RESPONSE OF BARLEY TO SOWING DATE AND IRRIGATION FREQUENCY

A

THESIS

BY

Md. Hafizur Rahman Hafiz
Student No. 0605005
Session: 2006-2007

MASTER OF SCIENCE
IN
CROP BOTANY

DEPARTMENT OF CROP BOTANY
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR

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DEDICATED

TO MY

BELOVED PARENTS AND ELDER BROTHER

ABSTRACT

In Bangladesh, barley is cultivated mostly on marginal land with low input supply. There is a scope to improve the yield of barley providing better agronomic practices. The study was conducted in Crop Botany Research Field and Laboratory, Hajee Mohammad Danesh Science and Technology University during the period of November, 2005 to March, 2006, Dinajpur to investigate the growth and yield of barley in relation to sowing date and irrigation frequency. Four sowing dates (viz. November 1, 15, 30 and December 15) and four levels of irrigations (viz. no irrigation, one, two and three irrigations at different days after sowing) were included as experimental treatments. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. From the study it was observed to attain most of phenological stages of barley required maximum days on November 1 sowing. The duration of seedling emergence and crown root initiation required the lowest days while tillering, booting, heading and maturity required the highest days on November 1 sowing crops. Present study also revealed that differences in sowing time significantly influenced TDM, LAI, LAD, CGR, RGR, NAR, and GGR. Irrigation frequency also influenced the above growth parameters significantly. The results also reveled that early November sowing with three irrigations gave the highest values of all the growth parameters. Relative leaf water content (RLWC) and chlorophyll content was significantly influenced due to variation in sowing time. Plant sowing in November 1 gave the highest values of RLWC and chlorophyll content. Irrigation frequency also significantly influenced the RLWC and chlorophyll content. Reverse with RLWC and chlorophyll content, proline accumulation was increased with decreasing levels of irrigation. Crops growing in delay sowing accumulated higher proline than early sowing. Significantly higher plant height, fertile tiller, spike length, fertile spikelets, 1000-grain weight, yield (2.89 t/ha) and HI was found in the plants sown in November 1 and the lowest yield (2.33 t/ha) was obtained in the crop sown in December 15 while infertile tillers and infertile spikelets showed a reverse result with delay in sowing time. The irrigation levels also significantly influenced yield and yield attributes. The highest yield (3.31 t/ha) was obtain from the plant growing with three irrigations while the lowest yield (1.85 t/ha) was found from no irrigation. The interaction between sowing date and irrigation frequency showed a significant variation among the growth, yield and yield attributes of barley. It is indicated that November 1 sowing with three irrigations showed the best performance in respect of growth, yield attributes and yield of barley.

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CHAPTER 1

INTRODUCTION

Barley is an ancient origin of agriculture itself from 5000-7000 B. C. Agro-ecological evidences show that barley was grown along with wheat from ancient times excavated agricultural sites (Mekni and Kurich, 1984). Barley (*Hordium vulgare* L.) is an important and popular grain crop that belongs to the family graminae and globally ranked fourth important cereal after rice, wheat and maize. Barley essentially a temperate crop and grown mainly in the former Soviet Union, Germany, China and United States. In Bangladesh both in terms of production and acreage, barley cultivation is very poor. Presently the crops covers an area of about 6000 acre and produces about 2000 metric ton in this country (BBS, 2004) with a very low average yield of 1.5 $mt.ha^{-1}$ as compared to other barley growing countries having a yield gap of 2.51 $mt.ha^{-1}$ (BBS, 2004). In Bangladesh, yearly acreage and production of barley has been gradually decreased (Appendix I).

Barley is considered as a minor cereals crop in Bangladesh which resembles wheat in most aspect. It is considered as a poor mans diet and is one of the cheapest available cereals for home consumptions. The most important use of barley throughout the world is as malt for manufacturing beverage and malt enriched food products. Regarding nutritional value, barley is comparable with wheat and rice (Appendix II) and even superior to wheat in some mineral and fibre content (Hales, 1992). Barley is rich in protein, minerals and fibre contents, the special type of water soluble fibre β-D glucan which is believed to be the active hypocholesterolaemic agent lowering plasma cholesterol (Jacson and Topping, 1991). Barley has several industrial uses in Bangladesh for which entrepreneurs and pharmaceutical companies has to import a large amount of barley grain and malt extract for manufacturing baby food and medicine. It is suggested that barley could be therapeutic diet for diabetic patients, a good diet for kidney patients and referred diet after convalescence (Ikegami *et al.*, 1991).

Bangladesh with a humid subtropical climate is suitable for growth and cultivation of a wide variety of tropical and subtropical crop species. The cropping pattern depends on number of factors such as climate, rainfall, temperature, flooding, solar radiation etc. topography of soil, soil properties and other socioeconomic conditions. In Bangladesh barley has been grown as a Rabi crop but the area had been reduced by Boro rice and other crops replacing it. October to early March is suitable for cultivation of barley in our country.

Future climatic changes are expected to increase risks of drought, which already represent the most common stress factor for growing barley (Rizza *et al.*, 2004). After harvest of transplanting Aman rice, suitable varieties of wheat are available but for their high cost involvement in production farmers can cultivate barley which required low input cost. The farmers can grow barley mostly on marginal land with low input supply on stored soil moisture. There is a scope to improve the yield of barley providing better agronomic practices.

Winter of Bangladesh is short and mild compared to the climate of temperate countries. So, sowing time of barley is at proper time is very important, yield and yield attributes are decreased with delay in planting (Ahmed *et al.*, 2006). Early planted crops had more tillers and ears/m^2, heavier grains and higher grain yields than late planted barley (Fischer and Maurer, 1978; Knapp and Knapp, 1978). Late sowing might expose the barley crop to higher temperature after at reproductive stage resulting reduced number of ears/m^2 and number of grains/ear as well as yield (Randhawa *et al.*, 1977; Chowdhury and Wardlaw, 1978). Better grain yield could be obtained when cool temperature prevails during anthesis period (Ishag and Ageeb, 1991).

The crop sown on stored or residual soil moisture generally suffers from moisture stress at different stages of development causing the reduction in growth and grain yield (Steoponkus *et al.*, 1982). Indirect problem arising from water deficiency are greater susceptibility to pests and diseases, poor fertilizer use efficiency and possible nutrient imbalance due to impaired water uptake (Lal, 1984). Water deficit at various stages of crop growth has direct effect on crop yield. The reduction in growth as a result of water deficit directly affect on plant system (Prasad and Singh, 1987). Germination and seedling establishment are vulnerable in water deficit soil. Severe water deficit at this stage can sustainally affect the crop establishment and ultimately the grain yield (Nowak *et al.*, 2005 and Pessarakli *et al.*, 2005). Plant height, number of ears per plant, number of grains per ear, 1000 grain weight are adversely affected by water stress (JianMin *et al.*, 2005; Singh *et al.*, 2005. Abdorrahmani *et al.*, 2005). The yield of plants receiving stress at tillering stress were generally higher than yield of plants having stress at booting stage (Cambell *et al.*, 1981).

Plant development and spikelet formation are readily inhibited by water stress in barley (Oosterhuis and Cartwright, 1983). Moisture deficit causes lower photosynthesis due to lower photosynthetic area and lower chlorophyll content. It also reduced translocation of photosynthates to the growing grains (Patra *et al.*, 1998). Inadequate water supply, often result in disruption of physiological process (Hanson and Hilz, 1982). Tillering, booting, heading are adversely affected by water stress at early growth stage and dry matter partition, leaf area indices, crop growth rate also affected with water deficit condition (Singh *et al.*, 2005; Rafiq *et al.*, 2005 and Baheri *et al.*, 2005).

So, the time of sowing and water management in barley bears good importance. Despite the potentiality of increase productivity and its high nutritive value, no attention had yet been paid to this crop to develop package of improved management practices required to achieve higher yield of this minor but potential cereal crop in Bangladesh. Therefore, keeping the view in mind, to increase barley yield through improved management practices the present investigation would be framed with the following objectives.

i) To know the effect of sowing date and irrigation levels on some phenological, morphophysiological and growth and growth parameters of barley.

ii) To know the effect of sowing date and irrigation levels on yield and yield attributes of barley.

CHAPTER 2

REVIEW OF LITERATURE

Barley (*Hordeum vulgare* L.) is one of the important minor supplementary cereal crops which received much attention of the various research workers throughout the world. Growth and development of barely is depending on many environmental factors. Investigation on the effects of sowing date and irrigation frequency is very important to identify the suitable time of sowing and irrigation frequency for better growth and yield of this crop. Vary little work has been done in our country to develop a sustainable improved management practices required to achieve higher yield of this minor cereal crop. But numerous works have been done in this area in different barley growing countries. However, information available in respect of response of barley to sowing date and irrigation frequency are presented in this chapter.

2.1 Effect of sowing date

The major non-monitory inputs for enhancing barley production is optimum time of sowing which is the most important agronomic factor affecting the growth and development of plants. Research works done at home and abroad showed that delay in sowing after the optimum time which coincides with the onset of seasonal rains, consistently reduced yields (O' Leary *et al.*, 1985). However, the important works regarding the sowing dates are presented below.

2.1.1 Phenological, morphophysiological and growth parameters

2.1.1.1 Booting, heading and maturity

Days to booting varied significantly due to variation in sowing date. Booting came earlier in water deficit condition where as it was little bit longer in irrigated situation (Moula, 1999). He also reported that the maximum days required to attaining the booting stage of the crop in November 15 i.e., early sowing. Statistically the similar days were required up to December 5 sowing. The minimum days required to boot the crop by December 25 and January 5 sowing i.e., late sowing respectively (Sharma and Thakur, 1996; Verma *et al.*, 1996).

Tomar and Mathur (1966) carried out an experiment on barley for the three consecutive years, 1961-62, 1962-63 and 1963-64 with three sowing dates viz., October 15, November 12, December 8; October 12, November 4, November 30 and October 10, November 5, December 4, respectively. On an average, the 1st and 2nd sowing maintained statistically superiority over the 3rd sowing. The lowest yield in case of 3rd sowing could be attributed to the fact that the crop had much reduced growth period while the 1st and 2nd sowing were favored by relatively longer growing period.

Hossain *et al.*, (1987) observed that the grain yield of wheat had decreasing trend due to late seeding. The late sown crop took at least 15 to 20 days less time to mature because of forced maturity due to rise of temperature in March and Moula (1999) reported that November 15 sowing required higher days to maturity than January 5 sowing in barley.

Saini and Dadhwal (1986) also reported that temperature affects the total growth period of wheat. Citing example they observed that 150 days life cycle of wheat in northern India, progressively declined to 100-110 days in central and 80-90 days in southern and western India due to increasing warm weather during growth period.

Sowing date affects difference in occurrence and duration of different phenophase. initiation of spike primordial, booting, heading and grain filling and maturity (BARI, 1990 and Saifuzzaman *et al.*, 1996).

Ghosh *et al.*, (2000) observed that delayed sowing decreased the number of days taken to reach maturity and similar result also suggested by Verma *et al.*, 1996 and singh *et al.*, 2005).

Dofing and Karlsson (2001) conduct an experiment in northern regions of the USA during the 1990 and 1991 growing seasons over 4 environments and he reported that the restriction of a single culm per plant decreased number of grains per spike by 2.2 grains and increased grain weight by 8.4 mg. Results suggested that the uniculm phenotype results in several favourable modifications of phenological development, which may be of practical value in regions where early maturity is important.

2.1.1.2 Total dry matter (TDM)

Total dry matter, the amount of dry matter accumulated in root, stem, leaf and ear, is a measure of productivity of a crop. Dry matter production of a crop is dependent on the size of the photosynthetic system or its activity as well as the length of its growth period during which photosynthesis continues (Watson, 1958). Cumulative dry matter accumulation is positively correlated with leaf area (Pandey *et al.*, 1978; Bullock *et al.*, 1988) but increased leaf area might not ensure higher dry matter there is higher net assimilation rate (NAR), sink strength (Evans, 1975) and higher growth rate (Bullock *et al.*, 1988).

Sowing time brought significant variation in dry matter accumulation in barley at most of the growth stages. In general, dry matter production decreased with delay in sowing. The trend was more consistent at 60, 75 and 90 DAE. November 15 sowing in all the growth stages produced significantly the highest dry matter and decreased significantly in the later sowings. The rate of total dry matter accumulation to 75 DAE of crop growth was highest in November 15 sown crop than in January 5 sown crop. Thus, 91% reduction in the rate of dry matter production was accounted for 50 days delay in sowing. The late sowing particularly January 5 could not attain higher amount of vegetative growth due to early inducement of flowering. Hence, the small crop duration due to shortening of the growth period from sowing to flowering associated with high temperature might have resulted in lowering of the dry matter production in the late sown crop (Sengupta *et al.*, 1948 and Moula, 1999). In the early sowings the phenological phases of plant vulnerable to thermal regimes coincided with optimum temperature attributed to more plant height and longer vegetative period produced almost the higher dry matter production (Moula, 1999).

Ryu *et al.*, (1992) found in Korea that the barley cv. Olbori, Kangbori and Suwaon 18 sown on September 21, October 11 and October 31 produced the highest rates of daily grain dry matter accumulation of 1.03- 1.94 mg/grain at 20-30 days after heading in the early and intermediate sowing and 0.88-1.88 mg/grain at 15-20 days after heading in the alter sowing.

Kerr *et al.*, (1992) found that delayed sowing of wheat caused a decrease in dry matter and kernel number (Kumar and Sharma, 1999 and Singh *et al.*, 2005).

2.1.1.3 Leaf area index (LAI)

Leaf area index, a ratio of total leaf area to unit land area (Watson, 1947), and is a functional size of the standing crop of unit land area (Hunt, 1978). Khan (1981) described LAI as a measure of leafiness and photosynthetic surface area of a crop and found to depend on the leaf growth, number leaves per plant, plant density, mode of branching and senescence. According to Watson (1952) leaf area is a better determinant of crop growth than NAR. Light interception by the canopy increased with the increase in LAI (Williams *et al.*, 1968; Bullock *et al.*, 1988). Eik and Hanway (1966) showed that leaf area index and grain yields are positively correlated up to a LAI of about 3.5.

The LAI of barley was significantly influenced by the date of sowing in all the growth stages. The LAI also decreased with delay sowing (Singh *et al.*, 1975; Abdel-Raouf *et al.*, 1983 and Moula, 1999) However, the highest LAI was recorded in November 15 sowing while the lowest value was in later sowings (Moula, 1999).

Hung and Miao (1982) showed that a LAI of 7.3 was the maximum that gave high grain yield. Mucci *et al.*, (1985) reported that LAI of duram wheat obtained maximum LAI (4.8) for early sowing and 5.1 for the late sowing. Ashraf and Bhatti (1998) reported that leaf area of wheat genotypes decreased with late sowing condition. November 15 also recorded higher LAI, CGR and gave 39% more than late sowing on 18 December.

2.1.1.4 Leaf area duration (LAD)

Usually leaf area duration is closely correlated with yield because interception of solar radiation over longer periods of time generally means greater total dry matter production. Large differences in total biomass yields are often result of duration of photosynthesis and the photosynthetic rate (Gardner *et al.*, 1985). Studies cited by Evans (1975) showed that the LAD could account for about half of the variation in grain.

2.1.1.5 Crop growth rate (CGR)

Crop growth rate is the rate of dry mater production per unit area of land per unit time (Hunt, 1978), and a reasonable approximation of canopy photosynthesis (Clawson *et al.*, 1986). Crop growth rate expressed by Watson (1952) as an index of the efficiency of the photosynthetic apparatus. Crop growth rate changes with growth (Tanaka, 1983) and reaches maximum at panicle emergence. It decreases soon after panicle emergence (Wilson and Ellis, 1981).

Sowing date exerted a significant variation on CGR in all the growth stages of barley. During vegetative stage the crop growth rate decreased with the delay in sowing and the similar trend was also observed in reproductive and grain filling stage (Moula, 1999). The later seeding had the least CGR because of smaller LAI in all the growth stages (Abdel-Raouf *et al.*, 1983). However, in all the growth stages November 15 sowing found to be better that all other sowing of which December 25 and January 5 sowing produced the least CGR (Moula, 1999).

Bhardwaj *et al.*, (1987) reported that CGR was positively correlated with assimilation of photosynthate. The maximum CGR of rice was found around 30-36 $g/m^2/d$ in the Philippines (Yoshida and Cook, 1971). BRRI (1985) observed a maximum CGR of 30 $g/m^2/day$ conducting an experiment with different varieties of wheat. Wheat sown on 24 November also recorded higher CGR and gave 39% more than late sowing on 18 December.

2.1.1.6 Relative growth rate (RGR)

Relative growth rate is the increase in plant dry matter per unit dry matter per unit time (Miedema, 1982). RGR represents the efficiency of the plant as a producer of new material and gives a measure of the plants economy in working (Hunt, 1978).

RGR is the highest in the early stage of plant development. Van Eijnatten (1963) represented higher RGR at early stage of development and then declined slowly. He also stated that variation in the NAR causes the RGR to fluctuate around the general trend.

2.1.1.7 Net assimilation rate (NAR)

The net assimilation rate is defined as the increase in dry weight per unit time per unit assimilating area (Milthrope and Moorby, 1979) and is the most important index of mean photosynthetic efficiency of a plant under a particular environment. Cox *et al.*, (1990) described NAR as the net gain of phytomass per unit of leaf area and time. NAR decreased with increase in LAI (Tanaka *et al.*, 1964). NAR would not be much affected by the change of LAI within a limit (Watson, 1958). Van Eijnatten (1963) showed that highest values of NAR were obtained during the 5th week of the plant development where maize plant completed its lifecycle at about 90 days. Wheat sown on 24 November also recorded higher NAR than late sowing on 18 December (Zende, 2005).

2.1.2 Chlorophyll content, proline content and relative leaf water content.

Engelmann (1982) suggested that light energy absorbed by chlorophyll is utilized for photosynthesis. However, after publication of fundamental monographs on chlorophyll and photosynthesis it has become customary to consider chlorophyll as the photosynthetic pigment per excellence. The rate of photosynthesis is increased with the chlorophyll content. Fleischer (1935) found out a relationship between chlorophyll content and rate of photosynthesis. Desai (1935) observed similar relationship between water content, chlorophyll content and rate of photosynthesis in some tropical plants at different temperature. Murata (1962) reported of definite relationship of photosynthetic activity with plant height, thickness of leaf, vegetative period, leaf area and dry matter production for a series of rice varieties mainly Japanese.

Working with 16 genotypes of wheat Ashraf and Bhatti (1998) reported that chlorophyll contents in all genotypes of wheat decreased with late sowing (Khatkar and Kuhad 2000).

Free proline is accumulated in plants in response to a wide range of biotic and abiotic stress such as water stress, salinity, temperature, pathogen infection, pollution and nutrient deficiency/toxicity (Hare and Cress, 1997). Maiti *et al.*, (2000) reviewed the accumulation of proline for osmotic adjustment is a mechanism that resistant plants have to adapt to abiotic stress factors such as salinity, high temperature and drought in various crop species.

Chaitanya *et al.*, (2001) found that proline accumulation was 1.5 fold in high temperature stressed mulberry leaves. Stewart and Lee (1974) postulated that under some circumstances, and in some plants, proline might be accumulated until it constitutes more than 10% of the dry weight of the stressed tissue, a concentration rarely exceeded by any single cellular components.

Kuo *et al.*, (1986) reported the effect of high temperature on proline content in tomato floral buds and leaves. The results indicated that proline content in anthers increased with advancing development of floral buds to a maximum at anthesis. They found that the pistil had less proline compared to anthers and could not accumulate with advancement of floral bud development in most of the cultivars under study. High temperature caused higher proline content in leaves. Normally the proline content of leaves was lower than that of anthers or pistils. They subsequently suggested that low proline accumulation in the leaves might be the result of high accumulation in the floral buds. Again, anthers need high proline to confer heat resistance to pollen germinating at high temperatures.

Hossain *et al.*, (1995) determined the proline content in different cultivars of Cabbage, Chinese cabbage and their hybrids under high temperature stress to identify differences in heat tolerance. Proline content of the leaves of inter-specific hybrids between Cabbage cultivar (c.v.) 'Yoshin' and Chinese cabbage (c.v.) Kenshin (*B. campestris* var. *pekinensis* L.) and between Chinese Kale c.v. Sen-yo-shirobana (*B. oleracea var. alboglabra* Bailey) and Kenshin was intermediate between those of their parents at 35^0C. The proline content of stalks and floral buds at 25^0C and 35^0C were found higher than leaves. There had a negative correlation between pollen viability and the rate of decrease of the proline content in the floral buds. It had been observed that the increase in proline content was 1.2, 1.6 and 1.8 times in the leaves of heat tolerant Cabbage c.v. 'Yoshin' and Chinese cabbage c.v. 'Kenshin' and Chinese Kale c.v. Full White, respectively. In contrast, the increase in the proline content of the heat sensitive cabbage c.v. YR Kinshun, Chinese cabbage c.v. 'Chihiri 70' and Chinese Kale c.v. 'Large leaf were 3.5, 17.6 and 3.6 folds respectively.

They finally suggested that proline accumulation may be used as a criterion for selection of heat tolerant genotypes in Brassica.

Bhattacharjee and Mukherjee (1996) and Park *et al.*, (2001) measured leaf proline content as water and high temperature stress indication in apple. They found that proline content was high in both water and high temperature stress and there was a significant interaction between root zone temperature and osmotic potential for proline and water content of leaves.

Wojciechowska *et al.*, (2001) determined free proline in five strains of white cabbage and found that free proline accumulated in cabbage heads stored both at low and high temperature. The considerable increase in proline level during short-term storage at room temperature was due to temperature rather than to water stress. Long term storage in a cold chamber induced proline accumulation.

The proline concentration in citrus leaves differed between species and cultivars in response to temperature. As the maximum air temperature increased during summer months (42-44^{0}C) and the minimum air temperature decreased during winter months (around 5-8^{0}C) the leaf proline content of orange cultivars gradually increased in both seasons to 12-13.6 and 13.8-14.8 mg/g (dry wt basis) in July and January, respectively. They also found that proline concentrations were significantly higher in young leaves than in old leaves in response to air temperature stress (Sabbah *et al.*, 1996). Hare and Cress (1997) reported the contribution of proline to oxidative respiration and involvement of proline metabolism in the regulation of intracellular redox potential and proline as stress related signal.

Hasan *et al.*, (2006) tested four wheat cultivars under normal and post anthesis heat stress condition by seeding them on November 30 and December 30 to evaluate the heat tolerance of wheat in relation to proline content and found that time to exceed 50% membrane leakage was about four times longer in Agrani, Kanchan and CB-30 (120-150 min.) and the cultivars were grouped as heat tolerant (HT) than in Sonora (30 min.) which considered as heat sensitive (HS). Due to post anthesis heat stress condition the HS cultivar Sonora in comparison to heat tolerance (HT) genotype exhibited larger decrease in kernel proline (47.2%) along with larger increase in flag leaf proline (122%).

2.1.3 Yield and yield attributes

Yield of crop is the function of some yield contributing parameters. Sowing time has a remarkable influence on yield of barley. The yield and yield parameters of barley varied from location to location due to the prevailing weather situation during pre-anthesis and post-anthesis development. Some of the pertinent literatures regarding effect of sowing time in different location of the world have been presented below.

2.1.3.1 Plant height

Plant height is the total length of plant from the soil to the top of the leaf. In the early stage of development, it is a good indicator for overall development. It is considered as an important plant character related to grain yield in barley. Plant height has been found to vary from variety to variety in barley and is dependent on genotype and cultural environment.

The plant height of barely was significantly influenced by date of planting. In an experiment Moula (1999) study the effect of sowing time on growth and development of barley varieties and reported that the tallest plant was recorded by November 25 sowing (111.8 cm) and the shortest plant was recorded by December 25 sowing (73.8 cm). Similar results have also been observed by Farid *et al.*, (1993) Photiades and Hadjechristodoulou (1984).

In a trial with cultivar Balaka in Joydebpur and Jessore, BARI (1984) reported that the tallest plant (76.83 cm) was obtained at Jessore when sowing was done on 20 November and shortest with 30 December sowing (Hossain and Farid, 1988).

Anderson and Oslen ((1992) reported that early sowing increased plant height (Ahmed *et al.*, in 1997) and it also increased loading percentage Anderson and Oslen, 1992 and Sarker *et al.*, 1996).

2.1.3.2 Tillers, effective tillers and non-effective tillers per plant

Tillering an effective way of increasing the leaf area per plant, decreases the sensitivity of yield to plant density. Upward, or intravaginal , axillary shoots in grasses are commonly referred to as tillers (Gardner,1985). Tillers emerge acropetally, beginning at the lowest nodes. In wheat the first tiller emerges from the coleoptile axil, in rice from the leaf-3 axil. It is an important yield contributing characters is tiller per plant. The wheat varieties differed significantly in producing total and fertile tillers per plant (Anonymous, 1972). The associations of yield and effective tillers were also reported by many scientists. Shrivastava *et al.*, (1998) studied relationship between various traits in wheat. They reported that yield had significant positive correlation with effective tillers per plant.

In a trial with wheat in Joydebpur and Jessore, BARI (1984) reported that the highest number of effective tillers/plant was obtained by 20 November sowing similar finding were reported by Sarker *et al.*, (1999).

A study was conducted by Fukushima *et al.*, (2001) in Japan to examine tiller development of wheat. Winter wheat variety Iwainodaichi and spring wheat variety Chikugoizumi were sown on 5 October (very early sowing), 5 November (early sowing) and 24 December (standard sowing). The maximum number of tillers per area was greater in Iwainodaichi than in Chikugoizumi with every date while the number of spikes per area was not greatly affected by cultivars. The emergence rate of tillers was greater in Iwainodaichi but most of those tillers were non productive.

Lupu (2001) conducted an experiment during 1997-99; winter wheat was studied in Moldavia in a monofactorial experiment at ten sowing times in intervals between 15 September and 20 November. The best conditions for their growth and development and the best yield results were obtained between 25 September and 15 October. Among the productivity parameters, the number of both grains and tillers per plant were the most affected by climatic factors.

2.1.3.3 Spike length, grains/spike and 1000 grain weight

The number of grains depends on the number of spikelets per ear and grains per spikelet. Alam (2003) reported that varietal differences were observed for number of ears per unit area and number of grains per ear. However, number of grains per ear varies depending on the genotype and its cultural conditions in which they are grown.

Ryu *et al*., (1992) concluded that the highest grain weight of barley was reached at 40 days after heading in early and intermediated sowing and 35 days in late sowing.

Zhao *et al*., (1985) conducted experiments on barley in China under two different sowing dates, viz. October 28 and November 17 in 1982-83 and November 7 and November 27 in 1983-84. They found that with delay in sowing tiller and ear number/10 plants decreased from 64 to 41 in 1982-83 and from 49 to 18 in 1983-84. The full growth period was shortened with delay in sowing.

Zende *et al*., (2005) An experiment was conducted during the 2002/03 rabi season in Akola, Maharashtra, India, to evaluate the effects of sowing time (15 November, 1 December and 15 December) on the growth and yield of durum wheat (*Triticum durum*) and concluded that The growth, yield and yield attributes, except for the spike length, showed significant increases when durum wheat crops were sown on 15 November compared with those sown on 1 December and 15 December.

Ram *et al*., (2004) A field experiment was conducted in Hisar, Haryana, India, during the 2001/02 rabi season to determine the effect of sowing date (10 October, 20 October, 30 October, 10 November and 20 November) and row spacing (22.5, 30.0 and 37.5 cm) on the yield and yield components of wheat cv. C-306. Wheat sown on 10 October gave the highest number of spikes per plant, number of grains per spike and grain yield. The highest 1000-grain weight, straw yield and biological yield was obtained with 20 October-sown wheat (Dofing and Karlsson, 2001; Singh and Dhaliwal, 2000; Samuel, 2000).

2.1.3.4 Yield

Yield of a crop depends on many factors. Martin and Leonard (1967) concluded that potential yield was governed by genetic factors, whereas the percentage of spikelet filled depended on source activity, which was function of the environment. Muleba *et al*., (1983) stated that grain yield of crop plants was a function of a number of factors and processes acting concurrently with light interception by the crop community metabolic efficiency of the plant, translocation efficiency of photosynthates from leaves to growing kernels ad sink capacity.

A field experiment was conducted by Ahmed *et al*., (2006) at Farming System Research and Development (FSRD) site, Chabbishnagar, Godari, Rajshahi under rainfed condition during rabi seasons of 2001-2002 and 2002-2003 to find out the suitable variety (BARI Barley-1, BARI Barley-2 and local) and sowing time of barley (30 November, 15 December and 30 December). They concluded that grain and straw yields increased significantly with early sowing (30 November) in all varieties in both the years. The results show that early sowing (30 November) combined with BARI Barley-1 gave the highest grain (2.55 t/ha) and straw yield (4.28 t/ha), whereas the lowest grain yield (1.23 t/ha) and straw yield (3.21 t/ha) was obtained from local variety with delay sowing.

Two barley cultivars were grown by Thomas (1995) in both well-watered and water stress conditions. He concluded that water use efficiency was higher in early-maturing barley cv. Corvette than in late-maturing cv. Triumph. He also reported that, biomass produced per unit evapotranspiration was higher in early-maturing barley cv. Corvette than in late-maturing cv. Triumph.

The growth of grain and shoots of 36 barley genotypes (18 2-rowed and 18 6-rowed) was studied by Gouis (2004) in northern France. A linear model showed that there was genotypic variation in both rate and duration of grain filling (GF) and shoot growth (SG). GF rate per grain was closely associated with kernel weight ($r = 0.58$ and $r = 0.82$ for the 2-rowed and the 6-rowed varieties, respectively). A strong negative phenotypic correlation was, however, found between GF rate per grain and duration for the 2-rowed genotypes ($r = -0.71$). SG and GF rates for the majority of genotypes were similar. On average, GF rate of 6-rowed was, however, higher than their SG rate (2.11 vs.1.93 g/m^2). Translocation of assimilates previously stored in vegetative parts may then explain the higher yield of 6-rowed genotypes. On average, SG stopped before GF and the means for the 2- rowed and 6-rowed varieties were not significantly different.

Singh *et al.*, (1989) found that grain yield of barley decreased at delayed sowing from December 10 to 25 and January 10 (Spaldon and Malnarova, 1991).

Porwal *et al.*, (1991) considered four sowing dates viz. October 31, November 15, December 15 and December 30. They concluded that grain yield of barley was maximum when sown on November 15 followed by November 30. They assessed that sowing date also significantly influenced 1000-grain weight of barley.

Farid *et al.*, (1993) conducted an experiment on sowing dates in 1987-88 having five sowing times started from November with 15 day intervals with three cultivars of barley viz. Centinella, AP-1-19 and AP-1-20. They observed that November 5 was found to be the optimum time for AP-1-20 and November 5 to December 5 for Centinella and AP-1-20, respectively. In general, all the cultivars of barley performed better when sown on November 5. In all cases yield was reduced significantly with delayed sowing beyond December 20.

Corny (1995) concluded from two years study in Ireland on malting barley cv. Blenhiem sown on March, early April and late April that the earliest sown spring barley generally gave the highest yield and the best quality grain.

BARI (1997) reported from the study in Jamalpur during the rabi season of 1997-98 on barley cv. Conquest that among the five sowing dates viz. November 5, November 20, December 5, December 20 and January 5, the grain yield was statistically different among those sowings. The crop sown on December 20 produced the lowest grain yield which was closely followed by that of January 5 sowing. A drastic reduction in grain yield was observed when the crop was sown on December 5 or later (Begum *et al.*, 1999).

2.1.3.5 Harvest index (HI)

Harvest index (HI) is the ratio of economic yield to biological yield (Donald and Hamblin, 1976), and is a useful index of assessing the extent of phytomass converted into useful economic yield (Gautam and Sharma, 1987). The economic yield of wheat is its grain. Biological yield of a crop is the TDM at final harvest (Donald and Hamblin, 1976).

Samuel *et al.*, (2000) reported that late sowing condition (6 January 1997) reduce the harvest index (36.1%) from (41.5%) of normal sowing condition (29 November 1996) in wheat.

Ehdaie *et al.*, (2001) reported that early sowing decreased harvest index. They reported that greater N supply increased shoot biomass by 29%, grain yield by 16% and protein by 5% but decreased harvest index by 10%. Ram *et al.*, (2004) found that the highest harvest index was obtained in November 20 sown wheat.

From the above review of literature it is evident that sowing time has a significant influence on yield and yield components of barley. The literature suggests that early or delay sowing other than optimum time reduces the grain yield of barley which is directly related with the temperature of the growing period of the crop. Reduction in grain yield is mainly attributed by the reduced number of spike $plant^{-1}$, grains $spike^{-1}$ and 1000 grain weight due to curtailment of period for development of these parameters.

2.2 Effect of irrigation

Supply of irrigation water or moistures has dramatists effect on growth, development and yield of any crop. Water deficit at various phases of crop growth has direct effect on crop yield. The reduction in growth as a result of water deficit (Prasad and Singh, 1987). Crop yields under dry land condition are related to seasonal rainfall, water use efficiency can be substantially improved by crop management practices (Harris *et al.*, 1991). The introduction of supplemental irrigation to winter grown cereals can potentially stabilize and increase yields, as well as increasing water use efficiency received both from rainfall and from irrigation (Oweis *et al.*, 1992). In Bangladesh, very little works have been done regarding agronomic practices of barley especially on the response of irrigation frequency. However, some available findings on the performance of barley and related crops like wheat and millet under irrigation are reviewed and presented below.

2.2.1 Phenological, morphophysiological and growth parameters

2.2.1.1 Maturity

It was observed that irrigation frequency had significant effect on days required to maturity of barley. Three irrigations (irrigations at 25 DAS +50 DAS +75 DAS) took the longest days to maturity that of two irrigations i.e., 25 DAS and 50 DAS (Moula (1999) and Anonymous (1998). They stated that increased irrigation number also required more days to maturity compared to control (Podsiado, 1999).

WonYul *et al.*, (1997) conducted an pot experiment to know the effects of water stress at heading, or 20 or 10 days before heading in barley cv. Milyang 12, Durubori, Olbori, Baegdong and Hyangmaeg and reveled that resistance to water stress was in the order Olbori > Milyang 12 = Durubori > Hyangmaeg > Baegdong.

2.2.1.2 Total dry matter (TDM)

Pessarakli *et al.*, (2005) A field experiment was conducted in Karaj, Iran, during the 1993/94 cropping season, to gather further information on the effects of water deficit on dry matter yield of straw and grains, protein content, starch, fibre and ash percentage of barley cv. Walfajr and wheat cv. Karaj I under the irrigation regimes of 7 (control) and 14 days intervals (stress). Total dry matter yields of straw and grains of both species decreased under stress. Nevertheless, the fluctuation in dry matter percentage of both plants and the plant parts was not significant. (Chaudhary and Sharma, 2003; Al-Satari *et al.*, 2001).

Torofder *et al.*, (1993) observed that increase in total dry matter (TDM) production in barley was noticed clearly up to three irrigations as compared to one or two irrigation. They also found that increased in TDM due to irrigation compared to control (on irrigation). Further, Grant *et al.*, (1991) reported from a field trial at Manitoba, Canada that under low moisture condition TDM production response was low and greater under high moisture condition. Similar result was also reported by many workers in barley (Rana *et al.*, 1988; Singh *et al.*, 1989; Anonymous, 1998; Moula, 1999). TDM production in pearl miller was increased significantly with the application of irrigation as compared to the treatments receiving no irrigation as reported by Verma (1993). However, Anonymous (1993) reported that increased in TDM due to increased number of irrigation in miller. Similar result was also reported by Prasad *et al.*, (1986) and Gaffer 1995).

2.2.1.3 Leaf area index (LAI)

Singh and Anureet (2001) carried out an experiment on malt barley cv. Alfa-93 was treated with 4 levels of irrigations, viz. I0 (no irrigation), I1 (one irrigation at tillering stage), I2 (one irrigation at flag leaf stage) and I3 (two irrigations, first at tillering and second at flag leaf stage), in Hisar, Haryana, India. And reported that treatment I3 significantly increased plant height, number of tillers, dry matter accumulation, leaf area index, yield (grain + straw) and yield attributes.

Moula (1999) conducted a field experiment during 1998-99 season on barley with two levels of irrigation viz. one at crown root initiation (CRI) and two both at CRI + booting stage and reported that leaf area index (LAI) increased over control and the highest was recorded at two irrigation schedule. Further, Rao and Agarwal (1984) conducted an experiment with barley and reported that increase in LAI by one supplemental irrigation at active tillering stage over no irrigation. On the other hand, Verma (1993) reported that LAI in pearl miller was increased significantly due to application of irrigation as compared to the treatment receiving no irrigation. Similar result was also reported by Rahman (1997) in foxtail miller and in wheat (Ashok and Sharma, 1997; Shaheb, 2004).

2.2.1.4 Crop growth rate (CGR)

Mostafavi and Niknejad (1983) conducted an experiment with barley under irrigated and rainfed condition in two separate fields and reported that crop growth rate (CGR) was greater under irrigated condition that in rainfed condition. Moula (1999) reported that CGR was increased with increase number of irrigation in barley. Pal *et al.*, (1996) further reported that CGR was higher in irrigated plants than in rainfed plants at all growth stage in wheat. They also reported that CGR increased with increase irrigation frequency (Rahman, 1997). Moreover, Prasad *et al.*, (1986) observed that increase in CGR in proso millet was noticed clearly up to two irrigations as compared to one irrigation.

2.2.1.5 Relative growth rate (RGR)

Moula (1999) conducted an experiment to know the effect of irrigation on growth an yield of barley and reported that relative growth rate (RGR) increased with increased number of irrigation. Similar result was also reported by Shaheb (2004) in wheat and in millet (Rahman, 1997). They reported that increase number of irrigation also increase RGR. Further, Verma (1993) observed that increase in RGR at early growth stage was due to irrigation compared to no irrigation of pearl millet.

2.2.1.6 Net assimilation rate (NAR)

Mandal *et al.*, (1991) conducted a field experiment in India during 1984-85 and 4986-87 on wheat with two levels of irrigation: one at crown root initiation (CRI) and two at CRI + booting stage and reported that NAR increased significantly with increasing levels of irrigation. Moula (1999) conducted an experiment to know the effect of irrigation on growth and yield of barley and reported that net assimilation rate (NAR) increased with increased number of irrigation. Similar result was also reported by Shaheb (2004) in wheat who reported that increased number of irrigation also increase NAR.

2.2.2 Chlorophyll content, proline content and relative leaf water content.

Singh and Patel (1996) in a greenhouse pot experiment wheat cv. WH-283 and WH-331 were subjected to water stress by withholding water until wilting occurred at tillering, flowering or grain filling stages. And observed that Leaf water potential, osmotic potential, relative water content and photosynthesis decreased in both cultivars and at all growth stages whereas respiration rate and accumulation of proline increased with water stress. The effects were more pronounced in WH-283 than WH-331. Water stress at flowering reduced grain yield more than water stress at tillering or grain filling.

A series of experiments was carried out by Ashraf *et al.*, (1994) on 4 wheat genotypes: tolerant (Chakwal-86 and DS-4) and susceptible (DS-17 and Pavon) to drought induced by PEG-6000 solutions (0 and -0.6 MPa). Water stress reduced root and shoot lengths, DW and chlorophyll (a, b and total) contents; the reduction was more pronounced in drought susceptible genotypes. Total phenols, peroxidase activity and chlorophyll a/b ratio increased under drought conditions.

Al-Tabbal *et al.*, (2005) Two greenhouse studies were conducted at the University of Jordan campus during the 2000/01 growing season to examine the influence of mepiquat chloride (1-dimethyl piperidinium chloride) and ethephon (2-chloroethyl-phosphonic acid) on leaf chlorophyll, soluble sugars, and proline contents of two wheat (*Triticum turgidum* var. *durum* [*T. durum*]) cultivars (Hourani and Petra) grown under various soil moisture levels. They concluded that water stress was found to reduce total chlorophyll and to increase proline contents as well as total soluble sugar of the two cultivars. Cultivar variation was observed, particularly in Petra cultivar which recorded the highest content of proline, total chlorophyll, and chlorophyll a compared to Hourani cultivar, while Hourani had higher total soluble sugar than Petra. A significant interaction between cultivars and water levels was observed on both total soluble sugar and proline contents and between water levels and sampling stage only for proline content. This indicates variation between the two cultivars at various stages in some of their biochemical constituents and this could be altered by both water deficit and growth regulators such as mepiquat chloride.

Podsiado (1999) In a field study in 1988-91 on sandy soil, 4 spring wheat cultivars were grown with or without irrigation and given no fertilizers, 50:40:50 kg NPK/ha, or 2 or 3 times these NPK rates. Irrigation and higher NPK rates generally increased the chlorophyll and carotenoid contents of the flag leaf. Irrigation decreased nitrate reductase activity and increased acid and alkaline phosphatase activities. Higher NPK rates increased nitrate reductase, peroxidase and alkaline phosphatase activities, but decreased acid phosphatase. Mineral, protein and amino acid contents are tabulated.

In field trials Karczmarczyk *et al.*, (1993) on good rye complex soil in 1984-89, winter wheat cv. Emika and triticale cv. Grado were grown with or without sprinkler irrigation and given 0, 90 or 150 kg N/ha in 3 split applications. Chlorophyll and carotenoid contents in flag leaves, stalks and spikes were determined at heading, flowering and the milk-ripe stage. Irrigation and increasing N rate increased the DW of the selected plant parts at each stage. Chlorophyll and carotenoid contents per organ were increased by N application and, in most cases, by irrigation. Chlorophyll and carotenoid contents per g DM increased with increasing N rate in all 3 plant parts at each stage. Irrigation significantly increased chlorophyll content per g DM at the milk-ripe stage in wheat and triticale, but at earlier stages the effects varied with growth stage and plant part. Effects of irrigation on carotenoid content per g DM were generally not significant. The combination of irrigation and high N rate delayed pigment decomposition and extended the period of photosynthetic activity.

Free proline accumulation was measured by Waldren and Teare (1974) in leaves of intact sorghum and soybean grown in growth chambers and subjected normal drought stress.

Stomatal diffusive resistance and leaf water potential were used to determine the degree of stress at the time of proline analysis. Free proline was not accumulated markedly in either species until each was serially stressed. indicating that proline is not sensitive indicator of dronght stress. Free proline was accumulated under less stress in soybean than in sorghum. Proline accumulation may be an indicator of drought resistance or susceptibility. Deora, *et al.*, (2001) reported that the chlorophyll content in wheat increased in stressed leaves as compared to normal leaves.

Drossopoulos *et al.*, (1987) reported large accumulations of proline in the leaves, stems, roots and flowers of wheat cultivars Yecora and Generoso with increases in water stress. Proline levels in response to water stress were higher in both cultivars at germination compared with seedling differentiation. Generoso accumulated more free proline in leaves, stems and roots at the different stages than did Yecora, while levels in the flower spikes of both cultivars were similar at a given water potential.

Proline accumulation in vitro stressed seedling leaf segments and its associations with a number of physiological responses induced by water deficit was studied by Tan and Halloran (1982) in 14 wheat cultivars with known drough resistance rankings. The cultivars varied in their capacity to accumulate proline, which was also inter-correlated with increases in total catabolic amino acids and sugars during stress. High relative growth rate of seedlings subjected to moderate water stress was bound to be strongly correlated with drought susceptibility.

2.2.3 Yield and yield attributes

2.2.3.1 Plant height

An experiment was carried out by Singh and Kumar (1976) on barley giving irrigation at active tillering stage and flag leaf stage. They found that irrigation increased plant height.

They further reported that irrigation at active tillering stage resulted in maximum plant height than in flag leaf stage. Plant height of barley increased with increased number of irrigation (Singh and Anureet, 2001). Similar result in barley was also reported by many researchers (Wahab and Singh, 1983; Prasad and Singh, 1987; Singh *et al.*, 1989; Kumar and Agarwal, 1991; Torofder *et al.*, 1993; Anonymous, 1998).

Al-Satari *et al.*, (2001) field trial was conducted at the Muwaqqar Research Station in the 1996/1997 growing season to evaluate the effect of three seeding rates and three water levels of supplemental irrigation on the forage and grain yield of two barley cultivars (ACSAD 176 and Rum). Supplemental irrigation was applied at three stages during the growth of the barley crop as follows: at germination, tillering and booting stages. A single clipping at the tillering stage produced the highest fresh and dry matter yield for both cultivars grown under the highest water level. By increasing both the seeding rate and supplemental irrigation, plant height, fresh matter yield, dry matter yield and biological yield were increased. (Podsiado, 1999; Jana and Mitra, 1995 and Yadav *et al.*, 1995).

2.2.3.2 Number of effective tillers per plant

Chaudhary and Sharma (2003) An experiment conducted in Rajasthan, India, during 1999-2000, on barley cultivars (RD 2035, RD 2503 and RD 2508) revealed that an increase in number of irrigations (up to 4) enhanced growth characters viz., total number of tillers and dry matter accumulation at 40 and 80 days after sowing (DAS) and at harvest. Dry matter accumulation at 40 and 80 DAS increased with 2 and 3 irrigations, respectively. Significant improvement in effective tillers, grains per ear, grain weight per ear and yield was recorded up to 4 irrigations. Grain, straw and biological yields (37.14, 65.10 and 102.24 q/ha, respectively) significantly increased up to 4 irrigations (Afzal *et al.*, 2006; Hamdy *et al.*, 2003; Borowczak *et al.*, 2003).

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The number of effective tillers plant^{-1} in barley was increased significantly due to irrigation as compared to no irrigation (Rao and Agarwal, 1984). Torofder *et al.*, (1993) observed that application of one irrigation at crown root initiation (CR) stage and two irrigations both at CRI and heading stage showed statistically similar number of effective tillers plant^{-1} but significantly increased over control (no irrigation). Similar result was reported by many researchers in barley (Uppal *et al.*, 1988; Singh *et al.*, 1989; Grant *et al.*, 1991; Kumar and Agarwal, 1991 and Anonymous, 1997).

On the other hand, number of effective tillers plant^{-1} increased gradually with increasing number of irrigation in wheat as reported by Islam (1997) and the highest effective tillers plant^{-1} was observed in application of three irrigation at 25, 50 and 70 DAS whereas the lowest was observed in control (no irrigation).

2.2.3.3 Spike length

Both significant and insignificant effect due to irrigation on spike length was observed in barley. Moula (1999) reported that length of spike was significantly influenced by irrigation and the longest spike length was obtained at two irrigation compared to one and no irrigation. Singh *et al.*, (1989) found that irrigations were optimum for spike growth and development. However, most of the researchers reported that panicle length increased with increase number of irrigation (Uppal *et al.*, 1998; singh *et al.*, 1989; Anonymous, 1997; Grant *et al.*, 1991 and Torofder *et al.*, 1993). In contrast, Anonymous (1998) reported that irrigation had no significant effect on panicle length in barley.

On the other hand, Verma (1993) reported that panicle length of pearl millet was significantly greater under irrigated condition than under non-irrigated condition. One irrigation at CRI stage or at maximum tillering stage increased panicle length over control (no irrigation). Further, Naser (1996) reported that two irrigations at 30 and 50 DAS significantly increased panicle length over control.

2.2.3.4 Number of grains per spike

Abdorrahmani *et al.*, (2005) find out the growth rate, yield and yield components of 4 wheat cultivars under rainfed conditions and 2 irrigation regimes (irrigation at sowing time and ear emergence, and irrigation at sowing time, ear emergence and grain filling) in Maragheh, Iran, during 1997-98. Crop growth rate, relative growth rate, dry matter accumulation per unit area, number of ears per unit area, number of grains per ear, 1000-grain weight, biological yield, grain yield, harvest index, plant height and productivity were evaluated. Drought stress reduced dry matter production, crop growth rate and relative growth rate. Green cover percentage, crop growth rate, and relative growth rate did not significantly vary among the cultivars. All traits except the number of grains per ear and harvest index were affected by water deficit. No significant variation was observed between irrigation regimes. The green cover percentage, plant height, crop growth rate, biological yield and productivity were significantly correlated with grain yield. The mean green cover had the greatest positive correlation with grain yield. This trait can be recommended as a suitable index for the evaluation of the field performance of various crops.

Torofder *et al.*, (1993) opinioned that supplemental irrigation had beneficial effect on barley. They concluded that application of one irrigation at CRI and two irrigations both at CRI and heading stage produced greater spikelets spike^{-1} than in control but within the irrigation treatmnents, there was no significant difference in spikelet number spike^{-1}. Again Prasad and Singh (1987) found that spikelet number spike^{-1} increased with increasing irrigation.

2.2.3.5 Thousand grain weight

Afzal *et al.*, (2006) in a Comparison of wheat and barley for yield and yield components under different irrigation patterns was studied at NWFP Agricultural University, Peshawar during Rabi 2003. Irrigation patterns significantly affected productive tillers m^{-2}, grains $spike^{-1}$ thousand grain weight, grain yield kg ha^{-1} and water use efficiency kg ha^{-1} mm^{-1}. Plot receiving four irrigations gave maximum productive tillers m^{-2} (226.27), grains $spike^{-1}$ (63.72), thousand grain weight (40.4 g), and grain yield (5024.27 kg ha^{-1}). Maximum water use efficiency (13.22 kg ha^{-1} mm^{-1}) was obtained from controlled plots to which only pre-sowing irrigation was applied plus effective rainfall.

Borowczak *et al.*, (2003) Experiments were conducted in 1993-96 to study the effects of irrigation and cultivation systems on the yields, yield components and sowing material quality of winter wheat, spring barley and pea. The yields of winter wheat, spring barley, and pea increased with high cultivation intensity. Irrigation increased the yields of winter wheat, spring barley, and pea by 11.3, 10.8 and 27.5%, respectively. An increase in the number of ears per unit area, number of grains per ear and 1000-grain weight of winter wheat and spring barley increased crop yields. The effect of cultivation on the changes in yield components was higher than irrigation. Irrigation and cultivation did not significantly differ the sowing value of winter wheat grain and pea seeds. High cultivation intensity deteriorated the sowing value of spring barley grain, especially under non-irrigated conditions.

Few researchers stated that irrigation had no significant influence on 1000-grain weight (Mostafavi and Niknejad, 1983; Rao and Agarwal, 1984). Further, Rahman (1997) reported that irrigation had no significant effect on 1000-grain weight of foxtail millet. On the other hand, Shaheb (2004) reported that irrigation had significant influenced on 1000-garin weight in wheat. Similar result was also reported by Yadav *et al.*, (1995); Patil *et al.*, (1996) and Abdorrahmani *et al.*, (2005).

2.2.3.6 Grain yield

Nowak *et al.*, (2005) a field experiment conducted in the years 2002-2004 in Samotwor near Wrocaw (Poland) assessed the usefulness in the cultivation of spring brewing barley cv. Scarlett on a light soil under sprinkler irrigation. Under natural precipitation the yields of barley grain ranged from 34.06 dt ha^{-1} (2002) to 54.16 dt ha^{-1} (2003). Sprinkler irrigation caused a 7.5% increase in the grain yield (Pessarakli *et al.*, 2005; Baheri *et al.* 2005; Chaudhary and Sharma, 2003; Hamdy *et al.*, 2003) They also reported that the protein, yield and the nitrogen content of the irrigated plants increased with increasing nitrogen, and were significantly lower than the non-irrigated plants (Afzal *et al.*, 2006; Nowak *et al.*, 2005; Borowczak *et al.*, 2003 and Al-Satari *et al.*, 2001).

Wojtasik (2004) in a Field and laboratory experiments were conducted during 1996-98 in Poland to evaluate the effect of sprinkling irrigation and fertilizer application on malt and fodder barley. Sprinkling irrigation and high rates of NPK fertilizers significantly increased photosynthesis, carbon dioxide assimilation (by 50%) and transpiration (by 30%). Similarly, both treatments increased nitrate reductase activity, stalk length and width, and leaf and ear size. Fodder barley gave the best results.

Wahab and Singh (1983) found that barley required two irrigations viz. one at active tillering stage and the other at flag leaf stage for satisfactory grain production. Again, Cheema *et al.*, (1983) conducted an experiment on barley cv. C-164 under one pre-sowing irrigation, one tillering, two at tillering and dough stage and three at tillering, flowering and dough stage and reported that barley could be grown successfully with 145 mm of available water stored in the 1.5 m profile through pre-sowing irrigation. Further, in a field trial on barley in India, Uppal *et al.*, (1988) observed that two irrigations both at active tillering and heading stage produced higher yield than that of one irrigation at active tillering stage. Similar result was also reported by Moula (1999); Kumar and agarwal (1991) and Torofder *et al.*, (1993) in barley. On the other hand, Anonymous (1997 and 1998) reported that grain yield increased with increasing number of irrigation in barley. Similar result was also reported by most of the researchers (Malik, 1978; Wahab and singh, 1983 and Grant *et al.*, 1991).

Hussain and Al-Jaloud (1998) In a field experiment in 1994-96 on a sandy to loamy sand soil at Dirab, Saudi Arabia, barley cv. Gusto was irrigation and reported that grain yield and water use efficiency also higher by irrigation. It is concluded that application of water would be sufficient to obtain optimum grain yield and high water use efficiency of barley in Saudi Arabia.

In millet and wheat, most of researchers reported that irrigation had significant influence on grain yield and grain yield increased with increased number of irrigation (Yadav *et al.*, 1995; Naser, 1996; Patil *et al.*, 1996; Ghosh *et al.*, 1997; Islam, 1997; Rahman, 1997 and Abdorrahmani *et al.*, 2005).

2.2.3.7 Harvest index

Two useful terms used to describe partitioning of dry matter by the plant are biological yield and economic yield the term biological yield was proposed by Gardner *et al.*, (1985) to represent the total dry matter accumulation of a plant's system. Harvest index reflects the proportion of assimilate distribution between economic and total biomass (Donald and Hamblin, 1976). Crop yield can be increased either by increasing the total dry matter produced in the field or by increasing the proportion of economic yield (the harvest index) or both.

Moula (1999) carried out an experiment on barley with two irrigations viz. no irrigation, one irrigation at CRI and two irrigations both at CRI and booting stage and reported that two irrigations had the highest harvest index (HI) followed by one irrigation and control (no irrigation) had the lowest HI. Similar result was also reported by Kumar and Agarwal (1991) and Torofder *et al.*, (1993) in barley. On the other hand, most of the researchers reported that HI increased under irrigation condition compared to control (no irrigation) in cereal crops (Verma, 1993; Ghosh, 1997 and Islam, 1997).

2.3 Interaction effect of sowing date and irrigation

In an experiment Thomas (1995) grown Two barley cultivars (early-maturing Corvette and late-maturing (Triumph) in well-watered and water stress conditions. He reported that in both well-watered and water stress conditions, barley produced a lower yield when sown in April than in mid-winter, as grain filling occurred in late winter/early spring, when radiation and temperature were low.

Singh *et al.*, (1975) conducted an experiment under rainfed condition with three dates of sowing viz. October 14, October 25 and November 4 in 1971-72 and October 19, October 29 and November 8 in 1972-73 and found that sowing of rainfed barley beyond that last week of October caused significant reduction in grain yield.

Sharma and Thakur (1996) in a field trial at Bajaura in the 1994/95 and 1995/96 rabi [winter] seasons, barley cv. HBL 113 was given different irrigation and sowing rate treatments. When sown during mid-November (optimum), barley only required one irrigation at 30 days after sowing (DAS), which increased the grain yield significantly over delayed irrigation at 45 DAS. After that no irrigation was required, as there was sufficient rainfall. In 1994/95 there was no significant yield difference between sowing rates of 60, 75 or 90 kg/ha, while in 1995/96 yield was higher at 90 than at 60 kg seed/ha.

Pal *et al*., (1996) A field experiment was conducted during the winter seasons of 1992/93 and 1993/94 on sandy loam soil of Ranchi, to study the effect of irrigation, sowing date on growth and yield of wheat cv. UP 262. Application of 4 irrigations gave higher leaf-area index (LAI), dry matter, crop-growth rate (CGR) and net assimilation rate (NAR), resulting in 43 and 14% higher grain yield (3.19 t/ha) than 2 (2.23 t) and 3 irrigations (2.78 t) respectively. Wheat sown on 24 November also recorded higher LAI, dry matter and CGR and gave 39% more grain yield (4.26 t/ha) than late sowing on 18 December (2.29 t). Sowing after 24 November reduced the grain yield by 37.5 kg/ha per day.

Pal *et al*., (1996) A field experiment was conducted during 1992-94 on a sandy loam soil at the university farm, Ranchi, India to estimate the heat-unit requirement for the phenological development of wheat under different irrigation regimes The onset of phenophases was delayed and the duration of phenophases beyond maximum tillering increased with increasing irrigation frequency, and it is suggested that this may be due to the retension of more physiologically active leaf area for a longer duration, such that irrigation at 4 growth stages resulted in a longer period between phenophases and a delay in the onset of maturity. Sowing in November resulted in 5, 6, 7, 8, 9, 10 and 10 extra days for the onset of flag-leaf emergence, boot, spike emergence, flowering, milk, soft dough and maturity stages, respectively, than the later-sown crop. However, a fixed amount of heat units was required to proceed from one phenophase to the other, irrespective of sowing date.

Parihar and Tripathi (1990) wheat sown at Kharagpur on 20 Nov., 30 Nov. and 10 Dec. 1978 and 5 Nov., 20 Nov. and 5 Dec. 1979 was given 50, 100 and 150 kg N/ha and irrigated at 0.6, 0.8 and 1.0 Irrigation Water: Cumulative Pan Evaporation (IW:CPE) ratios. Irrigation to 6 cm water depth was given 7, 6 and 4 times with 1.0, 0.8 and 0.6 IW: CPE ratios, respectively. Water use efficiency (WUE) was highest with 0.8 IW: CPE irrigation scheduling. Soil moisture extraction from the upper soil profile was highest with 1.0 IW: CPE irrigation due to proliferation of roots: soil moisture extraction from deeper layers was highest with 0.6 IW: CPE due to deeper rooting. Grain yields were 1793, 2608 and 2664 kg/ha in 1979 and 1734, 2471 and 2526 kg in 1980 with 0.6, 0.8 and 1.0 IW: CPE ratios, respectively. Grain yields and WUE were highest with sowing on 20 and 30 Nov.

Singh and Jain (2000) In a field trial during the winter seasons of 1993-95 in Udaipur, Rajasthan, India, durum wheat cv. Raj 1555 was sown on 1 November (early), 15 November (normal sowing date) or 2 December (late) and was irrigated at IW:CPE ratios of 0.25, 0.50 or 0.75 and given 40, 80 or 120 kg N/ha. Yield was greatest at the normal sowing date and increased with increasing irrigation and N rates. Late sowing gave the highest grain protein percentage, beta-carotene content and sedimentation value, while these decreased with increasing irrigation rate. Protein percentage and beta-carotene content were higher with 80 or 120 than 40 kg N. Yellow berry incidence decreased with delay in sowing and increasing N rate, and increased with increasing irrigation rate.

CHAPTER 3

MATERIALS AND METHODS

The experiment was conducted at the Crop Botany Research Field and Laboratory, Hajee Mohammad Danesh Science and Technology University, Dinajpur during the period of November, 2005 to March 2006. Details of the methodology of the experiment followed during the research period are presented in this chapter.

3.1 Experimental site and soil

The location of the experimental site was at $25^0 38'$ N latitude and $88^0 41'$ longitude and at the elevation of 34.5m above the sea level. The experimental site was medium high land and belonging to the Agro-ecological Zone 1 (AEZ-1) named Old Himalayan Piedmont Plain (FAO and UNDP, 1988). The soil was sandy loam and fertility status of the soil is presented in Appendix III.

3.2 Climate and weather

The experimental field was under subtropical climate characterized by rainfall during the month of April to September and scanty rainfall during November 2005 to March 20006. The means of meteorological information, like regularly precipitation, relative humidity, maximum temperature, minimum temperature and average temperature, day length and sunshine hours to the experimental site during the crop growing period are presented in Appendix IV.

3.3 Experimental design and layout

The experiment was laid out in a two factors (A. planting dates and B. Irrigation frequency) randomized complete block design (RCBD) with three replications. The experimental plot was first divided into three blocks each representing a replication. Each block then divided into sixteen unit plot of 2.5 m x 2.0 m sizes. The distance between block to block was 1 meter and plot to plot was 0.75 m.

3.4 Experimental treatments

The experiment comprised of two sets of factors such as (A) planting dates and (B) Irrigation frequency. The first set of factors consisted of four different date of sowing and were represented by the quote marks as.

(A) Sowing dates

S1 - November 1

S2 - November 15

S3 - November 30

S4 - December 15

The second set of factors consisted of four frequency of irrigation were represented by the quote marks as follows.

(B) Frequency of irrigation

IR0 - No irrigation (control)

IR1 - One irrigation (Early tillering stage)

IR2 - Two irrigations (Early tillering and booting stage)

IR3 - Three irrigations (Early tillering, booting and grain filling stage).

3.5 Land preparation

The land of the experimental field was first ploughed with a power tiller and then harrowed 7 days before the first date of sowing. It was then ploughed and cross ploughed with country plough. Weeds and stubbles were removed and the land was then levels by laddering to obtained desirable tilth. The corner of the land was spaded and larger clodes were broken into smaller pieces then the gross experimental area was divided into the unit plots maintaining the above mentioned spacing before sowing (each time) for loosening the soil and incorporating the basal fertilizers.

3.6 Fertilizer application

The land was uniformly fertilized with 100-86-30-22-3 kg for the supplement of N-P-K-S-Zn ha^{-1} in the form of urea, TSP, MP, Gypsum and Zinc sulfate respectively; in addition 10 ton cowdung ha^{-1} was applied in each experimental unit (BARC, 1997). One third of the urea and total amount of the rest of fertilizers were applied during final land preparation as basal. The individual plot were spaded and fertilizers were incorporated well before sowing. The remaining two third of urea was applied as top dressing at in equal split at 20 days after sowing during early tillering stage and at maximum tillering stage (35 days after sowing).

3.7 Sowing of seeds

The seeds of barley were hand sown in rows on 1, 15 and 30 November 2005 and 15 January 2006. Plant to plant and row to row distance was maintained at 4 and 25 cm respectively. Seeds were placed at about 3 cm depth from the soil surface and the seed rate was 120 kg ha^{-1}. BARI barley 5 used as planting material in the present study.

3.8 Irrigation

Irrigation water was applied as per experimental treatment stated earlier. A measured amount of water was applied with a bucket. An equal amount of 6 cm water was applied in each irrigation.

3.9 Thinning

Plants were thinning to maintain about 4 cm distance from one another at 24 DAS.

3.10 Weeding

Intercultural operation like weeding was done to maintain normal growth of the crop. Two hand weeding were done at 24 and 35 DAS.

3.11 General observation

The field was frequently observed to notice any changes in plants, pests and diseases attract to the crop and necessary action was taken for normal plant growth.

3.12 Sampling and data collection

To study the ontogenetic growth characteristics a total eleven harvests including final harvest were made. Data were collected on soil moisture, some phenological characteristics and yield and yield attributes. The first crop sampling was done at 20 DAS and continued with 10 days interval up to 100 DAS. From each plot five plants were randomly selected and uprooted for collected necessary parameters at every harvest. The plants were separated into leaves, stems, and spikes and the corresponding dry weight were recorded after oven drying at 80 ± 2^0C for 72 hours. The leaf area of each sample was measured by on digital leaf area meter (Model: CI 202, USA).

3.12.1 Soil moisture determination

The soil samples were collected by an augurs before and four days after irrigation from each plot at two different depth i.e., 0-15 cm and 15-30cm of soil depth. The sample was oven dried at 110^0C for 48 hours. Soil moisture was determined on the weight basis as follows:

$$\% \text{ soil moisture (weight basis)} = \frac{W_2 - W_1}{W_1} \times 100$$

Where, W_1 = fresh weight of soil

W_2 = weight of oven dry soil.

3.12.2 Phenological parameters

Following phonological parameters were observed and calculated.

i) Emergence: Days when 50% seeds were completed emergence.

a. Crown Root Initiation (CRI): Days when 50% of the plants produce crown root. CRI was counted from another extra plot which situated besides the experimental plot.

ii) Tillering: Days when 50% of the plants were completed tillers.

iii) Booting: Days when 50% of plants were in booting condition.

iv) Heading: Days when 50% of plants were completed spike emergence.

v) Maturity: Days when 80% of spikes become brown color.

vi) Leaf area per plant was measured by a digital leaf area meter (Model: CI 202, USA) at 10 days interval.

3.12.3 Morphophysiological and growth parameters

The growth analysis like LAI, LAD, RGR, CGR, NAR were carried out using the formulae of Radford (1967) and Hunt (1978).

i) **Total dry matter (TDM):** The total dry matter ($g.m^{-2}$) was calculated by summating of leaf dry weight, stem dry weight and ear dry weight (when present) and the dry weight was taken in an electrical balance.

ii) Leaf area index (LAI): It is the ratio of leaf area and ground area of a plant

$$LAI = \frac{1}{P} \times LA$$

iii) Leaf area duration (LAD): It expresses the magnitude and persistence of leaf area or leafiness during the period of crop growth (Gardner *et al.*, 1985).

$$LAD = \frac{(LAI_2 + LAI_1) \times (T_2 - T_1)}{2} \text{ day}$$

iv) Crop growth rate (CGR): Rate of dry matter production per mid of time per unit of land area.

$$CGR = \frac{W_2 - W_1}{P(T_2 - T_1)} \text{ g.m.}^{-2}\text{day}^{-1}$$

v) Relative growth rate (RGR): Rate of dry matter production per unit of dry matter per unit of time.

$$RGR = \frac{L_nW_2 - L_nW_1}{T_2 - T_1} \text{ g.g.}^{-1}\text{day}^{-1}$$

vi) Net assimilation rate (NAR): Rate of dry matter production per unit of leaf area per unit of time.

$$NAR = \frac{W_2 - W_1}{T_2 - T_1} \times \frac{L_nLA_2 - L_nLA_1}{LA_2 - LA_1} \text{ mg.cm.}^{-2}\text{day}^{-1}$$

Where,

LA = Total leaf area

LA_1 = Total leaf area at time T_1

LA_2 = Total leaf area at time T_2

W_1 = Total dry weight at time T_1

W_2 = Total dry weight at time T_2

P = Ground area

L_n = Natural logarithm

3.12.4 Relative leaf water content (RLWC)

Relative leaf water content (RLWC) was determined from the flag leaves. The leaves were collected at 8.00 am, 10.00 am, and 12.00 noon. Three leaves were taken from each replication. Their fresh weights were taken immediately and were sinked into water and kept in petridish for four hours. After four hours when the cells of the leaves become fully turgid, they were taken out from water and their turgid weights were taken immediately removing the adhere surface water with blotting paper by an electric balance. Then the leaves were dried in an oven and weighed. The relative leaf water content was calculated from the following formula (Barrs and Weatherly, 1962).

$$\text{Relative leaf water content (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

3.12.5 Estimation of proline

Proline content of flag leaf at 7 days after anthesis in barley grown in four different growing conditions was estimated. Flag leaves from each replication were collected and immediately kept in the ice-bag and brought to Crop Botany Laboratory of HSTU for proline estimation. One gram fresh weight of flag leaf was taken for proline estimation. Subsequently proline was estimated as Troll and Lindsley (1955).

At first Ninhydrin reagent was prepared in such a way so that it was utilized for proline estimation within two hours of preparation. For preparing Ninhydrin reagent, 30 ml glacial acetic acid and 30 ml 6 M orthophosphoric acid was mixed with 1.25 g of ninhydrin. It was subsequently heated and stirred gently to dissolve but the temperature was not allowed to exceed 70^0C. Proline standards were prepared for 0, 2, 4, 6, 8, 10, 12, 14, 16, 18 and 20 ppm with distilled water.

The fresh samples were crushed in mortar and pestle and homogenized the material in 10 ml 3% sulphosalicylic acid until no large segments of plant material remained. Homogenate was filtered through Whatman No. 2 filter paper and washed with 3% sulphosalicylic acid and the volume was set to 25 ml. Two ml of the filtrate and each standard proline solutions were then reacted with 2 ml of ninhydrin reagent and 2 ml of glacial acetic acid in a pyrex test tube, boiled for one hour at 100^0C in water bath covering the tube with aluminium foil to prevent excess evaporation. Subsequently, it was cooled in ice bath and 4 ml of toluene was added to each tube using a dispensor. Each tube was then shaken vigorously for 15 to 20 seconds in an electrical shaker and allowed to separate the layer for 30 minutes. The absorbance of clear solution was measured through spectrophotometer at 520 nm with pure toluene as a blank. Proline content was expressed on a fresh weight basis from the standard curve, using standard L-proline according to the method developed by to Troll and Lindsley (1955).

3.12.6 Chlorophyll content

Chlorophyll content of the flag leaf during anthesis was estimated according to Witham *et al.*, (1986). One mg of leaf was taken from different positions of the flag leaf. Chlorophyll was extracted with 80% aqueous acetone by using a mortar and pestle for grinding the tissue. The suspension was decanted into centrifuge tubes and centrifuged for 3 minutes. The clear green solution was then decanted from the colorless residue and made up to 10 ml with 80% acetone. The optical density (OD) of this solution was determined against

80% acetone as blank using a spectrophotometer at 645 and 663 nm. The chlorophyll a and b were determined according to the formulae used by Witham *et al.*, (1986) as follows:

Chlorophyll a = $(12.7A_2 - 2.694A_1) \times (V/1000 \times W)$

= mg chlorophyll a per gram fresh weight

Chlorophyll b = $(22.9\,A_1 - 2.69A_2) \times (V/1000 \times W)$

= mg chlorophyll b per gram fresh weight

Total Chlorophyll = $(20.21A_1 + 8.02A_2) \times (V/1000 \times W)$

Where, A_1 and A_2 are absorbance at wavelengths of 645 and 663nm, respectively.

3.12.7 Yield and yield attributes

Plant height

Plant height was measured from the base of the plant to the tip of the spike. Ten plants sample from each treatment were taken and means were calculated.

Fertile tillers per plant

The number of fertile tillers per plant was recorded at harvest. In that case ten plant samples from each treatment were taken randomly and means were calculated.

Infertile tillers per Plant

The number of infertile tillers per plant was recorded at harvest. In that case ten plant samples from each treatment were taken randomly and means were calculated.

Spike length

Spike length was measured from the base of the spike to the tip of the spike including the awn. Length of spikes collected from ten plants sample of each treatment and means were calculated.

Number of spikelets per spike

Numbers of spikelets per spike were counted manually. For this purpose all spikes collected from ten plants were considered.

Fertile spikelets per spike

Numbers of fertile spikelets per spike were counted manually. In this case all spikes collected from ten plants were considered.

Infertile spikelets per spike

Numbers of infertile spikelets per spike were counted manually. In this case all spikes collected from ten plants were considered.

Thousand grain weight

One thousand clean sun dried grains were counted from the seed stock obtained from the sample plants from each replication and weighed by using electronic balance.

Grain yield

The grains were separated by threshing plot wise and then sun dried and weighed. The grain weight was finally converted into tons ha^{-1}.

CHAPTER 4

RESULTS AND DISCUSSION

The results of the study have been presented in several Tables and Figures. Adequate discussion and possible interpretations whenever suitable have been provided in this chapter.

4.1 Soil Moisture

The variation of soil moisture percentage due to variation in sowing date and irrigation frequency were presented in Figure 1 and Figure 2. Both the figures 1 and 2 revealed that soil moisture percentage showed a significant lower trend with the delay in sowing time and an increasing trend with the increasing of irrigation frequency. In Figure 1 and Figure 2 we found that early sowing i.e., S1 (November 1) sowing with IR3 (Three irrigations applied at early tillering, booting and grain filling stage) gave the highest soil moisture percentage. While late sowing i.e., S4 (December 15) sowing with IR0 (No irrigation) gave the lowest soil moisture percentage in 0-15 cm and 15-30 cm of soil depth. This might be due to rapid loss of water during late sowing condition form soil through evapotranspiration. Cool temperature prevails during this period and low relative humidity may also reduce the soil moisture at late sowing condition (Appendix IV). These two figures also indicated that S2 (November 15) sowing with IR2 (Two irrigations applied at early tillering and booting stage) gave statistically similar moisture percentage on S3 (November 30) sowing with IR1 (one irrigation applied at early tillering stage). It was also clear that from Figure 1 and Figure 2 soil moisture percentage was more in 15-30 cm depth of soil than that of 0-15 cm.

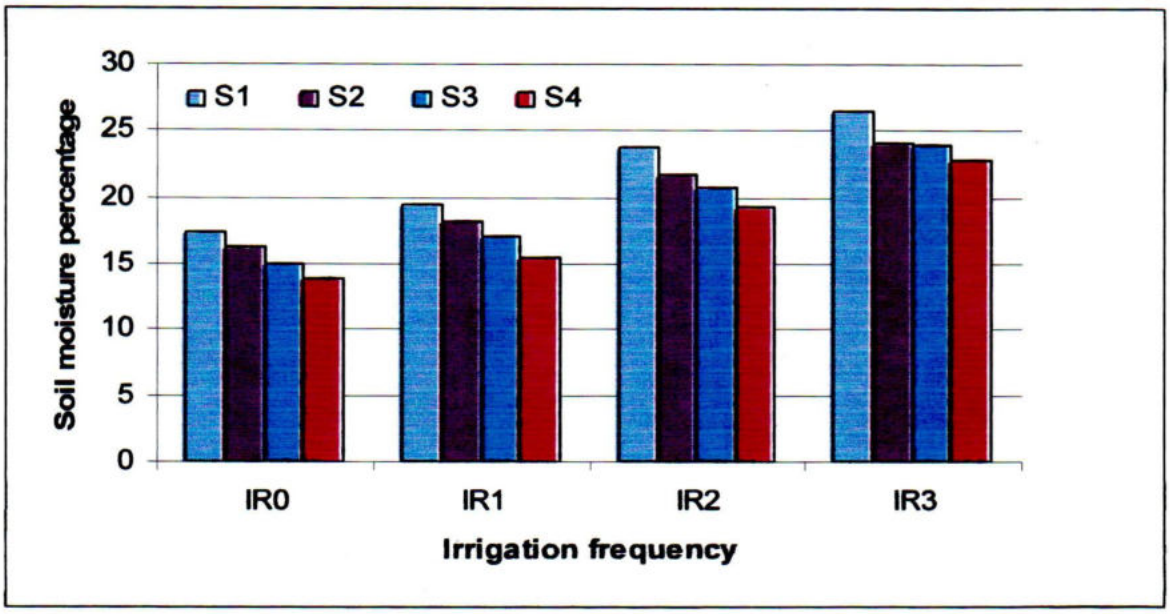

Figure 1. The pattern of soil moisture (% weight basis) with four sowing date (S1, S2, S3 and S4) under different irrigation frequency at 0-15 cm depth of soil

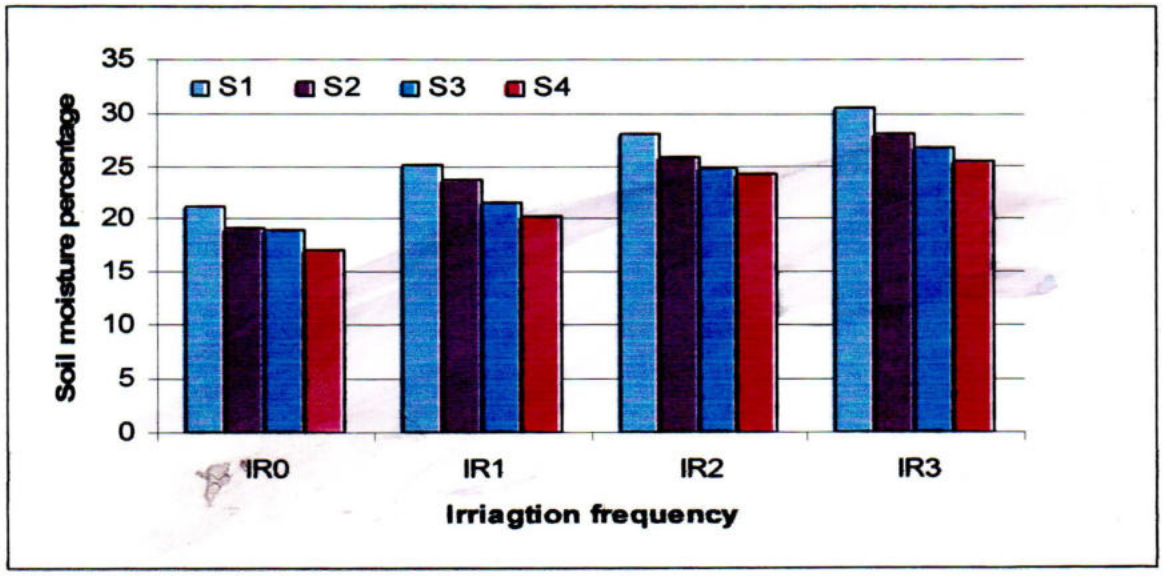

Figure 2. The pattern of soil moisture (% weight basis) with four sowing date (S1, S2, S3 and S4) under different irrigation frequency at 15-30 cm depth of soil

4.2 Phenological parameters

4.2.1 Days to emergence

The number of days required to complete emergence are presented in Table 1. Table revealed that seedling emergence was earlier in early sowing. It was found that November 1 sowing required the lowest days (6.06) for emergence. On the other hand December 15 sowing required the highest days (7.62). The earliness of seedling emergence in early sowing might be higher soil moisture than late sowing. The effect of irrigation and combination effect of seeding date and irrigation frequency was insignificant in case of emergence of seedling.

4.2.2 Days to crown root initiation

Days required for crown root initiation significantly varied under different sowing date are presented in Table 1. November 1 sowing required minimum days (17.75) to produce crown root. This was at par with November 15 sowing (18.25). The maximum days (19.72) required for crown root initiation was recorded from in December 15 sowing. Late sowing required highest days to produce crown root might be due to low soil moisture that lead to slow rate of crown root initiation. The effect of irrigation and interaction of sowing time and irrigation was insignificant for days required to crown root initiation in the present study.

4.2.3 Days to tillering

Days to tillering significantly varied under different seeding date are presented in Table 1. November 1 sowing required the highest days (22.83) to produce tiller which was statistically similar with November 15 and November 30 sowing (22.25, 22.33, respectively). It was observed that delayed sowing required comparatively less days (21.33) for tillering. It was found that maximum available soil moisture at early

Table 1. Some phenological parameters of barley as influenced by sowing date and irrigation frequency

Treatments	Germination (DAS)	Crown root initiation (DAS)	Tillering (DAS)	Booting (DAS)	Heading (DAS)	Maturity (DAS)
Sowing date						
S1	6.06 c	17.75 c	22.83 a	63.75 a	73.33 a	104.91 a
S2	6.40 c	18.25 c	22.25 a	60.66 b	69.66 b	103.66 b
S3	6.79 b	19.00 b	22.33 a	58.08 c	66.91 c	101.58 c
S4	7.62 a	19.72 a	21.33 b	56.58 d	64.58 d	98.08 d
Irrigation frequency						
IR0	7.43 a	18.91 a	22.41 a	54.33 c	61.25 c	96.83 d
IR1	7.38 a	19.50 a	21.41 a	59.75 b	67.50 b	101.16 c
IR2	7.42 a	19.83 a	21.75 a	62.16 a	72.50 a	103.91 b
IR3	7.41 a	19.00 a	22.16 a	62.83 a	73.25 a	106.33 a
Interaction						
S1 x IR0	6.93 a	19.00 a	22.33 a	57.00 gh	63.66 f-h	100.00 e
S1 x IR1	6.96 a	18.66 a	22.00 a	64.00 b	72.00 cd	104.00 d
S1 x IR2	6.50 a	19.00 a	23.00 a	67.00 a	80.33 a	107.00 ab
S1 x IR3	6.33 a	18.33 a	23.00 a	67.00 a	77.33 ab	108.66 a
S2 x IR0	6.60 a	18.33 a	22.66 a	54.66 e	61.66 hi	96.66 f
S2 x IR1	6.96 a	18.00 a	22.00 a	62.33 bc	70.33 c-e	104.33 cd
S2 x IR2	6.36 a	18.00 a	22.00 a	62.66 bc	72.66 cd	106.00 bc
S2 x IR3	6.66 a	18.66 a	22.33 a	63.00 bc	74.00 bc	107.66 ab
S3 x IR0	7.03 a	18.00 a	22.66 a	53.66 cd	60.66 hi	97.00 f
S3 x IR1	7.10 a	19.00 a	22.00 a	57.33 fg	65.33 fg	99.33 e
S3 x IR2	6.93 a	19.66 a	22.33 a	60.00 de	70.00 de	103.66 d
S3 x IR3	6.66 a	18.33 a	22.33 a	61.33 cd	71.66 cd	106.33 b
S4 x IR0	7.50 a	19.83 a	22.00 a	52.00 g	59.00 i	93.66 g
S4 x IR1	7.96 a	19.63 a	21.33 a	55.33 hi	62.33 g-i	97.00 f
S4 x IR2	7.36 a	19.76 a	21.00 a	59.00 ef	67.00 f	99.00 e
S4 x IR3	7.66 a	19.66 a	21.00 a	60.00 de	70.00 de	102.66 d
CV (%)	**9.69**	**6.4**	**4.26**	**6.82**	**5.24**	**7.70**

In a column figures having same letter(s) do not differ significantly at $P \leq 0.05$ by LSD.

sowing condition (Figure 1) that enhanced to produce early tiller in November 1. The effect of irrigation and combination effect of seeding date and irrigation frequency was insignificant in case days required to tillering in the present study.

4.2.4 Days to booting

Date of sowing had a significant effect on the days to booting of barley (Table 1). The November 1 sowing required maximum days to attain the booting stage of the crop (63.75). The minimum days (56.58) required for attaining booting stage of barley was in December 15 sowing. This result is similar with the results of Sharma and Thakur (1996) where they reported that minimum days required booting in crop by December 25 and January 5 sowing. Water deficit conditions hasten booting stage was also recorded by Verma *et al.*, (1996).

Days to booting varied significantly due to variation in irrigation levels (Table 1). Time taken for booting stage increased with increasing irrigation. The plants grown in IR3 condition needed the highest days (62.83) for booting followed by IR2 (62.16). The non-irrigated plants needed the lowest days (54.33) for booting in the present study.

A significant interaction effect was found between sowing dates and irrigation on days to booting (Table 1). The maximum days (67.00) required to attain the booting stage of the crop sown in November 1 with three irrigations. That was statistically similar with November 15 sowing with two irrigations (67.00). The second highest day (64.00) to attain booting was recorded in S1 X IR2. Which was at par with S2 X IR1, S2 X IR2 and S2 X IR3 (62.33, 62.66 and 63.00, respectively). The minimum days required to booting the crop in December 15 sowing with no irrigation (52.00) followed by S1 X IR0 (57.00). Lowest days to attaining the stage in late sowing condition with no irrigation might be due to water stress at this period hasten the booting in plant. Similar result also reported by Pal *et al.*, (1996) in wheat.

4.2.5 Days to heading

Days to heading significantly influenced by different date of seeding in barley (Table 1). The maximum days required to attain the heading stage of the crop sowing in November 1 (73.33) and the minimum days (64.58) required to heading of barley was in December 15 sowing. The possible causes of decreasing days required to attain heading stage in later sowing might be due to increase in temperature as well as low soil moisture which shortened the vegetative growth. This result is similar with the results of Sharma and Thakur (1996) where they reported that minimum days required for heading in crop by December 25 and January 5 sowing. Water deficit conditions hasten heading stage was also reported by Verma *et al.*, (1996).

Days to heading varied significantly due to variation in irrigation levels (Table 1). Time taken for heading stage increased with increasing irrigation. The plants grown in IR3 condition needed maximum days (73.25) for heading followed by IR2 (72.50). The non-irrigated plants required minimum days (61.25) for heading.

A significant interaction effect was found between sowing dates and irrigation on days to heading (Table 1). The maximum days (80.33) required to attain the heading stage of the crop sown in November 1 (early sowing) with two irrigations (IR2) which was at par with November 1 sowing (77.33) with three irrigations (IR3). The third highest days (74.00) needed to attain heading was observed in November 15 (S2) sowing with three irrigations and fourth highest days required to attain this stage was in S2 X IR2 (72.66). Statistically similar result was found in S1 X IR1 (72.00) and S3 X IR3 (71.66). The minimum days required for heading the crop observed in December 15 sowing with no irrigation (59.0) followed by November 30 sowing with no irrigation (60.66). In case of early sowing with three irrigations required maximum days to attain the stage might be due to rich in soil moisture and relatively low temperature lengthened the vegetative phase of the plant. Where as water stress in later sowing i.e., moisture scarcity and high temperature shortened the vegetative stage that helped to early booting in plant. Similar result also reported by Pal *et al.*, (1996) in wheat and Verma *et al.*, (1996) in millet. They reported that water deficit in during growth stage hasten the plant to reach in reproductive stage

4.2.6 Days to maturity

Days to maturity significantly varied under different sowing date (Table 1). Days to maturity decreased with delay in sowing. November 1 sowing required the highest days (104.91) to attaining maturity. It was observed (Table 1) that delayed sowing required comparatively short days (98.08) to mature the crop. Late sowing reduced the growth period, forcing premature ripening due to high temperature over the life cycle. On the other hand, early sowing was favored by relatively long growing period with optimum atmospheric temperature. Similar results reported by Ghosh *et al.*, (2000) in their experiment with wheat and they observed that delayed sowing decrease the number of days taken to reach maturity. Similar findings were also reported by Singh *et al.*, (2005).

Days to maturity varied significantly due to variation in irrigation levels (Table 1). Time taken for maturity stage increased with increasing irrigation. The plants grown in IR3 condition needed the highest days (106.33) for maturity. The non-irrigated plants needed the lowest days (96.83) for maturity in the present study. This result is similar with the results of Mostafavi and Niknejad (1983) they mentioned that under rainfed condition duration of ripening stage was decreased.

The interaction between sowing dates and irrigation were found significant on days to maturity in barley (Table 1). The maximum days (108.66) required for mature the crop in November 1 sowing with three irrigations. Statistically similar result was also found in November 30 (S3) with three irrigations (107.66) and early sowing with two irrigations (107.00). The next highest result was recorded in S3 X IR3 (106.33) followed by S2 X IR2 (106.33). The minimum days (93.66) were required in December 15 sowing by no irrigation (IR0) treatment. Late sowing with one irrigation needed the second lowest days (97.00) to attain the maturity stage. Water stress in later sowing i.e., moisture scarcity and high temperature shortened the life cycle that lead to early maturity in plant. Similar results also reported by Pal *et al.*, (1996). They reported that delayed sowing resulted a deleterious depletion of soil moisture thus reduced the flowering and as well as the maturity period mainly in the later sowings.

4.3 Morphophysiological and growth parameters

4.3.1 Total dry matter (TDM)

The effects of sowing time and irrigation frequency on total dry matter production of barley are presented in Figure 3. TDM production varied significantly due to differences in seeding date and irrigation frequency. Result revealed that the effect of irrigation frequency on TDM production pattern was almost similar for all sowings. It was observed that TDM increased steadily until 40 DAS and thereafter increased sharply with the advancement of the growth period. However, result indicated that TDM production increased with increasing irrigation frequency till 100 DAS and thereafter reach a constant level. The highest TDM production was observed in three irrigations at all growth stages in early sowing (S1) followed by two irrigations. In all cases early sowing produce higher TDM in each sampling date. Higher TDM in early sowing condition might be due to longer period for advancing their phenological stages. In contrast, control (IR0) had the lowest TDM at

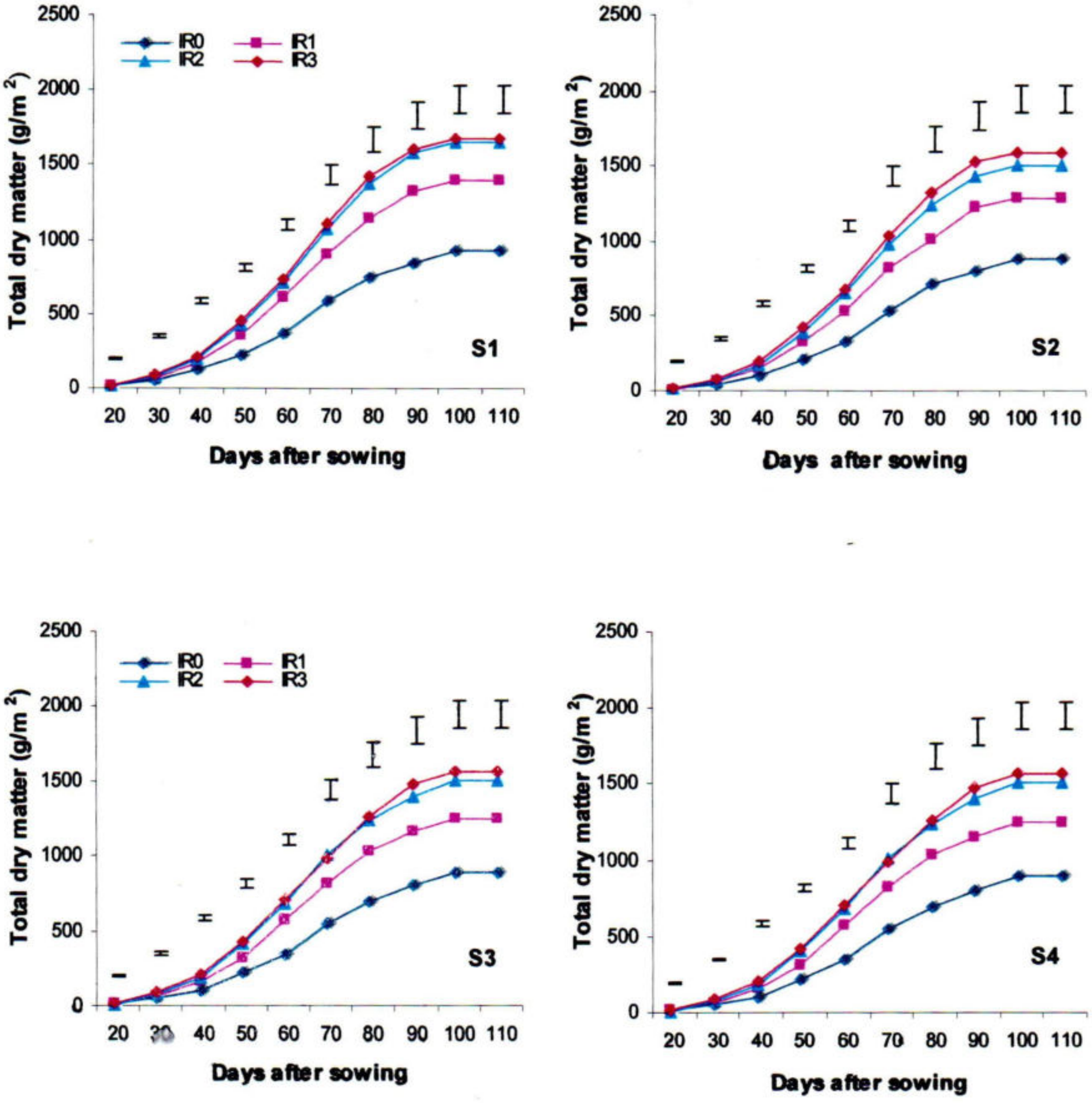

Figure 3. The pattern of total dry matter (g/m^2) accumulation with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

all growth stages. Increased TDM in irrigated plants was consequence of greater leaf area and thereby capturing of greater solar radiation and also produces more assimilates than the control. Similar result was also reported by Kumar and Agarwal (1991) in barley. They reported that TDM increased with increasing irrigation frequency at all growth stages. Similar findings also observed by Ryu *et al.*, (1992).

4.3.2 Leaf area index (LAI)

Leaf area index was evaluated for different seeding date and irrigation in barley (Figure 4). The pattern of LAI curves was found almost similar in each sowing for every irrigation. LAI varied significantly due to sowing time and irrigation frequency at 20, 30, 40, 50, 60, 70, 80, 90 and 100 DAS. The LAI values increased progressively up to 60-70 DAS and afterwards declined in the same way till maturity. The declining of leaf area after attaining a peak value was due to leaf rolling and senescence with aging. Early sowing (November 1) was found to have the ability to produce maximum LAI at 60 DAS with IR3 irrigation followed by IR2 and IR1 in each sowing. IR0 produced the lowest LAI in every case. S1, S2, S3 and S4 showed their highest value of LAI with three irrigations (IR3). This result is in agreements with Ashraf and Bhatti (1998). Result revealed that LAI increased with the increasing irrigation frequency. Result further revealed that LAI was greater in irrigated plots than in control plots (Figure 4). Among the irrigated plants IR3 gave the highest LAI in the present study. Higher LAI values due to increase in irrigation frequencies were also reported by Singh and Anureet (2001).

4.3.3 Leaf area duration (LAD)

Leaf area duration express the magnitude and persistence of leaf area or leafiness during the period of crop growth (Gardner *et al.*, 1985). LAD was evaluated for different sowing time and irrigation in barley (Figure 5). Result revealed that LAD increased with the

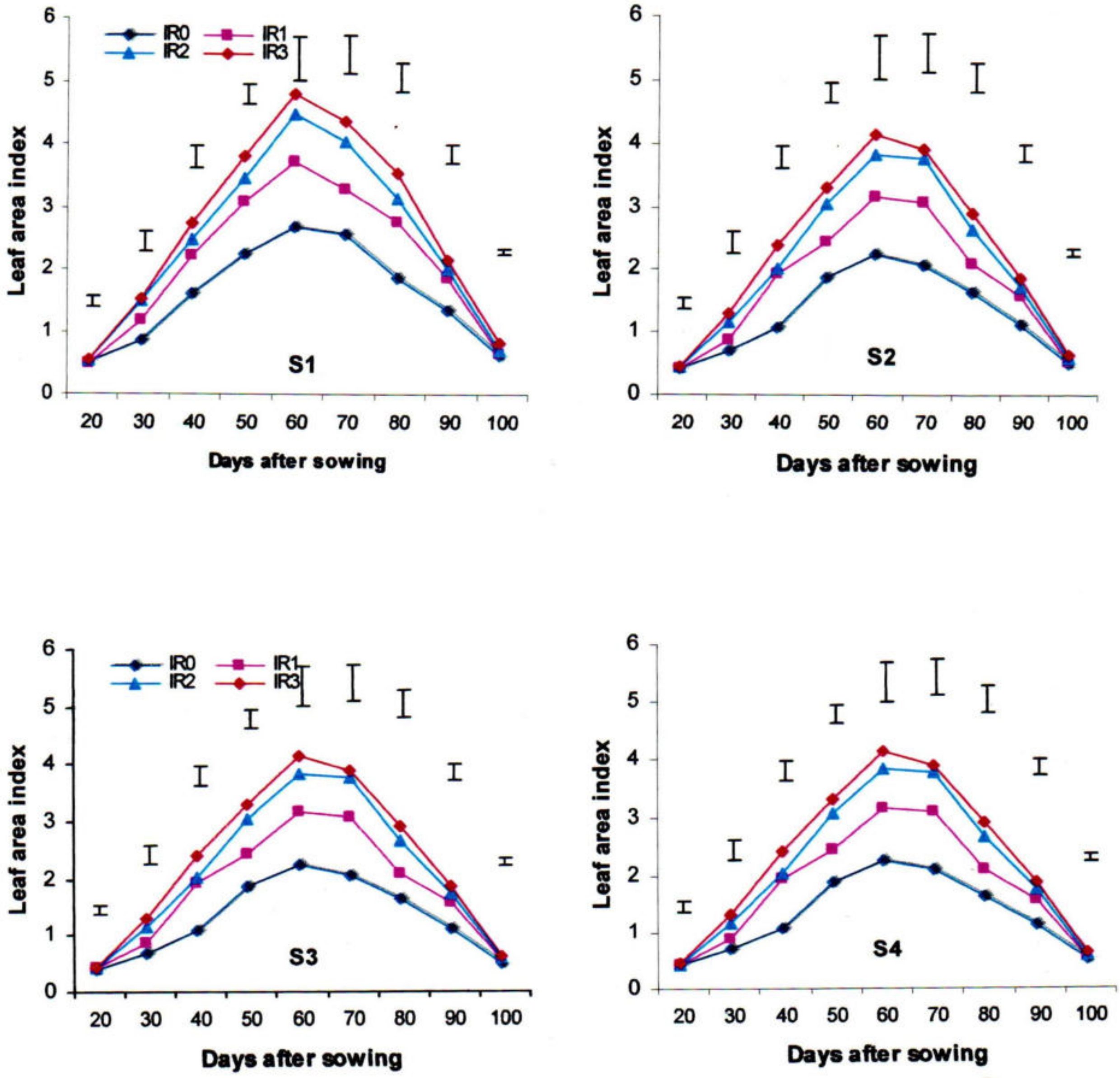

Figure 4. The pattern of leaf area index with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

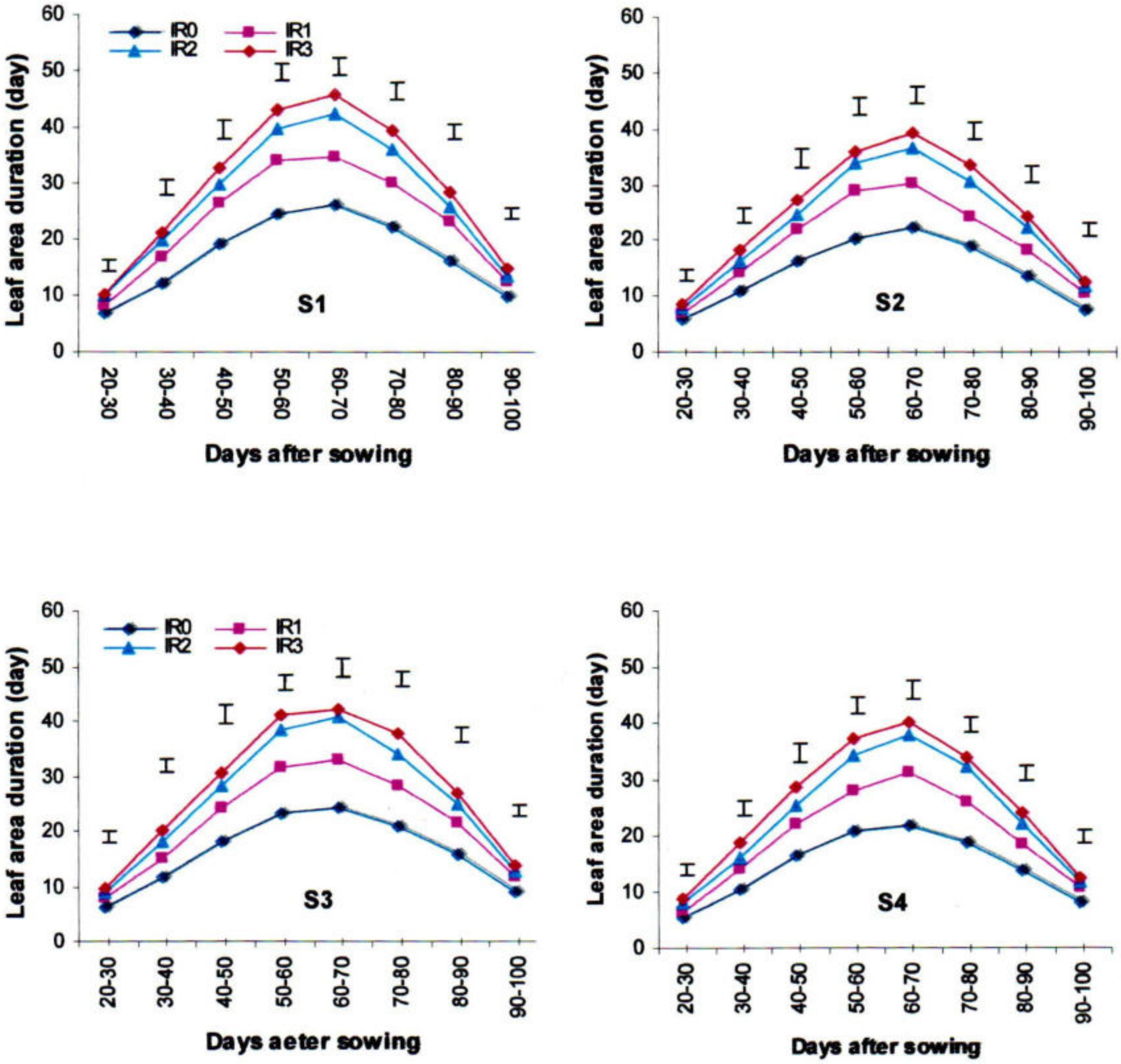

Figure 5. The pattern of leaf area duration (day) with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

increasing irrigation. The pattern of LAD curves was found almost similar in each sowing for every irrigation. LAD varied significantly due to sowing time and irrigation frequency at 20-30, 30-40, 40-50, 50-60, 60-70, 70-80, 80-90, and 90-100 DAS. The LAD values increased progressively up to 60-70 DAS and afterwards declined in the same way till maturity, the declining of leaf area after attaining a peak value was due to leaf rolling and senescence. Early sowing (November 1) was found to have the ability to produce maximum LAD at 60 DAS with IR3 irrigation which was followed by IR2 and IR1 in each sowing. IR0 produced the lowest LAD in every case. S1, S2, S3 and S4 showed their highest value of LAD with three irrigations (IR3). This result is in agreements with Pal *et al.*, (1996). Result further revealed that LAD was greater in irrigated plots than in control plots (Figure 5). Among the irrigated plants IR3 gave the highest LAD in the present study.

4.3.4 Crop growth rate (CGR)

Significant variation of CGR was found because of variation in sowing date and irrigation levels. Effects of sowing dates and irrigation on CGR are presented in Figure 6. Results revealed that the effect of irrigation frequency on CGR was almost similar for every sowing time. In all sowings and irrigation regimes CGR starting from a lower value. CGR of all sowings and irrigations reached a certain peak (60-70 DAS) and thereafter declined with lower positive values in all cases. Generally irrigation and early sowing enhanced CGR in all the cases. The highest CGR was observed in November 1 sowing with three irrigations and the lowest CGR was recorded in December 15 sowing with no irrigation at all growth stages. Similar result also reported by Pal *et al.*, (1996). The results of the present study also supported with the findings of Anonymous (1998) in barley he reported that CGR increased with increasing irrigation frequency at all growth stages.

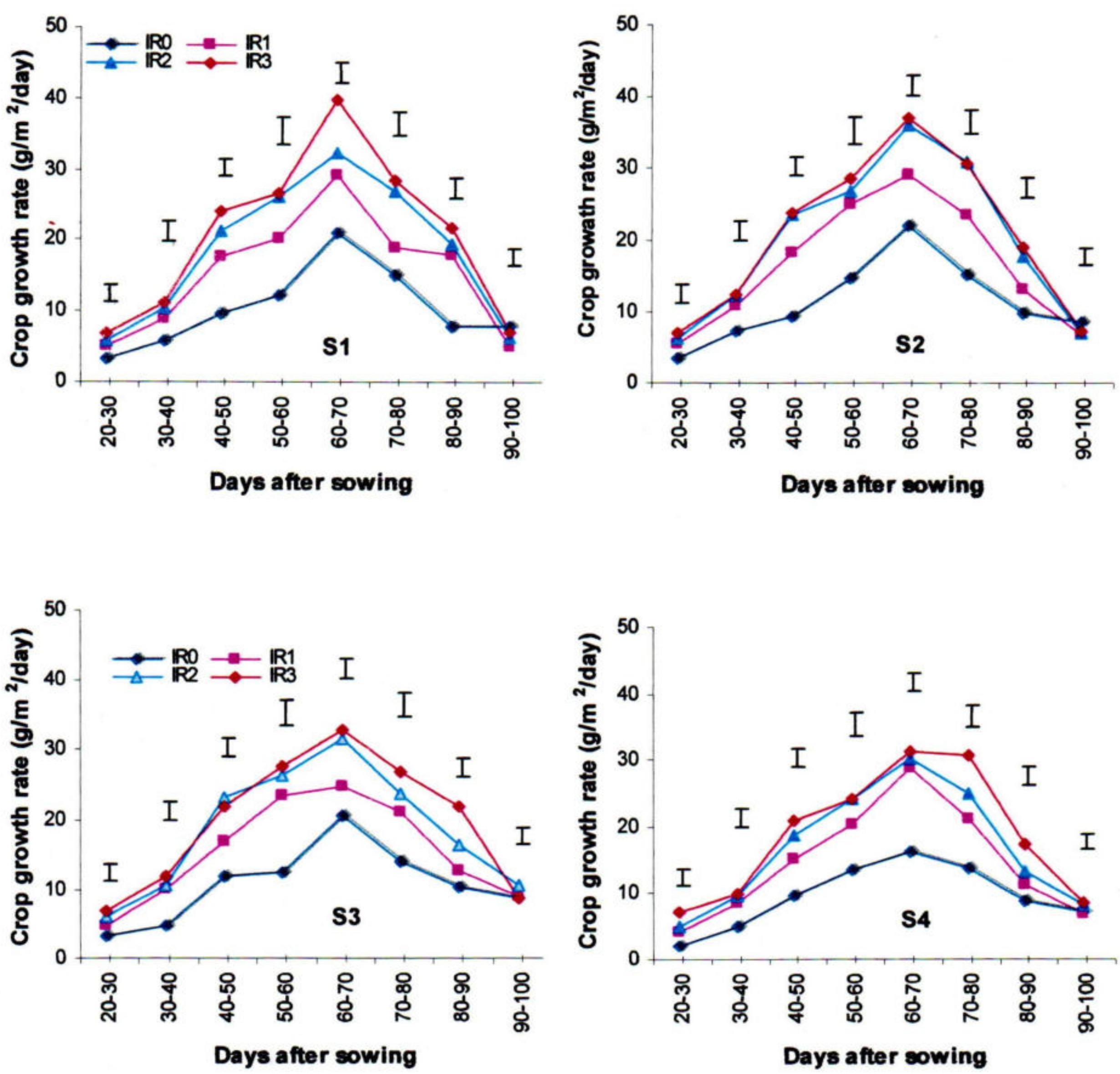

Figure 6. The pattern of crop growth rate (g/m^2/day) with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

4.3.5 Relative growth rate (RGR)

The influence of sowing time and irrigation on RGR was calculated from 20 to 100 DAS Irrespective of sowing time and irrigation, the RGR showed highest values in the early stage of plant development (Figure 7). This result partially alike with the findings of Van Eijnatten (1963) who stated that higher RGR at early stage of development and then a slow decline. Results revealed that irrigation frequency had significant influence on RGR at all growth stages except 90-100 DAS. There was an inverse relationship between RGR and plant age in all treatments. The RGR gave highest values at 20-30 DAS and then followed by a declining trend till maturity. However, result revealed that three irrigations produced maximum RGR when crops were planted in November 1. The control (IR0) gave the December 15. The results of the present study is in agreement with the results of Rahman (1997) where he observed greater RGR in irrigated plants and lower RGR in rainfed crops in his study with barley.

4.3.6 Net assimilation rate (NAR)

The NAR, the assimilatory power of the leaf, is a complex growth parameter and is regulate by environmental variables. The significant variation of NAR due to variation in sowing time and irrigation at different stages of growth is presented in Figure 8. NAR calculated by harvest interval method for all the sowing and irrigation regimes. Results revealed that there was an inverse relationship between NAR and plant age. The highest NAR was recorded at 20-30 DAS and then followed by a continued decrease until attaining the lowest at 90-100 DAS with heavy fluctuations for all sowing and irrigation treatments . However, result showed that three irrigations in early sowing (S1) had better influence on NAR of barley at most of the growth stages followed by two irrigations and one irrigation, respectively. Control (IR0) had the minimum NAR with December 15 sowing at all growth stages. The results of the present study was in agreement with the results of Moula

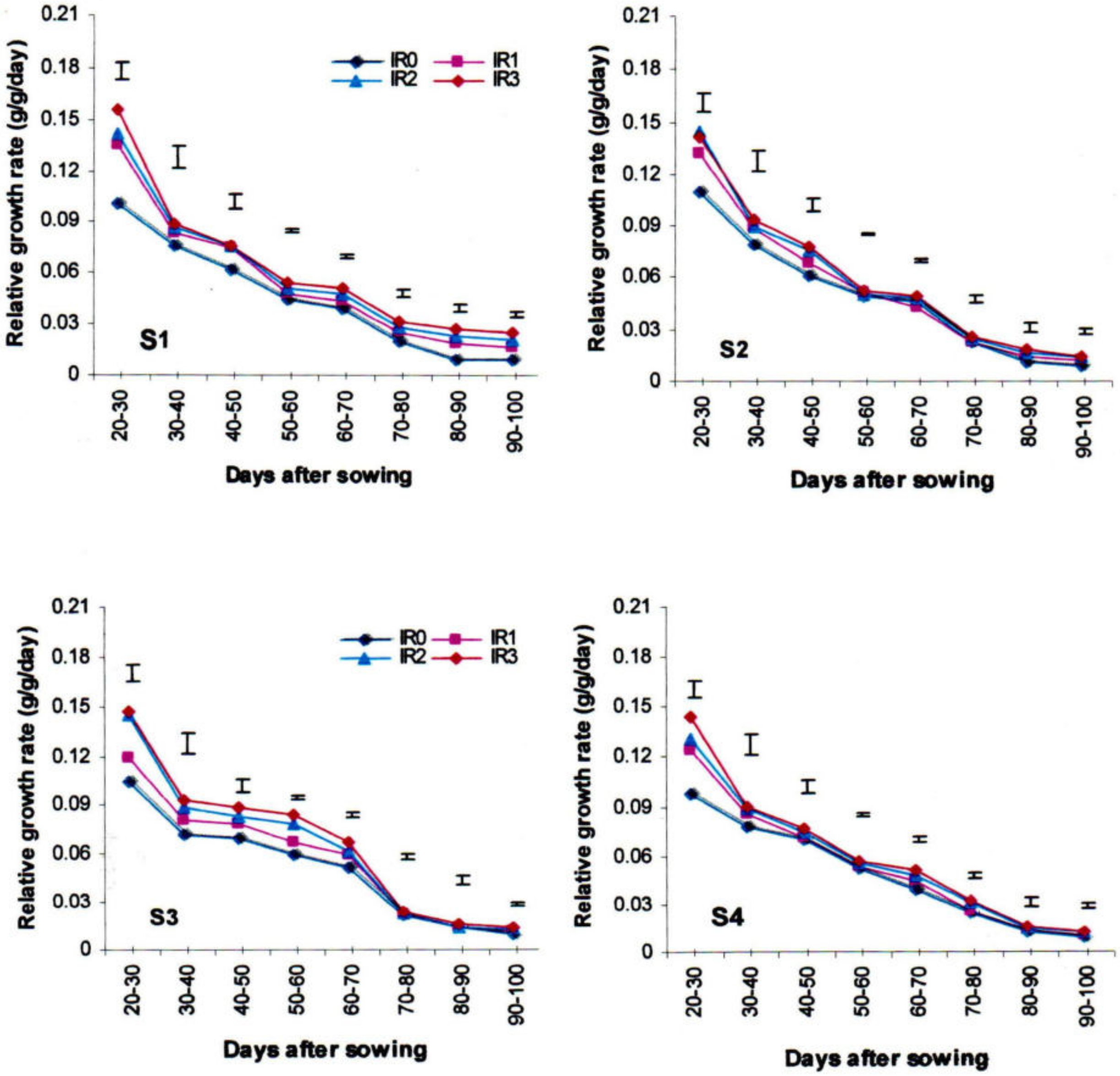

Figure 7. The pattern of relative growth rate (g/g/day) with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

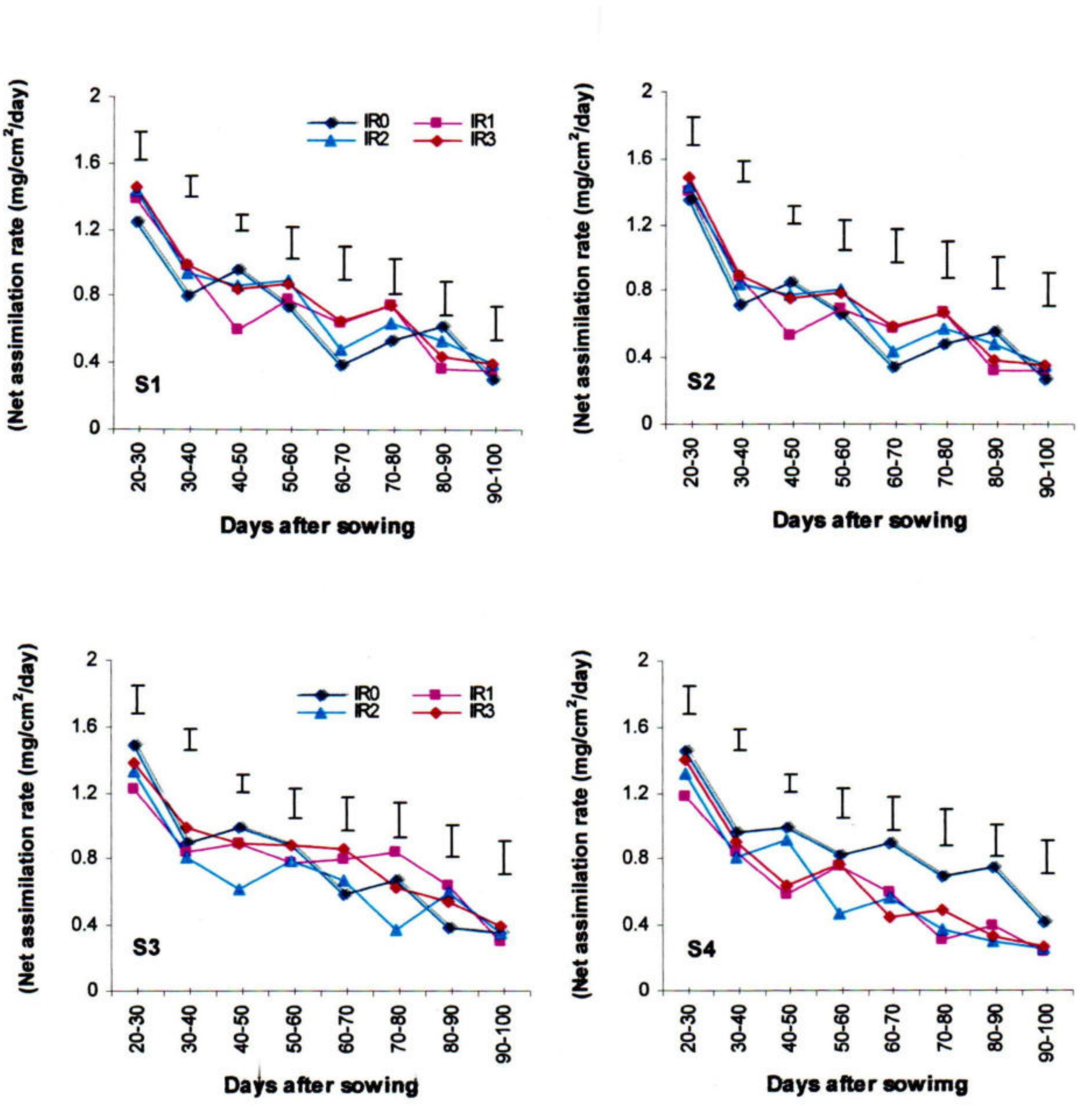

Figure 8. The pattern of net assimilation rate (mg/cm^2/day) with time in four sowing date (S1, S2, S3 and S4) under different irrigation frequency, vertical bars indicate LSD at 5% level of significance

(1999) and Pal *et al*., (1996) where they observed higher NAR in irrigated plants than in control.

4.4 Relative leaf water content (RLWC)

Relative leaf water content was calculated at three different times of the day and it was significantly varied with date of sowing (Table 2). RLWC showed a decreasing trend with the advancement of the day time. First sampling at 8:00 am gave highest RLWC and sampling at 12:00 noon showed lowest RLWC in the study. Early sowing (S1) gave the highest RLWC at 8.00 a.m., 10.00 a.m. and 12.00 noon (90.97%, 89.81% and 72.17%, respectively) while the lowest RLWC were recorded in late sowing (December 15) condition (84.91%, 79.44% and 66.26% at 8.00 am, 10.00 am and 12.00 noon, respectively).

Irrigation frequency also significantly affected the RLWC of barley (Table 2). RLWC showed an increasing trend with intensifying of irrigation frequency. three irrigations applied at early tillering, booting and grain filling stage gave the highest RLWC in all cases i.e., 93.75%, 90.07% and 77.35% (8.00 am, 10.00 am and 12.00 noon, respectively). This result is similar with the results of Sing and Patel (1996). They reported that RLWC was low in water stressed leaf.

Significant interaction also found between sowing date and irrigation levels on RLWC of barley (Table 2). Among the treatment combinations November 1 sowing with. three irrigations gave the highest RLWC in all cases i.e., 95.84%, 94.42% and 79.45% (8.00 am, 10.00 am and 12.00 noon, respectively). Which was at par in S2 sowing with three irrigations in all cases i.e., 8.00 am, 10.00 am and 12.00 noon (95.43%, 991.21% and 79.44%, respectively). The lowest RLWC gave in December 15 sowing with no irrigation at 8.00 am, 10.00 am and 12.00 noon (78.22%, 71.56% and 58.60%, respectively).

Table 2. Relative leaf water content, proline content and chlorophyll content of barley as influenced by sowing date and irrigation frequency

Treatments	Relative leaf water content (%)			Proline content (µg/g fresh weight)	Chlorophyll content (mg/g fresh weight)		
	8:00 am	10:00 am	12:00 am		a	b	Total
Sowing date							
S1	90.97 a	89.81 a	72.27 a	157.482 c	2.013 a	2.008 a	4.124 a
S2	88.84 ab	86.95 ab	71.07 a	171.094 bc	1.929 a	1.889 a	3.926 b
S3	87.31 bc	84.85 b	67.69 b	183.107 ab	1.520 b	1.454 b	2.967 c
S4	84.91 bc	79.44 c	66.26 c	191.113 a	1.428 b	1.421 b	2.875 d
Irrigation frequency							
IR0	80.03 c	80.30 c	61.72 d	218.807 a	1.443 c	1.481 c	2.952 d
IR1	86.20 b	84.26 b	65.85 c	199.270 b	1.716 b	1.633 b	3.410 c
IR2	91.26 a	86.42 ab	72.34 b	161.829 c	1.769 b	1.822 a	3.619 b
IR3	93.75 a	90.07 a	77.35 a	132.890 d	1.943 a	1.836 a	3.911 a
Interaction							
S1 x IR0	84.09 c-h	85.58 b-d	65.23 gh	198.132 b-d	1.600 e	1.648 cd	3.343 e
S1 x IR1	89.49 c-e	88.16 a-c	70.52 d-f	169.834 d-f	1.983 cd	1.954 ab	4.013 d
S1 x IR2	94.87 a-c	91.05 ab	73.89 b-d	145.691 e-g	2.158 a-c	2.203 a	4.374 bc
S1 x IR3	95.84 a	94.42 a	79.45 a	116.270 g	2.310 a	2.228 a	4.766 a
S2 x IR0	80.53 hi	83.23 b-d	62.84 hi	216.850 a-c	1.526 e-g	1.590 c-e	3.163 ef
S2 x IR1	86.10 d-g	85.87 b-d	67.06 fg	190.319 cd	1.868 d	1.814 bc	3.845 d
S2 x IR2	92.91 a-c	87.50 a-c	74.93 bc	156.660 ef	2.069 b-d	2.075 ab	4.150 cd
S2 x IR3	95.43 ab	91.21 ab	79.44 a	120.547 g	2.251 ab	2.076 ab	4.544 ab
S3 x IR0	80.47 a-i	80.71 cd	60.23 ij	227.028 ab	1.348 fg	1.344 e	2.673 g
S3 x IR1	85.83 d-h	84.45 b-d	64.28 g-i	197.410 b-d	1.569 ef	1.370 de	2.920 fg
S3 x IR2	89.93 b-d	86.68 a-d	71.27 cd	170.450 d-f	1.516 ef	1.539 c-e	3.075 ef
S3 x IR3	93.07 a-c	87.56 a-c	74.92 bc	137.539 fg	1.649 e	1.563 c-e	3.200 ef
S4 x IR0	78.22 i	71.56 e	58.60 j	233.219 a	1.298 g	1.344 e	2.627 g
S4 x IR1	83.39 f-i	78.55 de	61.54 h-j	199.517 b-d	1.442 e-g	1.395 de	2.862 fg
S4 x IR2	87.32 d-f	80.45 cd	69.30 ef	174.514 de	1.411 e-g	1.470 de	2.877 fg
S4 x IR3	90.71 a-d	87.06 a-d	75.61 ab	157.202 ef	1.562 ef	1.476 de	3.132 ef
CV (%)	**6.41**	**5.18**	**7.35**	**10.39**	**7.42**	**8.91**	**5.64**

In a column figures having same letter(s) do not differ significantly at $P \leq 0.05$ by LSD.

Statistically similar result was recorded in S2 X IR0 at 8.00 am (80.53%) and 12.00 noon (62.84%) in case of 10.00 am similar result was obtained in late seeding with one irrigation (78.55%). At early morning RLWC was maximum was due to lower transpiration during morning in all plant and it is minimum at noon due to high transpiration rate.

4.5 Proline content

Proline content in flag leaves of barely was significantly influenced by different sowing time (Table 2). From the table it was observed that proline accumulate increased with the delay sowing. Proline content was highest in December 15 sowing (191.113 μg/g fresh wt.) which significantly different from other sowings. Lowest proline content (157.428 μg/g fresh wt) was recorded in early sowing (November 1) seeding. This result is partially coinciding with the findings of Hasan *et al.*, (2007) and Engelmann (1982) in wheat and Maiti *et al.*, (2000) in various crops .

Irrigation frequency significantly affected the proline content in barley (Table 2). Proline content showed a decreasing trend with the increasing irrigation frequency. The result revealed that IR0 (no irrigation) condition gave highest proline content (218.807 μg/g fresh wt.) and IR3 (three irrigation) crops accumulated lowest proline content (132.890 μg/g fresh wt.). The results of the present study are in agreement with the results of Al-Tabbal *et al.*, (2005). They reported that proline concentration increase in water stressed leaves. Ashraf *et al.*, (1994) also reported that proline accumulation is least in irrigated plant.

A significant interaction was found between sowing time and irrigation on the proline content of barley leaves (Table 2). Among the treatment combination December 15 sowing with no irrigation gave highest proline content (233.219 μg/g fresh wt.). Which was at par with S3 X IR0 (227.028 μg/g fresh wt.). The third highest proline accumulation was recorded in late seeding with one irrigation (199.517 μg/g fresh wt.) followed by

November 15 sowing with one irrigation (190.319 μg/g fresh wt.). In November 15 sowing with three irrigations accumulated lowest proline content (120.547 μg/g fresh wt.) in the present study. Statistically similar result was recorded in early seeding with three irrigations (116.270 μg/g fresh wt.). The third lowest proline accumulation was obtained in November 30 sowing with three irrigations (137.239 μg/g fresh wt.) which was more or less statistically similar with S2 X IR3. Proline accumulation was highest in late sowing with no irrigation might be due to water stress and high temperature in that period. Similar result was reported by Hasan *et al.*, (2007) they reported that heat stress drought stress increase proline accumulation in wheat leaf.

4.6 Chlorophyll content

Chlorophyll content in flag leaf of barley significantly varied with date of sowing are presented in Table 2. In the present study it was observed that chlorophyll content decrease with delay sowing. The table showed that November 1 sowing gave the highest chlorophyll a, b, and total chlorophyll content (2.013, 2.008 and 4.124 mg/g fresh wt., respectively). These were statistically similar with November 15 sowing. The lowest chlorophyll a, b, and total chlorophyll content (1.428, 1.421 and 2.875 mg/g fresh wt., respectively) followed by November 30 sowing. Similar result also reported by Khatkar and Kuhad (2000).

Chlorophyll a, b, and total chlorophyll content in flag leaf of barley were significantly increased by irrigation frequency (Table 2). It was recorded that chlorophyll a, b and total chlorophyll content follow an increasing trend with increasing irrigation. The result revealed that three irrigations contain highest chlorophyll a, b and total chlorophyll content (1.943, 1.836 and 3.911 mg/g fresh wt., respectively) while IR0 (no irrigation) condition gave the lowest chlorophyll a, b and total chlorophyll content (1.443, 1.481 and 2.952 mg/g fresh wt., respectively). Similar result also reported by Deora *et al.*, (2001).

Significant interaction was also found between sowing date and irrigation levels on Chlorophyll content of barley (Table 2). Among the treatment combination November 1 sowing with three irrigations gave the highest chlorophyll a, b and total chlorophyll content (2.310, 2.228 and 4.766 mg/g fresh wt. respectively). Which was statistically similar with November 15 seeding with three irrigations in case of chlorophyll a, b, and total chlorophyll (2.251, 2.076 and 4.544 mg/g fresh wt. respectively). The third highest (1.983 and 1.945 mg/g fresh wt. respectively) chlorophyll a and b was recorded in early sowing with one irrigation. In case of total chlorophyll it was found in early sowing with two irrigations (4.374 mg/g fresh wt.). While December 15 sowing with no irrigation gave the lowest chlorophyll a, b and total chlorophyll content (1.298, 1.344 and 2.626 mg/g fresh wt., respectively). Which was at par with S2 X IR0 in case of chlorophyll a (1.384 mg/g fresh wt.) and late sowing with two irrigations in case of chlorophyll b and total chlorophyll (1.470 and 2.877 mg/g fresh wt. respectively).

4.7 Yield and yield attributes

4.7.1 Plant height

Plant height affected by date of sowing and irrigation are presented in Table 3. The results revealed that the plant height was significantly influenced by date of sowing. The tallest plant (105.71 cm) was recorded in November 1 sowing (S1) which was statistically similar with November 15 sowing (105.15 cm). The results also showed a trend of decreasing plant height as the sowing dates were delayed. Similar results have also been observed by Ahmed *et al.*, 1997; Anderson and Olsen, 1996. However, the shortest plant (100.72 cm) was recorded in December 15 sowing (S4). Photiades and Hadjechristodoulou (1984) also reported that late sowing tended to decline in plant height.

Table 3. Yield and yield attributes of barley as influenced by sowing date and irrigation frequency

Treatments	Plant height (cm)	Fertile tillers/ plant (No.)	Infertile tillers/ plant (No.)	Spike length (cm)	Fertile spikelets /spike (No.)	Infertile spikelets /spike (No.)	1000-grain weight (g)	Yield (t/ha)	Harvest index (%)
Sowing date									
S1	105.71 a	4.98 a	0.88 c	17.82 a	44.30 a	2.87 c	42.38 a	2.89 a	25.98 a
S2	105.15 a	4.37 b	1.04 b	17.20 b	41.68 a	3.30 b	41.68 a	2.77 ab	25.62 ab
S3	103.02 b	4.02 c	1.21 a	16.44 c	39.47 c	3.62 a	39.54 b	2.63 b	25.55 ab
S4	100.72 c	3.33 d	1.26 a	16.41 d	37.85 d	3.82 a	38.69 b	2.33 c	24.76 b
Irrigation frequency									
IR0	92.00 d	3.27 d	1.30 a	16.24 d	35.59 c	4.00 a	37.93 c	1.85 d	22.05 d
IR1	103.69 c	3.90 c	1.13 b	16.79 c	40.18 b	3.60 b	40.16 b	2.51 c	23.92 c
IR2	108.16 b	4.49 b	1.04 c	17.17 b	42.34 b	3.23 c	41.83 a	2.96 b	26.73 b
IR3	110.75 a	5.05a	0.92 d	17.66 a	45.20 a	2.79 d	42.34 a	3.31 a	29.20 a
Interaction									
S1 x IR0	93.77 h	3.87 d-f	1.01 g	16.94 d-f	38.60 gh	3.22 f-i	39.83 d-g	2.00 jk	21.85 fg
S1 x IR1	105.51 ef	4.68 c	0.91 hi	17.64 bc	43.68 cd	3.07 g-j	43.00 a-c	2.74 f-h	23.68 d-e
S1 x IR2	109.69 b-d	5.36 ab	0.85 ij	18.16 ab	45.65 bc	2.74 jk	43.46 ab	3.23 b-d	26.83 b
S1 x IR3	113.88 a	6.00 a	0.77 j	18.55 a	49.29 a	2.48 k	43.76 a	3.61 a	30.14 a
S2 x IR0	93.43 h	3.18 gh	1.21 cd	16.50 e-g	35.82 ij	3.88 b-d	38.71 e-g	1.89 kl	22.35 e-g
S2 x IR1	106.20 c-f	4.00 de	1.11 ef	16.92 d-f	40.36 fg	3.41 e-h	40.64 c-e	2.58 gh	24.78 cd
S2 x IR2	110.15 a-c	4.82 bc	0.99 gh	16.27 cd	43.50 cd	3.12 f-j	43.43 ab	3.15 c-e	27.44 b
S2 x IR3	110.91 ab	5.50 a	0.87 e	18.12 ab	47.06 ab	2.79 i-k	43.54 ab	3.48 b	27.66 ab
S3 x IR0	92.00 hi	3.13 e-g	1.15 b	15.95 hi	35.14 j	4.30 ab	37.81 gh	1.85 kl	21.49 g
S3 x IR1	102.93 fg	3.70 d-f	1.24 c	16.35 f-h	39.05 gh	3.80 c-e	38.72 e-g	2.47 hi	23.66 d-f
S3 x IR2	107.06 b-d	4.25 cd	1.14 de	16.68 d-g	40.85 e-g	3.53 d-g	40.26 d-g	2.92 d-f	27.09 b
S3 x IR3	110.10 a-e	4.71 c	1.03 fg	16.90 d-f	42.96 de	2.86 i-k	41.39 a-d	3.27 b-e	27.99 ab
S4 x IR0	88.82 i	2.61 h	1.55 a	15.70 i	32.82 k	4.62 a	35.35 h	1.66 l	22.52 e-g
S4 x IR1	100.14 g	3.22 f-h	1.26 c	16.26 g-i	37.65 hi	4.11 bc	38.28 fg	2.24 ij	23.89 c-e
S4 x IR2	105.76 d-f	3.53 e-g	1.19 c-e	16.59 e-g	39.36 f-h	3.54 d-f	40.18 d-g	2.55 g-i	25.60 bc
S4 x IR3	108.18 b-e	3.98 de	1.03 fg	17.10 c-e	41.58 d-f	4.05 h-j	40.97 c-d	2.87 e-g	27.02 b
CV (%)	**6.04**	**8.81**	**5.31**	**5.26**	**8.37**	**8.82**	**7.69**	**7.20**	**8.50**

In a column figures having same letter(s) do not differ significantly at $P \leq 0.05$ by LSD.

The results showed that different levels of irrigation had a significant variation in plant height (Table 3). Plant height was increased with the increasing frequency of irrigation. The tallest plant (110.75 cm) was recorded in three irrigations applied at early tillering stage, booting stage and grain filling stage, while the shortest plant (92.00 cm) was found in no irrigation treatment. The probable causes of the tallest plant in all the irrigation treatments might be due to increase in cell division, cell elongation, leaf expansion and photosynthesis by the plants. The results are in accordance with the findings of Sing and Anureet (2001) and Al-Satari *et al.*, (2001). On the other hand, water deficit in no irrigation treatment caused lower photosynthesis due to low photosynthetic area and also from the disturbance of mineral nutrients uptake and translocation of photosynthates to the growing parts thus reduced the plant height in no irrigation (IR0) situation (rainfed) in the present study. Similar findings also reported by Mostafavi and Niknejad (1983).

The interaction between date of sowing and irrigation was also found significant (Table 3). Among the different treatment combinations November 1 sowing with three irrigations produced tallest plant (113.88 cm) which was statistically similar in November 15 seeding with three irrigations (110.91 cm). The third tallest plant was recorded in November 15 sowing with two irrigations (110.15 cm) which was at par in S3 X IR3 (110.10 cm), next to this the subsequent tallest plant was obtained in S3 X IR2 (107.06 cm). The combination effect of December 15 sowing with no irrigation produced smallest plant (88.82 cm). Which was at par with November 30 sowing with three irrigations (92.00 cm). Results of present study are supported by the findings Moula, 1999.

4.7.2 Fertile tillers per plant

Sowing time produced a significant variation in number of fertile tillers per plant (Table 3). Number of fertile tillers per plant decreased with delay in sowing. Delayed sowing produced a higher number of barren tillers. The results revealed that November 1 sowing produced significantly highest number of fertile tillers per plant (4.98). The least number of fertile tillers per plant was recorded in December 15 sowing (3.33). This result was close conformity with the findings of Lupu (2001). Similar observations were also reported by Fukushima *et al.*, (2001) and Randhawa *et al.*, (1981).

The result exhibited that the number of fertile tillers per plant of barley was significantly influenced by irrigation treatment (Table 3). Number of fertile tillers per plant increased with increasing irrigation frequency. Three irrigations applied at early tillering stage, booting stage and grain filling stage gave the highest number of fertile tillers per plant (5.05) and the second highest number of fertile tillers per plant (4.49) was recorded from two irrigations. The lowest number of fertile tillers per plant was recorded in IR0 (Control) condition (3.27). Similar results were reported by Afzal *et al.*, 2006; Hamdy *et al.*, 2003; Chaudhary and Sharma, 2003).

Number of fertile tillers per plant was significantly influenced by the combination effect of seeding date and irrigation frequency (Table 3). Among the different treatment combination November 1 sowing with three irrigations produced highest number of fertile tillers per plant (6.00) which was statistically similar to November 15 sowing with three irrigations (5.50) and early sowing with two irrigations (5.36). December 15 sowing with no irrigation produced lowest number of fertile tillers per plant (2.61) which was at par with November 15 sowing with no irrigation.

4.7.3 Infertile tillers per plant

Effect of sowing time and irrigation frequency on the number of infertile tillers $plant^{-1}$ is presented in (Table 3). Date of sowing significantly influenced the number of infertile tillers $plant^{-1}$. November 1 sowing gave the lowest number of infertile tillers $plant^{-1}$ (0.88). While the highest number of infertile tillers $plant^{-1}$ was recorded in December 15 sowing

(1.26). Which was at par with November 30 sowing (1.21). The present result was partially coinciding with the results of Alam (2003).

The effect of irrigation frequency on the number of infertile tiller number plant^{-1} was statistically significant (Table 1). Results revealed that the number of infertile tillers plant^{-1} decreased with increased number of irrigation. The highest number of infertile tillers plant^{-1} (1.30) was observed in control (IR0) followed by one irrigation at early tillering stage (1.13). In contrast, the number of lowest infertile tillers plant^{-1}(0.92) was recorded in three irrigations applied at early tillering, booting and grain filling stage. Similar result was also reported by Rahman (2004) in wheat where observed that the number of infertile tillers plant^{-1} decreased with the increased number of irrigation.

A significant interaction was found between sowing time and irrigation in producing the number of infertile tillers plant^{-1} on barley is presented in Table 3. Among the different treatment combinations November 1 sowing with three irrigations produced the lowest number of infertile tillers plant^{-1} (0.77) and December 15 sowing with No irrigation produced the highest number of infertile tillers plant^{-1} (1.55).

4.7.4 Spike length

Significant variation in spike length was found (Table 3) with the variation of sowing time. It was observed that the length of spike decrease with the delay in sowing. The results revealed that November 1 sowing produced the tallest spike (17.82 cm) followed by November 15sowing. The shortest spike (16.41 cm) was recorded in December 15 sowing. Similar observations were also reported by Sarker *et al.*, 1996 and Begum *et al.*, (1999) in barley. The result was also in close conformity with results of BARI (1993) findings where it was observer that reduction in spike length from 9.91 to 8.13 cm due to delay in sowing for November 20 to December 25.

The results exhibited that spike length of barley was significantly influenced by irrigation treatment (Table 3). Spike length increased with increasing irrigation frequency. three irrigations applied at early tillering stage, booting stage and grain filling stage gave the tallest spike length (17.66 cm) and the second highest spike length (17.17 cm) was recorded in two irrigated plots which was statistically superior to IR0 (Control) irrigation (16.24 cm). Similar results were reported by Rahman (2004). Naser (1996) also observed increased spike length with increase irrigation levels.

Spike length was significantly influenced by the interaction effect of sowing time and irrigation frequency (Table 3). Among the different treatments in November 1 sowing with three irrigations produced tallest spike (18.55 cm) this was at per with early sowing with two irrigations (18.16 cm) and mid November sowing with three irrigations (18.12 cm). The fourth tallest spike was recorded in early sowing with one irrigation (17.64 cm) and next to this (17.27 cm) found in mid November seeding with three irrigations. December 15 sown with no irrigation produced smallest spike length (15.70 cm) and the second smallest spike was obtained in November 30 seeding with no irrigation. The present result was similar with the results of Moula. 1999.

4.7.5 Fertile spikelets per spike

Number of fertile spikelets spike^{-1} varied significantly due to different sowing dates (Table 3). The highest number of fertile spikelets spike^{-1} was observed in November 1 sowing (44.30). The next highest was obtained from November 15 sowing (41.68). However, the lowest number of fertile spikelets spike^{-1} was obtained from December 15 sowing (37.85). The result is in full agreement with the findings of by Ram *et al.*, (2004) I wheat where they observed number of spikelets spike^{-1} were maximum in the earlier sowing. Present study is also partially uniform with the results of Zende *et al.*, (2005).

A significant variation was due to increase in irrigation frequency on the number of fertile spikelets (Table 3). The highest number of fertile spikelets spike^{-1} (45.20) was found in three irrigations applied at early tillering stage, booting stage and grain filling stage. The second highest fertile spikelets spike^{-1} (42.34) was recorded in two irrigations. Which was statistically similar to the one irrigation at early tillering stage (40.18).The lowest number of fertile spikelets spike^{-1}was recorded with no irrigation (35.59). The result was supported by the findings of Abdorrahmani *et al.*, (2005) and Afzal *et al.*, (2006). They reported that higher number of fertile spikelets spike^{-1} was obtained with increased number of irrigation.

The interaction effect between sowing time and irrigation levels showed significant on the number of fertile spikelets spike^{-1} (Table 3). The highest number of spikelets spike^{-1} (49.29) was produced in November 1 sowing with three irrigations. Statistically similar result was recorded in November 15 seeding with three irrigations (47.06). The third highest number (45.65) of fertile spikelets spike^{-1} was obtained in early sowing with one irrigation, which was similar in S2 X IR2 (43.50). While January 15 sowing with no irrigation produced the lowest number of fertile spikelets spike^{-1} (32.82). Similar result also reported by Moula (1999).

4.7.6 Infertile spikelets per spike

Number of infertile spikelets spike^{-1} also varied significantly due to different sowing dates (Table 3). The highest number of infertile spikelets spike^{-1} was observed in December 15 sowing (3.82). Which was statistically similar to that of November 30 sowing (3.62). The lowest number of infertile spikelets spike^{-1} was obtained from November 1 sowing (2.87). The result is in full agreement with the findings obtained by Alam (2003).

Irrigation treatment significantly influenced the number of infertile spikelets spike^{-1} compared to no irrigation (Table 3). Result revealed that the number of infertile spikelets spike^{-1} decreased with increasing irrigation. The highest number of infertile spikelets spike^{-1} (4.00) was observed in control. On the other hand, the lowest infertile spikelets spike^{-1} (2.79) was recorded in three irrigations were applied at early tillering, booting and grain filling stage. Similar result was also reported by Rahman (2004) in wheat, where he observed that infertile spikelets spike^{-1} decreased with the increasing number of irrigation.

The interaction of sowing time and irrigation showed a significant variation in the number of infertile spikelets spike^{-1} (Table 3). The highest number of infertile spikelets spike^{-1} were produced in December 15 sowing with no irrigation (4.62) and the lowest number of spikelets/spike (2.84) produced in November1 sowing with no irrigation.

4.7.7 Thousand grain weight

Seeding dates produced a significant effect on 1000-garin weight (Table 3). The 1000-grain weight reduced as the sowing was delayed. The highest 1000-grain weight was found in November 1 sowing (42.38 g) which was statistically similar to November 15 sowing (41.68 g). The late sown (December 15) crop had the smaller grain weight (38.69 g). The results of the present study was similar with the findings of BARI (1997) reported that higher 1000-grain weight in barley in early sowing.

The results showed that 1000-grain weight differed significantly between the irrigation levels (Table 3). The Table revealed that 1000-grain weight increased with the increasing irrigation. The highest 1000-garin weight (42.34 g) was found in three irrigations were applied at early tillering, booting and grain filling stage which was statistically similar to that of two irrigations (41.83 g) while the lowest was in no irrigation treatment (37.93 g). The present result is fully similar with the results of Afzal *et al.*, (2006) they reported that plots receiving four irrigations gave the highest 1000-grain weight in barely. Similar result also reported by Rahman (2001); Kader and Begum. (1999).

Significant combine effect was also found between irrigation and sowing dates in terms of 1000-grain weight (Table 3). The highest 1000-grain weight was observed in crop sown in November 1 sowing with three irrigations (43.76 g). The second , third and fourth highest 1000- grain weight was observed in S1 X IR2, S2 X IR3 and S2 X IR2 (43.46, 43.54 and 43.43 g, respectively). and the lowest one was in December 15 sowing with no irrigation (35.35 g). Heaviest 1000-grain weight was in early sowing with three irrigations was due to tallest plant height, maximum fertile tillers per plant, minimum infertile tillers per plant, tallest spike length, highest fertile spikelets per spike and lowest infertile spikelets per spike that gave the heaviest 1000-grain weight.

4.7.8 Grain yield

Plating time significantly affect the grain yield of barley (Table 3). The highest grain yield was obtained from November 1 sowing (2.89 t/ha) which was at par with November 15 seeding (2.77 t/ha). These results are in close conformity with the results of Ahmed *et al.*. (2006). The lowest grain yields was recorded from December 15 sowing (2.33 t/ha). Late sowing put the crop under high evaporative demand at vegetative and grain filling stages, resulting in relatively low magnitude of all the yield attributes coupled with shortening of crop life and forced maturity during vegetative phase and high temperature at maturity adversely affected plant height, the number of spikelets spike^{-1} and the number of grains spike^{-1}, which ultimately reduced the grain yield. Similar observations were also reported by BARI (1997). On the other hand. the higher yield obtained from November 1 and November 15 sowing were mainly favoured by optimum atmospheric temperature probably supported the physiological processes and thereby attributed to higher number of higher number of spikelets/ spike as well as higher 1000-grain weight (Begum *et al.*, 1999).

Irrigation significantly influenced the grain yield of barley (Table 3). The results revealed that grain yield increased with the increasing irrigation frequency. The highest grain yield

(3.31 t/ha) was produced by three irrigations applied at early tillering, booting and grain filling stage followed by two irrigations at early tillering and booting stage (2.96 t/ ha). No irrigation treatment produced significantly lowest yield (1.85 t/ha). Similar findings have also been reported by Nowak *et al.*, (2005); Baheri *et al.*, (2005) where they reported that irrigation increase the grin yield. The results obtained in the study are also in close conformity with the findings of Borowczak *et al.*, (2003) they observed that application of one irrigation at CRI and two irrigations at CRI and heading stage in barley produced identical yields. Yield reduction in no irrigation due to water shortage was attributed to reduce productive tillers plant^{-1}, spike length, fertile spikelets spike^{-1} and reduced 1000-grain weight. Moreover, the reduction in yield could be attributed to reduced photosynthetic activity by partial closure of stomata and decrease in supply of CO_2 under water stress condition (Kramer, 1972). On the other hand, seed yield increased with irrigation probably due to positive effect of irrigation for higher number of spikelets spike^{-1}, grains/spike and 1000-grain weight as observed in the present study and also because of optimum moisture helped in proper utilization of nutrients.

Sowing time and irrigation interacted significantly in grain yield (Table 3). The result indicated that the highest grain yield (3.61 t/ha) was found in November 1 sown with three irrigations applied at early tillering, booting and grain filling stage. The lowest grain yield (1.66 t/ha) was noticed in December 15 sowing with no irrigation. Similar results were reported by Pal *et al.*, (1996); Sing and Jain (2000). From the overall growth period and biochemical test it was observed that in early sowing and irrigated condition booting, heading, maturity take highest days i.e., maximum growth period and LAI, LAD, CGR, RGR, NAR, TDM production also maximum that help to increase yield of crop. It was also found that RLWC and Chlorophyll a, b and total chlorophyll was highest in early sowing with three irrigations which increase the yield of barley.

4.7.9 Harvest index (HI)

Harvest index showed a significant variation due to different dates of sowing (Table 3). The highest value (25.98%) was obtained by November 1 sowing which was closely followed by November 15 sowing. The lowest harvest index (24.76%) was obtained in December 15 sowing. This result is fully similar with the results of Ram *et al.*, (2004) They also reported that the highest harvest index were obtained in 20 November-sown wheat. On the other hand Ehdaie *et al.*, (2001) reported that early sowing decreased harvest index.

Significant variation in harvest index was found due to irrigation level (Table 3). three irrigations at early tillering, booting and grain filling stage gave significantly highest harvest index (29.20%). The lowest harvest index was found in no irrigation treatment (20.08%). Similar result was also reported by Moula (1999) he observed that HI increased with the increasing number of irrigation. However, the increase in harvest index with the increase number of irrigation might be due to more mobilization of assimilates to the sink. Decrease in harvest index in no irrigation condition (control) has also been reported by Shaheb (2004).

The interaction effect of sowing date and irrigation had significant variation in HI (Table 3). The highest harvest index (30.14%) was observed in November 1 sowings with three irrigations. The lowest value (21.49%) was obtained in November 30 sowing with no irrigation.

CHAPTER 5

SUMMARY AND CONCLUSION

The experiment was carried out to evaluate the response of barley to sowing dates and irrigation frequency at the Research Field and Laboratory of Crop Botany Department, Hajee Mohammad Danesh Science and Technology University, Dinajpur during the period of November 2005 to December 2006. The experimental area belong to Old Himalayan Piedmont Plain (AEZ-1) having sandy loamy soil with pH 6.1. The experimental treatments were four dates of sowing (November 1, 15, 30 and December 15) and four levels of irrigations (No irrigation, one, two, three irrigations at different days after sowing). The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. The unit plot size was 2.5 m x 2.0 m. The distance between block to block 1 meter and plot to plot was 0.75 m, plant to plant and row to row distance was maintained 4 and 25 cm, respectively.

Observations were made on soil moisture, some phenological parameters such as days to emergence, crown root initiation, tillering, booting, heading and maturity, growth parameters like TDM, LAI, LAD, CGR, RGR, NAR and GGR. Observation were also made on RLWC, proline and content chlorophyll content, yield and yield attributes like plant height, fertile tillers per plant, infertile tillers per plant, spike length, fertile spikelets per spike, infertile spikelets per spike, thousand grain weight, grain yield and harvest index.

Soil moisture status significantly influenced by sowing dates and irrigation levels. The results revealed that S1 (November 1) showed the highest soil moisture status while the S4 (December 15) showed lowest soil moisture percentage in the present study in every depth. In case of irrigation frequency IR3 (three irrigations applied at early tillering, booting and grain filling stage) plots gave highest soil moisture status in every case. On the other hand

IR2 (two irrigations) and IR1 (one irrigation) showed lower soil moisture status than IR3. Sowing time and irrigation interacted significantly on soil moistures content. The plots of S1 (November 1) with three irrigations showed the highest soil moisture contents and the plot of S4 (December 15) with IR0 showed the lowest values of soil moisture in each case.

Sowing dates significantly influenced all the phenological parameters. Tillering, booting, heading and maturity required comparatively more days (22.83, 63.75, 73.33, and 104.91 days, respectively) while emergence and crown root initiation required comparatively less days (6.06 and 17.75 days, respectively) when crops planted in November 1. On the other hand delay sowing (December 15) gave reverse results in all cases. Effect of irrigation on emergence, crown root initiation and tillering was insignificant. Three irrigations required the highest days to booting, heading and maturity (62.83, 73.25 and 106.33 days, respectively) while control irrigation requires the lowest days in all cases. Interaction effect of sowing dates and irrigation showed significant variation for all the phenological parameters. Early sowing (November 15) with three irrigations (IR3) showed the best performance in all cases.

Growth parameters like TDM, LAI, LAD, CGR, RGR and NAR were significantly influenced by seeding date. Early sowing (November 1) perform better in relation to TDM, LAI, LAD, CGR, RGR and NAR than the late sowing condition. Irrigation frequency also influenced those parameters significantly. Sowing time and irrigation also interacted significantly for all those growth parameters. November 1 sowing (S1) showed better performance for all the growth parameters with three irrigations (IR3).

Relative leaf water content (RLWC), proline content and chlorophyll content were significantly influenced by sowing dates and irrigation. The highest values of RLWC at 8.00 am (90.97%), 10.00 am (89.81%) and 12.00 noon (72.27%) were observed in early sowing while late sowing showed the lowest values of RLWC at the same time of the day.

The plants receiving three irrigations gave higher values of RLWC at 8.00 am (93.75%), 10.00 am (90.07%) and 12.00 noon (77.35%) than control plots. However, interaction between November 1 sowing with three irrigations produced the highest values of RLWC at the same time of the day. Proline content was found the highest (191.113 µg/g fresh weight) in late sowing (December 15) and it was lowest (175.428 µg/g fresh weight) in early sowing (November 1). On the other hand control plot (IR0) gave the highest proline content (218.807 µg/g fresh weight) in contrast with three irrigations (132.890 µg/g fresh weight). Interaction of December 15 sowing with no irrigation accumulated the highest proline (233.219 µg/g fresh weight). Chlorophyll a, b and total chlorophyll content were the highest (2.013, 2.008 and 4.124 mg/g fresh weight) in the plants sown in November 1 while lowest chlorophyll content was found in late sown crops. Three irrigations gave the highest chlorophyll a, b and total chlorophyll content (1.943, 1.836 and 3.911 mg/g fresh weight) than the control one. From the present study it was also revealed that early sowing (S1) with three irrigations gave the highest chlorophyll a, b and total chlorophyll content (2.310, 2.228 and 4.766 mg/g fresh weight).

Grain growth rate (GGR) was also significantly influenced by sowing time and irrigation frequency. In the present study GGR was the highest in late sown crop than early sowing. Three irrigations gave the highest value of GGR during early stage of grain development. Interaction of sowing time and irrigations December 15 sowing and IR3 irrigation gave the highest GGR vale.

Yield attributes, yield and harvest index of barley significantly influenced by seeding dates and irrigation frequency. The highest plant height (105.71 cm) was recorded in early sowing (November 1) and the lowest (100.72 cm) in late sowing (December 15) condition which was at par with November 15 sowing. Three irrigations gave the highest plant height (110.75 cm) and the lowest (92.00 cm) was obtained from control plot. The interaction of

November 1 sowing with three irrigations gave the tallest plant (113.88 cm) and 15 December sowing with no irrigation produced the smallest plant (88.82 cm). The highest fertile tillers (4.98) was recorded in early sown (November 1) and the lowest (3.33) in December 15. Three irrigations gave the highest fertile tillers per plant (5.05) while lowest in control (3.27). Interaction of November 1 sowing with three irrigations showed the better performance in this regard. While the number of infertile tillers per plant showed a reverse result for all the treatments. The longest spike length (17.82cm) was recorded in early sowing (November 1) while the shortest (16.41 cm) one in late sowing (December 15). Three irrigations produce the longest spike length (17.66 cm) and the shortest (16.24 cm) one found with no irrigation. Interaction of early sowing with three irrigations gave the longest spike length (18.55 cm) than late sowing with control (IR0). The highest (44.30) number of fertile spikelets per spike was recorded in November 1 sowing while the smallest number (37.85) in late sowing (December 15). Plots receiving three irrigations gave the highest number (45.20) of fertile spikelets per spike than the control Plot (35.59). Interaction between early sowing with three irrigations showed better performance in this regards. On the other hand infertile spikelets per spike showed a reverse result in case of all the treatments.

The 1000-grain weight was highest (42.38 g) in early sowing and the lowest (38.69g) in late sowing condition, which was at par with November 15 sowing. Three irrigated plots gave the highest (42.34 g) 1000 grain weight in contrast with control (37.93 g). The heaviest (43.76g) 1000-grain was obtained by the interaction of November 15 sowing with three irrigations and the lightest (35.35g) grain was obtained from the interaction of December 15 with control condition. The maximum grain yield (2.89 t/ha) was recorded in early sowing (November 1) while the lowest grain yield (2.33 t/ha) was in December 15 sowing. Three irrigated crops gave the highest yield (3.31 t/ha) in November 1 sowing which was at par with November 15 sowing. The lowest gain yield (1.85 t/ha) was recorded in control condition. Interaction of sowing time and irrigation showed significant effect on grain yield. It was revealed that November 1 sowing with three irrigation gave the highest (3.61 t/ha) grain yield while the lowest yield (1.66 t/ha) was noticed in December 15 with no irrigation. The highest value of harvest index (25.98%) was observed in early sowing followed by November 15 sowing. The lowest value of harvest index (24.76%) was obtained in December 15 sowing. Three irrigations gave the highest value of harvest index (29.20%) while control gave the lowest value (22.05 %). Interaction between November 15 sowing with three irrigations showed the best performance in this regard.

In conclusion, the study revealed that early sowing (November 1) performed better in relation to growth, yield attributes and yield of barley. Three irrigations at early tillering, booting and grain filling stages seemed to be suitable for the same. On the other hand early sowing with three irrigations performed the best for improving the yield of barley. However further investigations are essential to reached at firm conclusion.

REFERENCES

Abdel-Raouf, M. S., Kandil, A., Gheith, E. M. S. and N. Mahros. 1983. Associations between growth attributes of barley and grain yield under different seeding dates. Ann. Agril. Sci. Moshtohor, Egypt. 19 (1): 45-55.

Abdorrahmani, B. Gholosani, K. G. and M. Esfahani. 2005. The effect of supplementary irrigation on the growth index, yield and yield components of wheat. Agric. Sci. Tabriz. 15(1): 51-67.

Afzal, A., Ahmad, S., Khan, A. and M. Amin. 2006. Comparison of wheat and barley for yield and yield components under different irrigation patterns. Sarhad J. Agric. 22(1): 7-11.

Ahmed, R., Munir, L., Zada, A. and Z. Shah. 1997. Response of wheat varieties to different planting dates at chitral valley. Sarhad J. of Agriculture. 13 (4): 323-327.

Ahmed, S., Islam, M. S., Salam, A. and M. F. Hossain. 2006. Effect of sowing time on the yield attributes of barley in High Barind Tract. Bangladesh J. Agril. Res. 31(2): 231-239.

Alam, M. Z. 2003. Influence of planting dates and nitrogen levels on growth, grain yield and nitrogen utilization of barley. Ph. D. Thesis. Department of Botany. University of Rajshhi, Rajshahi.

Al-Satari, Y. A., Kafawin, O., Ghawi, I. and H. M. Saoub. 2001. Response of two barley cultivars to three seeding rates under supplemental irrigation. Arab Gulf J. Scie. Res. 19(1): 7-11.

Al-Tabbal, J. A., Ayad, J. Y. and O. M. Kafawin. 2005. Effect of water deficit and plant growth regulators on leaf chlorophyll, proline and total soluble sugar content of two durum wheat cultivars (*Triticum turgidum* L. *var. durum*). Dirasat Agril. Sci. 32(2): 195-204.

Anderson, A. and C. C. Olsen. 1992. Sowing date and nitrogen fertilizer application in different cultivars of winter wheat. Tidsskrift Plontevel (Denmark). 95(5): 441-451.

Anonymous. 1972. Study on the effect of different methods of planting on some varieties of wheat. M. Sc. (Ag.) thesis in Agronomy, BAU, Mymensingh. pp. 19-32.

Anonymous. 1993. 'Titas a new variety of millet. A leaflet published by Bangladesh Agricultural Research Institute. Joydedpur, Gazipur.

Anonymous. 1997. Effect of sowing date and irrigation on the yield of barley. Annual report (1996-97) of Bangladesh Agriculture Research Institute, Joydedpur, Gazipur. pp. 33-38.

Anonymous. 1998. Effect of sowing date and irrigation on the yield of barley. Annual report (1997-98) of Bangladesh Agriculture Research Institute, Joydedpur, Gazipur. pp. 20-25.

Ashok, K. and D. K. Sharma. 1997. Dry matter and nutrient accumulation of wheat as influenced by irrigation in sodic soil. Indian J. agril. Res. 31: 217-221

Ashraf, M. Y. and A. S. Bhatti. 1998. Effect of delayed sowing on some parameters of photosynthesis in wheat (*Triticum aestivum* L.). Wheat information service. 86: 46-48.

Ashraf, M. Y., Azmi, A. R., Khan, A. H. and S. A. Ala. 1994. Effect of water stress on total phenols, peroxidase activity and chlorophyll content in wheat (*Triticum aestivum* L.). Acta Physiol. Planta. 16(3): 185-191.

Baheri, S. F., Javanshir, A., Kazemi, H. and S. Aharizad. 2005. The effects of irrigation at different phenological stages on some traits in spring barley genotypes. Iranian J. Agril. Sci. 36(1): 169-176.

BARC (Bangladesh Agricultural Research Council). 1997. Fertilizer Recommendation Guide. Published By BARC, Farmgate, Dhaka. P. 56.

BARI (Bangladesh Agricultural Research Institute) 1984. Annual Report of 1981-82. Joydebpur, Gazipur. pp. 12-20.

BARI (Bangladesh Agricultural Research Institute). 1997. Effect of sowing date and irrigation on the yield of barley. Res. report, 1996-97. Bangladesh Agril. Res. Inst., Jamalpur. pp. 33-38.

BARI. (Bangladesh Agricultural Research Institute). 1993. Annual Report of 1992. Joydebpur, Gazipur. pp. 34-41.

BARI. (Bangladesh Agricultural Research Institute).1990. Means of wheat production by profitable method (A Booklet in Bangla). Wheat Research Centre, Bangladesh Agril. Res. Inst. Nashipur, Dinajpur. pp. 5-6.

Barrs, H. D. and P. E. Weatherley. 1962. A re-examination of relative turgidity technique for estimating water deficits in leaves. Aust. J. biol. Sci. 15: 413-428.

BBS (Bangladesh Bureau of statistics). 2004. Hand book of Agricultural statistics. December, 2004. Ministry of Planning. Govt. People's Repub. Bangladesh. P. 141.

Begum, S., Moula, M. G., Rahman, M. A. and D. Nessa. 1999. Effect of sowing time and seed rate on the yield of barley. Bangladesh J. Agril. Sci. 26(2): 81-85.

Bhardwaj, S. N., Warrior, A. and K. P. Sing. 1987. Water stress on grain weight bread wheat. Indian J. Plant Physiol. 30 (4): 432.

Bhattacharjes, B. D. E. S. and A. K. Mukherjee. 1996. Short-term heat shock and cold shock induced proline accumulation in relation to calcium involvement in *Lycopersicon esculentum* (Mill) cultured cells and seedlings. Indian J. Plant Physiol. 1(1): 32-35.

Borowczak, F., Grzes, S. and K. Rebarz. 2003. Influence of irrigation and cultivation system on the yields, yielding components and quality of sowing materials of winter wheat, spring barley and pea. J. Res. Applications in Agril. Engineering. 48(3): 38-42.

BRRI (Bangladesh Rice Research Institute). 1985. Annual Report for 1982. Jodebpur, Gazipur, Bangladesh. BRRI pub. No. 79. pp. 236-238.

Bullock, D. G., Neilsen, R. L. and W. E. Nyquist. 1988. A growth analysis comparison of corn grown in conventional and equidistant plant spacing. Crop Sci. 28: 254-258.

Campbell, C. A., Davidson, H. R. and G. E. Winkleman. 1981. Effect of nitrogen, temperature on growth stage and duration of moisture stress on yield components and protein content of Maniton spring wheat. Can. J. Plant Sci. 61: 549-563.

Chaitanya, K. V., Sundar, D. and A. R. Reddy. 2001. Mulberry leaf metabolism under high temperature stress. Biologica Plantarum. 44(3): 379-384.

Chaudhary, T. and D. D. Sharma. 2003. Response of barley (*Hordeum vulgare* L.) to different varieties and irrigation levels. Current Agric. 27(1/2): 139-141.

Cheema, S. S., Cander, K., Kundra, H. and O. P. Malhotra. 1983. Growth and yield of barley under varying soil moisture levels. Indian J. Agron. 28: 20-22.

Chowdhury, S. I. and I. F. Wardlaw. 1978. The effect of temperature on kernel development in cereals. Aust. J. Agric. Res. 29: 205-223.

Clawson, K. L., Specht, J. E. and B. L. Blad. 1986. Growth analysis of Soybean isolines differing in pubescence density. Agron. J. 78: 164-172.

Corny, M. J. 1995. A note on the effect of sowing date and fertilizer on the yield, grain nitrogen and screening content of spring-sown malting barley. Irish J. Agrial. And Food Res. 34(1): 69-73.

Cox, W. J., Zobel, R. W., Van, E. H. M. and D. J. Otis. 1990. Growth, development and yield of maize under different tillage systems in the northern USA. Soil Tillage Res. 18: 295-31.

Deora, V. S., Shah, M. A. A. and A. Joshi. 2001. Effect of moisture stress on wheat genotypes Crop, Research, Hisar. 21(1): 24-26.

Desai, B. L. 1935. Relation among chlorophyll content, water content and rate of photosynthesis in some tropical plants at different temperature. Ann. Bot. 47: 69-88.

Dofing, S. M. and M. G. Karlsson. 2001. Growth and development of uniculm and conventional tillering lines. Agron. J. 85 (1): 58-61.

Donald, C. M. and J. Hamblin. 1976. The biological yield and harvest index of cereals as agronomic and plant breeding criteria. Adv. Agron. 28: 361-405.

Drossopoulos, J. B., Karamanos, A. L. and C. A. Niavis. 1987. Changes in ethanol soluble carbohydrate during the development of two wheat cultivars subjected to different water stress. Ann. Bot. 87: 173-180.

Ehdaie, B., Skakiba, M. R. and J. G. Waines. 2001. Sowing date and nitrogen input influence nitrogen use efficiency in spring bread and durum wheat genotypes. J. of Plant Nutrition. 24 (6): 899-919.

Eik, K. and J. J. Hanway. 1966. Leaf area in relation to yield of corn grain. Agron. J. 58: 16-18.

Eissa, A. M., Eldin, T. M. S. and A. M. Dawood. 1994. Planting date in relation to yield and yield components of wheat in AL-Qassim region. Arab Gulf. J. Sci. Res. 12 (3): 449 - 464.

Engelmann, R. 1982. The relation between maximum rate of photosynthesis and concentration of chlorophyll. Gen. Physiol. 12: 609-622.

Evans, L. T. 1975. The physiological basis of crop yield. In. Crop physiology: Some case histories edited by Evans, L. T., London, Cambridge Univ. Press. pp. 327-355.

FAO (Food and Agriculture Organization). And UNDP (United Nations Development Programme). 1988. Land Resources Appraisal of Bangladesh for Agricultural

Development. Report No. 2. Agro-ecological Regions of Bangladesh. FAO, Rome. Italy. pp. 212-221.

Farid, S. M., Hossain, A. and A. B. M. Salahuddin. 1993. Sowing date effects on the yield of three cultivars of barley. Bangladesh J. Agril. Sci. 20(1): 41-45.

Fischer, R. A. and R. Maurer. 1978. Drought resistance in spring wheat cultivars. I. Grain yield responses. Aust. J. Agric. Res. 29: 897-912.

Fleischer, W. E. 1935. The relation between rate of chlorophyll content and rate of photosynthesis. Gen. Physiol. 18: 573-597.

Fukushima, A., Kusuola, O. and M. Furohata. 2001. Tiller development of winter type wheat Iwainodaichi sown early in the south western part of Japan. Japanese J. Crop Sci. 70: (2) 173-178.

Gaffer, M. A. 1995. Development of management practices of millets for higher production. BAU Res. Prog. Report 9: 30-33.

Gardner, F. P., Pearch, R. B. and R. L. Mitchell. 1985. Physiology of crop plants. Iowa State University Press, Ames. pp. 187-208.

Gautom, R. C. and K. C. Sharma. 1987. Dry matter accumulation under different planting schemes and plant densities of rice. Indian J. Agric. Res. 21: 101-109.

Ghosh, A., Puste, M. and A. Ghosh. 1997. Effect of irrigation and inoculation on growth and yield of wheat and lentil grown pure and intercropping systems. Indian J. agric. Sci. 67: 571-574.

Ghosh, D. C., Nandi, P. and B. Dev. 2000. Phenological development and productivity of wheat (*Triticum aestivum*) at different dates of sowing. Indians J. Agr. Sci. 70(6): 39 -395.

Gouis, J. le. 2004. Grain filling and shoot growth of 2-row and 6-row winter barley varieties. Agron. J. 13 (6): 545-552.

Grant, C. A., Gaure, I. E., Gehl, D. T. and L. D. Bailey. 1991. Yield response of semi dwarf and conventional height barley cultivars to nitrogen fertilizer under varying moisture conditions. Canadian J. Plant Sci. 71: 361-371.

Hales, J. 1992. Eat, smart, fell good, look great. Reader's digest. April issue. P. 63.

Hamdy, A., Sardo, V. and K. A. F. Ghanem. 2005. Saline water in supplemental irrigation of wheat and barley under rainfed agriculture. Agricultural Water Management. 78 (1/2): 122-127.

Hanson, A. D. and W. D. Hitz. 1982. Metaolic responses of mesophytes to plant water deficits. Ann. Rev. Plant Physiol. 33:163-203.

Hare, P. D. and W. A. Cress. 1997. Metabolic implications of stress induced proline accumulation in plants. Plant growth Regulation. 21(2): 79-102.

Harris, H. C., Copper, P. J. M. and M. Pala. 1991. Soil and crop management for improved water use efficiency in rainfed areas. Proc. Intl. Workshop. Ankara, turkey, 15-19 May, 1989. ICARDA, Aleppo, Syria.

Hasan, M. A., Ahmed, J. U., Bahadur, M. M., Haque, M. M. and S. Sikder. 2007. Effect of late planting heat stress on membrane thermostability, proline content and heat susceptibility index of different wheat cultivars. J. Natn. Sci. Foundation Sri Lanka. 35(2): 109-117.

Hossain, M. A. and N. Alam. 1986. Effect of date of sowing and seed rate on the yield of wheat (var. Kanchan) under irrigated condition. Bangladesh Soc. Agron. Conf. Abst. P. 8.

Hossain, M. A. and S. M. Farid. 1988. Influence of sowing date seed rate on two varieties of wheat. Bangladesh J. Agril. Res. 13 (2): 36-41.

Hossain, M. A., Barma, N. C. D., Rahman, S., Mosumder, M. K. and M. A. Islam. 1987. Effect of seedling dates on the yield and maturity of spring wheat. In: Proc. 12th Annual Bangladesh Sci. Conf. BAAS. pp. 10-11.

Hossain, M. M., Takeda, H. and T. Senboku. 1995. Proline content in *Brassica* under high temperature stress. JIRCAS J. 2: 87-93.

Hung, P. S. and B. S. Miao. 1982. A study of high yielding cultivation of Indica rice cultivars 76-01 on an area of 100 m^2 in north .Tiangsu. J. Nanjung. Agron. Coll. No. l: 12-21.

Hunt, R. R. 1978. Plant growth analysis studies. In: Biology Series No. 96. Edward Arnold Ltd. Bedford Square London. pp. 1-67.

Hussain, G. and A. A. Al-Jaloud. 1998. Effect of irrigation and nitrogen on yield, yield components and water use efficiency of barley in Saudi Arabia. Agricultural Water Management. 36 (1): 55-70.

Ikegami, S., Tsuchihashi, F., Nakamura, K. and S. Innami. 1991. Effects of barley on development of diabetes in rats. J. Japanese soc. Nutrition and Food Sci. 44 (6): 447-454.

Ishag. H. M. and O. A. A. Ageeb. 1991. The physiology of grain yield in wheat in an irrigated tropical environment. Expt. Agric. 27: 71-77.

Islam, M. S. 1997. Growth and yield response of wheat to irrigation and nitrogen application. M. Sc (Ag.) Thesis, Dept. Soil sci. Bangladesh Agril. Univ. Mymensingh .

Jacson, K. A. and D. L. Topping. 1991. The hypocholesterolaemic effect of oat bran, barley and malted barley. Proc. Nutrition Soc. Australia 16: 138.

Jana. P. K. and A. K. Mitra. 1995. Effect of irrigaoin on growth, yield and consumption use efficiency of wheat in Terai soils of North Bengal, India. In: Proc. Agro-ecosystem management, India. P.52-56.

JianMin, L., Eneji, A. E., Liu-Sheng, D., Inanaga, S. and L. ZhaoHu. 2005. Saving irrigation water for winter wheat with phosphorus application in the North China Plain. J. Plant-Nutrition. 28(11): 2001-2010.

Kader, M. A. and F. Begum. 1999. Effect of irrigation and nitrogen on the yield and protein content of wheat. Bangaldesh J. agril. Sci. 26(2): 1-5.

Karczmarczyk, S., Koszanski, Z. and C. Podsiado. 1993. Course of some physiological processes and yield of winter wheat and triticale under the influence of sprinkler irrigation and nitrogen fertilizer application. I. Chlorophyll and carotenoid content in some organs of winter wheat and triticale. Acta Agrobotanica. 46(2): 15-30.

Katiya, R. P. 1980. Developmental changes in LAI and growth parameters in chickpea *(Cicer arietinum* L.). Indian J. Agric. Sci. 50: 684-691.

Kerr, N. J., Delance, R. J. and K. H. M. Siddique. 1992. Early sowing wheat cultivar of suitable maturity increase grain yield of spring wheat in a sort season environment. Aust. J. Expt. Agric. 32(6): 717-723.

Khatkar, D. A. and M. S. Kuhad. 2000. Short term salinity induced changes in two wheat cultivars at different growth stages. Biologia-plantanum 43(4): 624-632.

Knapp, W. R. and K. S. Knapp. 1978. Response of winter wheat to date of sowing and fall fertilizer. Agron. J. 70 (6): 1048-1053.

Kou, C. G., Chen, H. M. and L. H. Ma. 1986. Effect of high temperature on proline content in tomato floral buds and leaves. J. Amer. Soc. Hort. Sci. 11: 734-750.

Kramer, P. J. 1972. Water stress and carbohydrate metabolism. Plant and soil water relationship: A modern synthesis. Tata Mc. Graw-Hill pub.com. Ltd. New Delhi, India. pp. 368-372.

Kumar, R. and S. N. Sharma. 1999. Effect of nitrogen on dry matter and nutrient accumulation pattern in wheat (*Titicum aestivum*) under different dates of sowing. Ind. J. Agron. 44 (4): 738-744.

Kumar, V. and S. K. Agarwal. 1991. Effect of irrigation and nitrogen on the yield of barley (*Hordeum vulgare*) varieties. Indian J. Agron. 36(4): 518-521.

Lal, R. 1984. Management of soil physical properties for soil and water conservation and seed bed preparation in West Africa. In: An overview of upland rice research. IRRI, Los Banos, Laguna Philippines. pp. 383-385.

Lupu, C. 2001. The influence of sowing time on yield and productivity elements in winter wheat in hilly region of Moldavia. Analele Institutului de Cercetari pentru Cereale si Plante Tehnice, Fundulea. 68: 207-214.

Maiti, R. K., L. S. Moreno and E. P.Wesche. 2000. Responses of some crops to various abiotic stress factors and its physiological and biochemical basis of resistance: A review. Agricultural Reviews, Puebla-72820, Mexico. 21(3): 155-167.

Malik, B. S. 1971. Response of barley to soil moisture regimes and nitrogen levels. Indian J. Agron. 16(1): 43-45.

Mandal, B, K., Saha, A., Kunda, T. K. and A. K. Ghorai. 1991. Wheat based intercropping and the mulch on growth and yield. Indian J. Agron. 36: 23-29.

Martin, J. H. and W. H. Leonard. 1967. Principles of Field Crop Production. The McMillan and Co. New York. pp. 786-798.

Mekhni, M. S. and A. Kurich. 1984. Barley, its world status and production condition in Western Asia, N. Africa and neighboring countries. RACHIS. 3: (June).

Miedema, P. 1982. The effects of low temperature on *Zea mays*. Adv. Agron. 35: 93-128.

Milthrope, F. L. and J. Moorby. 1979. An introduction to Crop Physiology. Cambridge University Press, Cambridge. P. 244.

Mostafavi, M. and M. Niknejad. 1983. Variability of yield and other plant characteristics of barley under irrigated and rainfed conditions. Iran Agril. Res. 2: 51-58.

Moula, M. G. 1999. Effect of date of planning and irrigation on the growth and yield of barley. M. Sc. (Ag.) Thesis, Dept. Agron. Bangladesh Agril. Univ., Mymensingh.

Mucci, F., Postiglionc, L. and M. M. R. Lanza. 1985. A study on growth development and yield of wheat (*Titicum duram* Desf. *T. aestivum*) and Lupins (*Lupinus albus* L) under different environmental conditions. Riuista diAgronomia. 19(4): 333-346.

Muleba, N., Hart, T. G. and G. M. Paulsen. 1983. Physiological factors affecting maize (*Zea mays* L.) yields under tropical and temperate conditions. Tropical Agriculture. 60: 3-10.

Murata, Y. 1962. Studies on photosynthesis rice and its significance in crop production. Nogyo Gijutsu ken Kyusho Kokoku Bull Nat. Inst. Agric. Sci. Ser. 9: 1-69.

Naser, H. M. 1996. Response of wheat to irrigation. M. Sc (Ag.) Thesis, Dept. Soil. Sci. Bangladesh Agril. Univ., Mymensingh.

Nowak, L., Chylinska, E. and K. Chmura. 2005. Usefulness of three kinds of nitrogen fertilisers in cultivation of brewing barley on light soil under sprinkling irrigation. Acta Scientiarum Polonorum Formatio Circumiectus. 4(2): 77-83.

O' Leary, G. J., Connor, D. J. and D. H. White. 1985. Effect of sowing time on growth, yield and water use of rainfed wheat in the Wimmera, Vic. Aust. J. Agric. Res. 36(2): 187-196.

Oosterhuis, D. M. and P. M. Cartwright. 1983. Spike differentiation and floret survival in semidwarf spring wheat as affected by water stress and photoperiod. Crop Sci. 23: 711-717.

Oweis, T., Zeidan, H. and A. Taimeh. 1992. Modeling approach for optimizing supplemental irrigation management. Proc. Int. Conf. On Supplemeral Irrigation and Drought water Management. Bari, Italy. 1st Agron. Mediterraneo. Bari.

Pal, S. K., Kaur, J., Thakur, R., Verma, U. N. and M. singh. 1996. Effect of irrigation, seeding date and fertilizer on growth and yields of wheat. Indian J. Agron. 41: 386-389.

Pal, S. K., Verma, U. N., Singh, M. K. and R. Thakur. 1996. Heat unit requirement for phenological development of wheat *(Triticum aestivum* L.) under different levels of irrigation, seedling date and fertilizer. Indian J. Agric. Sci. 66 (7): 397-400.

Pandey, R. K., Saxena, M. C. and V. B. Singh. 1978. Growth analysis of blackgram genotypes. Indian J. Agric. Sci. 48: 466-473.

Parihar, S. S. and R. S. Tripathi. 1990. Yield, water use and nutrients uptake of wheat as influenced by sowing time, irrigation and nitrogen levels. Madras Agric. J. 77 (7-8): 309-316.

Park, J., Roy, H., Hwang, K. and M. S. Yiem. 2001. Effect of water stress induced by polyethylene glycol and root zone temperature on growth and mineral contents of Fuji/M. 26 apple. J. Korean Society for Hort. Sci. 42(4): 435-438.

Patil, E. N., Jawale, S. M. and D. D. Deora. 1996. Effect of irrigation and fertilizer on the productivity of cultivated wheat. Indian J. Agron. 41: 494-495.

Patra, A. K., Tripathy, S. K., Samui, R. C., Panda, P. K. and M. K. Nanda.. 1998. Effect of sowing date, irrigation and spacing on nutrient content and uptake by groundnut. Indian J. agron. 43: 469-463.

Penning de Vires, F. W. T., Witlage, J. M. and D. Kremer. 1979. Rate of respiration and increase in structural dry matter in young wheat, ryegrass and maize plants in relation to temperature, to water stress and to their sugar content. Ann. Bot. 44: 595-609.

Pessarakli, M. M., Morgan, P. V. and J. J. Gilbert. 2005. Dry-matter yield, protein synthesis, starch, and fiber content of barley and wheat plants under two irrigation regimes. J. Plant Nutrition. 28(7): 1227-1241.

Photiades, I. and A. Hadjechristodoulou. 1984. Sowing date, sowing depth, seeed rate and row spacing on wheat and barley under dry land conitions. Field Crop Res. 9(2): 151-162.

Podsiado, C., Koszanski, Z. and I. I. Zbiec. 1999. Response of some spring barley cultivars to irrigation and mineral fertilization. Part II. Canopy architecture and yield structure. Folia Univ. Agric. Stetinensis, Agricultura. (73): 131-137.

Porwal, M. K., Dhakar, L. L., Bhatnagar, G. S. and P. C. Chaplot. 1991. Response of barley (*Hordeum vulgare*) verities to sowing date in Southern Rajasthan. Indian J. Agron. 36(4): 596-597.

Prasad, K. and V. Singh. 1987. Effect of soil moisture regimens and fertilizer on barley. Indian J. Agron. 32: 151-154.

Prasad, U. K., Pandey, R. D., Gupta, P. K. and N. N. sharma. 1986. Effect of irrigation on growth, water requirement, water use efficiency and yield of summer proso millet. Indian J. Agron. 31: 280-284.

Prashad, V .V .S., Pandey, R. K. and M. C. Sexena. 1978. Physiological analysis of yield variation in gram *(Cicer arientinum)* genotypes. Indian J. Plant Physiol. 21: 228-234.

Radford, P. J. 1967. Growth analysis formulae their use and abuse. Crop Sci. 7: 171-175.

Rafiq, M., Hussain, A., Ahmad, A., Basra, S., Shah, M. A. and A. W. Javed. 2005. Effect of irrigation on agronomic traits of wheat (*Triticum aestivum* L.). Int. J. Biol. Biotec. 2(3): 751-759.

Rahman, A. 2004. Effect of irrigation on nitrogen uptake, yield and yield attributes of wheat varieties. A Ph. D. thesis. Department of Botany. University of Rajshahi, Rajshahi.

Rahman, M. M. 1997. Effect of different levels of irrigation and nitrogen on the yield and yield contributing characters of foxtail millet. M. Sc. (Ag.) thesis, Dept. Agron., Bangladesh Agril. Univ., Mymensingh.

Rahman, M. S., Sarker, A. M., Islam, M. A. and N. K. Paul. 2001. Effect of soil moisture on grain yield of Wheat (*Triticum aestivum* L.) cultivars. Environment and Ecology. 19 (2) : 304-308.

Ram, B., Pahuja, S. S. and D. Singh. 2004. Effect of sowing time and row spacing on the yield attributes and yield of wheat variety C-306. Haryana J. Agron. 20(1/2): 105-106.

Rana, R. K., Sharma, S. C., Malik, R. S. and N. Kumer. 1988. Effect of moisture stress on yield performance in barley (*Hordeum vulgare*). Indian J. Agril. Sci. 58(7): 543-545.

Randhawa, A. S., Dhiollion, S. S. and D. Singh. 1981. Productivity of wheat varieties, as influenced by the time of sowing. J. Res. Punjab Agril. Univ. 18(3): 227-233.

Randhawa, A. S., Jolly, R. S. and S. S. Dhillon. 1977. Response of wheat and barley to nitrogen and different dates of sowing. Crop Imp.. 4(1): 89-94.

Rao, P. and S. K. Agrawal. 1984. Response of barley (*Hordeum vulgare*) to soil moisture conservation practices and supplemental irrigation. Indian J. Agron. 29(4): 495-500.

Rizza, F., Badeck, F. W., Cattivelli, L., Lidestri, O., Fonzo, N. di. and A. M. Stanca. 2004. Use of a water stress index to identify barley genotypes adapted to rainfed and irrigated conditions. Crop Sci. 44(6): 2127-2137.

Ryu, Y. H., Lee, C. G. and Y. W. Ha. 1992. The effects of sowing date on grain filling and related traits in winter barley. Korean J. Crop Sci. 37(1): 93-103.

Sabbah, S. M., Hamady, M. A. E. and H. M. Abdel-Kader. 1996. Seasonal changes in leaf proline concentration of some citrus cultivars and rootstocks in relation to air temperature stress. Alexandria J. Agric. Res. 41(3): 233-245.

Saifuzzaman, M., Begum, S. N., Begum, F., and W. Sultana. 1996. Effect of sowing dates on growth stages of short and long duration wheat (*Triticum aestivum* L.) Bangladesh J. Sci. and Ind. Res. 31(l): 46-52.

Saini A. D. and V. K. Dadhwal. 1986. Heat unit requirement during the period of grain growth in wheat and its application for adjusting sowing dates in different region. Indian J. Agric. 56 (4): 447-452.

Samuel, S. R., Deshmukh, P. S., Sairam, R. K. and S. R. Krshwaha. 2000. Influence of benzyl adenine application on yield and yield components in wheat genotypes under normal and late planting condition. Indian J. of Plant Physiology. 5(3): 240-243.

Sarkar, M. A. R., Islam, M. A. and A. K. M. Zakaria. 1996. Performance of modern cultivars of wheat under different dates of planting. Bangladesh J. Agril. Sci. 23(1): 81-86.

Sarkar, S., Singh, S. K., Singh, S. R. and A. P. Singh. 1999. Influence of initial profile water status and nitrogen doses on yield and evapotranspiration rate of dryland barley. J. Indian Soc. Soil Sci. 47 (1): 22-28.

Sengupta, J. C., Sen, N. K. and D. K. Mukherjee. 1948. Effect of sowing time on growth and development of Jute. Indian J. Agric. Sci. 8: 129-136.

Shaheb, M. R. 2004. Effect of time of irrigation and split application of nitrogen on the growth and yield of wheat. M. Sc. (Ag.) thesis, Dept. Agron. Bangladesh Agril. Univ., Mymensingh.

Sharma, V. and D. R. Thakur. 1996. Effect of irrigation and seed rate on two row malt barley (*Hordeum distichum*) in Kullu valley of H. P. Himachal J. Agric. Res. 22(1/2): 5-9.

Shrivastava, R. B., Singh, V. P. and D. Singh. 1998. Component characters of grain yield and harvest index in wheat. Indian J. Agric. Res. 2(2): 65-74.

Sing, T. and G. S. Dhaliwal. 2000. Performance of wheat varieties under late sowing conditions in south western region of Punjab. J. Res. Punjab Agril. Univ. 37 (3-4): 181-183.

Singh, A. K. and G. L. Jain. 2000. Effect of sowing time, irrigation and nitrogen on grain yield and quality of durum wheat (*Triticum durum*). Indian J. Agril. Sci. 70(8): 532-533.

Singh, J and A. L. Patel. 1996. Water status, gaseous exchange, proline accumulation and yield of wheat in response to water stress. Ann. Biol. Ludhiana. 12(1): 77-81.

Singh, J., Malik, A. S. and J. Singh. 1989. Response of late sown wheat, barley and lentil to irrigation levels. Haryana J. Agron. 5(1): 52-56.

Singh, K. N., Misra, B. N. and M. Prasad. 1975. Effect of time of sowing, seed rate and seed soaking on grain yield of rainfed barley. Indian J. Agron. 20(1): 26-28.

Singh, P. V. P. and K. Anureet. 2001. Effect of different levels of nitrogen and irrigation on growth and yield of malt barley var. Alfa-93. Crop Res. Hisar. 21(3): 261-264.

Singh, S., Dhindwal, A. S., Sheoran, P. and M. S. Bhattoo. 2005. Dry matter accumulation, partitioning and translocation in late-sown wheat (*Triticum aestivum*) under different irrigation levels. Ann. Agri-Bio-Res.10(2): 151-154.

Singh, S., Sheoran, P., Dhindwal, A. S. and M. S. Bhattoo. 2005. Influence of irrigation levels on productivity, water use and crop coefficient of late sown wheat (*Triticum aestivum*). Environment Ecol. 23(4): 801-805.

Singh, T. and V. Kumar. 1976. Water use efficiency of barley as affected by supplemental irrigation. Indian J. Agric. Sci. 46(12): 575-579.

Spaldon, E. and J. Malnarova. 1991. Agro-ecological aspects of sowing date and sowing rates on different winter barley cultivars. Rostlinna Vyroba. 37(9-10): 707-714.

Steoponkus, P. L., Shahan, K. W. and J. M. Cutler. 1982. Osmotic adjustment in rice. In: Drought resistance in crops with emphasis on rice. IRRI, Philippines. pp. 181-194.

Stewart, G. R. and, J. A. Lee. 1974. The role of proline accumulation in halophytes. Planta, 120: 279-289.

Tan, B. H. and G. M. Halloran. 1982. Variation and correlation of proline accumulation in spring wheat cultivars. Crop Sci. 22: 465-469.

Tanaka, A. 1983. Physiological aspects of productivity. In: Potential productivity of field crops under different environments. IRRI. Los Banos, Philippines. pp. 61-99.

Tanaka, A., Navasero, S. A., Garcia, C. V., Paraoe, F. T. and Z. E. Romire. 1964. Growth habit of the rice plant in the tropics and its effect on the nitrogen responses. IRRI. Philippines. Tech. Bull. 3: 73.

Thomas, F. S. 1995. Growth and yield response of barley and chickpea to water stress under three environments in southeast Queensland. III. Water use efficiency, transpiration efficiency and soil evaporation. Aust. J. Agric. Res. 46 (1): 49-60.

Tomar, P. S. and O. P. Mathur. 1966. Effect of time of sowing on yield of different varieties of barley under water scarcity condition in Rajasthan. Indian J. Agron. 11(2): 173-177.

Torofder, G. S., Hossain, M. A. and M. M. Alam. 1993. Effect of tillage and irrigation on the yield of barley. Bangladesh J. Agric. Sci. 20: 61-67.

Troll, W. and J. Lindsley. 1955. A photometric method for the determination of proline. J. Biol. Chem. 215: 655-660.

Uppal, H. S., Cheema, S. S. and S. Singh. 1988. Response of barley varieties to different levels of irrigation and nitrogen. Crop Imp. 15: 142-145.

Van Eijnatten, C. L. M. 1963. A study of the development of two varieties of maize at Ibadan, Nigeria, J. Agric. Sci. Camb. 61: 65-72.

Verma, O. P. S. 1993. Response of pearl millet hybrids to irrigation applied different physiological stages of crop growth. Indian J. Agron. 38: 215-217.

Wahab, K. and K. N. Singh. 1983. Effect of irrigation applied at different critical growth stages on growth characters and yield of hulled and hull-less barley. Indian J. Agron. 28(4): 412-417.

Waldren, R. P. and I. D. Teare. 1974. Free proline accumulation in drought stressed plant under laboratory conditions. Plant and Soil. 40: 689-692.

Watson, D. J. 1947. Comparative physiological studies on growth of species and varieties and between years. Ann. Bot. 11: 41-76.

Watson, D. J. 1952. The physiological basis of variation in yield. Adv. Agron. 4: 1401-1452.

Watson, D. J. 1958. The dependence of net assimilation rate on leaf area index. Ann. Bot. 22: 37-54.

Williams, W. A., Loomis, R. S., Duncan, W. G., Dovart, A. and A. F. Nunez. 1968. Canopy architecture at various population densities and the growth and grain yield of corn. Crop Sci. 8: 303-308.

Willlson, J. H. and R. D. Ellis. 1981. Supply of dry matter from stem and grain rice growth under dry land conditions. Int. Rice. Res. Newsl. 6(1): 22-24.

Witham, F. H., Blaydes, D. F. and R. M. Devlin.1986. Chlorophyll absorption spectrum and quantitative determination. Excercises in plant physiology. pp. 128-131.

Wojciechowska, R., Leja, M., Mareczek, A. and S. Rozek. 2000. Metabolism of amino acids in white cabbage leaves as a response to post harvest conditions. Sodininkyste ir Darzininkyste. Poland. 19(3): 396-401.

Wojtasik, D. 2004. Effect of sprinkling irrigation and mineral fertilisation on malt and fodder barley cultivated on light soil. Part II. Yield and quality of grain. Acta Scientiarum Polonorum Agricultura. 3(2): 131-142.

WonYul, C., YongWoong, K. and P. JongHwan. 1997. Grain yield and physiological responses of water stress at reproductive stage in barley. Korean J. Crop Sci. 42(3): 263-269.

Yadav, B. S., Verma, B. L. and A. Ramdeo. 1995. Irrigation requirement of wheat under shallow water table condition. J. Indian Soc. Sci. 43: 259-261.

Yoshida, S. and J. H. Cook. 1971. Growth performance of on improved rice variety in the tropics. Int. Rice comm. Newsl. 20: 1-2.

Zende, N. B., Sethi, H. N., Karunakar, A. P. and D. J. Jiotode. 2005. Effect of sowing time and fertility levels on growth and yield of durum wheat genotypes. Res. Crops. 6(2): 190-191.

Zhao, I. Q., Lu, M. Q. and G. Li. 1985. Influence of sowing dates on the growth and development of barley cv. Zhepi. Zhejiang Agril. Sci. 5: 217-221.

Appendix III. Results of physical and chemical analysis of the soil samples taken from the experimental plot before planting

Characteristics	Analytical data
Textural Class	Sandy Loam
Organic matter (%)	1.1
Soil pH	6.1
total N%	0.06
P	5.91 µg/g soil
S	21.44 ,,
B	0.39 ,,
Mn	9.4 ,,
Zn	3.0 ,,
Na	0.12 me/100 g soil
Ca	1.8 ,,
Mg	0.30 ,,
K	0.15 ,,

Source: The physical and chemical analysis of soil samples were done by SRDI, Dinajpur.

Appendix IV. Monthly temperature (^{0}C), relative humidity (%), total rainfall (mm), sunshine hour and ET (mm) during the growing period from November 2005 to December 2006

Month	Temperature (^{0}C)		Relative humidity (%)			Rainfall (mm)	Sunshine hours	ET (mm)
	Maximum	Minimum	Maximum	Minimum	Mean			
November, 2005	28.50	14.15	98.50	39.15	80.00	00.00	9.50	2.10
December, 2005	24.95	12.21	91.00	32.67	61.83	00.00	9.90	2.80
January 2006	22.77	11.05	90.0	31.00	60.50	00.00	5.39	2.78
February 2006	27.27	15.23	85.33	27.67	56.50	00.00	5.48	2.68
March 2006	32.97	17.71	85.8	17.67	59.33	00.00	8.84	6.20

Source: Meteorological sub station, Rajbati, Dinajpur.