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REVIEW ARTICLE

ADVANCEMENT OF AGRONOMIC PRACTICES IN MALTING BARLEY-A REVIEW

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ABSTRACT

Various agronomic practices have profound effect on productivity and malt quality of barley (*Hordeum vulgare* L.). In this paper, discussed the influence of varieties, tillage methods and time of sowing, dose and time of nitrogen application, irrigation scheduling on the growth, productivity and malt quality of barley. This article helps to the researcher to plan the further studies to enhance the productivity of malt barley to strengthen the malting industry.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a hardy crop which is grown throughout the temperate and tropical regions of the world. In production, it ranks fourth after rice, maize and wheat and is usually used as food for human beings and feed for animals and poultry. It is also a valuable input for industries for extracting malt to be utilized in brewing, distillation, baby foods, cocoa malt drinks and ayurvedic medicines. Barley is preferred over other cereals for malting purpose because its glumes and hulls are firmly cemented to the kernel, which remain attached to the grain after threshing. Hull protects the coleoptile from damage during processing, as coleoptile grows and elongates under the hull. Hull acts as a filter for separation of soluble materials. Kernel texture of steeped barley is also somewhat firmer than that of wheat and rye. Processing of barley grain for malting largely depends upon several factors viz ; protein content of the grain, time taken for germination, uniformity in grain size, husk content, 1000 kernel weight and kernel plumpness etc. High protein content in grain is undesirable, because malt extract is inversely related to grain protein content (Verma *et al*., 2003). Different management variables influence the productivity, protein content and other quality parameters which have direct bearing on the malt quality of barley grain. The agronomic practices for malt grade barley are altogether different from its grain crop. Amongst these, time and methods of sowing, tillage, irrigation, nitrogen levels and stage of nitrogen application greatly affect the productivity and malt quality of barley.

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Varietal performance

Two types of barley varieties viz. 2-row and 6-row are generally cultivated. The grains of two row variety are plump, uniform in size and possess other desirable characteristics like protein content, high diastatic power and α-amylase activity for malt purposes whereas, in case of six row varieties kernel plumpness and uniformity in size is lacking. Generally 2- row varieties are preferred over 6- row for malt purposes (Singh *et al*., 1974). Plump kernels, containing high proportion of starch and low to medium protein are preferred for preparation of good quality malt. Two row varieties with 1000- grain weight more than 45 g, kernel protein content between 9 to 11 per cent, malt extract 80 per cent and diastatic power from 80 to 120^{0}L and 6- row varieties with 1000-grain weight more than 42 g, kernel protein content varying from 9 to 11.5 per cent, malt extract 78 per cent and diastatic power 90- 130^{0}L have been reported to be suitable for malt purposes (Verma *et al*., 2004). Variety PL 172 (6-row) had significantly higher grain hardiness, husk content and protein content than that in VJM 201 (2-row), while, the later variety had significantly higher kernel plumpness, test weight and starch content (Singh 2005). Sardana and Zhang (2005b) from China reported the superiority of variety 92-11 over Xiumei-3 for grain yield and malt quality parameters such as low β-glucan and high β-amylase activity, which they attributed to genetic constitutions of two varieties. In another 3 year study, DWR 28 (2-row malt barley variety) found to be superior over check BCU 73 in yield as well as in malt quality parameters (Anonymous 2004). Genotypes VJM-201 (2-row) gave significant higher grain yield, than all other varieties at Ludhiana (Punjab) (Anonymous 2003).

Karwasra *et al*., (1998) from Rohtak reported that significantly higher number of ear bearing shoots, grain yield ear^{-1}, test weight and grain yield of barley were recorded in variety BG 25, which was significantly higher than C 138, BH 75 and BH 87 on sandy loam soil. However, Therrein *et al*., (1994) observed large differences among cultivars for malt extract and significant negative correlation between diastatic power (DP) and malt extract (ME) at W. Manitoba. Darwinkel (1991) reported that Hasso (6-row) produced a higher number of grains per ear but few ears and moderate 1000- grain weight than Marinka or Flamenco (2-row). Higher number of ears but low grain number and very high 1000-grain weight was recorded with cv. Marinka. Hamachi and Yoshida (1990) observed that husk thickness of cv. Nirasaki Nijo, Nishino Gold and Yoshika 16 was less than those of Amagi Niji and Kimiyataka. The weight and content of husk of variety Nirasaki Nijo and Nishino Gold was 1.93 g/1000 grains and 6.1%, respectively and in Amagi Niji and Kimiyataka, it was 2.57-2.65 g/1000 grains and 7.8-7.9 %, respectively. Verma and Singh (1989a) at Agra found that variety Jyoti (6-row) accumulated maximum total dry matter (35.3 g 0.057 m^{-2} at harvest mainly through spikes) on sandy loam soil that was significantly superior to DL 102 and DL 150 (2-row) and at par with Cliper and HBL 102 (2-row). The latter two varieties accumulated dry matter more through culms and shoot height, respectively.

Methods of sowing

Growth, yield components and yield

Tillage influences water intake storage and evapotranspiration from the soil by the plant roots and also the microbial activity. The barley (*Hordeum, vulgare* L.) sown on flat beds(FB) gave significantly more grain yield (7.2 – 14.5%) over furrow irrigated raised bed system (FIRBS) at Durgapura, Hisar and Varanasi (Anonymous 2006). The barley sown on FIRBS gave significantly more grain yield (2.5%) over (FB) at Varanasi, respectively (Anonymous 2005). The barley sown on FB gave 12.8% more grain yield over FIRBS, at Hisar (Anonymous 2004). According to Cantero-Martinez *et al* (2003) tillage systems in most cases have limited impact on grain yield of barley. At Ludhiana found that grain yield of barley in ZT and CT was statistically at par, but grains weight and ear length were slightly higher in ZT as compared to CT (Anonymous 2006). However, Dhima *et al* (2006) reported that barley grain yield was not affected by tillage in first year, whereas in second year, grain yield with minimum tillage (MT) was 14% lower compared to reduced tillage (RT) and CT. William (2005) reported that there was no difference in the plant stand between no-tillage (NT) and CT, but grain yield was reduced by 5% in NT in part because of less water in the seed zone compared with CT during early plant development. Disruption of capillary continuity with CT appeared to restrict upward movement of water, resulting in greater retention of water in the seed zone. Cantero-Martinez *et al* (2003) reported that ZT achieved slightly, but not significantly, greater growth, yield contributing characters and yields than the tilled treatments. On an average, there were 4 and 13% greater yield than MT and 9 and 14% greater yield than CT. The use of conservation tillage in the Northeast of Ebro Valley improved the yield of barley. Lopez *et al*. (1996) and William *et al*. (1999) reported that NT spring sowing can produce equal or higher grain yields than CT and can provide environmental and potential soil quality benefits in dry land farming areas. Barley yielded more with greater WUE in NT than CT. Legere *et al*. (1997) found that barley biomass m^{-2}, head density m^{-2}, 1000- grain weight and yields produced under NT were comparable to mould board plough in the autumn, followed by spring secondary tillage. Lopez and Arrue (1997) reported that NT proved inferior as the poor early growth of barley with NT resulted in a 53% reduction in grain yield compared to CT. This unfavourable crop response to NT was due to lower soil moisture at the time of sowing and during early growth. Ellis *et al*. (1997) observed that direct drilling (ZT) reduced growth of seminal roots of young plants and early shoot growth. Generally, tillage promotes soil mineral N content. Therefore, under semiarid conditions, for equal rates of N applied, yields were favoured in CT in wet years and in NT during dry years (Cantero-Martinez *et al*., 1995a). Grant *et al*. (1991) compared RT with CT in a rotation of four crops (wheat, oats, barley, potatoes), all grown in each year. RT was successful in cereals throughout the trials. Ciha (1982) reported more test weight, 100-kernel weight and per cent plump kernels and statistically similar plant height and grain yields of spring barley under CT, conservation and NT. Ellis *et al*., (1997) reported slightly more number of fertile ears m^{-2}, grains ear^{-1} and equal grain yield in direct-drilled, deep tillage and ploughing treatments. Elliott *et al*. (1997) and Brown (1979) reported that under favorable conditions, yields under NT were equal to or higher than that grown by CT. Hakimi and Kachru (1976) reported that tillage system using the field cultivator and discing usually resulted in yield advantage over mould board ploughing, and NT. The NT resulted in the lowest yield due to competition from weeds. In addition, increasing the depth of cultivation (5, 15 and 25 cm) decreased the yield under all tillage treatments. Ellis *et al*. (1997) reported that mould board ploughing, deep and shallow tined cultivation followed by conventional seed-bed preparation, and direct drilling in winter wheat and spring barley were comparable on a calcareous clay soil. At sowing the moisture content, bulk density and resistance to penetration in the surface layer of soil of uncultivated land were all greater than in soil that had been ploughed or cultivated deeply. Below 10 cm, moisture content was less and root penetration was greater in the uncultivated soil.

Grain and malt quality

Sowing on FB resulted in slightly higher hectoliter weight and protein percentage compared to FIRBS of barley (Anonymous 2005a). However, FIRBS resulted in slightly higher 1000-grain weight compared to FB of barley (Anonymous 2004). Legere *et al*. (1997) found that barley 1000-grain weight under NT was comparable to those in a tillage system that includes mould board ploough in the autumn, followed by spring secondary tillage. Ciha (1982) observed that test weight, 100-kernel weight and per cent plump kernels were significantly increased with NT (standing stubble) when compared to CT. Feed and malting cultivars were equally well adapted to NT as and CT (Ullrich and Muir 1986).

Dates of sowing

Growth, yield components and yield

Optimum time of sowing of barely has been investigated by several workers. Mehta and Beniwal (2008) reported lower incidence of covered smut of barley as the sowing was delayed i.e. (8th to 19th to 30th November). At several location Agra, Durgapura, Hisar, Karnal, Ludhiana and Sriganganagar, late sowing (10-16 December) resulted in significantly lower grain yield of malt barley, ear head, grains ear-1 and 1000-grain weight as compared to 12-18 November sowing (Anonymous 2006). Late sowing of barley (15 December) gave lower yield, ear head, plant height and number of grains ear-1 , 1000-grain weight as compared to 15 November sown crop at Vijapur in Gujarat (Patel *et al.,* 2004). Barr (2002) reported that sowing too early will reduce grain protein, but will increase the potential for disease problems and lodging. Not only yield but quality was also affected by planting dates. Date of sowing, an important cultural practice, can be easily manipulated for realizing potential yield of crop, as growing season establishes the yield potential of a crop (Tisdale *et al.,* 2002). There was significant reduction in grain and biological yield and other yield attributes of barley with delay in sowing beyond 1st week of November at Durgapura (Anonymous 1996). Conry (1995) from Ireland reported that sowing date had a pronounced effect on grain yield of spring malting barley in all three years. Sowing in January or February gave significantly higher yields than March and April sowing. The April-sown barley gave significantly lower yield than earlier-sown crops. Significant reduction in grain yield of malt barley was observed with delay in planting from 4 May to 22 May (Weston *et al.,* 1993). Similar observations were reported by Zubriski *et al*., (1970). At Banswara, Rajasthan (India), Porwal *et al.* (1991) reported that 31 October sown crop gave less grain yield and ear head, and 1000-grain weight as compare to 15 November sown crop. Lauer and Partridge (1990) also reported significant reduction in grain yield of malt barley as the planting was delayed from 15 April up to 15 May. Relaying of barley in cotton produced significantly higher grain yield as compared with barley sown after the harvest of cotton. Increase in grain yield in the early crop was attributed primarily to significantly more fertile tillers plant-1, grains spike-1 and a comparatively better plant population and 1000-seed weight (Noworolik and Pecio 1990 and Conry and Hegarty 1992). Early planting increased tiller number but also increased tiller dieback. Conversely, delayed planting of spring barley reduced tiller numbers per plant but increased the proportion of tillers that survive (Lauer and Partridge 1990).Harris (1984) reported reduction in plant population m-2 due to delay in sowing. Number of grains spike-1 increased significantly when barley was sown as a relay crop than that recorded for barley sown after the harvest the cotton crop. Kirby (1969) and Noworolik (1989) reported similar effects of late sowing. Rao and Wattal (1986) reported inconsistent trend in ear bearing tillers because of sowing dates that delayed planting around the second week of December reduced the growing season and adversely affected the yield. Kirby and Ellis (1980) reported that delay in sowing reduced the number of leaves stem^{-1} and number of tillers because of the reduced growth period of crop. Contrary to above studies, Aggarwal *et al*. (1971) reported that highest grain yield was obtained when crop was sown on 20 November as compared to earlier sowing. Anand (1958) reported that there was no effect of the time of sowing (27 October to 16 November) on the final height of the plants, but the relative increase showed that the plants sown later grew much faster.

Grain and malt quality

It is desired to maximize grain yield and kernel plumpness while retaining grain protein content in optimum range. Often management strategies which maximize grain yield do not optimize grain protein and malting quality. Delayed sowing (10-16 December) caused significant reduction in mean 1000 grains weight as compared to 12-18 November (normal) sowing at Agra, Durgapura, Hisar, Karnal, Ludhiana and Sriganganagar (Anonymous 2006). Weston *et al* (1993) observed significant reduction in malt extract, kernel plumpness, grain protein content, but increase in soluble wort protein, diastatic power, α-amylase activity under dry land farming though the difference were non significant as planting was delayed from 4 to 22 May. Lauer and Partridge (1990) observed reduction in kernel weight by 14% and kernel plumpness by 2% when planting was delayed from 20 April to 19 May. They further observed that grain protein content was not affected by different planting dates under irrigated condition and even tended to decrease it slightly. Similar results were reported by Beard (1961). Fedak and Mack (1977) reported an inverse relation between planting date and β-glucan level and increase in protein content and diastatic power with delay in sowing. Similarly, Zubriski *et al*., (1970) reported the reduction of kernel plumpness by 9.8% and increase in protein content by 0.7% in mid May over the end April planted crop.

Nitrogen

Nitrogen (N) is an essential element for plant growth which is required in large amount as compared to major elements. N fertilization increases cell size, elongation and division that determine growth and development parameters. N is vital for growth and development of crop and it is an indispensable component of plant protoplasm and plays an important role in chlorophyll synthesis. N is the main constituent of amino acids, which are precursor of proteins. Increase N supply to a crop results in increased protein content in grain (Briggs 1978).

Doses

Growth, yield components and yield

N is essential to achieve optimum productivity of malting barley. However, heavy doses of N may cause lodging. A number of workers have reported an increase in grain yield and yield attributing characters of barley with increasing dose of N. The application of N (30, 60, and 90 kg ha^{-1}) significantly increased average grain yield in both tillage methods i.e., FIRBS and FB sowing at Durgapura and Varanasi (Anonymous 2006). Sandhu (2006) reported that grain yield of barley increased significantly with application of N up to 78 kgha^{-1} as a result of better plant height, effective tillers, leaf area index, dry matter accumulation (DMA), grains ear^{-1}, 1000-grain weight and N uptake as compared to lower doses. Singh and Singh (2005) at Varanasi reported significant increase in ears m^{-2}, grains $ears^{-1}$, 1000 grain weight, grain and straw yield with increased doses of N from 20 to 80 kg ha^{-1}. Similar results were reported by Fathi *et al*. (1997). Patel *et al*. (2004) reported a significant increase in grain yield with the application of N from 60 kg to 100 kg ha^{-1}. However, the increase in grain yield with 100 kg over 80 kg was non-significant. Pertrie *et al*. (2002) observed marked increase in grain yield with the application of 55.5 kg N ha^{-1} compared to control. Cantero-Martinez *et al*. (2003) reported that medium and high levels of added N increased the yield of barley to about 30% above zero N. Grain number increased with N fertilization. Dhukea *et al*. (1998), Saini and Thakur (1999) and Paramjit *et al*. (2001) at Hisar reported that significantly increased growth, yield attributes and yield of malt barley with the highest level of 90 kgNha^{-1}. However, Subhash *et al*. (1998) also reported that improvement in yield attributes with N application. Application of 60 kg N ha^{-1} significantly increased the yield attributes over 30 kg N ha^{-1} but was at par with 90 kg N. Karwasra *et al*. (1998) reported significant increase in the yield attributes and grain yield with application of 20 and 40 kg N ha^{-1} over the control while a reduction in grain yield was observed at 60 kg N ha^{-1}. Fathi *et al*. (1997) reported that the optimum rates of N for DMA and spike emergence were 80 kg ha^{-1} (Prokhorov *et al*., 1998). Allam (1997) reported that yield components increased with increasing N rate. Charles *et al*. (1997) observed that application of 67 kg N ha^{-1} increased plant height, which was at par with 135 kg N ha^{-1}. Conry (1995) from south-east of Ireland reported that 125 kg N ha^{-1} significantly increased grain yield in all three experiments and 150 kg N ha^{-1} gave a further significant increase in yield in two of the experiments. Therefore, under semiarid conditions, for equal rates of N applied, yields were favoured in tilled plots in wet years and in NT during dry ones (Cantero-Martinez *et al*., 1995a). Cantero-Martinez *et al*. (1995) and Cooper *et al*. (1987) reported that in the winter cereal areas of grain yields range between 10 and 50 q ha^{-1} with 60-150 kg of N applied per hectare. Yield increase from N application and recovery of applied N in barley were lower under ZT than CT when urea was applied by broadcasting. Awasthi and Bhan (1994) reported that barley LAI increased with increasing levels of N from 0 to 60 kg N ha^{-1}. Singh *et al*. (1993) found that ear-bearing tillers, ear length and grains ear^{-1} were significantly higher at 80 kg N ha^{-1} compared to lower doses. However, when urea was banded, the yield increase from N application and N recovery from the fertilizer N were similar in ZT and CT (Malhi and Nyborg 1992). Carter (1993) found that grain yield of different barley genotypes increased with increase in N rate from 0 to 60 kg N ha^{-1}. Gonzalez *et al*. (1992) at Toledo, Spain reported that increasing N rate from 0 to 160 kg N ha^{-1} increased grain yield and similar increase in straw yield and harvest index were observed. Mishra *et al*. (1991) found that the highest grain yield obtained with 120 kg N ha^{-1}, was at par with 80 kg N ha^{-1}. Increasing levels of N fertilization promoted yield by stimulating shoot and root growth (Weston *et al*., 1993). NUE decreased under low soil moisture conditions and decreased with increasing levels of available N (Grant *et al*., 1991). Birch and Long (1990) reported significant increase in total number of tillers m^{-2} and grain yield of barley with increase in N rates (0-200 kg ha^{-1}). However, total tiller number and fertile tiller percentage was reduced with increasing N rates. Similar trends were evident in total dry matter yield at maturity. However, total tiller number increased with the highest level of N (Kozlowska-Ptaszynska 1990). Francakova (1985) and Ondruch (1991) found that 1000-grain weight increased with increasing levels of N. Verma and Singh (1989) reported that grain yield increased significantly with increase in N doses from 0 to 60 kg N ha^{-1}. Paterson and Potts (1985) found that increasing N increased yield but decreased grain weight in direct drilled barley. El-latif *et al*. (1984) observed that tillers per plant, ears per plant, grain per ear, ear length, grain weight per ear and 1000-grain weight increased with the increase in N. Hooda and Kalra (1981) found that DMA at different growth stages increased with the increase in N levels reported similar findings by Misra *et al*. (1982). Brunetti *et al*. (1982) found that application N from 0-91 kg per ha resulted in increased DMA, crop growth rate, photosynthetic efficiency, RGR, LAI, NAR and leaf area duration. LAI reached a maximum at late jointing and CGR and photosynthetic efficiency before heading and at the milk stage. A decrease in leaf area, growth and dry weight of N deficient barley seedling was also reported by Natr and Apel (1983). N application also increased plant height and number of tillers per plant (El-latif *et al*., 1982, 1984, Hassan *et al*., 1984 and Ray *et al*., 1989). However, reported increase in plant height by N application. An increase in dry matter production, crop growth rate and relative growth rate with increase in application of N from 0-90 kg ha^{-1} was reported by Brunetti *et al*. (1982) and Hooda and Kalra (1981). Under rainfed conditions, Aggarwal and De (1977) reported an increase in barley grain yield over control with 30 and 60 kg N ha^{-1} on sandy loam soil. Singh *et al*. (1978) reported that grain yield increased significantly with increase in N rate from 0 to 40 kg N ha^{-1}.

Grain and malt quality

N is a vital component of nucleon proteins and nucleic acids which carry the heredity matrix control and direct the synthesis of protein and enzymes. Therefore, a proper supply of N to plants helps them to accumulate protein in their seeds and to increase their weight. N fertilizers are effective in increasing yield and quality of grain. However, N usually increased the yield and quality of seeds in crops. Nevertheless, if N supply exceeds that of P and K, the growing quality of seeds may decline. N fertilizer application though increases yield of malting barley, it may also increase grain protein above desirable levels. Malting barley grain protein should be between 11.5 – 13.5% on 12.0% grain moisture content. The application of 30, 60, and 90 kg N ha^{-1} produced grain protein of 12.7, 13.1 and 13.9% and 1000 grain weight of 46.0 g, 47.9 g and 47.6 g, respectively (Anonymous 2006). Singh and Singh (2005) observed a higher protein content at 80 kg N ha^{-1}as compared with 20, 40, and 60 kg N ha^{-1}. Similar results were reported by Petrie *et al*. (2002). Thompson *et al*. (2004) reported that additions of N fertilizer may cause lodging and increase grain protein above desirable levels. Xu *et al*. (2004) found that protein content of grains increased while the starch content decreased with increasing N rates from 0 to 225 kg ha^{-1}. Verma *et al*. (2003) reported that increase in the N levels increased the diastatic power, hot water extract and decreased the wort filtration rate but was within the permissible limits even at 90 kg N ha^{-1}. Ruiter (1999) reported that increasing N application (0, 50, 100 and 150 kg N ha^{-1}) increased wort β-glucan and wort N but lowered the N- index. Fathi *et al*. (1997) reported an increase in the grain protein content up to highest rate of added N (0 to 105 kg N ha^{-1}). Conry (1995) observed that increasing increments of fertilizer N (100, 125, 150 kg ha^{-1}) significantly increased grain N of spring malting barley in all nine experiments. Weston *et al* (1993) reported that nitrogen (0-200 kg ha^{-1}) significantly increased grain protein, soluble wort N, diastatic power and α-amylase activity and decreased kernel weight, kernel plumpness and fine grind malt extract. Grant *et al*., *l* (1991) observed that at low rates of applied N, any increase in protein accumulation is diluted by increases in plant growth. Increasing rates of N increased protein accumulation as the response to plant growth rate decreased.

Clancy *et al*. (1991) reported that 90 kg N ha^{-1} reduced percentage of plump kernels by 4% but did not affect test weight compared to 45 kg N ha^{-1}. Higher N level increased both total grain protein and soluble malt protein by 7%. Higher N also significantly increased α-amylase by 25 and diastatic power by 15%, while malt extract was unaffected. Lauer and Patridge (1990) revealed that N significantly increased spring malting barley grain protein from 102 g to 121 g kg^{-1} as N rates increased from 0 to 202 kg ha^{-1}, however, there was slight decrease in kernel plumpness. Similarly, Birch and Long (1990) observed an increase in grain protein with the increase in N rates from 0 to 200 kg ha^{-1} on alluvial clay loam soil. Verma and Singh (1989) revealed that uptake of N through grain and straw and removal of N by whole plant were appreciably increased with every increase in the rate of N from 0 to 60 kg ha^{-1}. Smith and Gyles (1988) observed an increase in the accumulation of fertilizer N in barley grain from 0.36 to 2.0 g N m^{-2} when N application at sowing was increased from 2.8 to 9.1 g N m^{-2}. Stark and Brown (1987) reported that malting barley grain protein was unacceptably high (>120 g ha^{-1}) when soil plus fertilizer N was >210 kg ha^{-1} under irrigated condition. Paterson and Potts (1985) found that increasing N increased grain protein yield but decreased grain weight. Similar results were reported by Kandera and Zat'ko (1979). Application of 90 kg N ha^{-1} increased the protein content by 1.5 per cent and decreased the starch content by 1.4 per cent. Singh *et al*., (1978) revealed that increase in N supply from 0 to 40 kg N ha^{-1} has non-significant effect on protein content in grain, diastatic power and extract percentage value. Nitrogen fertilization of malting barley, however must be carefully managed because malting quality characteristic, such as grain protein, percentage of plump kernels, α-amylase activity, diastatic power and malt extract often become unacceptable as fertilization is increased for maximum yield (Zubriski *et al*., 1970).

Time of application

Growth, yield components and yield

N is known to be vital for growth and development of crop. Reasonable grain yield can be obtained only if plant makes sufficient vegetative growth due to availability of sufficient N at appropriate growth stage. Elmobarak *et al*. (2007) application of N at 86 kg N ha^{-1} in a two equal splits at sowing and at 30 DAS gave the higher grain yield. Roy and Singh (2006) reported that three splits applications of N gave highest number of ears, ear weight, ear length, number of grains, test weight and significantly higher grain yield and straw yield as compared to one or two splits. Singh *et al*. *l* (2006) reported highest plant height and effective tillers with three equal splits (at sowing, at 1st irrigation and at jointing) and dry matter and spike length, spike weight, number of grains, grain weight and straw yield with two equal splits (at sowing and at 1st irrigation) as compare to single application of N (at sowing). Singh and Singh (2005) reported two splits of N (1/3 at sowing and 2/3 at first irrigation) resulted in higher values of yield components viz; ears, grains ear^{-1}, 1000 grain weight and significantly higher grain yield and uptake of N over three splits (1/3 at sowing, 1/3 after first irrigation and 1/3 after second irrigation). At Ludhiana, maximum plant height and effective tillers with three equal splits i.e. at sowing, at 1st irrigation and at jointing while maximum dry matter and spike length, spike weight, grain weight and straw yield (53.1q ha^{-1}) with two equal splits (at sowing and at 1st irrigation) were recorded as compared to single application of nitrogen i.e. at sowing (Singh 2005).

Sardana and Zhang (2005b) studied the effect of time of N application on growth and yield of 2 row varieties in China. They tried three N-application schedules i.e. full at tillering, full at booting stage and half at tillering + half at booting stage and found that application of full dose at tillering produced maximum grain yield, which was significantly higher than its application at boot stage. N application in 2 equal splits at tillering and boot stage also produced significantly higher grain yield than its application at boot stage alone. Thus it appeared that application of sufficient amount of N at tillering is essential to realize higher grain yield. Munir and Shatanawi (2001) reported that application of N in three splits increased the spike number, 1000 grain weight, total biological yield and increase in grain yield significantly. Petrie *et al*. (2002) observed non conspicuous differences in grain yield of barley due to application of N in spring or fall. Similarly, Singh *et al*. (1974) also reported non-significant difference in grain yield of 2-row barley with single and split application of N. However, significant increase in grain yield of malt barley was observed when N was applied in two split doses as 1/3 at sowing + 2/3 with 1st irrigation over all other N application schedules viz. 1/3rd at sowing + 1/3rd with 1st irrigation + 1/3rd with 2nd irrigation or 1/2 at sowing + 1/2 with 1st irrigation (Anonymous 2001). Darwinkel (1983) reported that period between stem elongation and anthesis is the period when N demand by the crop is the highest due to rapid leaf expansion, stem growth and ear development. Foote and Batchelder (1953) reported yield increase in barley when N was applied at seeding time or when the plants were 6 inch tall over applying the N before plowing.

Grain and malt quality

Application of full dose of N at early growth stages may not be able to meet the nutritional needs of crop up to maturity whereas its application at later stages may increase the grain protein content, thus lowering malt quality. Effect of time of N application on malt quality has been investigated by some workers. Chen *et al*. (2006) conducted a field experiment on a clay loam at China and revealed that grain β- amylase activity and protein concentration were significantly higher in treatments either where all nitrogen fertilizer was applied at booting stage only or equally applied at two leaf stage and booting stage as compared to the treatment where whole of nitrogen was top dressed at two leaf stage only. On the other hand, grain weight and malt extract decreased with increased nitrogen application at booting stage only. Singh *et al*. (2006) reported highest grain hardiness, husk content, protein content, α-amylase activity, diastatic power and lowest test weight, kernel plumpness weight, starch content, malt recovery and malt yield with application of N in three splits as compared to one or two splits application of N. Roy and Singh (2006) reported that three splits of N gave significantly highest protein content and statistically at par starch as compare to one split. Sardana and Zhang (2005a) found that application of N at tillering stage produced the highest kernel weight and lowest β-glucan content as well as kernel protein content, whereas application full dose at boot stage or half at tillering + half at boot stage lowered the malt quality. Singh and Singh (2005) reported that three splits of N application resulted in significantly higher protein content than two splits of N. Singh (2005) conducted an experiment at Ludhiana on sandy loam soil and observed highest grain hardiness, husk content, protein content, α-amylase activity, diastatic power and lowest test weight, kernel plumpness weight, starch content, malt recovery and malt yield with application of N in three splits ($1/3^{rd}$ at sowing + $1/3^{rd}$ at first irrigation and $1/3^{rd}$ at jointing) as compared to one (whole at sowing) or two split ($1/2^{nd}$ at sowing and $1/2^{nd}$ at first irrigation) application of nitrogen. Ruiter and Brooking (1994) showed that quality could be enhanced by post- anthesis N application without excessive grain N accumulation provided the pre-anthesis management ensured near-optimal crop growth. Bulman and Smith (1993) observed significantly higher grain protein content with application of N in split doses than a single application of equivalent dose of N at seeding in case of spring barley. Singh *et al*., (1974) reported that application of full dose of N at the time of sowing keeps the N content and all other malting parameters within the desirable limit. They further reported that split application though improved the grain yield to some extent but detrimental to malting quality.

Irrigation scheduling

Growth, yield components and yield

Water is required by plants for the manufacture of carbohydrates, to maintain hydration of protoplasm and as a vehicle for the transport of foods and mineral elements. Yield components that are influenced by water stress depend mainly on the timing of the stress in relation to the development of plant organs that influence the economic yield, Time and numbers of irrigations have been reported to influence growth and yield of barley. Elmobarak *et al*. (2007) revealed that irrigation after every 10 days gave the highest plant height, dry weight and grain yield. Mmmnouie *et al*. (2006) studied with five irrigation levels (0, 25, 50, 75 and 100% crop water requirements) and reported that highest number of spikes, number of grains, 1000-grain weight and grain yield under 100% crop water requirement compared to lower levels. Ruiter *et al*. (2006) concluded that full drought was likely to affect both grain number and grain size development, while the fully irrigated treatment provided optimum conditions for both processes. Sandhu (2006) revealed that application of three irrigations with first irrigation at 6 WAS increased growth characters along with a significant increase in the number of effective tillers, grains ear^{-1} and 1000-grain weight, grain and straw yields as compared to one or two irrigation treatments. The grain yield in the FIRBS and on flat bed sowing methods with application of irrigations first irrigation applied 30 DAS was significantly higher than the first irrigation applied 45 DAS and subsequent irrigations applied at 60, and 90 DAS (Anonymous 2005). Cantero-Martinez *et al*. (2003) examined yield and water-use efficiency (WUE) of barley under three levels of N fertilization (zero, medium and high) and three soil management systems viz; NT, RT or MT and CT. The use of conservation tillage in the Ebro Valley improved the yield of barley and its WUE. Paramjit *et al*. (2001) from Hisar reported that application of two irrigations at (tillering and flag leaf stage) produced significantly higher grain yield than single irrigation either at tillering or at flag leaf stage. They reported that application of two irrigations significantly increased the plant height, number of tillers, DMA, LAI, yield and yield attributes as compared to other treatments of irrigation. Singh (2000) also at Ludhiana observed non significant impact of first irrigation applied at 14, 21 and 28 DAS on crop growth, yield attributes and grain yield of wheat, irrespective of tillage levels, while the interaction effect of time of first irrigation and tillage level revealed significant improvement in grain yield, when first irrigation to NT sown wheat crop was applied at 14 DAS instead of 21 and 28 DAS as compared to CT. Interestingly, the delay of first irrigation up to 28 DAS caused significant reduction in grain yield in NT sown wheat as compared to CT.

Ruiter (1999) studied the effect of five levels of soil moisture viz., fully irrigated, rainfed, early drought, late drought and full drought and reported that maximum grain yield was obtained under fully irrigated treatment (no plant moisture stress) and it was 16 q higher than full drought treatment. Lopez and Arrue (1997) compared the effects of CT (mouldboard plough) and RT (chisel plough) on winter barley (*Hordeum, vulgare* L.) WUE under both continuous cropping and cereal-fallow rotation. Similar crop response between the CT and RT fallowing in the cereal-fallow rotation proved to be an inefficient practice for improving soil water storage and subsequent crop yield, under both conventional and conservation management. Singh (1995) recorded 25 per cent saving of post sowing irrigation water in bed planting system of wheat establishment over border method of irrigation under conventional flat sowing. Cantero-Martinez *et al*. (1995) and Cooper *et al*. (1987) reported that barley yielded more in NT than the tilled treatments and greater WUE_y and WUE_b in the NT occurred because of better WU in the pre-anthesis period. Other authors have reported the same effect under such conditions (Lopez-Bellido *et al*., 1996). ZT was associated with greater WUE and better soil water conservation than MT or CT (McAndrew *et al*., 1994). A number of factors have been shown to influence the WUE of barley. It was improved by addition of fertilizer N, P and K, or rotation of barley with

Vicia sativa (Andersen *et al*., 1992 and Harris 1994). Conservation tillage considered to be as an alternative to CT to slow evaporation losses and to increase water storage and water use by crops (Fereres *et al*., 1993). Bergner and Teichmann (1993) found the largest yield reductions if water stress occurred during jointing and pre-anthesis. Harvest index and yield were shown to decrease with increased water deficit (Salam *et al*., 1991). Yadav (1991) at Kota reported that six irrigations at IW: CPE of 0.8 gave higher consumptive use as compared to three and four irrigations given at 0.4 and 0.6 IW: CPE, respectively. Higher WUE obtained with four *irrigations* as compared to six irrigations. At Sri Ganganagar, WUE increased with increasing irrigation frequency (Rathore *et al*., 1991).

Barley for malting purpose requires grain that is low in total protein and high in starch, Malting quality is adversely affected by water stress during grain filing (Smith and Gyles 1988). They further reported that accumulation of N in the plant was higher under rainfed conditions compared with irrigated conditions. Cantero-Martinez *et al*. (1995) and Cooper *et al*. (1987) discussed the high potential to improve WUE of winter cereals in areas with rainfall below 500 mm as in the Mediterranean region. Other workers have reported similar effect under such conditions (Lopez-Bellido *et al*., 1996). Prasad and Singh (1987) conducted a study at Agra and reported that there was significant increase in grain yield with 75% available soil moisture (ASM) as compared to 50% ASM . The greatest yield reduction was observed when stress was applied at heading and maintained for at least 14 days. Tbileh (1986) found that CGR, LAI, plant height and tiller number increased with increasing soil moisture. The early drought influenced processes involved in determining grain number (Fischer, 1985), while the effect of late drought was anticipated to influence grain expansion alone (Aspinall, 1965). Rao and Agarwal (1984) and Navolotskii and Lyashok (1984) observed that effective tillers, grains ear^{-1} and 1000-grain weight increased with increasing number of irrigations. Wahab and Singh (1983) found that irrigation had significant favourable influence on effective tillers, mean flag leaf area and DMA in barley. A similar response was found for the number of ears per plant (Morgan and Riggs 1981). Number of grains per main-shoot ear was reduced by drought stress applied at heading but not when the stress was applied from 32 days after heading until harvest. Grain size was significantly reduced by all treatments. Warsi and Lal (1979) reported higher yields of barley with three irrigations applied at tillering (30 to 35 DAS), jointing (60-69 days) and milk stage (90 days). They assessed tillering as the most sensitive stage for irrigation. Singh *et al*., *l* (1978) observed that one irrigation applied either at active tillering stage (30-35 DAS) or at leaf stage (60-65 DAS) gave significantly higher grain yield of barley over no irrigation though the differences between these two treatments were non significant. Grain yield obtained with irrigation at milk stage was at par with that of no irrigation (Singh *et al*., 1978a).

Mkamanga and Singh (1976) reported that two irrigations at active tillering stage and the flag leaf increased grain yields of barley by 4.2 q ha^{-1}over one irrigation at tillering stage. Garg and Saraswat (1975) reported that in the absence of any winter shower, three irrigations at early tillering, flowering and milking stages were needed for getting higher yield of barley. Restricting irrigation at any of these three stages reduced the yield significantly. Warsi *et al*., (1973) observed that three irrigations applied at tillering, jointing and milk stages produced consistently higher grain yield. They further observed that among the combination of two irrigations at tillering and jointing or jointing and milk stages gave 2.1 and 4.0 q ha^{-1} lower yield than at tillering and milk stages. Withholding irrigation at tillering caused irreparable loss to the crop which could not be overcome by subsequent irrigations. A timely application of single irrigation at tillering was as effective as two irrigations at jointing and milk stage. Sharma and Singh (1973) observed that there was a consistent increase in the nitrogen and phosphorus uptake with the increase in the available soil moisture. Singh (1977) stated that N content at flowering and protein content in grain decreased with increasing levels of irrigation but, total uptake of N increased by increasing the number of irrigations. There was a rapid fall in NO_3 concentration of shoot in waterlogged barley (Drew and Sisworo 1979). N uptake in the plant increased significantly. Pandey and Mukherji (1966) observed that two post-sowing irrigations, one at 30 days after germination and other at pre-flowering stage significantly increased grain yield of barley over one post-sowing irrigation either at 30 days after germination or at pre-flowering stage. Schreiber and Stanberry (1965) reported that low moisture tensions during pollination increased yield and during internode elongation increased number of spikes plant^{-1} and kernels spike^{-1}.

Grain and malt quality

Mmmnouie *et al*. (2006) reported lowest proline content under 100 % crop water requirement compared to lower levels when irrigations were was applied at 0, 25, 50, 75, and 100% crop water requirement. Sandhu (2006) revealed that significantly higher malt recovery and maximum malt yield were recorded with irrigation applied at under 6 WAS + BS + SDS as a result of maximum kernel plumpness, minimum protein content, maximum starch and malt quality parameter viz; α-amylase activity and diastatic power as compared to one or two irrigation treatments. Paynter and Young (2004) at Western Australia demonstrated improvements in grain plumpness, grain quality and malting quality with irrigation during the early stages of growth. Verma *et al*. (2003) studied the effect of three irrigation levels, viz. one irrigation (30 DAS), two irrigations (30 and 60 DAS) and three irrigations (30, 60 and 90 DAS) on malt quality and reported that more number of irrigations significantly increased the diastatic power, malt yield, kolbach index and malt homogeneity. Ruiter (1999) studied the effect of five levels of soil moisture regime (fully irrigated, rainfed, early drought, late drought and full drought) and reported best grain quality of malt barley from fully irrigated plots. Grain quality (N concentration) was influenced indirectly by the soil water stress. This effect occurred through a reduced assimilatory capacity of the crops as demonstrated by the reduction in grain size in later sown crops. Coles *et al*. (1991) reported that avoidance of moisture deficits by timely irrigation gave the best malting quality. Water shortages before anthesis influenced malt quality less than droughts at later stage of growth. As moisture level increased, protein concentration decreased while protein yield and total N uptake increased (Grant *et al*., 1991). Lauer and Partridge (1990) observed that grain protein content was not affected when crop was grown under minimum water stress. Similar results were reported by Beard (1961). Smith and Gyles (1988) observed that accumulation of fertilizer N in the plant was higher under rainfed conditions compared with the under irrigated conditions. Morgan and Riggs (1981) studied the effects on grain and malt characters, of drought stress applied at different stages of grain development and ripening in spring barley. Grain size was significantly reduced by drought treatments. Raw-grain characters known to be correlated with malt extract were found to be affected by the treatments. Grain N content, barley extract viscosity and the rate of sedimentation of barley flour in ethanol were all increased by drought stress, with degree of response varying with the length and timing of the period of drought. Malt extracts were reduced by drought stress whether this was applied early or late in grain development. Singh *et al*. (1978) reported that increased supply of irrigation reduced the protein content and diastatic power content in grain to a certain extent. However differences in diastatic power and potential extract values were non significant. Singh *et al*. (1978a) also reported that the increased frequency of irrigation reduced the protein content in grain of barley. Thompson *et al*. (1976) reported that irrigation improved quality of barley grain in respect of malt extract. Increasing the number of irrigations above two gave only marginal improvements in quality. Cheema *et al*. (1969) reported higher protein per cent in grain of barley grown under unirrigated conditions as compared to irrigated conditions.

Nutrient uptake

Effect of application of nutrients

Roy and Singh (2006) reported that application of highest dose of 90 kg N ha^{-1} gave significant highest uptake of N, P and K as compared to lower doses. Sandhu (2006) reported significantly higher uptake of N with the application of 78 kg N ha^{-1} as compared to lower doses. Singh and Singh (2005) reported that application of N doses in two splits (1/3 at sowing and 2/3 at first irrigation) gave significant highest uptake of N as compared to its application at sowing only. Application of 80 kg N ha^{-1} gave significantly highest uptake as compared to lower doses. Late sowing of barley (15 December) recorded minimum uptake of N and P, whereas timely sowing (15 November) recorded maximum N and P uptake. Application of 100 kg N ha^{-1} and 40 kg P ha^{-1} recorded maximum uptake as compared to lower doses of N and P (Patel *et al*., 2004). Kumawat *et al*. (1999) found that grain N content increased by application of 60 kg N and with 30 kg S ha^{-1} compared to lower doses. According to Turk and Al-Jamali (1998), higher N and P uptake were recorded with increasing N and P levels. Ruiter *et al.* (1998) and Peterson (1996) reported that N fertilizer significantly increased N uptake. According to Patel *et al.* (1997) application of 60 kg N + 40 kg P + 30 kg K + Zn 1.5 per cent gave the highest nutrient uptake. Grant *et al*. (1996) found that low soil N and P content were correlated with yield increase in response to N and P applications. Awashti and Bhan (1994) reported that N uptake increased significantly up to 40 kg N, P uptake increased with 20 kg N and K uptake increased up to 50 kg N. NUE was highest with 40 kg N ha^{-1}. Carreck and Christian (1992) reported that N application linearly increased grain N concentration, 25 kg N ha^{-1} gave 0.1 per cent increase. Verma and Singh (1989) reported significant increase in N content and uptake in grain and straw increased significantly with increase in N doses from 0 to 60 kg ha^{-1}, respectively. Verma and Singh (1989) found that N uptake increased with increasing N rates (0-60 kg). Smith and Gyles (1988) observed increase in the accumulation of fertilizer N in barley grain from 0.36 to 2.0 g N m^{-2} when N application at sowing was increased from 2.8 to 9.1 g N m^{-2}. Kumar *et al* (1987) observed that total uptake of N increased up to 80 kg N ha^{-1}. Prasad and Singh (1987) observed that significantly higher uptake N, P and K by grain and N, P and K by straw with application of fertilizer from (0 to 60 kg N ha^{-1} + 40 kg P_2O_5 ha^{-1}). Plant N concentration increased with N supply (Leigh and Johnston 1985). Straw N concentrations increased with N fertilization (Kucey 1987 and Bulman and Smith 1993) and are higher in drier environments (Grant *et al*., 1991). There was an increase in N and P content (El-Latif *et al*., 1982) and their uptake (Mishra *et al*., 1982a) in grain and straw of barley with the application of N fertilizer. Singh *et al*. (1978) reported that N uptake in grain and straw increased significantly with increase in N rates from 0 to 40 kg ha^{-1}.

Effect of irrigation

Soil moisture is one of the most important factors that affects nutrient uptake by influencing as it is involved in the solubilisation and transportation of nutrient elements from soil to plant roots and then to the entire plant system. According to Philips (1966) under low soil moisture supply, a vapour gap may be formed round the root by their decreased turgor pressure under water stress. Such a gap if present would reduce the availability of the nutrients to the root probably due to lesser contact between roots and water particles causing drastic reduction in dry matter production. Straw N concentrations are higher in drier environments (Grant *et al*., 1991). Sandhu (2006) revealed that the percent N content decreased while N uptake increased significantly with the application of three irrigations when first irrigation was applied at 6 WAS as compared to one or two irrigations. Prasad and Singh (1987) observed that significantly higher uptake of N, P and K by barley grain and of N, P and K by straw with increasing available soil moisture from 25 to 75%. There was a rapid fall in NO_3 concentration of shoot in waterlogged barley (Drew and Sisworo 1979). Singh *et al*., (1978) reported that N uptake in grain and straw increased significantly with increase from one to three irrigations. Singh (1977) stated that plant N content at flowering and protein content in grain at maturity decreased with increasing levels of irrigation but total uptake of N increased by increasing the number of irrigations. Sharma and Singh (1973) observed that there was a consistent increase in the N and P uptake with the increase in the available soil moisture. Similar were the findings of Bajpai and Mertia (1977) and Singh (1973, 1978). Shortriya *et al*. (1974) reported that N in plants increased as a result of increased DMA with the increase in moisture level.

Interaction Effects

In a field experiment conducted on sandy loam soil at Ludhiana, Singh (2008) observed that three splits (half nitrogen was applied before pre sowing irrigation, $1/4^{th}$ at tillering stage and $1/4^{th}$ at boot stage) with 75 kg N ha^{-1} gave significantly higher malt yield, which was statistically at par with three and two splits (half of nitrogen before pre sowing irrigation and half at maximum tillering stage) with 90 kg N ha^{-1}. The FIRBS sowing along with 60 kg N ha^{-1} gave malt barley grain yield, which was statistically at par with the application of 90 kg N ha^{-1} in FB sowing (Anonymous 2006). Roy and Singh (2006) conducted an experiment at Hissar on sandy loam soil observed that application of 90 kg N ha^{-1} in three splits i.e. 1/3rd at sowing + 1/3rd at first irrigation and 1/3rd at flowering to malt barley resulted in obtaining the maximum grain yield. However, the yield obtained with a single dose of 90 kg N ha^{-1} at sowing was statistically at par with 60 kg N ha^{-1} with two splits (half at sowing and half at first irrigation) and 30 kg N ha^{-1} in three splits. The barley sown on grain yield in the FIRBS and FB with the application of irrigations at 30, 60, and 90 DAS gave the significantly higher grain yield than the irrigations applied at 45, 60, and 90 DAS (Anonymous 2005). Verma *et al*. (2003) studied the effect of three irrigation levels (30, 30 and 60 and 30, 60 and 90 DAS) and three N levels (30, 60 and 90 kg N ha^{-1}) on different malt quality parameters of barley. They reported that interaction effects of irrigation × N were highly significant for diastatic power, which increased with irrigation and N application. The interaction effect was also significant for malt yield, malt friability and malt homogeneity. Cantero-Martinez *et al*. (2003) conducted study to examine yield and WUE of barley under three levels of N fertilization (zero, medium and high) and three soil management systems viz; NT, MT or RT and CT. N increased the yield by about 30 per cent over zero N. Generally, tillage promotes soil mineral N content. Therefore, under semiarid conditions, for equal rates of N applied, yields is favoured in tilled plots in wet years and in NT during dry ones (Cantero-Martinez *et al*., 1995a).

Ruiter (1999) reported that the best quality was obtained from treatment that minimized the impact of water shortage during grain filling. The interaction of irrigation and N treatment was significant for grain nitrogen. Grant *et al*. (1991) reported a negative correlation of protein concentration with soil moisture and N level, which showed greater protein concentration with 40 kg N ha^{-1} at low moisture than with 200 kg N ha^{-1} at high moisture levels. Lauer and Partridge (1990) found no significant interaction between planting date and N rate for yield and yield components, except for tiller survival. Villiers *et al*. (1988) compared the effect of single application of 50 kg N ha^{-1} at sowing and split application of 150 kg N ha^{-1} at different growth stages. The N application in splits increased total N, soluble N, free amino N, α - amylase and □-amylase activity**.** Kandera and Zat'ko (1980) identified that average grain yield without fertilizer was 6.20 t ha^{-1} and increased to a maximum of 7.13 t ha^{-1} by 60 kg ha^{-1} applied as a single dressing whereas further increase to 90 kg ha^{-1} decreased grain yield to 6.99 t ha^{-1} and there was no differences between application of nitrogen in one or two dressing. Singh *et al*. (1978) revealed that N × irrigation interaction was significant and 40 kg N with one irrigation gave higher yield with 20 kg N and two irrigations. Increased supply of both, N and irrigation significantly augmented the N uptake in the plant. Kumar (1977) reported significant interaction between soil moisture and N levels and indicated response of greater magnitude to irrigation under higher levels of N. Khurana and Guliani (1977) reported significant interaction between soil moisture and N levels and indicated response of greater magnitude to irrigation under higher levels of N.

Lodging

Lodging can reduce yield by reducing the size and number of grains. Lodging alters plant growth and development. It affects flowering, reduces photosynthetic capabilities of the plant due to self shading of leaves and panicles, thus affecting carbohydrate assimilation. Severe lodging interferes with the transport of nutrients and moisture from the soil and thus with food storage in the developing kernels. Incomplete filling results in small kernels, lowered carbohydrate content, and lower test weight. Lodging often contributes to uneven maturity, high moisture content and loss of grain quality due to sprouting and possible moulding. Lodging is reported to be the most limiting factor in attaining high yields from increased N fertilization, especially during humid conditions. The effects of lodging on yield losses depend on the growth stage of the plant, the weather conditions prevailing after lodging has taken place, and the severity of lodging. A reduction in the number of ears per plant is the yield component most affected by lodging in the mid-to late-vegetative stage (Harry 2006). Thompson *et al*., (2004) reported that additions of N fertilizer is essential for increasing yield, but nitrogen fertilizer additions may cause lodging and increase grain protein above desirable levels. Barr (2002) reported that sowing too early will reduce grain protein, but will increase the potential for disease problems and lodging. Tripathi (1999) noticed that bed sown wheat gave significantly higher grain yield than conventional sowing by reducing lodging score and increasing yield attributes. Baethgen *et al*., (1995) reported that high rate of N application at early growing season produced high tiller populations with tall, weak stems leading to lodging at later growth stage. Lodging resulted in incomplete spike emergence and reduced tiller survival and consequently, reduced grain weights (Bridger *et al*., 1995). Mabuchi (1993) reported that lodging in barley increased α-amylase and this led to lower amount of malt that could be extracted from the barley grain during brewing. The greatest lodging–induced reductions in potential grain yield occur when crops are lodged flat at anthesis or early grain filling stage. Such type of lodging has been reported to reduce yields of barley by 28-65 percent. Jedal and Helm (1991) reported that yield losses were significant with lodging at heading and soft-dough stages with average yield losses of 1.3 ± 0.5 and 1.2 ± 0.7 t ha^{-1}, respectively. However kernel weight reduced and percent thin kernel increased by lodging at the soft-dough stage. Lodging in small grain cereals reduces yield and quality. Lodging can cause yield losses directly by reducing photosynthesis and indirectly by promoting conditions conductive to disease development and increased harvest losses (Stoskopf 1985). Among the small grain cereals, barley is the second most susceptible to lodging after oat (*Avena sativa* L.) Lodging near the time of heading is the most detrimental for barley and yields can be decreased by as much as 38%. The lodging occurring during grain filling caused more severe reductions in grain yield and 1000-grain weight (Sisler and Olson (1951). Weibel and Pendleton (1964) observed smaller yield losses when lodging occurred at later stage of development. Artificial lodging at ear emergence, milk, soft dough and hard dough stages reduced yield by 31, 25, 20 and

12 percent, respectively. Day and Dickson (1958) observed that artificial 45° lodging of spring barley grown as a winter annual under flood irrigation had little effect on barley and malt quality, but lodging at 90° caused increases in barley N, malt N, wort N, diastatic power, α-amylase and decreased barley and malt kernel weights and malt extract percentage, but had very little effect on the ratio of wort N to malt N or of β-amylase to α-amylase.

Malt losses

Holopainen *et al*. (2005) reported that during malting, the steelier barley samples produced less root mass, but showed higher respiration losses and higher activities of starch-hydrolyzing enzymes. Malts made from steelier barley had a less friable structure, with more urea-soluble D hordein and more free amino N and soluble protein. The reason for these differences may lie in the structure or localization of the hordeins as well as the possible effects of endosperm packing on water uptake and movement of enzymes. Trust *et al*., (1995) reported that dry matter losses ranged from 8 to 19 per cent, α-amylase activity determined by colorimetric assay ranged from 25 to 183 U/g, with two cultivars having activity levels similar to that of commercial barley malt. Reduction in pasting viscosity was significantly correlated with a-amylase activity. Sorghum diastatic power (SDU) was positively correlated to cx-amylase activity in cultivars with SDU values >30. P-Amylase activity was low, ranging from 11 to 41 U/g. The jar malting method yielded malts with lower dry matter losses and low levels of a-amylase and P-amylase activity, except for one cultivar. To obtain the highest levels of enzyme activity with the lowest dry matter losses, malting conditions need to be controlled and optimized. Sumathi *et al*. (1995) reported that malting losses ranged between 12 to 27 percent over a period of 48 hours in all legumes. Germination beyond 48 hours resulted in considerably higher malting losses without much effect on viscosity. Smart *et al*. (1993) found that as the seed moisture content (SMC) increased, the malting losses in barley increased. In buckwheat a similar trend was observed with 45% SMC was found to have the highest malting losses. This can be explained by the following: (i) a higher steeping loss was observed determined with increased SMC. (ii) a higher rootlet length was observed with increased SMC. Since rootlets are removed during malt cleaning, malts with longer rootlets will result in higher malting losses. In general, malting losses of barley are recorded between 6.5% and 10.5%. When these limits are applied to malting buckwheat, the malting loss of B45 (10.74%) is at the upper limit of this range. Lower malting losses were determined in 35% (7.43%) SMC and 45% SMC (7.89%), respectively. Palmer *et al*. (1989) reported malting losses of 15-20% in sorghum compared to 7% in barley. Dry matter losses were significantly correlated to respiration loss, root and shoot loss, x-amylase activity, diastatic power, and reduction in paste viscosity. Respiration losses of malted sorghum were higher than losses due to root and shoot growth. Morgan and Riggs (1981) reported that malting loss increased, germinative energy reduced and wort filtration time increased by late stress. Lawrence *et al*. (1964) reported that the malting losses associated with malting process can be divided into two groups: uncontrolled and controlled losses. The uncontrolled losses are those over which the maltster has no control. One of these losses was during steeping or soaking of kernels in water prior to germination step, with the resulting extraction of soluble materials from the grain and their subsequent removal when the water is drained from the steeped grain. The steeping losses normally amount to about 1%. There was another loss of weight over which maltster has no control. The controllable losses occur during the germination process. As the grain begins to grow, it respires and liberates carbon dioxide (respiration loss) and amounts to 5-8% of the weight of the barley put into process. In addition, as the seed grows it puts out rootlets, which are removed in the kilning and cleaning process of malting and are lost. The rootlets loss from 3-5% of the weight of barley occurs in process. Novellie (1962) reported that respiration losses correlated negatively with test weight and starch content, and positively with x-amylase activity.

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