Growth and developmental responses of height and leaf color isogenic barley, Hordeum vulgare L., lines to cultural treatments
by Bharat Prasad Singh

A thesis submitted to the Graduate Faculty in partial fulfuliment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Crop and Soil Science
Montana State University

Abstract:
In 1970, the responses of a two row commercial cultivar, Compana (C), and its medium height isogenic, Erectoides Compana (Ec), and a six row commercial cultivar, Titan (tall Titan, TT), and its height isogenics, Titan Belonee (medium Titan, MT), and Titan Beebee (short Titan, ST), to N fertilization, irrigation, and row spacing (population) treatments were compared. Vegetative plant characteristics studied included number of adventitious roots/plant, number of tillers/ unit land area, leaf number/plant, area/leaf, maximum leaf area/plant, leaf dry weight/plant, and plant dry weight/unit land area. Grain yields, grain yield components, and grain protein percentage were also obtained. N fertilization affected plant growth and grain yield much more than either irrigation or row spacing. For C, Ec, TT, MT, and ST with N fertilization maximum leaf areas/plant were 163, 154, 283 2.38, and 148 dm2, plant dry weights were 71, 66, 71, 76, and 52 g/1.8 dm2, and grain yields were 4257, 4283, 3910, 3695, and 2945 kg/ha, respectively. These values represent average increases in maximum leaf area/plant, plant dry weight/unit land area, and grain yield of 116, 105, and 50%, respectively. Vegetative, grain yield, and grain protein responses to N fertilization, irrigation, and row spacing of the short statured lines were similar to, or greater than, their normal isogenic lines except for area/leaf and leaf area/plant. The results indicate that the use of well adapted short statured barley lines will not reduce returns from investments in N fertilization and irrigation. In addition, the risk of loss from lodging would be reduced by changing from present tall commercial cultivars to the shorter lines.

In 1971, we studied the vegetative growth and water use of a normal green leaf color commercial cultivar, Liberty (L), and its two lighter leaf color isogenics, Pale Green Liberty, (PGL) and Golden Liberty (GL), grown at 8, 24, 49, 100% of full sunlight. Number of tillers/plant, number of leaves/plant, leaf area/plant, leaf dry weight/plant, dry weight/plant, specific leaf weight (SLW), and. chlorophyll content were obtained. For 8, 24, 49, and 100% of full sunlight, mean values for maximum leaf areas were 270, 278, 328, and 310 cm2/ plant, and dry weights at harvest were 1.7, 2.9, 3.6, and 4.7 g/plant, respectively. Mean values for L, PGL, and GL were maximum leaf areas 217, 319, 353, cm2/plant, and dry weights at harvest 3.1, 2.9, 3.9 g/ plant, respectively. Leaf area development of GL was much slower than for L but dry matter yields were not reduced. Depletion of available soil water was delayed about 1 week by shading (24% of full sunlight) and about 2 weeks by the lighter leaf color of the GL line. Further research is needed to study the water use efficiency of light green barley lines.

GROWTH AND DEVELOPMENTAL RESPONSES OF HEIGHT AND LEAF COLOR ISOGENIC BARLEY, HORDEUM VULGARE L., LINES TO CULTURAL TREATMENTS

by

BHARAT PRASAD SINGH

A thesis submitted to the Graduate Faculty in partial
fulfullment of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Crop and Soil Science

Approved:

K. C. Feltner
Head, Major Department

Jarvis H. Brown
Chairman, Examining Committee

Henry L. Parsons
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

August, 1972

ACKNOWLEDGMENTS

The author is grateful to those who assisted him in the preparation of this thesis. Special gratitude is extended to Dr. J. H. Brown, Dr. E. R. Hehn, and Professor R. F. Eslick for their assistance during my stay at Montana State University and in my preparation of this thesis.

The author is also thankful to his wife, Archana, for the participation and encouragement during the preparation of this thesis.

ABSTRACT

In 1970, the responses of a two row commercial cultivar, Compana (C), and its medium height isogenic, Erectoides Compana (Ec), and a six row commercial cultivar, Titan (tall Titan, TT), and its height isogenics, Titan Belonee (medium Titan, MT), and Titan Beebee (short Titan, ST), to N fertilization, irrigation, and row spacing (population) treatments were compared. Vegetative plant characteristics studied included number of adventitious roots/plant, number of tillers/unit land area, leaf number/plant, area/leaf, maximum leaf area/plant, leaf dry weight/plant, and plant dry weight/unit land area. Grain yields, grain yield components, and grain protein percentage were also obtained. N fertilization affected plant growth and grain yield much more than either irrigation or row spacing. For C, Ec, TT, MT, and ST with N fertilization maximum leaf areas/plant were 163, 154, 283 238, and 148 dm^2, plant dry weights were 71, 66, 71, 76, and 52 g/1.8 dm^2, and grain yields were 4257, 4283, 3910, 3695, and 2945 kg/ha, respectively. These values represent average increases in maximum leaf area/plant, plant dry weight/unit land area, and grain yield of 116, 105, and 50%, respectively. Vegetative, grain yield, and grain protein responses to N fertilization, irrigation, and row spacing of the short statured lines were similar to, or greater than, their normal isogenic lines except for area/leaf and leaf area/plant. The results indicate that the use of well adapted short statured barley lines will not reduce returns from investments in N fertilization and irrigation. In addition, the risk of loss from lodging would be reduced by changing from present tall commercial cultivars to the shorter lines.

In 1971, we studied the vegetative growth and water use of a normal green leaf color commercial cultivar, Liberty (L), and its two lighter leaf color isogenics, Pale Green Liberty, (PGL) and Golden Liberty (GL), grown at 8, 24, 49, 100% of full sunlight. Number of tillers/plant, number of leaves/plant, leaf area/plant, leaf dry weight/plant, dry weight/plant, specific leaf weight (SLW), and chlorophyll content were obtained. For 8, 24, 49, and 100% of full sunlight, mean values for maximum leaf areas were 270, 278, 328, and 310 cm^2/plant, and dry weights at harvest were 1.7, 2.9, 3.6, and 4.7 g/plant, respectively. Mean values for L, PGL, and GL were maximum leaf areas 217, 319, 353, cm^2/plant, and dry weights at harvest 3.1, 2.9, 3.9 g/plant, respectively. Leaf area development of GL was much slower than for L but dry matter yields were not reduced. Depletion of available soil water was delayed about 1 week by shading (24% of full sunlight) and about 2 weeks by the lighter leaf color of the GL line. Further research is needed to study the water use efficiency of light green barley lines.

TABLE OF CONTENTS I[1/]

1/ A separate barley leaf color study, done in 1971, is discussed beginning with the Table of Contents II following page 67.

LIST OF TABLES I

Context Tables

LIST OF TABLES I

Context Tables
(Continued)

Appendix Table

TABLE OF CONTENTS II

LIST OF TABLES II

Context Tables

LIST OF FIGURES II

LIST OF FIGURES II
(Continued)

INTRODUCTION

Present day agriculture relies heavily on the use of commercial fertilizer and irrigation for higher yields. Most of the present commercial cultivars of barley, however, are susceptible to lodging when fertilized and irrigated. We probably have not been able to find the maximum yield potential of the available cultivars because when a certain high level of management for yield is reached, the crop lodges, grains fail to fill properly and harvest losses increase. In an effort to prevent damage from lodging, short and stiff strawed lines have been developed. Thorough knowledge of how semi-dwarfing genes influence various aspects of morphological plant development is needed to exploit the agronomic value and adaptation of this plant characteristic to the fullest extent. It is also essential to know the response of semi-dwarf plants to various cultural treatments in comparison to the present commercial cultivars of barley.

This investigation was designed to study the response to nitrogen fertilization, irrigation, and row-width of short statured two row and six row barley lines in comparison to the responses of their normal commercial isogenics.

LITERATURE REVIEW

Response of cereals to Nitrogen (N) fertilization and irrigation

N fertilization

The results of numerous fertilizer experiments up to 1942 have been reviewed by Olson and his associates. Most of the experiments have shown an appreciable yield response from nitrogen fertilizer alone or in combination with P and K. The magnitude of response and the significance of cultivar-fertilizer interactions, however, have varied considerably. Pendleton et al. (1953), in Illinois, found a significant difference in the yield response of barley cultivars to varying levels of nitrogen fertilization. Brown et al. (1961), in Georgia, studied the response of seven oat cultivars to different levels of fertilization and obtained significant cultivar x N fertilizer interactions for plant height, straw weight, grain yield, and grain protein content. In a four year experiment with barley, Frey et al. (1952) obtained a significant interaction between cultivars and fertilizer treatments only during those two years in which the Michigan weather was not favorable for barley production. During the other two years of this study when the weather was favorable for barley growth, no cultivar x fertilizer interaction for grain yield was obtained. Gregory and Crowther (1928), in England, reported no differential grain yield response for five cultivars of barley produced at different combination levels of N, P, and K. The cultivars, however, showed differential responses of yields of straw, roots and

and total top weight with different fertilizer treatments. Brown (1971)[1/], working on dryland in Montana's Gallatin Valley reported significant interactions between barley cultivars and N rates for plant height, straw yields, grain yield, test weight, grain protein, plumpness, and grain weights.

The grain yield is a function of (a) the number of spikes per unit area, (b) the number of grains per spike, and (c) the average weight per grain. Woodward (1966), in Utah, found that increase in yield of wheat by nitrogen fertilization was mostly due to increased culms per unit area. There was no increase in kernels per spike or in grain weight from N fertilization. Gasser and Iordanou (1967), in England, observed an increase in the number of spikes, total dry weight, and grain yield of barley with the application of N fertilizers. N application did not affect the weight per spike. Reisenauer and Dickson (1961), in Washington, found that yield increase from 80 to 120 lbs per acre of nitrogen resulted from the production of more but smaller kernels.

Hunter et al. (1958) found that protein content of Oregon grown pastry wheats was not increased appreciably by N fertilizer unless more was applied than necessary for maximum or near maximum yields. Martin and Mikkelsen (1960), working with barley in . . .

1/ Brown, P. L. 1971. Annual Research Report. USDA, ARS-SWC, Northern Plains Branch, Bozeman, Montana.

California found that high rates of N fertilization were required to raise the percent grain protein appreciably on soils which were deficient in nitrogen. Even their lowest rates of N increased the protein level of the grain on soils which were not N deficient or in years when drought prevented yield responses on N deficient soils. McNeal and Davis (1954), in Montana, observed a decrease in percent grain protein of wheat from low N fertilization rates. Higher N fertilizer rates, however, significantly increased the protein content of the grain.

Irrigation

Bauer, Young and Ozbun (1965), in North Dakota, reported increased yields of wheat and barley with an increase in the available soil water, both with and without fertilizers. Bendelow (1958) and Sosulski and Bendelow (1964) also obtained significant increases in grain yield of barley grown under irrigation in Alberta, Canada. Irrigation increased the weight of the grain but invariably lowered the nitrogen content of the grain. Harris and Pittman (1922) reported an increase in plant height, tillering, grain weight, and head size of barley grown under irrigation in Utah. Widtsoe and Stewart (1912) found that there was an increase in the relative amount of ash and a decrease in per cent protein with irrigation of cereal grain grown in Utah.

Robins and Domingo (1962), in Washington, observed spring wheat yield depressions of 10-35 per cent from severe moisture stress. Reductions were greatest when moisture stress was imposed during and following heading or during the maturing process. Moisture stress immediately preceding heading resulted in marked second growth which increased spike population but delayed the date of maturity. Moisture stress during and following heading generally resulted in fewer productive spikes, fewer spikelets per spike, and fewer grains per spikelet. Spike and grain productions were generally decreased by moisture stress late in the development of the plant. Grain weight was greatly reduced by moisture stress immediately preceding maturity. Plant height at harvest was depressed by moisture stress prior to or during heading.

Gaastra (1959) reported that moisture stress increased resistance to gas movement through the leaf mesophyll. Brouwer (1961) found that moisture stress tends to cause closure of stomata, thereby increasing resistance to diffusion of gases (water vapor and CO_2) through stomata. Moss et al. (1961) suggested that moisture stress reduces photosynthesis by limiting CO_2 supply to the chloroplast. Baker and Musgrave (1964) reported approximately 50 per cent reduction in photosynthesis in corn under moisture stresses where signs of wilt were barely visible.

N fertilization x irrigation

Luebs and Laag (1967) emphasized the importance of the ratio of available water to available nitrogen for barley grain yield under non-irrigated conditions, particularly in winter rainfall areas where moisture is usually deficient from heading to crop maturity. Stanberry and Lowrey (1965), in Arizona, obtained much greater barley yield increases from application of N than from cultivar or irrigation treatments. N increased yields about 400%, whereas the "wet" moisture treatment exceeded the "dry" treatment by only 36%. When these two treatments were combined, however, the increase exceeded 570%, indicating that each treatment contributed its maximum effect only when the other was adequate. Barley without added N used about 80% as much moisture and produced less than 20% as much grain as barley receiving adequate N. Consequently, moisture utilization efficiency (M.U.E.) for grain production was about three times as high with abundant N as with no added N.

Ramig and Rhoades (1963), using different levels of preplant moisture with nitrogen application in Nebraska, found markedly greater straw-grain ratios in winter wheat when the moisture level was low. This indicated that with a low moisture level, nitrogen resulted in marked vegetative growth but moisture limited grain yield. Robins and Domingo (1962) in a study of the effect of moisture and nitrogen on spring wheat at Pullman, Washington found no significant interaction between the effects of nitrogen and moisture on yield.

Response of cereals to population density-Maize

Maize researchers have been advocating high plant populations to achieve high grain yield. Allison and Watson (1966) reported that when maize was grown at low populations in Rhodesia more leaves were produced than needed to fill the grain. When some leaves were removed, the grain received a larger fraction of the dry matter produced after flowering. High populations resulted in more ears per unit of land, thus creating a larger "sink" for the photosynthate. Denmead et al. (1962) reported a greater absorption of radiant energy with narrower row width and thus an increase in the energy available for photosynthesis. Colville and Burnside (1963) noted that inadequate plant populations caused inefficient light interception which in turn increased soil temperature and contributed to greater evaporative compared to transpirative water losses. Excessive light reaching the soil surface also increases weed growth. Yao and Shaw (1964) observed increased efficiency of water use and greater light interception with narrow rows. However, Timmons et al. (1966) and Olson (1971) observed that populations did not effect total water use in maize; the efficiency of water use was proportional to yield.

Response of cereals to population density-small grains and sorghum

Hansen et al. (1962) reported that narrower row spacing resulted in greater oat yields. Foth et al. (1964) in a three year study to evaluate the effect of row spacing on oats performance found that oats grown in the narrow rows consistently had more panicles (or culms) per unit area and a higher yield of grain and straw than with the wider spaced rows. Of the yield components, seed weight was effected the least by row spacing and had the least effect on yield.

Working in Canada with wheat, oats, and barley, at three locations and over a three year period, Guitard et al. (1961) reported an increase in the number of plants per acre and a decrease in the number of fertile spikes per plant with successive increases in the seeding rate. There were reduction in the number of kernels per spike and in the 1,000-kernel weight. Demirlicakmak et al. (1963) observed that the heaviest rate of seeding produced the lightest weight kernels, and vice versa. Fewer tillers were produced under heavy competition.

Middleton et al. (1964), in North Carolina, grew three cultivars of winter barley at row widths of 8 and 16 inches and 3 rates of seeding in the row to study the effect of seeding rate and row width on yield and yield components. Decreasing the rate of seeding decreased the number of fertile spikes per unit area and increased the number of seeds per spike. The weight of 1,000 seeds and test weight per bushel were not affected significantly. Significant differences in yields were not found between 8 and 16 inch rows or at different seeding rates in the row.

Woodward (1956) observed that lower rates of seeding spring barley, oats, and wheat, on irrigated soils in the Western United States, resulted in stiffer straw, larger spikes, and higher test weight. Day and Thompson (1970) noted that the conventional barley planting rates of 112 kg/ha in Arizona could be decreased by 50% without decreasing grain yields. They noted, however, that as the date of seeding was delayed beyond the optimum for grain production, the seeding rate should be increased. This is because later planted crops have a shorter vegetative period for tillering and root development.

It has been shown in many instances (Arnon and Blum, 1965, Grimes and Musick, 1960, Karchi and Rudich, 1966, Stickler, 1964, and Stickler and Younis, 1966) that grain yield of sorghum is not drastically affected by a wide range of plant densities. This is due to its ability to compensate by shifting grain yield components in response to avaliable space. Under severe drouth conditions at Hays, Kansas, Brown (1959) found that wider row spacing and low plant population increased grain sorghum yields significantly.

Siemans (1963) reported that grain protein content in spring wheat increased from 15.1 to 18.5% as distance between rows was increased from 15 to 76 cm. He found no cultivar x row spacing interaction in a test involving four wheat cultivars.

Interrelationship between different crop characteristics

Black (1970) observed that the number of spikes per ha in wheat was linearly related to adventitious roots per plant at the end of tillering. The regression of grain yield on number of adventitious roots per plant accounted for 93% of the variation in grain yield.

Demirlicakmak et al. (1963) reported that tillering capacity, taken alone, was not a good indicator of yield in barley. In their experiment, the cultivar 'Gateway' produced the most tillers, but was lowest in yield.

Loomis and Williams (1963) have stated that the leaf area, manner of leaf display, and CO_2 supply are the major limiting factors to total seasonal yields in maize. The maximum possible production efficiency was calculated to be a conversion of 53 per cent of solar radiation to chemical energy, or 15 micrograms net dry matter per calory of solar radiation. It should be noted that these calculations are for maize plants which have a photosynthetic pathway that differs from that of wheat, oats, and barley. Allison (1969) pointed out that the leaf area of maize remains nearly constant for much of the time between flowering and maturity. So to maximize the supply of dry matter to the grain, plant density should be such that optimum leaf area index is reached at the time of flowering.

Watson et al. (1939) reported that there was very little carbohydrate translocation to the spike from below the flag leaf in barley. Thorne (1965) reported that CO_2 fixation by ear and flag leaf between ear emergence and maturity accounted for most of the final grain dry weight. Photosynthesis in the flag leaf and the net CO_2 uptake by the spike each provided about half of the carbohydrate in the grain. Saghir, Khan, and Worzella (1968) shaded various parts of the culm from the lowest internode to the spike and found that the spike was the most critical plant part effecting grain development of wheat and barley. The removal of the top leaf had an effect on grain yield that was second to shading of the spike. Shading the stem or removal of the lower leaves caused an effect similar to but less marked than removal of the top leaf. Frey-Wyssling and Buttrose (1959) have cited the following evidences favoring the proposal that spike, rather than non-spike materials are preferentially used in grain filling (and floret respiration); (a) the proximity of awns and glumes to grains, as compared to stem and leaf sheath; (b) carbon fixed within a floret is not transported outside that floret; and (c) consideration of sugar and nitrogen transport in the plant suggests that the material elaborated in the spike is preferentially used by grains.

Neatby and McCalla (1938) observed that high yielding barley cultivars had a marked tendency to be low in protein. Correlation coefficients from a number of their experiments were all negative for the comparison of yield and protein content and ranged in magnitude from -0.21 to -0.88. Meredith et al. (1942) obtained a decrease in the nitrogen content of barley grain with an increase in 1,000 kernel weight. Middleton et al. (1961) determined protein percentage of 18 barley cultivars grown in a uniform nursery. The differences in protein content among cultivars were highly significant, but there was no significant correlation between grain yield and protein content of cultivars.

Genetics of plant height in barley

Plant height in barley is a very complex characteristic and is only partially determined by the H loci (Nilan, 1964). Shakudo and Kawase (1951) observed that the genes, LK, I, Uz, and rn inhibitors (factors for fertility of lateral florets) determines the height of culms through their pleiotropic influence on the length of awns and spikes. Leonard, Robertson, and Mann (1956) showed that the genes Uz and br acted in a complementary manner to determine plant height. Kump (1947) observed that long stem was dominant to short stem and it was controlled by a single gene.

EXPERIMENTAL PROCEDURES

Experimental site

This study was conducted in 1970 at the Field Research Laboratory, West of Bozeman, Montana. The soil at the Field Research Laboratory is Amsterdam silt loam. The nitrate nitrogen contents of the successive layers of the experimental plot were:

Layer	Nitrate Nitrogen (ppm)
0 - 15 cm	3.80
15 - 30 cm	1.75
30 - 61 cm	2.15
61 - 91 cm	1.25
91 - 122 cm	6.05
122 - 152 cm	4.05
152 - 183 cm	6.65

Climate and weather conditions

The Field Research Laboratory is situated at 45°41'N latitude and 111°09'E longitude. It has a semi-arid, temperate climate. A summary of the climatic data by months for the calendar year 1970, and average for the period 1958-1970 at the Field Research Laboratory, are given in Appendix Table 15[1/].

1/ Caprio, J. M. 1971. Weather data at Agricultural Experiment Stations in Montana. Mimeographed report.

Experimental Material

Three six row height isogenics and 2 two row height isogenics of barley were grown.

Two row lines

1. Compana - Compana is one of the many selections made at the Field Research Laboratory, Aberdeen, Idaho, from the tenth generation composite of 32 different crosses. The selection was tested by the Montana Agricultural Experiment Station and released in 1941. It is a white seeded, semi-smooth awned, drought resistant, early to mid-season maturing, high yielding barley cultivar. Seeds are large, plump, and thin hulled. Straw is weak and susceptible to lodging. It is classified as feed barley.[1/]

2. Erectoides Compana - It is a spontaneous, medium statured, mutant derived from Compana.

Six row lines

1. Titan - Titan was obtained as a result of the cross Trebi x Gabron, made at the University of Alberta, Edmonton, Canada. It was released in 1943. It is a mid-season, stiff straw cultivar of barley with small to medium sized kernels. It is classified as a feed barley.[1/]

1/ Barley Variety Dictionary, 1970. Malting Barley Improvement Association, Milwaukee, Wisconsin.

2. Titan Belonee - It is a medium statured isogenic of Titan developed by back crossing at the Montana Field Research Laboratory.

3. Titan Beebee - It is a short statured isogenic of Titan developed at the Montana Field Rsearch Laboratory.

Experimental Design

A split plot experimental design with 40 treatments replicated three times was used. The main plots were 48.8 m long and 6.1 m wide. The treatments within any split were allocated randomly. The allocation of treatments were made in the following manner:

Split	Treatments
First split	0 kg N per ha 72 kg N per ha
Second split	No irrigation rrigation
Third split	15 cm row-spacing 30 cm row-spacing
Fourth split	Lines Compana Erectoides Compana Titan Titan Belonee Titan Beebee

Field operations

Nitrogen as ammonium nitrate (33% N) was applied at the rate of 72 kg N per ha to the plots assigned the N fertilization treatment.

Phosphorus as triple superphosphate (45% P_2O_5), potassium as potassium chloride (60% K_2O) and sulfur as gypsum (18% S) were applied to all plots at the rate of 18 kg P and K and 9 kg S per ha. Fertilizers were broadcast before planting. A tractor mounted cone seeder was used for planting the entire field in 30 cm rows. A manually operated single row cone seeder was then used to obtain 15 cm row spacing.

A sprinkler irrigation system was used for irrigating plots assigned the irrigation treatment. Irrigation was applied three times during the growing season. Weeding operations were carried out manually.

Method of study

Vegetative growth

Sampling was done three times, first at the end of the tillering period on June 17, second at the end of the stem extension period on July 2, and last at the flowering period on July 20. Samples were collected from an area 60 cm long and 30 cm wide. The following observations were recorded:

(i) Number of plants per sample

(ii) Number of adventitious roots per plant - the estimate was based on the average of a random 10 plant subsample.

(iii) Number of tillers per sample

(iv) Number of leaves per plant - the estimate was based on the average of a random 10 plant subsample. Only the leaves with open collar were included in the leaf count.

(v) Area per leaf - area per leaf estimates were based on the average of the leaf area of 20 randomly selected leaves. An air-flow planimeter as described by Jenkins (1959) was used for measuring the leaf area. Leaf area measurements included only the area of the leaf blade.

(vi) Leaf area of flag leaf - at the time of the third sampling, 20 randomly selected flag leaves were used to estimate the average flag leaf area.

(vii) Leaf area per plant - leaf areas per plant were calculated only for the second sampling date. The second sampling was taken at the end of the vegetative phase, so it should give an estimate of the maximum leaf area per plant. Values for the leaf area per plant were arrived at by multiplying the number of leaves per plant by average area per leaf.

(viii) Dry weight per plant leaf - dry weight per plant leaf was obtained at the second sampling date.

(ix) Plant height - length of the main stem from the base to the topmost exposed collar was recorded as plant height at the first two sampling dates. Length of the plant from the base of the main stem to the end of spike, awn excluded, was recorded as plant height at the third sampling date.

(x) Plant dry weight - the above ground plant parts of the sample were dried in the oven and recorded as plant dry weight.

Components of grain yield, grain yield, and protein percentage

Just prior to harvesting all plants from samples 120 cm long and 30 cm wide area were collected for the yield component analysis. The number of spikes bearing mature grain and tillers without mature spikes were counted separately. One hundred randomly selected mature grain bearing spikes were used to determine the number of grains per spike. Weight per grain was estimated from weighing 1,000 grains.

The plants were trimmed immediately preceding harvesting from both ends so that only the central 2.4 meter remained in each row. The middle three rows in 30 cm row spacing and the middle six rows in 15 cm row spacing were harvested with a gasoline powered mower with a mounted catcher on the sickle bar. The sickle bar was at the ground level, resulting in recovery of essentially all spikes from harvested area. Threshing of the grain was done in the field with a Vogel plot thresher.

Lodging severity indexes were estimated for each plot at harvest. These values can be influenced greatly by adjacent plots and difference between replications. Lodging severity indexes were not indicative of the detrimental effect on grain yield, since most lodging occurred after grain maturation. Therefore these values are not reported.

Grain protein percentage was determined by the modified

Kjeldahl's method[1/] (AOAC, 1965). Grain test weight was recorded by AACC method 84-10[2/].

1/ Association of Official Agricultural Chemists. 1965. Official methods of analysis, (10th Ed.). The Association, Washington, D.C.

2/ American Association of Cereal Chemists. 1962. Cereal Laboratory methods, (7th Ed.). The Association. St. Paul, Minn.

RESULTS AND DISCUSSION

Plant life is associated with numerous physiological processes, from planting to the harvest of the crop. Both genetic and environmental considerations regulate the physiological processes of the plant. The interrelation of these processes dictate growth and development.

Murata (1970) has divided grain yield formation in grain crops into the following three phases: (i) the formation of organs for nutrient absorption and photosynthesis; (ii) formation of flower organs and the "yield container"; and (iii) production, accumulation translocation of grain yield contents.

The number of plants germinating per unit area under favorable germinating conditions is a function of the number of seeds planted. In this experiment, the number of seeds planted per row was kept constant. The plots with 15 cm row spacing were seeded with double the number of seeds per unit area as for the 30 cm spacing. Plant counts revealed no influence of nitrogen, irrigation or lines on the number of plants per unit area (Table 1, p 21). As expected, a highly significant increase in plants per unit area resulted from

Table 1. Analysis of variance for various barley plant characteristics: (Plants/1.8 dm^2; Adventitious roots/plant, Tillers/1.8 dm^2; Fully expanded leaves/per plant; Leaf area (cm^2/20 leaves); Flag leaf area (cm^2/20 leaves); Maximum leaf area/per plant (cm^2/plant); Maximum leaf weight/per plant (g/plant); (Plant height (cm); (Plant dry weight (g/1.8 cm^2);Grain yield (g/2.3m^2); No. of spikes/3.6 dm^2; No. of grains/50 spikes; grain weight (g/1,000 grains); grain protein %; Test weight (lb/bu).

		MEAN SQUARES			
			No. of adventitious roots/plant		
Source	DF	Plants/ 1.8 dm^2	End of tillering	End of stem extension	Flowering
Rep (R)	2	46	1.1	13	13
Nitrogen (N)	1	294	186.0*	294	683*
Error a (Ea)	2	28	8.0	13	17
Irrigation (I)	1	218	1.0	8	35
N x I	1	186	1.1	22	82
Error b (Eb)	4	204	1.4	7	9
Spacing (S)	1	21440**	1.0	302 *	1660**
N x S	1	94	1.4	42	32*
I x S	1	63	2.8	12	4
N x I x S	1	104	14.0*	47	21
Error c (Ec)	8	42	1.9	43	6
Lines (L)	4	114	2.0	43 *	216**
N x L	4	106	1.9	3.3	16
I x L	4	120	1.2	4.5	38*
S x L	4	120	4.9**	7.2	37*
N x I x L	4	179	1.6	3.2	12
N x S x L	4	189	1.4	3.7	16
I x S x L	4	139	1.3	2.3	11
N x I x S x L	4	186	0.51	3.7	6
Error d (Ed)	64	100	0.98	3.6	12
Total	119				

* Significant at 0.05 level
** Significant at 0.01 level

Table 1. (continued)

	MEAN SQUARES					
	No. of tillers/1.8 dm^2			No. of fully expanded leaves/plant		
Source	End of tillering	End of stem extension	Flowering	End of tillering	End of stem extension	Flowering
R	2981	468	5057	1.2	8	51
N	37465**	63112**	78694*	99 **	469*	839 **
Ea	342	559	1422	0.71	15	0.34
I	1002	464	11078*	1.1	3.3	93
N x I	529	472	5589*	4.2	5.6	134
Eb	654	675	341	2.0	9.0	23
S	47124**	25637**	16263**	1.2	149 **	909**
N x S	7520	2448	4118*	6.4*	1.4	57
I x S	853	74334	1549	1.0	2.5	20
N x I x S	832	661	2475*	1.5	7.2	52
Ec	375	838	440	0.7	2.4	21
L	3909**	4328**	3756**	3.7 **	9.0*	31**
N x L	691	449	1105	2.8 *	2.0	6
I x L	286	537	407	1.3	2.0	16*
S x L	233	894	1335	1.5	1.8	15*
N x I x L	406	532	2105*	1.5	1.2	10
N x S x L	554	1520*	619	0.5	5.1	6
I x S x L	760	471	434	1.2	1.7	9
N x I x S x L	803	379	845	1.1	1.5	14
Ed	368	557	728	1.0	2.6	5.4

Table 1. (continued)

	MEAN SQUARES					
	Leaf area (cm^2/20 leaves)			Flag leaf area (cm^2/20 leaves)	Max leaf area/plant (cm^2/plant)	Max leaf weight/plant (g/plant)
Source	End of tillering	End of stem extension	Flowering			
R	4969	3677	626	316	2606	0.06
N	23213*	479562**	486795**	123200**	108863*	6.2 **
Ea	785	3677	6524	250	5229	0.02
I	113	572	1286	1098	3321	0.006
N x I	130	1116	1752	2042	6554	0.013
Eb	125	641	1824	1054	4991	0.006
S	3532*	14083*	5507	1086	11995*	0.27
N x S	119	1825	15664	7285*	544	0.00
I x S	715	1790	1030	405	4496	0.00
N x I x S	298	3328	1801	686	1310	0.00
Ec	419	1974	1498	656	1187	0.04
L	1215*	31253**	21298**	18875**	25238**	0.20
N x L	375	6751**	11440**	4490**	9875**	0.02
I x L	409	1273	1123	661	2703	0.00
S x L	798	821	2509	990	2906	0.01
N x I x L	684	1261	6510**	1385	1796	0.04
N x S x L	375	1910	2425	1888**	1680	0.02
I x S x L	306	3084	2797	484	1470	0.03
N x I x S x L	370	782	2441	479	1894	0.01
Ed	453	1271	1319	419	2316	0.03

Table 1. (continued)

	MEAN SQUARES					
	Plant height (cm)			Plant dry weight (g/1.8 dm^2)		
Source	End of tillering	End of stem extension	Flowering	End of tillering	End of stem extension	Flowering
R	14	131	233	36	45	1630
N	236*	5177*	6912*	1877*	33852**	107700*
Ea	7.4	203	361	34	293	1896
I	3.5	56	788**	15	361	3549
N x I	8	323	620**	11	468	4605*
Eb	4	64	17	12	348	555
S	3	44	256**	640**	4314**	4467
N x S	9	199	14	182**	1998	1227
I x S	3	95	150**	16	121	1202
N x I x S	12	30	48	24	118	1120
Ec	1	47	12	6	209	852
L	134**	1184**	2009**	107**	1005**	5595**
N x L	5	80**	110**	25**	156	1090
I x L	1	17	29	13	123	1009
S x L	2	90**	48	4	395*	1885**
N x I x L	5	50	59*	15	177	1400*
N x S x L	3	41	23	6	261	442
I x S x L	1	20	16	13	93	337
N x I x S x L	1	24	30	14	128	875
Ed	2	20	20	6	129	491