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Effects of Nitrogen Fertilizer Rates on Growth, Yield Components and Yield of Food Barley (*Hordeum vulgare* L.): A Review

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Abstract

Barley is an important food crop in the highlands of different countries. In Ethiopia barley is grown mainly as a low input staple food crop in the higher altitudes, on steep slopes, eroded lands, or in moisture stress areas. Barley is the major cereal crop grown by subsistence farmers in the highlands mainly under rainfed conditions with minimum or no external inputs. Barley is produced mainly for human consumption and is one of the most important staple food crops. However, its productivity is constrained by a number of problems. Among these inadequate uses of N fertilizer the most important ones. The amount of nitrogen that a barley crop needs to maximize yield and quality will depend on the seasonal conditions, soil type, and rotational history of the soil as well as the potential yield of the crop. The rate of uptake and partition of N is largely determined by supply and demand during various stages of plant growth. Soil N supply, for example, must be high at tillering, stem elongation, booting, heading, and grain filling requiring a greater amount of the development and growth of its reproductive organs and for an enhanced and high accumulation of proteins in the kernel. Nitrogen is needed for the early tiller development of barley to set up the crop for high yield potential. Spilt N application had little effect on yield but decreased lodging and spike population with increased grain weight. Increased grain yield with increased in nitrogen level. However, increasing N fertility beyond a certain limit induced lodging and ultimately decreased grain yield and its components.

Keywords: Barley; Grain; Nitrogen fertilizer; Yield

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Introduction

Background and Justification

Barley (*Hordeum Vulgare*), is a cereal plant that belongs to the grass family Poaceae and it is an edible grain. There are 32 species with in Hordeum genus, all with basic chromosome number of x=7, and other species have diploid (2n=2x=14) chromosomes. They also tetraploid and hexaploid *Hordeum* species (2n=4x=28), (2n=6x=42) respectively [1].

Cultivated barley comes in two varieties, distinguished by the number of rows of flowers on its flower spike. Six-row barley has its spike notched on opposite sides, with three spikelets at each notch, each containing a small individual flower, or floret, that develops a kernel. Two-row barley has central florets that produce kernels and lateral florets that are normally sterile. Whereas six-row barley has higher protein content and is more suited for animal feed, two-row barley has higher sugar content and is thus more commonly used for malt production [2].

Currently, in a global scale barley, producing continent include Russia (16.9 ton/ha), France (11.2 ton/ha), Germany (9.6 ton/ha), Australia (9.3 ton/ha), Spain (9.1 ton/ha) while the world average yield per hectare accounts about (29.5). In addition to this data, FAOSTAT [3] reported five leading countries in barley production in a global scale ranking in descending order like Canada accounting for 35 ton/ha, Ukraine 29.6 ton/ha, Turkey 26.9 ton/ha Australia 22.4 ton/ha and Russian Federation accounts 21.6 ton/ha. Ethiopia is one of the major producers of barley in Sub-Saharan Africa and the second-largest producer in Africa next to Morocco, accounting for about 26 percent of the total barley production in the continent [4]. In 2017/18, about 3.5 million smallholder farmers grew barley on more than 0.95 million Meher hectares of land and produce 2.053 million tons.

Barley with its long history of cultivation it's deeply rooted in the consumption habit of the population for utilized in more diverse forms than any other cereals. Its grain used as human food in the form of bread, dehulled and roasted barley grain, porridge, soup, and for malting purposes [5]. According to Grando and Macepherson [6], barley straw is a good source of animal feed, especially during the dry season and also useful material for thatching roofs of houses and uses as beddings. Despite the huge importance of barley as food and malt, in its productivity is quite low due to poor soil fertility. Particularly deficiency of nitrogen and phosphorous is the main factor that severely reduces the yield of barley [7].

Nitrogen is one of the major plant nutrients were the satisfactory level of grain and foliage production on vertisol depends on its adequate supply. Although nitrogen requirements of crop met through the addition of nitrogen fertilizer, it is an expensive input and these reflect its low consumption in Ethiopia highlands [8]. Nitrogen plays a vital role in all living tissue of the plant. No other elements have such an effect on promoting vigorous plant growth. Abundant of protein tends to increase the size of the leaves accordingly, to bring about an increase in carbohydrate synthesis [9]. Nitrogen plays a vital role in increasing the yield of the crop. The application of proper amount of nitrogen is key to obtain better crop of barely. High nitrogen supply favors the conversion of carbohydrate into protein which in turn promotes the formation of protoplast. Careful monitoring of fertilizer application, especially nitrogen is effective in preventing the lodging. Timing of nitrogen application is particularly important in this context. Dividing the nitrogen into two or three splits and applying as needed by crop plant helps to reduce lodging [10]. Nitrogen stimulates tillering, may be due to its effect on cytokine synthesis and barely reacts to early N by producing more tillers per plant and by exhibiting a higher percentage survival of tillers [9]. The finding of Biruk and Demelash [11], reported that the number of fertile tillers highly significantly affected by the rates of nitrogen. Heading of barley with increased N rate might be attributed to application of N rate promoted vigorous vegetative growth and development of the plants possibly due to synchrony of the time of the need of the plant for uptake of the nutrient and availability of the nutrient in the soil [11].

More nitrogen applied treatments delayed in maturity might be due to extended vegetative growth instead of reproductive growth. Nitrogen is one of the major plant nutrients were the satisfactory level of grain and foliage production on vertisol depend on its adequate supply. Although nitrogen requirements of crop met through the addition of nitrogen fertilizer, it is an expensive input and these reflect its low consumption in Ethiopia highlands [8]. Nitrogen plays a vital role in all living tissue of the plant. No other elements have such an effect on promoting vigorous plant growth. Abundant protein tends to increase the size of the leaves accordingly, to bring about an increase in carbohydrate synthesis [8].

Nitrogen stimulates tillering, may be due to its effect on cytokine synthesis and barely reacts to early N by producing more tillers per plant and by exhibiting a higher percentage survival of tillers [9]. Heading of barley with increased N rate might be attributed to application of N rate promoted vigorous vegetative growth and development of the plants possibly due to synchrony of the time of the need of the plant for uptake of the nutrient and availability of the nutrient in the soil [11].

The yield attributes and quality of food barley seed is therefore, dependent on appropriate dose of nitrogen. Sustaining soil and soil fertility in intensive cropping systems for higher yields and better quality can be achieved through optimum levels of fertilizer application. Thus, information on fertility status of soils and crop response to different soil fertility management is very crucial to come up with profitable and sustainable crop production. Besides this, the optimum dose of nitrogen depends on the climate and soil of the location as well as variety used [12].

Nitrogen is a key nutrient input for achieving a higher yield of barley. Barley is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization [13]. The most important role of nitrogen in the plant is its presence in the structure of the protein and nucleic acids, which are the most important building and information substances from which the living material or protoplasm of every cell is made. Nitrogen increased plant height, spike length, number of the tiller, and this increase is led to much greater production of dry matter and grain yield [14].

Objective

To review the effect of nitrogen fertilizer rates on growth, yield components, and yield of food barley.

Literature Review

Origin and Genetic Diversity of Barley

Barley (*Hordeum vulgar L.*) was first domesticated about 10,000 years ago from its wild relative, *H. vulgare* ssp *spontaneum*, in the area of the Middle East known as the Fertile Crescent. *H. vulgare* ssp. *spontaneum* still grows in the Middle East and adjacent regions of North Africa, in both natural and disturbed habitats, such as abandoned fields and roadsides, an area of relatively abundant water in Western Asia, and near the Nile river of north east Africa and center of origin in Abyssinia and south-eastern Asia. Wild barley (*H. vulgare* ssp. *spontaneum*) ranges from North Africa and Crete in the west, to Tibet in the east [15]. The genus *Hordeum* has centres of diversity in central and south western Asia, western North America, southern South America, and in the Mediterranean [2]. *Hordeum* species occur in a wide range of habitats. The majority of the wild perennial species grow in moist environments whereas the annual species are mostly restricted to open habitats and disturbed areas. Many species have adapted to extreme environments and many have tolerance to cold and saline conditions [2].

Botanical Description of Barley

Barley (*Hordeum vulgarel.*) is a member of Poaceae, family of an annual monocotyledonous cereal. It belonging to the tribe Triticeae, and is evolutionarily closely related to two other small grain cereal species, wheat, and rye. The Tritceae tribe is a temperate plant group containing several economically important cereal and forage as well as about 350 wild species. The genus *Hordeum* is unusual among the Tritceae as it contains both annual species such as *H. vulgare* and *H. marinum* and perennial species such as *H. bulbosum* [16].

The barley plant has several cylindrical culms (tillers) with hollow internodes separated by solid nodes. Typically there are 5-7 internodes in a culm which increase in length and are progressively smaller in diameter towards the tip. The number of tillers per plant is influenced by plant density of crop stand, genetic and environmental factors. Though the height of culms is affected by genetic and environmental factors, the height of individual culms in the same plant may vary. Single leaves, consisting of a tubular sheath and blade, are borne alternately on opposite sides at each internode. The leaf sheath encases the culm and extends from the node to which it is attached to almost the whole length of the next internode. At the junction of the sheath and the blade, two colorless or pigmented lateral projections called auricles or 'claws' are also formed. The leaf-blade is long, flat and narrow with parallel veins. Barley's flower (inflorescence), commonly called 'ear' (spike of spikelets), is distinguishable into two morphological types-six-rowed and two-rowed [17].

In six-row barley, all of the spikelets in a triplet are fertile and able to develop into grains. The central seeds are round and fat, but the lateral seeds tend to be slightly asymmetric. In two-row barley, however, only the central spikelet is both male and female fertile. The two lateral spikelets are smaller with reduced stamens and a rudimentary ovary and stigma. Therefore, the lateral spikelets of two-row barley are sterile, and only a single seed is produced at each node of the spike, giving it a flat appearance. Each spike may carry 25-60 kernels in six rowed varieties or 15-30 kernels in two-rowed varieties [18].

Production, Productivity, and Distribution of Barley

Cereal production and marketing are the means of livelihood for millions of households in Ethiopia and is the single largest sub-sector within Ethiopia's agriculture, far exceeding all others in terms of its share in rural employment, agricultural land use, calorie intake, and contribution to national income [16]. Ethiopia is ranked twenty-first in the world in barley production with a share of 1.2 percent of the world's total production [19]. It is the fifth most important cereal crop in Ethiopia after teff, wheat, corn, and sorghum. Ethiopia is the second-largest producer of barley in Africa next to Morocco, accounting for about 26 percent of the total barley production in the continent [4]. According to Shahidur et al. [4], about 4.5 million smallholder farmers grew barley on more than 1 million hectares of land. The total production has been increasing steadily over the past decade it has increased from 1.1 million metric tons in 2003/2004 to 1.9 million tons in 2013/2014, which is equivalent to an annualized growth rate of 6 percent per year. According to USAD reports on assessments of commodity and trade, Barley cultivation is widely distributed across the country on over one million hectares of land and by more than four million small holder farmers. It is cultivated by smallholders in every region of Ethiopia, since it is able to grow at all elevations, but it performs best at the higher elevations in the northern and central regions of the country [4].

Importance of Barley Crop in Ethiopia

According to Kemelew & Alemayehu [20], reports that, among the major cereals, barley ranks fifth in area, productivity, and total production in Ethiopia as a whole it matures early and an emergency crop bridging the critical food shortage. Barley accounts for over 60% of the food of the people in the high lands of Ethiopia. It is used in diverse recipes that have deep roots in culture and tradition. Some recipes such as fine flour of well-roasted barley grain moistened with water, butter or oil), and *Chiko* (fine flour soaked with butter alone), which have a long shelf life, can only be prepared from barley grain. Other recipes, such as de-hulled and roasted barley grain served as a snack, and thick porridge are most popular when made from barley grain, but can be prepared from other cereals also. Barley is the preferred grain, after teff, for making the traditional bread, which can be used either solely or in combination with teff flour or other cereal flours. Other recipes, such as bread, thin, unleavened, dry bread, and soup can be prepared with only barley or blended with other cereals flours [6].

Effect of Nitrogen Fertilizer Rates on Growth of Barley

Plant height

According to Mohammad et al.[21], plant height was increased significantly in response to increasing the rate of fertilizer from nil up to 69 N kg ha^{-1}, i.e. the minimum plant height was obtained at a fertilizer rate of 0 N kg or nil (87.97cm) while the maximum plant height (96.52 cm) was obtained at fertilizer rates of 69 N kg ha^{-1}, the medium plant height (90.82 cm and 93.23 cm) was obtained from 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively, this result is consistent with the study of who reported that significant differences were observed on plant height of barley due to various levels of nitrogen fertilizer application.

According to Walter et al. [22], Plant height was maximum (107.38 cm) when nitrogen was applied at the rate of 100 kg ha^{-1}, followed by 80 kg N ha^{-1}with plant height (103.88 cm). The probable reason might be that optimum nitrogen supply played an essential role in plant growth and development.

Spike length

Aghdam and Samadiyan [21] report showed that spike length was also significantly increased with increasing N level. The higher spike length (8.34 cm) was obtained from nitrogen fertilizer rate of 69 N kg per ha and the spike length (7.97) was obtained from at fertilizer rate of 46 N kg ha^{1} shorter than nitrogen rate of 69 N kg ha^{1}, while the minimum spike length (7.16) was obtained from at fertilizer rate of 0 N kg ha^{-1}. Spike length became higher at higher dose of N possibly due to higher availability of nitrogen.

According to [22], the maximum lengthy spikes (18.25 cm) highest grain spike-1 (27.13), 1000 grain weight (36.99 g), grain yield (2187 kg ha^{-1}), and biological yield (7481 kg ha^{-1}) was produced by the application of 100 kg N ha^{-1}.

Effect of Nitrogen Fertilizer Rates on Yield and Yield Component of Food Barley

Nitrogen is a major requirement for the high yield of barley and nitrogen fertilization is often essential on the soil of low organic matter content or when re cropping after non-legumes because non-legumes must have the capacity to efficiently uptake legume-derived N [23]. Crop response to N fertilizer is influenced by a factor such as nitrogen fertilizer management, soil type, crop sequence and supply of residual and mineralized nitrogen [24]. When plants are deficient in N, they become stunted and yellow in appearance. Nitrogen deficiency in cereals results in restricted, poor tillering, thinner and smaller stems, premature ripening of grains are and the low number of ears per unit area and the low number of grain per ear [9]. Proper fertilizer regimes may increase the quantity of enzymes involved in cellular metabolism and regulatory processes during kernel development, such as those controlling starch and protein biosynthesis. The grains are small but often relatively high in protein content, due to a decrease in the import of carbohydrate into grains during the later stages of the grain filling stage [9]. The rate N fertilizer application is among the most critical decision for malting barley production due to its large impact on grain yield, yield components and quality. Nitrogen fertilizer is applied in order to the increase agronomic yield and improves grain quality. High rates of nitrogen application increase the protein content and especially the hordein component, which is of poor nutritive value when compared with other proteins [25]. The amount of N to be applied depends on the difference between crop requirement and the supply of available soil N which depend on mineralization of organic matter and residual nitrogen from previous application. Optimal nitrogen fertilization is essential for achieving successful, high yielding barley crop. On soil low in available N application of moderate rate of nitrogen usually result in yield increases. When soil nitrogen level is high or high rate of nitrogen is applied, both yield and protein content is increased as well as the risk of lodging. Careful monitoring of fertilizer application, especially nitrogen is effective in preventing the lodging. Timing of nitrogen application is particularly important in this context. Dividing the nitrogen into two or three splits and applying as needed by the crop plant helps to reduce lodging [10].

Nitrogen fertilization has an important effect on the final harvest; therefore, if this element is not available in a sufficient amount yield is impaired. Barley is very sensitive to insufficient nitrogen and very responsive to nitrogen fertilization means that deficiencies of nitrogen result in diminishing grain number and yield of barley. On the other hand, excessive use of nitrogen in barley causes lush succulent growth, more lodging, low thousand-grain weight, low spike, delayed maturity, greater susceptibility to diseases and pests, and causes economic loss as well as reduced yield and quality of barley seed [24].

Barley farmers in Ethiopia have not fully adopted modern inputs like fertilizer that help boost production (CSA, 2018). The yield attribute and quality of food barley seed are therefore, dependent on the appropriate dose of nitrogen. Nitrogen fertilization has a crucial effect on barley yield which results harmed by either shortage or excess of this element [26].

Total tiller

According to Mohammad et al. [1] an increasing the rate of nitrogen nil up to 69 N kg/ha, the maximum number of total tiller (336.3 per m^2) obtained at fertilizer rate of 69 N kg/ha but the minimum number of total tiller (249.3 per $m^{2)}$ was obtained from fertilizer rate of 0 N kg/ha, while the medium number of total tiller (267.0/m^2 and 314.7/m^2) at fertilizer rate of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively. This may be the contribution of N fertilizer, as the treatments that received N responded more total tillers compared with zero N received treatment.

Number of productive tiller

According to Wakene et al. [27] the number of the productive tiller of the plant is the most important character, which ensured the highest yield. Increased level of nitrogen increased number of fertile tillers $plant^{-1}$. The maximum number of the fertile tiller (295.5 per m^2) was obtained from a fertilizer rate of 69 N kg ha^{-1}, while the minimum number of the fertile tiller (253.3 per m^2) was obtained from at fertilizer rate of 0 N kg ha^{-1} and 262.3 number of fertile tiller per m^2 and 269.4 number of fertile tiller per m^2 were obtained from fertilizer rate of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively (27).

According to Walter et al.[22] more productive tillers m^{-2} (305.25), lengthy spikes (18.25 cm) highest grain $spike^{-1}$ (27.13), 1000 grain weight (36.99 g), grain yield (2187 kg ha^{-1}), and biological yield (7481 kg ha^{-1}) was produced by the application of 100 kg N ha^{-1}.

Biomass yield

The highest biomass yield (12.35 t ha^{-1}) was obtained from the highest nitrogen rate (69kg N/ha) and the lowest biomass yield (7.78 t ha^{-1}) was obtained at nil N rate, while the biomass yields (9.73 and 11.37 t ha^{-1}) were obtained at fertilizer rate of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively. This might be a significant increase in plant height, tillering, spike length and grain yield from N application ultimately contributed to the increased crop biomass yield [21].

According to Wakene et al. [27] the highest biomass yield of 8.78 t ha^{-1} was recorded at the treatment received 120 kg N ha^{-1} while the lowest biomass yield of 6.51 t ha^{-1} was obtained at the treatment received zero nitrogen rates. Similarly, Hadi et al. [28] reported that an increase in N levels significantly enhanced the biological yield as nitrogen at 120 kg ha^{-1} yielded maximum (11642.78 kg) biological yield followed by 80 kg ha^{-1} (9392.22kg). Minimum (7224.11kg) biological yield was provided by N at 40 kg ha^{-1}.

Straw yield

Increasing the rate of nitrogen was increased straw yield of barley varieties up to higher level of nitrogen application. Similar to grain yield, the straw yield continued increasing significantly with the increase in nitrogen fertilizer rate [11]. The finding of Shafi et al. [29] reported that straw yield of barley affected by different N levels. According to the report of Shafi et al. [29] the highest straw yield (9.27 t ha^{-1}) was obtained from at fertilizer rate of 69 N kg ha^{-1} while the lowest straw yield (6.4 t ha^{-1}) was obtained from at fertilizer rate of 0 N kg ha^{-1} and 7.72 t ha^{-1} and 8.25 t ha^{-1} straw yield were obtained from fertilizer rate of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively.

Thousand Kernels weight

According to Biruk and Demelash [11], the highest thousand kernels weight (43.34 g) was obtained from fertilizer rate of 69 N kg ha^{-1} however the lowest thousand kernels weights (41.43 g) was obtained from fertilizer rate of 0 N kg ha^{-1} and 41.90 g and 42.93 g thousand kernels weight were obtained from fertilizer rates of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively. The increasing rate of nitrogen application was increased thousand kernel weights [11].

According to Walter et al. [22] maximum 1000 grain weight (36.99 g), grain yield (2187 kg ha^{-1}), and biological yield (7481 kg ha^{-1}) were produced by the application of 100 kg N ha^{-1}.

Harvest index

Harvest index as a quantitative trait is an indicator of plant efficiency to distribute dry matter in grain i.e., higher harvest index implies higher partitioning of dry matter into the seed. Shahryari and Mollasadeghi [30], reported that the maximum mean harvest index (27.85%) was recorded at higher level of nitrogen rate (69 kg N ha^{-1}) while the minimum harvest index (19.73%) was recorded at control (0 N kg ha^{-1}) treatment.

Grain yield

The reports of Amare and Adane [31] showed as the increase in grain yield in response to the increasing rate of nitrogen from nil to 69 N kg per ha could be attributed to enhanced availability of the nutrient for uptake by the plants and increased photoassimilate production that would eventually lead to improved partitioning of carbohydrate to the grains. The highest grain yield (3.52 t ha^{-1}) was obtained from at fertilizer rate of 69 N kg ha^{-1}, while the lowest grain yield (1.97 t ha^{-1}) was obtained from 0 N kg ha^{-1} and 2.54 t ha^{-1} grain yield and 2.90 t ha^{-1} grain yield were obtained from at fertilizer rate of 23 N kg ha^{-1} and 46 N kg ha^{-1} respectively. The significant increase in grain yield in response to the increased application of N fertilizer could be attributed to enhanced availability and uptake of N by the roots of barley plants [31].

According to Walter et al. [22] more productive tillers (305.25 m^{-2}), lengthy spikes (18.25 cm) highest grain $spike^{-1}$ (27.13 cm), 1000 grain weight (36.99 g), grain yield (2187 kg ha^{-1}) and biological yield (7481 kg ha^{-1}) was produced by the application of 100 kg N ha^{-1}.

Summary and Conclusion

Barley (*Hordeum vulgare L.*) is a grass of the family Poaceae. Barley is one of the most important cereal crops in the world, ranking fourth in the production area next to wheat, maize, and rice. Barley with its long history of cultivation it's deeply rooted in the consumption habit of the population for utilized in more diverse forms than any other cereals. Its grain is used as human food in the form of bread, dehulled and roasted barley grain, porridge, soup, and for malting purposes. Despite the huge importance of barley as food and malt, in its productivity is quite low due to poor soil fertility and the use of low yield of the prevalent local varieties. Particularly deficiency of nitrogen and phosphorous is the main factor that severely reduces the yield of barley. Cereal production and marketing are the means of livelihood for millions of households in Ethiopia and is the single largest sub-sector within Ethiopia's agriculture, far exceeding all others in terms of its share in rural employment, agricultural land use, calorie intake, and contribution to national income. Ethiopia is ranked twenty-first in the world in barley production with a share of 1.2% of the world's total production. It is used in diverse recipes that have deep roots in culture and tradition. Some recipes such as fine flour of well-roasted barley grain moistened with water, butter or oil), and Chiko (fine flour soaked with butter alone), which have a long shelf life, can only be prepared from barley grain. Nitrogen is a major requirement for the high yield of barley and nitrogen fertilization is often essential on the soil of low organic matter content or when re cropping after non-legumes. Crop response to N fertilizer is influenced by a factor such as nitrogen fertilizer management, soil type, crop sequence, and supply of residual and mineralized nitrogen. When plants are deficient in N, they become stunted and yellow in appearance. Nitrogen deficiency in cereals results in restricted, poor tillering, thinner and smaller stems, premature ripening of grains are and the low number of ears per unit area and the low number of grain per ear. The Amount of N affects single spike weight and the spike weight increased as the amount of N increased. N application increased spike length, plant height, number of the tiller, grain weight, grain yield which increased the level of nitrogen and also increased grain yield with an increased level of nitrogen.

Recommendation

Barley is the most important cereal crop in the world after wheat, maize, and rice, and is among the top ten crop plants in the world. However large numbers of farmers are not using improved technologies such as nitrogen fertilizer. It has been selected as one of the target crops in the strategic goal of attaining national food self-sufficiency, income generation, poverty alleviation, and achieving socio-economic growth of the county. However, its production and productivity are low due to the use of inappropriate nitrogen fertilizer rates. Nitrogen fertilizer is very important to the growth and improves yields of barley, so the farmers should use the appropriate rate of nitrogen fertilizer to increase plant height, spike length, number of fertile tiller grain weight, and grain yield of barley.

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