatment at 45 DAS. At 60 DAS, 75 DAS and 90 DAS the highest dry matter weight was recorded from S₁ treatment which was statistically similar to S₂ treatment and the lowest dry matter weight in S₄ treatment. When plants grown under full sunlight higher rate of photosynthesis occur and higher amount of dry matter is produced as the spike length, number of spikelet per spike and the grain number per spike increased under full light condition. When the radiation levels reduced to some extent (S₂ and S₄) the result is more or less similar to the full sunlight condition. When plants grown under reduced light condition as 25% of full sunlight the dry weight reduced significantly as the spike length, number of spikelet per spike and the grain number per spike decreased drastically.

Plant population had significant effect on dry matter production at 45 DAS but non-significant effect then after (Table 6 and Appendix 4). At 45 DAS the highest dry matter was observed in P₃ (5.65 g) treatment where plant population was 230 plant m⁻² which was statistically similar to the P₂ (5.24 g) treatment where population was 200 plant m⁻². On the contrary, the lowest weight of dry matter was recorded from P₁ (4.30 g) where population was 160 plant m⁻². From 45 DAS, till the maturity of wheat the weight of dry matter was non-significant due to plant population. However, numerically the highest dry weight was obtained from P₃ (12.84 g) treatment and the lowest dry weight was found in P₁ (10.49 g) treatment at 60 DAS. At 75 DAS and 90 DAS the highest dry weight was recorded from P₁ and P₂ treatment whereas the lowest dry matter was obtained from P₃ treatment. The reason might be at early stage of growth plant height and leaves number were significantly varied among population densities as a result the dry matter was varied. Ferreira and Souza (2001) in maize and Sedghi *et al.* (2008) in sunflower also reported that both LAI and dry matter accumulation increased with increasing plant density. Later the plant where the population density is lower produce more tiller than the plant grown at higher population density and which contributes to significantly similar dry matter weight in P₁, P₂ and P₃ treatment at later stages.

The interaction effect of radiation levels and plant population on dry matter weight of wheat varies significantly at all stages except at 60 DAS (Table 7 and Appendix 4). The

highest dry weight was recorded from P₃S₂ (6.69 g) which was statistically similar to P₁S₁ (6.46 g), P₃S₁ (6.14 g) and P₂S₁ (6.11 g) at 45 DAS. On the other hand, the lowest dry weight found in P₁S₄ (2.18g) treatment which was statistically similar to P₂S₄ (4.02 g) and P₃S₄ (4.33 g) at 45 DAS. At 60 DAS, 75 DAS and 90 DAS the highest dry weight observed in P₂S₁ which was statistically similar to P₃S₁ and P₁S₁ treatment whereas the lowest dry matter weight was observed in P₁S₄ (8.39 g) at 60 DAS. At 75 DAS lowest dry matter weight was in P₂S₄ (12.8 g) and at 90 DAS in P₃S₄ (17.19 g) which was statistically similar to P₂S₄ and P₁S₄ treatment. This result showed that at full sunlight with the optimum plant population the dry weight of plant is highest but when increasing plant population or when plant grown at optimum plant population this did not increase the dry weight when the solar radiation level decreased to 25%.

Table 6. Effect of plant population on dry matter of wheat at different DAS

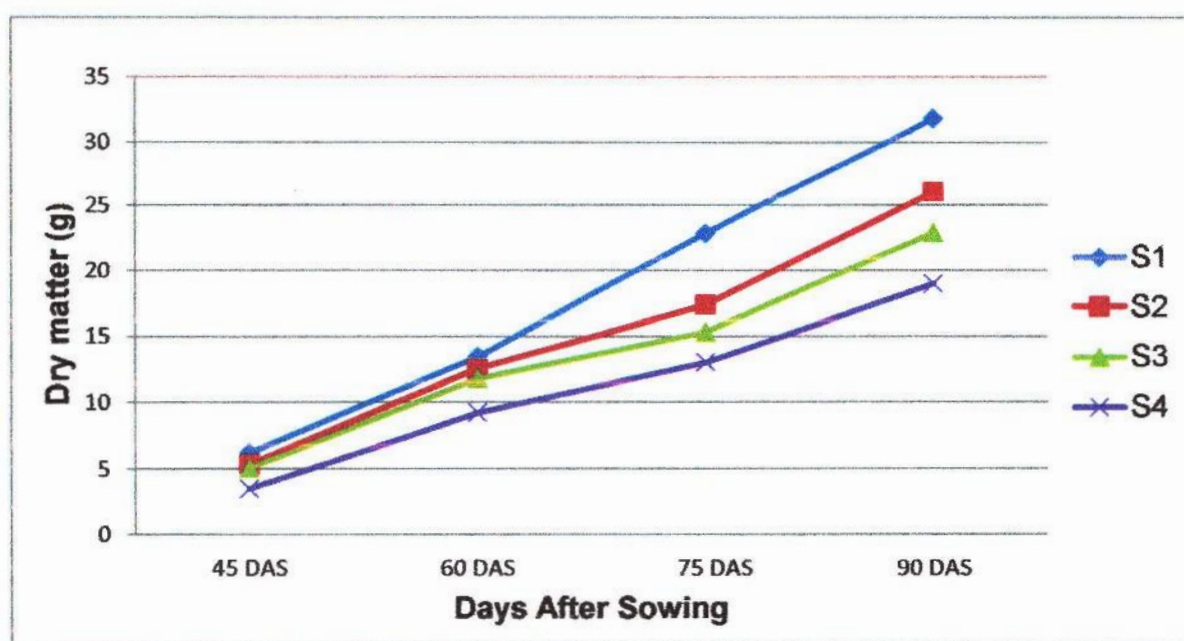


Fig. 3: Effect of radiation levels on dry matter weight (g) of wheat at different DAS

[S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

Table 6. Effect of plant population on dry matter of wheat at different DAS

Plant Population	Dry matter (g)			
	45 DAS	60 DAS	75 DAS	90 DAS
P ₁	4.30 b	10.49	17.38	26.70
P ₂	5.24ab	11.92	17.33	25.57
P ₃	5.65a	12.84	16.76	23.19
Level of significance	0.01	NS	NS	NS
CV (%)	19.67	25.44	24.14	19.32

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly.

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻²]

Table 7. Interactive effect of radiation and plant population on dry matter of wheat

Treatment Combination	Dry matter (g)			
	45 DAS	60 DAS	75 DAS	90 DAS
P ₁ S ₁	6.46ab	12.22	20.99ab	30.23ab
P ₂ S ₁	6.11ab	15.24	25.46a	33.21a
P ₃ S ₁	6.14ab	12.82	22.12ab	32.15a
P ₁ S ₂	3.72bc	9.833	15.02ab	19.49ab
P ₂ S ₂	5.77ab	10.93	16.77ab	27.72ab
P ₃ S ₂	6.69a	16.86	20.40ab	30.93ab
P ₁ S ₃	4.85abc	11.51	17.95ab	23.94ab
P ₂ S ₃	5.06abc	11.51	14.44ab	22.75ab
P ₃ S ₃	5.43ab	12.44	13.65ab	22.02ab
P ₁ S ₄	2.18c	8.39	13.09b	19.11ab
P ₂ S ₄	4.02abc	10.01	12.84b	20.61ab
P ₃ S ₄	4.33abc	9.25	13.16b	17.19b
Level of significance	0.05	NS	0.05	0.05
CV (%)	19.67	25.44	24.14	19.32

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly. [P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻², S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

4.5 Number of spikelet per spike

It was observed from the result of the present study that number of spikelet per spike differ significantly within different solar radiation levels (Fig. 4 and Appendix 5). The highest number of spikelet per spike was found in S_1 treatment which was statistically similar to S_2 treatment followed by S_3 treatment and the lowest number of spikelet per spike observed in S_4 treatment at 60 DAS and 75 DAS. At 90 DAS the maximum number of spikelet per spike found in S_1 (18.59) treatment followed by S_2 (17.63) treatment which was statistically similar to S_3 (16.82) treatment and the minimum number of spikelet per spike found in S_4 (16.24). At harvest, highest number of spikelet per spike was found in S_1 (18.83) and S_2 (18.31) whereas the lowest number of spikelet per spike in S_4 (16.81) treatment. The plants grown under open sunlight have the maximum rate of photosynthesis and this might be responsible for the highest number of spikelet per spike in S_1 and the lowest number spikelet per spike in S_4 treatment.

Significant differences observed among different plant population in respect of number of spikelet per spike at 60 DAS (Table 8 and Appendix 5). At 60 DAS highest number of spikelet per spike found in P_3 (16.95) treatment which was statistically similar to the P_2 (16.18) treatment and the lowest number of spikelet per spike was recorded from P_1 (15.60) treatment. At 75 DAS, 90 DAS and at harvest no significant variation was observed within the different plant population. However numerically highest number of spikelet per spike was obtained from P_3 treatment and the lowest spikelet number per spike was obtained from P_1 treatment. Qu *et al.* reported that grain yield was improved with increasing plant density as a result of the increased spikelets number.

Number of spikelet per spike varied significantly due to the combined effect of radiation levels and plant population at all the growth stages except at harvest (Table 9 and Appendix 5). The highest number of spikelet per spike was recorded from P_2S_1 treatment from 45 DAS to the harvest and the lowest number of spikelet per spike was obtained from P_1S_4 treatment at 60 DAS, 75 DAS and 90 DAS except at harvest where the lowest number of spikelet was recorded from the P_2S_4 (16.33) treatment which is statistically similar to the P_1S_4 (16.77) treatment. The spikelet number per spike increased where the plant population were optimum with the full light condition whereas decreasing plant population did not affect the spikelet number per spike where light was minimum that means 25 % of light was available to the plant. At very low light condition it affects the number of spikelet negatively

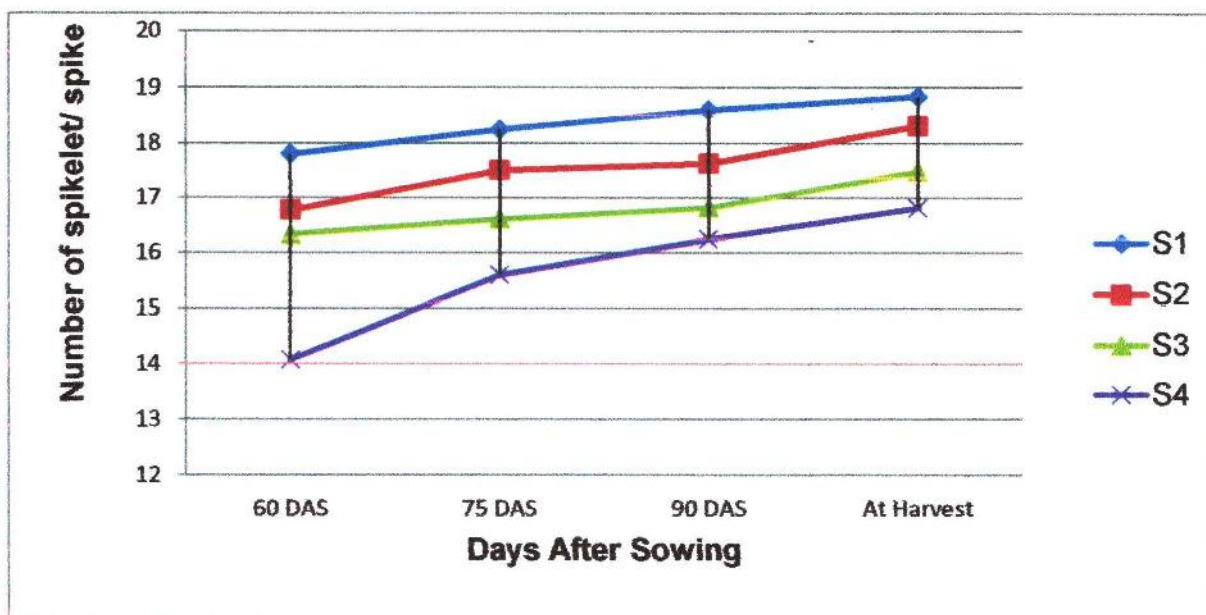


Fig. 4: Effect of radiation levels on number of spikelet per spike of wheat at different DAS

[S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

Table 8. Effect of plant population on number spikelet per spike of wheat at different DAS

Plant Population	Number of spikelet per spike			
	60 DAS	75 DAS	90 DAS	At Harvest
P ₁	15.60b	16.62	16.885	17.71
P ₂	16.18ab	16.98	17.543	17.89
P ₃	16.95a	17.37	17.533	17.99
Level of significance	0.01	NS	NS	NS
CV (%)	5.44	4.71	3.53	3.38

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻²]

4.6 Length of spike

Significant variations were observed among the radiation levels in respect of length of spike (Table 10 and Appendix 6). The highest spike length was recorded from the S_1 treatment (17.73 cm) which was statistically similar to the treatment S_2 (16.38 cm). The lowest length of spike was found in S_4 (14.83 cm) treatment which was statistically similar to the treatment S_3 (15.73 cm). Under full sunlight the spike of wheat was highest as the plants get more light for photosynthesis and ultimately the dry matter accumulation was higher as a result of higher length of spikes. Changes in radiation level during the spike growth period affected the length of the spike which had effect on grain yield. This data was supported by Abbate *et al.* (1997).

There was significant variation among different plant population in respect of length of spikes (Table 11 and Appendix 6). Maximum length of spike was observed P_1 (16.78 cm) which was statistically similar to the treatment P_2 (16.45 cm). The minimum length of spike was found in treatment P_3 (15.27 cm). Shafi *et al.* (2012) reported that highest plant population had a negative impact on ear length. This may be due to the fact that available nutrients, moisture, space and light become limited in high plant population due to high competition for growth resources between plants.

Spike length significantly varied due to the interaction effect of radiation levels and plant population (Table 12 and Appendix 6). The highest length of spike was recorded from the P_1S_1 (18.42) treatment which was statistically similar to the P_2S_1 (16.76 cm). The lowest spike length was obtained from the P_3S_4 (13.55 cm) which was statistically similar to the P_3S_3 (14.23 cm). When planting density is low with full sunlight the spike length increased but at lower population density it did not increase when grown under low light condition. Increasing the plant population density over the optimum decreases the length of spike significantly.

4.7 Number of grains per spike

There were significant differences among the radiation levels in respect of number of grains per spike (Table 10 and Appendix 6). Number of grains per spike ranged from 50.27 to 36.04 that showed in table 9. The highest number of grains recorded from the S_1 (50.27) treatment which was statistically similar to S_2 (47.39) treatment. The lowest number of grains were obtained from S_4 (36.04) which was statistically similar to S_3 (41.99) treatment. Willey and Holliday (1971) and Fischer (1975) found that applying shade to spring wheat during 30 days preceding anthesis (during the spike growth period), caused an appreciable decrease in yield by reducing number of grains m^{-2} .

There were significant differences among different plant population in regard of number of grain per spike (Table 11 and Appendix 6). Number of grain ranged from 45.46 to 42.02. Maximum number of grain per spike was recorded from P_2 (45.46) treatment which was statistically similar to P_1 (44.28) treatment. The minimum number of grain per spike was observed in P_3 (42.02) treatment. With increasing plant population, number of grains ear^{-1} decreased in a linear manner reported by Shafi *et al.* (2012). This could be due to the fact that in high planting density, photosynthetic capability of plants was reduced due to the low light interception that negatively affected number of grains ear^{-1} .

Combined effect of radiation levels and plant population on number of grain per spike was found statistically significant (Table 12 and Appendix 6). The highest number of grain per spike was recorded from the P_2S_1 (52.40) treatment combination which was statistically similar to P_1S_1 (50.28) treatment combination. The lowest number of grain per spike was obtained from P_3S_4 (34.93), P_2S_4 (37.05) and P_1S_4 (36.13) treatment which was statistically similar to P_3S_2 (44.43), P_1S_3 (42.12), P_2S_3 (43.27) and P_3S_3 (40.58) treatment combinations. Plants grown under full sunlight with optimum population density had the maximum number of grains per spike whereas plants grown under diffused sunlight where 25% of light was available significantly reduce the grain number per spike regardless the population density.

4.8 Weight of 1000-grains

It was observed from the result of the present study that radiation levels differ significantly in regard to weight of 1000-grains (Table 10 and Appendix 6). Among the radiation levels the highest 1000-grain weight was found in treatment S_1 (51.88 g) which was statistically similar to S_2 (49.34 g) and S_3 (47.97 g) and the lowest weight of 1000-grains observed in treatment S_4 (42.81 g). The major effect of shading was to reduce number of grains m^{-2} without any effect on weight per grain except 25% light that means 75% of shading. Jenner (1979) found that shading produced smaller grains, slower rates of accumulation of dry matter in the grains, and lower final grain weights.

The study also revealed that the effect of plant population was statistically non-significant in respect of weight of 1000-grains (Table 11 and Appendix 6). Numerically, the highest weight of 1000-grains due to the effect of plant population was recorded from P_1 (49.03 g) treatment followed by P_2 (48.67 g) treatment. The lowest 1000-grains weight was obtained from P_3 (46.29 g) treatment. The maximum 1000-grain weight (38.7 g) was obtained when normal seed rate of 100 kg ha^{-1} was used. Further increase in seed rate did not show any positive effect on grain weight (Baloch *et al.*, 2010).

There was significant combined effect of radiation levels and plant population on 1000-grains weight (Table 12 and Appendix 6). The highest weight of 1000-grains were recorded from the P_2S_1 (53.53 g) followed by P_1S_1 (52.25 g). On the other hand the lowest weight of 1000-grains observed from the P_3S_4 (39.11 g) which was statistically similar to P_2S_4 (43.62 g). Plants grown under full sunlight with optimum population had the highest 1000 grain weight on the other hand plants grown under 55% and 25% of available light had the lowest 1000 grain weight which is not significantly affected by population density.

4.9 Grain yield

Radiation levels had significant effect on grain yield of wheat (Table 10 and Appendix 6). The plants grown under full ambient light produced highest grain yield S_1 (3.82 t/ha) where plants grown under full ambient light followed by S_2 (3.17 t/ha) where 75% of light and S_3 (2.94 t/ha) where 55% light was available to the plants. Whereas, the plant grown under 25% of full ambient light produced the lowest grain yield S_4 (1.88 t/ha). In S_2 , in S_3 and S_4 treatment the yield reduction is 17.16%, 23.04% and 50.74% respectively compared to control. 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). Many studies have revealed that shading can reduce crop dry matter accumulation and yield (Islam *et al.*, 1993, Slafer *et al.*, 1994; Wang *et al.*, 2003; Demotes-Mainarda and Jeuffroy, 2004).

In the present study, grain yield was affected significantly by the number of plant population (Table 11 and Appendix 6). The highest grain yield was obtained from P₃ (3.16 t/ha) where 230 plant m⁻² which was statistically similar to P₂ (2.96 t/ha) where 200 plant m⁻². On the other hand the lowest grain yield was recorded from the P₁ (2.74 t/ha) where 160 plant m⁻² were grown. The grain yield was decreased by 7.43% for 160 plant m⁻² (P₁) and increased by 6.75% for 230 plant m⁻² (P₃) over control, 200 plant m⁻² (P₂). Increased planting density also increase the grain yield as the total number of plants increased as a result total number of grains also increased which contribute to higher grain yield production. On the other hand, decreasing plant population the grain yield production also decreased as the total number of plant decreased. Increased plant population could lead to increased yields under optimal climatic condition reported by (Bavec and Bavec, 2002).

The present study revealed that there was significant combined effect of radiation levels and plant population on grain yield (Table 12 and Appendix 6). The highest grain yield was found in treatment combination P₃S₁ (3.94 t/ha) where full sunlight was available with 230 plant m⁻² which was statistically similar to P₂S₁ (3.86 t/ha) treatment combination where full sunlight was available with 200 plant m⁻² followed by P₁S₁ (3.66 t/ha) where full sunlight was available with 160 plant m⁻² and P₃S₂ (3.55 t/ha) treatment where 75% light was available with 230 plant m⁻². On the contrary, the lowest grain yield found in treatment P₁S₄ (1.62 t/ha) where 25% was available with 160 plant m⁻² followed by P₃S₄ (1.84 t/ha) where 25% light was available with 230 plant m⁻² and P₂S₄ (2.19 t/ha) treatment combination where 25% light was available with 200 plant m⁻².

4.10 Straw yield

There was significant effect of radiation levels on straw yield of wheat (Table 10 and Appendix 6). The plants grown under full ambient light (S₁) produced maximum straw yield (4.81 t/ha) followed by S₂ (3.98 t/ha) where 75% of light and S₃ (3.69 t/ha) where 55% light was available to the plants. Whereas, the plant grown under 25% of full ambient light (S₄) produced the lowest grain yield (2.85 t/ha). In full sunlight condition

the straw yield increased as the dry matter accumulation increased in that condition compared to reduced light.

The present study revealed that there was significant effect of different plant population on straw yield of wheat (Table 11 and Appendix 6). The highest straw yield obtained from P_3 (4.04 t/ha) where 230 plant m^{-2} which was statistically similar to P_2 (3.93 t/ha) where 200 plant m^{-2} , whereas the lowest straw yield was recorded from the P_1 (3.52 t/ha) where 160 plant m^{-2} were grown. This might be due to the increasing total plant population also increased the total straw yield and decreasing the population density also decreased the straw yield.

The combined effect of radiation levels and plant population on straw yield was statistically significant (Table 12 and Appendix 6). Full sunlight with 230 plant m^{-2} produced the highest straw yield (5.13 t/ha) which was statistically similar to full sunlight with 200 plant m^{-2} (5.00 t/ha) followed by full sunlight with 160 plant m^{-2} (4.31 t/ha), P_3S_2 (4.12 t/ha) where 75% of light was available with 230 plant m^{-2} and P_2S_2 (4.11 t/ha) treatment combination where 75% of light was available with 200 plant m^{-2} . On the contrary, the lowest straw yield was found in treatment P_1S_4 (2.39 t/ha) where 25% of full ambient light was available with 160 plant m^{-2} followed by P_3S_4 (3.07 t/ha) where 25% of full ambient light was available with 230 plant m^{-2} and P_2S_4 (3.08 t/ha) where 25% of full ambient light was available with 200 plant m^{-2} .

4.11 Biological yield

Radiation levels had significant effect on biological yield of wheat (Table 10 and Appendix 6). The plants grown under full ambient light (S_1) produced highest biological yield (8.63 t/ha) followed by S_2 (7.14 t/ha) where 75% of light and S_3 (6.63 t/ha) where 55% light was available to the plants because the grain yield and straw yield of these treatments were high. On the other hand the lowest biological yield was found in the plants grown under 25% of full ambient light S_4 (4.73 t/ha).

The present study revealed that the biological yield was affected significantly by different plant population (Table 11 and Appendix 6). The highest biological yield was obtained from P_3 (7.20 t/ha) where 230 plant m^{-2} which was statistically similar to P_2 (6.89 t/ha) where 200 plant m^{-2} . On the other hand the lowest biological yield was obtained from the P_1 (6.25 t/ha) where 160 plant m^{-2} were grown. This data was supported by Plensicar &

Kustori (2005) who stated that biological yield increased at higher population density and decreased at lower population density.

There was significant combined effect of radiation levels and plant population on biological yield (Table 12 and Appendix 6). The highest biological yield was found in treatment P_3S_1 (9.07 t/ha) which was statistically similar to P_2S_1 (8.86 t/ha) treatment combination followed by P_1S_1 (7.96 t/ha) and P_3S_2 (7.67 t/ha) treatment combinations. On the contrary, the lowest biological yield was found in treatment P_1S_4 (4.00 t/ha) followed by P_3S_4 (4.92 t/ha) and P_2S_4 (5.27 t/ha) treatment combinations.

4.12 Harvest Index

It is evident from the result of the present study that there was significant effect of radiation levels on harvest index of wheat (Table 10 and Appendix 6). The highest harvest index was observed in S_2 (44.25%) and S_1 (44.24%) treatment and the lowest harvest index in S_4 (39.81%) treatment.

Results showed that plant population had no significant variation in harvest index of wheat (Table 11 and Appendix 6). However, numerically the highest harvest index was recorded from P_3 (43.34%) which was similar to P_1 (43.27%) and the lowest harvest index was in P_2 (42.73%) treatment. Ahmad & Khan (2002) reported that increase in plant density increased harvest index.

The combined effect of radiation levels and plant population on harvest index of wheat was statistically significant (Table 12 and Appendix 6). The highest percentage of harvest index was found in P_3S_2 (46.26%) and P_1S_1 (45.76%), P_1S_3 (44.51%) and P_3S_3 (46.05%) treatment combinations. On the other hand, the lowest percentage of harvest index obtained from P_3S_4 (37.52%) treatment combination.

Table 10. Effect of radiation levels on yield and yield contributing characters of wheat at harvest

Radiation Level	Length of spike (cm)	Grain /spike (no.)	1000 grain weight (g)	Grain Yield (t/ha)	Straw Yield (t/ha)	Biological Yield (t/ha)	HI (%)
S ₁	17.73a	50.27a	51.88a	3.82a (0.0)	4.81a	8.63a	44.24a
S ₂	16.38ab	47.3a	49.34a	3.17b (-17.16)	3.98b	7.14 b	44.25a
S ₃	15.73b	41.99b	47.97a	2.94b (-23.04)	3.69b	6.63b	44.14a
S ₄	14.83 b	36.04c	42.81b	1.88c (-50.74)	2.85c	4.73c	39.81b
Level of significance	0.01	0.01	0.01	0.01	0.01	0.01	0.01
CV (%)	7.59	7.34	6.90	12.96	12.96	12.21	4.42

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly

[S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

Negative values in the bracket represent the percentage of reduction grain yield over control.

Table 11. Effect of plant population on yield and yield contributing characters of wheat at harvest

Plant Population	Length of spike (cm)	Grain /spike (no.)	1000 grain weight (g)	Grain Yield (t/ha)	Straw Yield (t/ha)	Biological Yield (t/ha)	HI (%)
P ₁	16.78a	44.28ab	49.03	2.74b (-7.43)	3.52b	6.25 b	43.27
P ₂	16.45ab	45.46a	48.67	2.96ab (0.0)	3.93a	6.89ab	42.73
P ₃	15.27b	42.02 b	46.29	3.16a (+6.75)	4.04a	7.20a	43.34
Level of significance	0.05	0.05	NS	0.05	0.05	0.05	NS
CV (%)	7.59	7.34	6.90	12.96	12.96	12.21	4.42

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻²] Positive and negative value in the bracket represents the percentage of reduction and increase of grain yield respectively over control.

Table 12. Interactive effect of radiation levels and plant population on yield and yield contributing characters of wheat at harvest

Treatment Combination	Length of spike (cm)	Grain /spike (no.)	1000 grain weight (g)	Grain Yield (t/ha)	Straw Yield (t/ha)	Biological yield (t/ha)	HI (%)
P ₁ S ₁	18.42a	50.28ab	52.25ab	3.66 abc	4.31 ab	7.96ab	45.76a
P ₂ S ₁	17.67ab	52.40a	53.53a	3.86 ab	5.00 a	8.86 a	43.44ab
P ₃ S ₁	17.10abc	48.12abc	49.86ab	3.94a	5.13 a	9.07 a	43.53ab
P ₁ S ₂	16.85abc	48.60abc	47.83abc	2.72b-f	3.70cd	6.44 bcd	42.36ab
P ₂ S ₂	16.12abc	49.13abc	50.33ab	3.23 a-d	4.11a-d	7.33abc	44.11ab
P ₃ S ₂	16.19abc	44.43a-d	49.85ab	3.55 abc	4.12a-d	7.67 ab	46.26a
P ₁ S ₃	16.59abc	42.12bcd	50.36ab	2.95a-e	3.68 cd	6.63 bcd	44.51a
P ₂ S ₃	16.37abc	43.27a-d	47.21abc	2.56 c-f	3.54cde	6.11b-e	41.85ab
P ₃ S ₃	14.23bc	40.58cd	46.33abc	3.29 a-d	3.85bcd	7.15abc	46.05a
P ₁ S ₄	15.27ab	36.13d	45.70abc	1.62f	2.39e	4.00e	40.44ab
P ₂ S ₄	15.67ab	37.05d	43.62bc	2.19def	3.08 de	5.27cde	41.49ab
P ₃ S ₄	13.55b	34.9d	39.11c	1.84ef	3.07 de	4.92 de	37.52b
Level of significance	0.05	0.05	0.05	0.05	0.05	0.05	0.05
CV (%)	7.59	7.34	6.90	12.96	12.96	12.21	4.42

In a column figures having similar letter (s) do not differ significantly whereas figures with dissimilar letter(s) differ significantly

[P₁=160 plant m⁻², P₂=200 plant m⁻², P₃=230 plant m⁻², S₁= Full sunlight, S₂= 75% light, S₃= 55% light, S₄= 25% light]

CHAPTER V

SUMMARY AND CONCLUSION

An experiment on the performance of wheat under radiation levels with different plant population density was conducted at the Professor Purnendu Gain Field Laboratory, Agrotechnology Discipline, Khulna University, Khulna during the period from November 2018 to March 2019. The experiment included four radiation levels viz. S_1 = Full sunlight, S_2 = 75% light (25% reduction of light), S_3 = 55% light (45% reduction of light), S_4 = 25% light (75 %reduction of light) and three plant population density viz. P_1 = 160 plant m^{-2} , P_2 = 200 plant m^{-2} , P_3 = 230 plant m^{-2} where line spacing was 20 cm, plot to plot distance was 1 m and block to block distance was 1.0 m. The individual plot size was 6 m^2 . Two factors experiment was laid out in the randomized complete block design (RCBD) with three replications. Land preparation and sowing was done in 16 November 2018 and the fertilizers were applied as per BARI recommendations. Agronomic management practices were applied as and when necessary. The crop was harvested at maturity on 9 March 2019. Data on crop growth, yield contributing characters and yield were collected.

It was evident from the study that the radiation levels and plant population density and the combined effect exerted significant influence on plant height, leaf number, tiller number, dry matter, and number of spikelet per spike, length of spike, number of grains per spike, weight of 1000-grains, grain yield, straw yield, biological yield and harvest index with a few exceptions.

The highest grain yield (3.82 t/ha), maximum number of spikelet per spike (18.83), highest spike length (17.73 cm), highest number of grains (50.27), highest 1000-grain weight (51.88 g), maximum straw yield (4.81 t/ha), highest biological yield (8.63 t/ha) were found in S_1 treatment which was statistically similar to S_2 treatment except plant height at harvest and final grain yield. The tallest plants were found in S_3 (93.76 cm) which was statistically similar to S_1 and for grain yield S_1 significantly differed from S_2 , S_3 and S_4 treatments. On the other hand, the lowest grain yield (1.88 t/ha), minimum number of spikelet per spike (16.81), lowest spike length (14.83 cm), minimum number of grains (36.04), lowest 1000-grain weight (42.81 g), minimum straw yield (2.85 t/ha), minimum biological yield (4.73 t/ha) and harvest index (34.81%) were found in S_4

treatment. The lowest dry matter per plant and the shortest plant recorded in S₄ (89.50cm) treatment.

The present study revealed that 230 plants m⁻² produced the highest grain yield (3.15 t/ha) which was statistically similar to the optimum plant population density (200 plants m⁻²). The highest length of spike (16.78 cm) and thousand grains weight (49.03 g) was obtained from 160 plants m⁻² which was statistically similar to length of spike and thousand grains weight produced from the 200 plants m⁻². The tallest plant found where 230 plants were grown per square meter. On the contrary, 160 plants m⁻² resulted in the lowest grain yield (2.73 t/ha) and the lower spike length (15.27 cm) and comparatively lower grain number per spike was produced from 230 plants m⁻².

The plants grown under full sunlight with 230 plants m⁻² showed the best performance, produced the highest grain yield (3.94 t/ha) which was statistically similar to the yield produced by 200 plants m⁻². The maximum spike length (18.42 cm) was obtained from P₁S₁ which was statistically similar to the spike length (17.67 cm) P₂S₁ treatment. The highest number of grain per spike (52.40) and 1000-grain weight (53.53 g) was observed in P₂S₁ treatment which was statistically similar to number of grain per spike (50.28) and 1000-grains weight (52.25 g) of P₁S₁. Whereas, poor performance showed by plants grown under 25 % of available light with 160 plant m⁻², which produced the lowest grain yield (1.62 t ha⁻¹). The minimum spike length (13.55 cm), lowest number of grain per spike (34.93) and the lowest 1000-grain weight (39.11 g) was obtained from P₃S₄ where number of plant was 230 per square meter under 25% of full ambient light.

From the study the following conclusion could be made:

1. Wheat plants grown under the full sunlight produced highest yield and as the radiation level decreases it reduced the yield of wheat significantly. When plants grown under 25% of light the yield loss was about 51%. The low light drastically affected the grain filling ultimately greater yield loss occur.
2. The higher plant density increase the grain yield as the total number of plant increases but the optimum plant population density found to produce almost similar grain yield. So we can conclude that the optimum plant population density is more profitable than the high plant population density as less seeds were used.

3. Full sunlight with 230 plant m^{-2} produce highest grain yield and full light with 20% increase or decrease in plant population had no significant impact on grain yield.
4. Low radiation (25%) with all population densities produced low yield. Finally, it can be said that wheat grain yield was decreased due to reduction of solar radiation (25% or more) but yield loss with 25% less light can be recovered by increasing plant population by some extent (15%).

Similar research can be conducted in other regions of the country to verify the results and to make a concrete finding of this study.

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APPENDICES

Appendix 1: Solar radiation levels during growing period of wheat from November 2018 to March 2019

Treatment	Radiation Level ($\times 1000$ Lux)							
	45 DAS		60 DAS		75 DAS		90 DAS	
	Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower
P ₁ S ₁	590	252	600	205	597	215	609	211
P ₁ S ₂	456	240	412	202	415	190	392	190
P ₁ S ₃	345	105	302	102	316	106	322	109
P ₁ S ₄	185	119	166	95	112	109	125	99
P ₂ S ₁	590	233	598	200	597	210	609	202
P ₂ S ₂	478	116	342	104	336	105	408	125
P ₂ S ₃	376	101	300	97	305	100	300	104
P ₂ S ₄	153	98	162	94	145	76	112	90
P ₃ S ₁	590	103	600	95	600	104	609	102
P ₃ S ₂	459	97	381	100	391	101	389	99
P ₃ S ₃	357	93	290	84	306	86	310	95
P ₃ S ₄	186	66	159	74	113	74	160	75

[Note: The radiation levels was measured using luxmeter]

Appendix 2: Analysis of variance for plant height of wheat

Source of variation	Degree of freedom (df)	Mean Square Value (MS)				
		Plant height (cm)				
		45 DAS	60 DAS	75 DAS	90 DAS	At Harvest
Replication	2	37.42	25.34	0.421	1.96	6.28
Population (A)	2	225.52**	292.28**	79.30**	25.43*	29.62
Radiation levels (B)	3	216.598**	465.01**	81.71**	89.89**	54.31**
A × B	6	156.99**	40.81**	10.56*	8.99*	8.61*
Error	22	12.79	10.27	5.85	5.46	9.34

Appendix 3: Analysis of variance for leaf number and tiller number of wheat

Source of variation	Degree of freedom (df)	Mean Square Value (MS)							
		Leaf number				Tiller number			
		45 DAS	60 DAS	75 DAS	90 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Replication	2	7.46	1.07	2.04	3.65	0.97	0.07	0.68	0.42
Population (A)	2	15.69**	2.28	25.26**	0.35	0.19	0.42	0.21	0.19
Radiation levels (B)	3	22.53**	2.28	4.19	8.52	4.32**	0.95*	1.92**	2.67*
A × B	6	5.40*	15.45	10.09*	8.52	0.38*	1.19**	0.91*	0.42
Error	22	1.67	3.95	3.93	5.12	0.22	0.23	0.36	0.53

Appendix 4: Analysis of variance for dry matter per plant of wheat

Source of variation	Degree of freedom (df)	Mean Square Value (MS)			
		Dry matter (g)			
		45 DAS	60 DAS	75 DAS	90 DAS
Replication	2	2.16	11.24	0.67	40.80
Population (A)	2	5.71**	16.92	1.43	28.30
Radiation levels (B)	3	11.68**	29.57*	158.59**	266.81**
A × B	6	1.89*	12.17	17.71*	31.46*
Error	22	0.99	8.94	17.15	23.22

Appendix 5: Analysis of variance for number of spikelet per spike of wheat

Source of variation	Degree of freedom (df)	Mean Square Value (MS)			
		Number of spikelet per spike			
		60 DAS	75 DAS	90 DAS	At Harvest
Replication	2	0.01	0.43	0.17	0.02
Population (A)	2	5.64**	0.74	1.21	0.33
Radiation levels (B)	3	15.65**	6.73**	4.63**	3.97**
A × B	6	0.98*	0.35*	0.14*	0.23*
Error	22	0.79	0.64	0.38	0.36

Appendix 6: Analysis of variance of the data yield and yield contributing characters of wheat

Source of variation	Degree of freedom (df)	Mean Square Value (MS)						
		Length of spike (cm)	Grain no/spike	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	HI (%)
Replication	2	0.26	17.21	29.70	0.03	0.40	0.63	7.37
Population (A)	2	7.58*	36.77*	131.33	5.38*	5.33*	22.28*	42.59
Radiation levels (B)	3	13.40**	354.48**	26.75**	0.53**	0.55**	1.89**	13.47**
A × B	6	1.03*	1.88*	12.16*	0.23*	0.27*	0.95*	3.36*
Error	22	1.50	10.38	10.959	0.14	0.23	0.67	3.72