Yield Response of Spring Barley, *Hordeum vulgare* L., to Plant Density and Nitrogen Fertilization.

by

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Suggested short title

Plant Density and Nitrogen Effects on Barley.

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ABSTRACT

The pursuit of higher yields per unit of ground area is a constant challenge for agronomists, and plant density is one of the factors that limit the yields of field crops (Clements 1904; Day 1977).

Loyola, Laurier, Conquest, Q.B.60.2 and Q.B.59.28 spring barleys, were grown during 1977 (Exp.1) and 1978 (Exp. 2) in the field at several plant populations, ranging from 170 to 686 plants m^{-2}, at three levels of nitrogen, 0, 34 and 68 Kg N ha^{-1}.

In both experiments, increased plant density reduced the number of tillers $plant^{-1}$, plant height, the number of ears $plant^{-1}$, the number of grains ear^{-1}, 1000 - grain weight and the harvest index; whereas, the number of ears m^{-2} was increased. Yield and grains m^{-2} were reduced by above-optimum plant densities in the case of Loyola, Laurier and Conquest; whereas, Q.B.60.2 and Q.B.59.28 generally did not show reductions in yield by plant density.

Nitrogen increased the number of tillers $plant^{-1}$, tillers m^{-2}, plant height, grains ear^{-1}, grains m^{-2} and yield, but reduced 1000 - grain weight and harvest index.

RESUME

La poursuite de l'augmentation des rendements agricoles par unité de superficie est un défi continuel pour des agronomes; de plus la quantité de plantes par unité de superficie est un des facteurs limitant le rendement de la récolte. (Clements, 1904; Day, 1977).

Les variétés de l'orge du printemps, Loyola, Laurier, Conquest, Q.B.60.2 et Q.B.59.28, ont été cultivées à l'extérieur durant des années 1977 (Exp. 1) et 1978 (Exp. 2). Chacune de celles-ci ont été assignées plusieurs populations de plantes dans la même superficie, allant de 170 à 686 plants m^{-2}, et trois taux d'applications d'azote, 0, 34 et 68 Kg. d'azote ha^{-1}.

Dans les deux expériences, une population de plantes plus élevées a reduit le nombre de talles (tiges secondaires) par plante, la hauter de la plante, la quantité d'epis par plante, le nombre de semences par epi, le poids mesuré par milles semences et l'indice de la récolte; néanmoins le nombre d'epis par m^2 a été augmenté. Le rendement et la quantité de semences m^{-2} ont été reduits lorsque une population de plantes au-dessus l'optimum a été employéè, dans les cas de Loyola, Laurier et Conquest. Cependant, Q.B.60.2 et Q.B.59.28 n'ont pas demontré des réductions de rendement causées par le facteur de population des

plantes.

L'application d'azote a augmenté le nombre des talles par plante, des talles m^{-2}, la hauteur des plantes, les semences par epi, les semences m^{-2} et le rendement des plantes mais l'ajoutement d'azote a réduit le poid mesuré de mille semences et l'index de la récolte.

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1.- INTRODUCTION

The pursuit of higher yields per unit of ground area is a permanent challenge for agronomists. Within this context, the yield of field crops may be limited by several environmental factors that range from carbon dioxide concentration in the atmosphere to plant genotype. Day (1977) grouped these factors into three sections according to "the energy cost of relieving them" (Table 1.1).

Table 1.1.- The major factors limiting field crop productivity. (From Day, 1977).

FIXED	1.- CO_2 concentration.
	2.- Length of growing season.
	3.- Total sunshine.
	4.- Soil type.
EXPENSIVE TO VARY	5.- Available moisture (irrigation).
	6.- Soil fertility (fertilizers).
	7.- Pests and diseases (pesticides).
	8.- Weeds (cultivation, herbicides).
	9.- Storage after harvest.
	10.- Nutritional value.
	11.- Marketing.

INEXPENSIVE TO VARY	12.- Crop density	
	13.- Planting date.	
	14.- Seed quality.	
	15.- Crop genotype.	

Though somewhat simplified, Table 1.1 may give an overview of the most important physical and biological factors that limit and often reduce yields. Among them can be distinguished plant density, soil fertility and crop genotype.

In general, the barley plant is sharply affected in its grain yield by plant density (Kirby, 1967), and no further increases in grain yield are attained when the seed rate is increased to above-optimum populations. However, in recent times new approaches in plant physiology and plant breeding may give in the near future substantial advances in the effort to break the plant density barrier and increase grain yield, on the basis of new genotypes adapted to crowded environments.

The present study was oriented with the main objective of testing the responses of several barley cultivars to plant density and nitrogen fertilization under field conditions.

2.- REVIEW OF LITERATURE

2.1.- Plant Population - Yield Relationships.

The interactions between the growth of a plant community and the factors of the environment, is one of several statements proposed in plant ecology to define the term "competition", (Black, 1966).

Clements (1904), as cited by Black (1966), defined competition as "... a question of the reaction of a plant upon the physical factors which encompass it, and of the effect of these modified factors upon the adjacent plants".

From Clements' definition, it is clear that the competition within a plant community is the result of the environmental effect on the individual plants and in the opinion of Black (1966), the studies of competition should "be restricted to the individual plant level".

In accordance with this criterion, the present work was approached as a study of the growth of a plant community at the population level, in which the population is the biological factor affected by modifications in the environment and the results are related to land area.

Most agricultural crops are populations of individual plants with almost identical genotype, starting growth at much the same time from seeds of similar size and quality, evenly distributed over an area of soil. Usually, seedlings growing at a wide range of densities show an initial period of growth in which there is no interplant competition. The plants are widely distributed and they do not interfere with each other, but later in the season, mutual interference appears and the growth is depressed, especially at high densities, where each plant suffers intense competition with its yield being reduced to 20% or 10% or less of the yield of an isolated plant (Donald, 1968). The departure of the growth rate from that of the isolated plant is a function of competition among the population and depends on the initial plant density, the rate of growth and the genotype. The resulting responses give interrelationships between yield (weight per unit area) and density (number of plants per unit area) in combination with other environmental factors.

In cereal crops, extensive agronomic and physiological studies have been done upon the effects of seeding density on yield. Holliday (1960 a), supported by his work and reviewing that of other workers, stated that two distinct relations exist between yield and plant population.

First, the relationship between total dry matter production and plant density can be graphically represented by an asymptotic curve (Figure 2.1). Total dry matter rises with increasing plant density, reaching a ceiling point of maximum production, which then remains constant, despite further increments in seed rate.

On the other hand, grain yield is affected by seed rate in a different way. As plant number per unit area is increased, the grain yield increases up to a maximum, which finally declines with further increments of density, showing a "flattopped" parabolic type of response curve (Figure 2.1).

Donald (1963) in an exhaustive monograph, reviewed the effect of competition on several agricultural plants. He has suggested that the response curves of grain yield and total dry matter weight are interdependent and the minimum density giving the plateau yield of a dry matter is also the density at which grain yield is maximum.

It has been seen (Holliday, 1960 a) that the point of inversion in the yield response curves varies considerably in different experiments. The precise form of the curve is determined by the genotype and its interrelationships with the environment. The number of plants required per unit area cannot be too small or not all the potential production will be attained, nor can it be too large, or excessive plant competition will reduce the efficiency of the genotype.

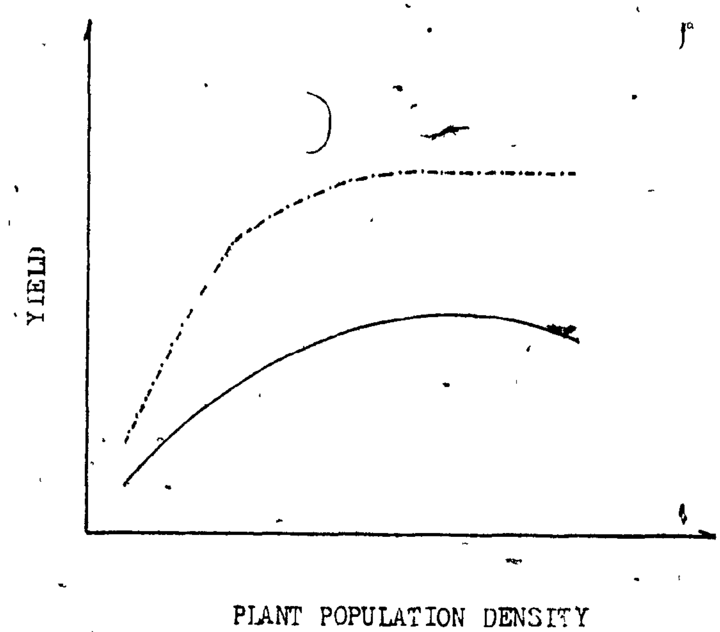

Figure 2.1.- Typical effect of plant density on biological yield (total dry matter) -.-.-.-.- and on economical yield (grain) ,———, in cereals.

In his review, Donald (1963) did an analysis of the environmental factors involved in the nature of plant competition, namely: water, nutrients, light, oxygen and carbon dioxide. In connection with the relationship between nutrient supply and plant density, Donald proposed: "... there is sufficient evidence to derive the general principle that as the fertility status is improved, so the density required to give maximum yield by annual crops will increase. Conversely, as density is increased, so the response to an added nutrient will continue to a higher level of application."

Thorne and Blacklock (1971) analyzed the effect of nitrogen on the growth and yield of wheat sown at different densities. In their work, no interaction between increased levels of nitrogen and plant density was found. Under both conditions, low and high density, nitrogen application increased grain yields at medium rates (125 Kg N ha^{-1}) but not at high rates (200 Kg N ha^{-1}). Nitrogen decreased weight per grain but had no effect on the number of grains per spikelet or per ear; the number of ears per square meter was increased slightly. In all cases, total dry matter was increased by nitrogen application.

In further experiments (Pearman et al. 1977, 1978) Thorne's group observed that grain yield was increased by nitrogen fertilization but less than leaf area and dry weight of the vegetative parts of the plant, although the uptake of carbon dioxide by the two top leaves, per unit land area, increased almost as much as leaf area. Explanations suggested for this apparent inefficiency in grain production of crops given large amounts of nitrogen were that the grains provided an inadequate sink, so that photosynthate was diverted to the stem and later stored or lost by respiration. This explanation was confirmed in the 1978 experiment, in which the inefficiency of the leaves of crops given much nitrogen, in producing grain, may be explained in terms of the effect of nitrogen on respiration.

The effect of water supply on plant density, has been analyzed in Donald's paper (1963), and he emphasized an old principle in agricultural practice, that the optimum density in any annual crop will be further reduced in drier environments than in wet ones. This statement has been illustrated by Karper (Karper, 1929, as cited by Donald, 1968), who in ten years of experiments with grain sorghum production, showed how the response of grain yield to plant density can be affected by rainfall and genotype. Two "cultivars", Kafir and Milo, were grown at different spacings from 3 to 36 inches in the row and a constant distance of 36 inches between rows. Kafir, a not-free-tillering plant, was more sensitive to different levels of moisture in the soil, giving its maximum yield at a high density in wet seasons, while the free-tillering "cultivar", Milo, produced its maximum yield at wide spacings in either wet or dry seasons (31.6 and 3 inches of rainfall respectively) due to its capacity for tillering, compensating for low densities under wet conditions.

When water is a non-limiting factor in crop production, positive responses of grain yield can be expected from higher densities, particularly in some genotypes.

In wheat, Pelton (1969) found in Western Canada, that although different densities of spring wheat used almost the same total amount of water, the most rapid use of water in earlier stages of growth in the high density treatments led to water deficits, which affected grain yield; wheat produced less at high densities under water stress.

In barley, (Kirby, 1970) evapotranspiration was estimated from plots with plants grown at a range of densities from 50 to 1600 plants m^{-2}. From the heading stage onwards, transpiration exceeded rainfall and a soil water deficit occurred. This early onset of water deficit may have led to reduced growth at the high densities over the latter part of the grain filling period, or before, causing the reduced grain size and lower grain yield found at the highest densities (400-1600 plants m^{-2}).

In maize, many workers have studied the effect of plant density on yield: Alessi and Power (1965); Bunting (1971). Voldeng and Blackman (1974) have shown that the relationships between total dry matter yield and density may be graphically represented by an asymptotic curve; i.e. at high plant populations, the total dry matter yields do not decline; remaining constant at all higher densities. However, when water supply was in limited amounts, greater shoot yields were obtained at the lower densities. These phenomena were observed by Bunting (1971) and the low shoot yields were related to low rainfall in one particular year.

Summing up in Donald's words: "Little is known of this interaction between density and competition for water, beyond the broad generalization that as the water status is improved, so can more plants share the supply without suffering stress".

Milthorpe (1961), as cited by Donald (1963), states the general principle that "the greater the amount of leaf growth made before plants come into contact with each other, the more extensive will be the root system and the less likely is the plant to suffer from drought. The higher the density, the smaller the plant at any time during ontogeny, and the higher the water content at which shortage of water is experienced."

Competition for light can become the main limiting factor in crop production when nutrients and water are provided in adequate supply. As stated by Donald (1963): "If there is a non-limiting supply of nutrients and water and if there are enough plants, then the yield will be governed by the growth form of the plants in the community and their capacity to intercept and use the light. When this limit is reached, the only means of increasing yield is to turn to a genotype with greater capacity to intercept and use light." With optimum light intensity, the plant community that is able to intercept solar radiation in the shortest period of time for more efficient use of light, while maintaining a minimum of intraplant competition with an adequate LAI (leaf area index) may give the higher crop growth rates.

2.2.- Plant Population - Yield Relationships in the Barley Plant.

The effect of plant density upon the growth and yield of barley has been extensively studied, especially by J.M. Kirby, who has dedicated ten years (1967-1977) of work to the subject matter.

Kirby (1967) studied the response of spring barley to plant density. Four cultivars were selected according to row number (2 row and 6 row types) and tillering capacity. There were four levels of plant density: 100, 200, 400 and 800 plants m^{-2}.

Plant density affected the yield and growth parameters of fundamental importance, namely: relative growth rate (RGR), harvest index (HI), leaf area index (LAI), net assimilation rate (NAR), leaf area duration (D) and the ratio of grain dry matter to leaf area duration (G).

Total dry matter was increased by a small amount (100 g m^{-2}) with increasing density, but grain yield declined sharply from a maximum obtained at an intermediate density (200 plants m^{-2}) to a minimum at the highest density.

The number of ears and spikelet number per unit area were increased in relation to increments in plant population, but spikelet number per ear, ear number per plant and weight per grain, all fell, responding in the opposite manner, in such a way that there was a mutual counterbalance among the components of yield, tending to compensate for plant density.

In general, it seems that 1000 - grain weight was the parameter more affected by plant density, falling from about 42 g in the lowest density to about 32 g in the highest. Therefore, in this experiment, it has been suggested that lower grain yields at high populations were caused by a reduction of the grain size during grain filling and not by a smaller size of the ear, "unless the size of the grain was determined before grain filling" (Kirby, 1967).

Although there was a small increment of total dry matter weight at high densities, it was not significant, indicating that maximum grain yield was obtained when the curve of total dry matter as a function of density became asymptotic. The reduction of grain yield may be explained by the harvest index (Donald and Hamblin, 1976) which was reduced from 0.42 at the widest spacing to 0.38 in the closest spacing. The reduction in harvest index may be the result of a depression in the RGR, mainly after ear emergence, where for the lowest seed rate there was a mean value of 0.43 g g^{-1} $week^{-1}$, while for the highest seed rate, it was only 0.25 g g^{-1} $week^{-1}$.

Thus, it seems clear that plant density reduced the capacity of the leaves for producing dry matter after anthesis and this was reflected mainly in a smaller grain size. However, further experiments upon the effect of plant population on grain yield (Willey and Holliday, 1971 a, b) have demonstrated that grain yield was unaltered by a drastic reduction of carbohydrate synthesis during the grain filling period, by means of a shading technique. Therefore, grain yield reductions in above-optimum populations are not entirely due to a deficient supply of assimilates to the ear during the period of grain filling. They may be explained in terms of pre-anthesis development of the ear, because shading effects during ear development reduced grain yield, along with 1000 - grain weight and in particular the number of grains per ear. The decrease in the weight of the grain suggests a possible reduction in the potential size of the subsequent grains at this stage.

If potential grain yield is determined at the ear development stage in barley, the number of grains per ear, and in consequence the number of grains per unit ground area, may be the most important determinant of yield (Willey and Holliday, 1971 a). A reduction in this parameter under high density conditions may lead to lower grain yields. This statement contradicts the conclusion of Kirby (1967) that 1000 - grain weight was responsible for reducing grain yields under high plant populations.

In a morphogenetic study, Kirby and Faris (1970) shed more light on this discussion because the most attention was paid to ear development in the main shoot of Proctor barley grown at different densities, ranging from 50 to 1600 plants m^{-2}.

Plant density affected leaf number, leaf size, stem and internode length, apex development and primordia production.

The number of fully developed leaves was reduced from 10.2 in the 50 plants m^{-2} treatment to 8.0 in the highest density.

Under high populations the lamina and the sheath lengths of the lower leaves were increased, and lamina width was decreased.

At high densities, stem elongation started earlier and absolute growth rates were lower. The final stem length was reduced because growth finished earlier.

The apex development was faster in the high density treatments, reaching the double ridge stage six days earlier in the highest density treatment.

The rate of primordium production was little affected by density, but primordium production stopped first in the 1600 plants m^{-2} treatment.

The sudden end of primordium production in the high density treatments, which resulted in shorter ears, was probably due to morphological deficiencies of the apex and high concentrations of gibberellic acid in the tissue; the high levels of gibberellins promoted earlier growth and earlier competition for nutrients, which were limited by a poorly developed vascular tissue, resulting in starvation and death of the apex tip. (Kirby and Faris, 1970).

In the context of searching for interactions between cultivar and plant density, the experiments described above have shown that barley plant is highly susceptible to variations in plant density changing its morphology and adapting to different environments. The data from these experiments indicate that an explanation of the decrease in yield at high populations is to be found within the relationship of the yield components to grain yield, mainly 1000 - grain weight and grains per ear; now we know that a barley plant adapted to high density must have a large ear, which appears as the most sensitive structure to plant density; yet until to now, little has been said about the relationship between other morphological features of the barley plant and plant density, such as tillering habit and leaf disposition.

For instance, Finlay et al. (1971) studied the effect of seeding rate on yield of different cultivars of barley. The cultivars were selected on the basis of their morphological distinction and yielding ability. Cultivars with erect leaves were compared to plants with droopy and wide leaves.

Results of the experiment showed that differences in cultivar morphology were related to different responses of the yield components but not to differences in yield, i.e., erect-leaf types produced an increased number of ears per unit area, together with a reduced number of grains per ear, in comparison to their droopy leaved equivalents.

Although erect-leaved types were unrelated to higher yields, it seems that they may be more adapted to crowded plant populations (Donald, 1968).

In relation to tillering habit, from an agronomic point of view it has been generally considered as a favourable characteristic, especially under conditions where good plant establishment is doubtful and tillering may be an advantageous source of extra-tillers for failures. However, Donald (1968) has suggested that under very specific conditions, i.e., highly controlled environments and an adequate plant stand, the normal tillering plant may be surpassed by a non-tillering type of plant.

Following this direction, studies of Cannell (1969 a), Kirby and Faris (1972), and Kirby and Jones (1977) have been focused on the tillering pattern in barley cultivars and its relationship to the rest of the yield components.

Cannell (1969 a) found that the proportion of grain yield contributed by the main stem ear was as much as 20 - 25% higher than that by any of the tillers and about 51.6% of the total grain yield under low nitrogen conditions (28 Kg N ha^{-1}), but only 25.9% in high nitrogen fertilization (88 Kg N ha^{-1}).

The second most important culm was the first tiller in the axil of the first true leaf, which produced 26.7% of the total grain yield and was unaffected by nitrogen fertilization. In addition, the main shoot ear had the highest grain weight, a higher number of grains and the heaviest grain, followed by the first tiller ear.

According to these results, one may consider the rest of the tillers as unnecessary and Cannell (1969 a) discussed the desirability of uniculm cultivars, concluding that single stalked plants may not be desirable on the basis of their extremely difficult management for successful grain production.

Kirby and Faris (1972) reported two phases in the tiller development of barley grown at different densities. In the early stages of growth, or first phase, the effect of interplant competition was not evident. Tiller bud formation was unaffected by high density; in other words, five tiller buds were formed in the high density planting (1600 plants m^{-2}) from a maximum of six, in the lowest density (50 plants m^{-2}).

The second developmental phase, when a tiller appeared above the subtending leaf sheath, was affected by plant density. In the 50 plants m^{-2} treatment, 92% of the formed buds produced a tiller, while this percentage was lowered to 83% in the 100 plants m^{-2} population, 66% for 200 plants m^{-2} density, 52%, 34% and 19% in the 400, 800 and 1600 plants m^{-2} treatments, respectively.

The tiller buds initiated in the first phase consumed assimilates and minerals produced or absorbed in other areas of the plant, because they were not capable of performing photosynthesis or competed for light (Rawson and Donald, 1969). At the time these tillers are growing, the apex of the main shoot is producing primordia at a very high rate (Kirby and Faris, 1970), destined to form spikelets, and a competition for minerals and assimilates may be established. Later on, when the buds are transformed into tillers, they may still receive assimilates exported from the main shoot and this may affect the rate of transpiration in the whole plant.

A number of the formed tillers die at an early stage, without bearing any ear, thus all the plant resources used to promote the growth of these young and unproductive tillers may be considered as wasteful.

2.3.- The Concept of Ideotype.

Donald (1968) proposed a wheat plant ideotype, suitable for densely populated communities. His model was conceived as a single-stalked or uniculm type, among other characteristics. This advocacy for the uniculm plant is based on the interrelationships between a genotype, its competitive ability and the environment. That is, for this specific "ideal" genotype, it is expected to exploit with high efficiency the environmental resources with a minimum of intra and interplant competition in a densely populated community for higher grain yield and for greater grain quality.

Furthermore, the ideotype should be able not only to produce higher total dry matter yields, but it must also be capable of giving higher harvest indices. The successful cultivar should increase biological yield at high density or fertility with a good capacity to maintain a high harvest index (Donald and Hamblin, 1976).

The model proposed by Donald (1968) was idealized for a highly favourable environment and was supported by a considerable theoretical knowledge and experimental evidence. Such a model should comprise several features:

1.- Short, strong stem.- Under high fertility conditions, the presence of a short stem is desirable in order to avoid lodging and should be resistant enough to stand wind force.

2.- Erect leaves.- Non-drooping leaves may allow more efficient use of the incident light in dense communities. In barley, this was demonstrated by Angus et al. (1972) who found greater photosynthetic efficiency in cultivars with erect leaves, especially at high densities. Similar conclusions were reached by Tanner et al. (1966), who found a strong association between high yields and erect leaves among barley and other small-grain plants.

3.- Few, small leaves.- Theoretical considerations have postulated that populations adapted to high fertilizer applications and perhaps high density, tend to have smaller leaves; in addition, smaller leaves tend also to be erect in comparison with larger leaves, which are more likely to be curved downward. It is possible too, that small leaves present a reduced surface for potential transpiration.

Hamblin and Donald (1974) found a strong relationship between grain yield and shorter leaves, under community conditions, especially at high nitrogen level.

4.- Large ear.- Larger ears are related to higher harvest indices. Heavy ears are especially important for the uniculm plant, being unable to produce tillers; ear size is the only phenotypic adaptation to adverse environmental conditions.

5.- Erect ear.- Drooping ears may be less efficient for light interception.

6.- Presence of awns.- There is ample experimental evidence that supports the presence of awns on the ear. Biscoe et al. (1973) found the presence of awns more important in barley than in wheat. The larger barley awns were responsible for about 35% of the total photosynthesis of the ear. Johnson et al. (1975) also reported an increased rate of net photosynthesis for awned ears.

7.- Single culm.- Some possible advantages of the uniculm cereal plant have been already discussed in this review. The principal aspects of intra-plant competition in barley have been considered.

Of course, not everything may be considered advantageous in the model presented here. The environmental conditions in which the ideotype is going to grow must present several conditions that fit the specific requirements of the plant for maximum yield response. For instance, the planting density should be increased, the amount of fertilizer has to be higher; the uniculm is unable to compete efficiently with weeds; it is more susceptible to frost or drought conditions; finally and perhaps the most important, the water supply should guarantee a uniform and dense plant stand because the model being unable to produce tillers, has lost the plasticity of the multiculm plant. Yet in the long term, the uniculm ear could have a greater plasticity, and then it could replace the role of the tillers in adaptation to a range of seasonal limitations (Donald, 1968).

2.4.- The Barley Ideotype.

Many, if not all, of the wheat ideotype features could be translated to the barley plant, keeping in mind that the physiology of barley resembles that of wheat (Thorne, 1966). In fact, there is a considerable number of cereal workers involved in the development of a successful barley ideotype, which does not differ much from the model described. Klinck (1967), Fiddian (1967), and Reid and Wiebe (1968) among others, have suggested the advantages of a single stalked barley cultivar, called "uniculm" by R. G. Shands (as cited by Klinck, 1967), who obtained the Kindred type of uniculm after seed irradiation of the normal cultivar.

Klinck (1967) reported important advances in the controlled evolution of this new type, by means of plant breeding. After several crosses and careful selection, a number of uniculm plants with improved agronomic characteristics over the parental uniculm type, were obtained. The original uniculm Kindred exhibited several undesirable features in its morphology, such as an abnormal head, mainly, in which large segments produced no seed. In his work, Klinck discussed the usefulness of the new cultivar in comparison to the multiculm barley, in which, as it was mentioned before, useless tillers may interfere with the full development of the main head.

In order to prove this last assumption, a uniculm barley cultivar (a mutant of Proctor, produced in 1951 in the Plant Breeding Institute, Cambridge) was tested in the field against the multitillered Proctor spring barley (Kirby, 1973 a). The technique was an analysis of growth in which detailed measurements of the main shoot, leaf, internode and ear development were made. In addition, the number of primordia was counted, recording the shoot apex stages of development as well.

Both uniculm and multiculm Proctor are of similar genotype, differing only by a single recessive gene that supresses tillering (Kirby, 1973 a).

The results showed that uniculm barley produced higher growth rates and in consequence greater final size. The absence of competition in uniculm, from secondary shoots, was expected to affect not only the vegetative development but the ear size as well. However, the ears of the two genotypes did not differ in relative growth rate and it was assumed that the lowered growth rates of uniculm during the grain filling period were due to the abnormal development of the ear, abnormalities that were expressed by severe reductions in the number of spikelets.

In this case, the inability of the uniculm Proctor to produce spikelets did not allow to establish comparisons.

A further study on the development of uniculm barley, (Kirby, 1973 b) revealed that uniculm ears were affected by high temperatures. In these experiments a Kindred uniculm (Klinck, 1967) was included and the main objective was to determine the nature of the abnormal plants. The material was treated with different photoperiods and temperatures, (both suggested as promotors of abnormalities). The degree of abnormality ranged from almost normal plants to several morphological aberrations, i.e.:

1.- Three nodes with opposite spikelets.

2.- Supernumerary parts. Two complete spikelets occupying the median spikelet position.

3.- Branched rachis.

4.- Bare nodes. Nodes in the rachis with no spikelets.

5.- Twin florets. Two florets in one spikelet.

6.- Abnormal rachilla.

7.- One-ranked spikelets. Normal spikelet triplets at each node, but only on one side of the rachis.

8.- Collar-like abnormality.

9.- Aborted apex. Apex ceassed growth after formation of the last leaf.

10.- Tubular leaf. The flag leaf presented fused margins surrounding the ear.

The plants were grown in constant-environment rooms at 7, 17 or 26°C under constant illumination. The degree of abnormality was increased in each temperature treatment, ranging from 33% to 100%.

The induced abnormalities resembled the damage caused by 2, 4-D (2,4-dichlorophenoxyacetic acid) and the effects were related to a temperature sensitive change in the IAA (indol-3 yl-acetic acid) metabolism of the plant associated with the uniculm characteristic (Kirby, 1973 b).

Up to now, research work on barley had been unable to demonstrate in practice the primary hypothesis formulated years before (Klinck, 1967; Donald, 1968) in which it had been stated that cultivars bearing only one productive head, with no interference from secondary tillers, should be capable of giving higher grain yields.

An alternative methodology to support that hypothesis was established by Kirby and Jones (1977), in which the effect of tiller growth on the growth and the final size of the main shoot was assessed.

At an appropriate stage of development, primary tiller buds of Proctor barley were removed by surgical methods. In other experiments the main shoot was removed from the embryo and the size of the coleoptile tiller was measured.

When the developing tiller buds were removed, the rate of leaf emergence and the number of leaves were greater in the main shoot; dry weight of the main shoot also was increased two fold and the main shoot grain dry weight exceeded that of the control (untouched plant) by about 35%. The number of grains on the main shoot was greater by about 21% in the detillered plants and the grains were heavier as well.

When the main shoot apex was removed, the coleoptile tiller resembled the growth of the main shoot, having more leaves and more spikelets than the control plant coleoptile tiller.

The major conclusion from this work is the proof that unproductive tillers, i.e., tillers with no ears, may compete with the main shoot at early stages of development when the formation and growth of tiller buds is little affected by plant density (Kirby and Faris, 1972). Therefore, even at high densities, when the tillering survival may be affected, those tillers that die early "and make no contribution to the final grain yield", should be considered as "wasteful" and their production "may reduce the final grain yield" (Kirby and Jones, 1977).

3.- MATERIALS AND METHODS

Two field experiments (1 and 2) were carried out at the Macdonald College Agronomy Research Station (Lat. 45° 26' N, Long 73°56' W) during 1977 and 1978, respectively.

Experiment 1 was sown on a well-drained clay loam soil (range 604) in the spring of 1977. Experiment 2 was planted on a sandy loam (range 927) in the spring of 1978. The sites were prepared according to normal agricultural practice and received basal dressings of 340 Kg ha^{-1} of 5-10-10 commercial fertilizer.

Some details of the rainfall pattern, for 1977 and 1978 are given later in figure 3.1. In both years, May and July were below "normal". May 1977 was considered as an extremely dry month and July 1978 may be considered as just a dry month. In May 1977, the precipitation was the lowest in ten years and only 33% of the "normal" rainfall.

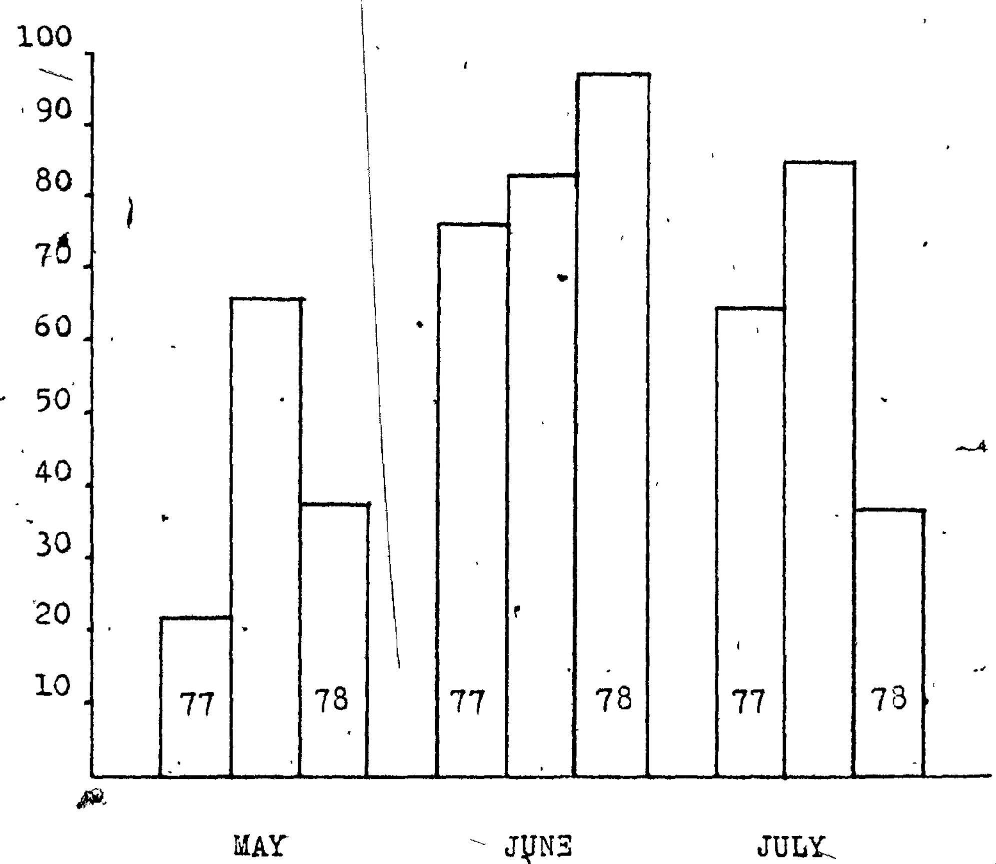

Figure 3.1.- Rainfall pattern in 1977 and 1978, as compared to the average. (mm).

3.1.- Experiment 1.

3.1.1.- Cultivars.- Five cultivars (six row type) of spring barley (<u>Hordeum vulgare</u> L.), differing in yielding ability, tillering capacity and morphological characteristics were selected for this study. Cultivar names and some of their features are presented in the Table 3.1.

Table 3.1.- Characteristics of cultivars used in Experiment 1.

Cultivar	Tillering capacity	Yielding ability at normal density
Q.B. 59.28	nil	low
Q.B. 60.2	nil	low
Laurier	medium	high
Loyola	medium	high
Conquest	high	medium

The seed of all cultivars was tested under greenhouse conditions for germination and emergence ability in boxes containing a mixture (V/V) of soil (3), peat moss (1), sand (0.5) and perlite (0.5). The results of the test showed that 96% of the seed germinated well; therefore, the seed was considered as of good quality.

3.1.2.- Treatments and Design.- The cultivars were studied at three plant populations. The expected plant densities, assuming 100% of seedling emergence, were 170,250 and 500 plants m^{-2}. These plant populations were calculated according to the weight of 1000 grain samples, randomly extracted from each cultivar seed lot, and the precise number of seeds per row was attained.

In the field, different plant populations resulting from changing the distance between rows from 30 cm (170 plants m^{-2}), to 20 cm (250 plants m^{-2}) and 10 cm (500 plants m^{-2}), keeping constant the plant number within the row at 2 cm distance from each other.

Three levels of nitrogen, 0, 34, and 68 Kg ha^{-1}, in the form of ammonium nitrate were studied.

The treatments were laid-out in a split-split-plot experimental design, with nitrogen levels as main plots, plant densities as sub-plots and the cultivars as sub-sub-plots. The sub-sub-plots were of 3.8 m x 1.2 m of surface. There were three replicates.

The plots were sown from April 29 to May 1 by a hand-operated, modified cone seeder and the nitrogen application was done at the three-leaf stage of growth, with a Planet Junior seeder.

Weed-control was done by hoe in the 30 cm row-spaced plots and by hand in the intermediate and densest treatments. However, some weeds were present in the experiment, especially in the medium density. This problem in the field forced elimination of the intermediate plant populations from the discussion.

At the end of the growing season, when the plants were fully ripe (with no green coloration), 2 m^2 from each sub-sub-plot were harvested by hand, pulling out the plants carefully. A 1000 cm^2 sample was separated from the 2 m^2 harvested plot for some calculations. As soon as possible, all the harvested material was placed in a hot-air dryer at 60° C.

The data collected in this experiment included:

1.- Number of days from planting to heading, (when 50% of the culms in each plot had visible ears).

2.- Number of plants per square meter.

3.- Number of tillers per square meter.

4.- Ear number per square meter.

5.- Number of ears per plant.

6.- Number of tillers per plant.

7.- Total above ground dry matter weight (biological yield) in grams per square meter.

8.- Grain yield (economical yield). Expressed in grams per square meter.

9.- Thousand-grain weights.

10.- Number of grains per ear, (estimated from the grain yield divided by number of ears per square meter, divided by mean grain weight).

11.- Number of grains per square meter.

12.- Harvest index.

Points 2 to 6 were counted from the 1000 cm^2 sample. The data was statistically analyzed by an electronic computer, using the SAS package.

3.2.- Experiment 2.

3.2.1.- Cultivars.- Three cultivars (six row type) of spring barley, Laurier, Q.B.60.2 and Q.B.59.28, were selected for study on the basis of their performance in the field (previous experiment).

The seed was tested for germination capacity using the method reported for experiment 1, and the results showed a good (95%) percentage of germination.

3.2.2.- Treatments and Design.- The cultivars were studied at three plant populations, and assuming 100% of seedling emergence, they were as follows: 250, 500 and 1000 plants m^{-2}, respectively. The plant populations were calculated in accordance with several seed rates using the same procedure described previously (experiment 1). However, in this experiment the distances between rows were from 20 cm (250 plants m^{-2}) to 10 cm (500 plants m^{-2}) and 5 cm (1000 plants m^{-2}).

Three nitrogen dosages, 0, 34 and 68 Kg ha^{-1}, were applied to the soil again and their effect on the growth and yield of barley was assessed.

The experiment was laid-out in the field as was described previously (experiment 1), but with four replicates.

The plots were planted from May 11 to May 14, as described before (experiment 1), except that this year a wooden frame with aluminum rails was especially built in order to improve the seeding. The cone-seeder machine was placed on the rails and the frame was moved each time to the following row. This procedure allowed a highly precise distance between rows, and at the same time the machine-operator always walked on the frame boards, causing no damage to the seedbed. Also, the machine was smoother in its operation because the wheels ran on the rails instead of on the ground.

The nitrogen was applied by hand, as soon as the plants within the rows were visible.

In 1978, weed-control was done by herbicide (418 g ha^{-1} of 2,4-D). A very accurate broad-leaf weed control was obtained and the remaining weeds were eliminated by hand.

No weed interference was observed in this experiment.

At maturity, plots of 2 m^2 were divided in two portions, one of them with 2000 cm^2 was selected at random and harvested by hand, the plants being pulled carefully and placed in cotton bags. The greater portion was cut with a sickle and the harvested material bagged separately from the sample. As soon as possible, the material was stored and treated as described before (experiment 1).

The data collected in experiment 2 comprised:

1.- Number of days to heading.

2.- Plant height. Measured as the mean height between the lowest and highest ears from the central portion of the plot.

3.- Number of plants per square meter.

4.- Number of tillers per plant.

5.- Number of ears per plant.

6.- Number of tillers per square meter.

7.- Number of ears per square meter.

8.- Total above ground dry matter weight (biological yield), measured from the total plot and expressed in grams per square meter.

9.- Grain yield (economical yield). Measured from the whole plot and described in grams per square meter.

10.- Thousand-grain weights.

11.- Number of grains per ear (calculated as described before in experiment 1).

12.- Number of grains per square meter.

13.- Harvest index.

Variables 3 to 7 were estimated from the 2000 cm^2 sample. The data was statistically analyzed as described elsewhere (experiment 1).

4.- RESULTS AND DISCUSSION

4.1.- Experiment 1.

4.1.1.- Plant Number.- This experiment was severely affected by very dry weather, during the initial stages of growth in May. Seed germination was reduced by deficient moisture and the expected number of plants, assuming 100% seed germination, for the different plant densities was consequently inferior. Plant establishment was especially affected in plots with higher seed rates, where approximately 49% of the planted seeds failed to emerge, whereas 30% and 14% were observed in the 20 cm and 30 cm spaced row plots, respectively.

In Figure 4.1 and Table 4.1 are presented in detail, some of the characteristics describing this situation in the field.

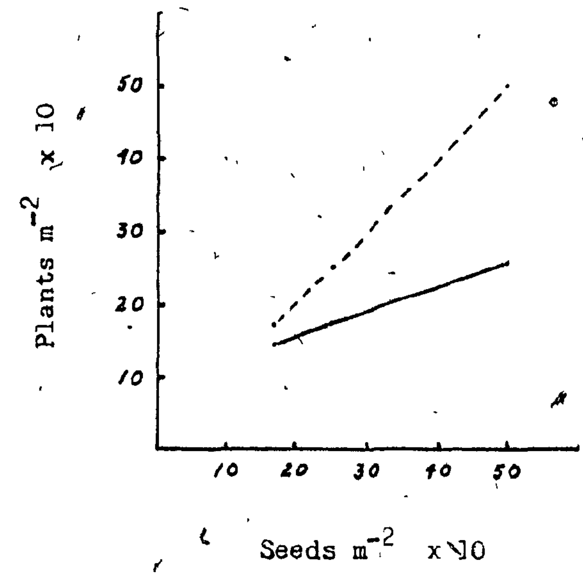

Figure 4.1.- Number of expected plants (m^{-2}), -----; actual number* of plants at maturity (m^{-2}), ———; and number of seeds (m^{-2}).

*Means of five cultivars, three levels of nitrogen and three replicates.

Table 4.1.- Mean* seed rates, seed density, mean** plant establishment, mean** plant density (at maturity) and row spacing.

SEED RATE Kg ha^{-1}	SEED DENSITY seeds m^{-2}	ESTABLISHMENT percentage	PLANT DENSITY plants m^{-2}	ROW SPACING cm
84	170	86.5	147	30
126	250	70.0	175	20
252	500	51.4	257	10

*Mean of five cultivars, calculated on the basis of 1000 - grain weights.

**Mean of five cultivars at three levels of nitrogen and three replicates.

The levels of significance for the various treatments and interactions of some crop parameters are shown below in Table 4.2.

Table 4.2.- Variance ratios of the main treatments and interactions for some of the crop parameters under study in Experiment 1.

Source of Variation	Plants per m^2	Ears per Plant	Grains per Ear	1000 Grains Weight	Grains per m^2	Total D.Matter Yield	Grain Yield
Nitrogen (N)	0.98	1.26	0.07	0.23	1.36	1.91	1.12
Plant Density (D)	37.40**	23.33**	5.98*	29.42**	4.48*	1.70	4.15*
N x D	5.29*	1.46	2.25	0.48	0.86	0.09	0.30
Cultivar (C)	2.92*	22.67**	14.49**	96.17**	86.83**	45.75**	82.93**
N x C	1.16	1.24	1.16	2.62*	1.10	1.33	1.24
D x C	0.27	4.33**	2.71*	1.59	7.40**	5.42**	8.32**
N x D x C	0.79	0.45	1.61	0.95	1.99*	1.82*	1.96*

*Significant at 0.05 level.

**Significant at 0.01 level.

According to Table 4.2 the significant value for the density treatment, indicates that there was a significant difference among the three plant densities. The Duncan's New Multiple Range Test (DNMRT) at the 5% probability level, (Appendix, Table 1) showed that the difference was established mainly between the highest plant population (257 plants m^{-2}) and the lowest one (147 plants m^{-2}). On the other hand, a non significant difference was found between the lowest density and the intermediate density (175 plants m^{-2}); therefore, in this discussion, for the most part only two levels of plant density (147 and 257 plants m^{-2}) will be considered.

Also, the analysis of variance for the variable PLANT NUMBER, Appendix, Table 1, showed a significant interaction between nitrogen and plant density. This interaction was found linked to the intermediate density.

The unexpected and undesirable significant value for cultivars and after the DNMRT at the 5% level was done, indicated that Q.B.59.28 had an inferior number of plants in comparison to the other cultivars (Appendix, Table 1). Only 54% of the seed planted for Q.B.59.28 produced plants. For this reason, the discussion will be centered mainly on Laurier, Loyola, Conquest and Q.B.60.2.

4.1.2.- Tiller Number

4.1.2.1.- Tillers per Plant. Although N increased slightly the mean number of tillers per plant, the differences were not significant (Appendix, Table 2).

However, this variable was significantly affected by plant density. The number of tillers per plant was reduced in general (considering the means of five cultivars and three levels of nitrogen) from 0.88 in the lowest density to 0.42 tillers per plant in the highest density.

At all densities, Conquest produced the largest number of tillers (Appendix, Table 2). In general, Conquest gave 1.29 tillers per plant, significantly more than Laurier (0.98) and Loyola (0.93). Nevertheless, the cultivars had significant differences only at the lowest density. Under more severe competition (highest density), no significant differences were detected and the numbers were 0.89, 0.60 and 0.59 for Conquest, Loyola and Laurier, respectively (Appendix, Table 2).

A great portion of tillers produced at the lowest density, did not produce any ear, and this could have reduced the total grain yield of a plant. It has been established (Kirby and Jones, 1977) that tillers which do not contribute to the final grain yield may be regarded as wasteful and in consequence, may reduce the grain yield. A great production of tillers in plants at wider row spacing can be considered as an advantageous feature, yet only up to a certain point, in which excessive tillering may be undesirable.

In this study, Conquest was more exhuberant in its tillering than other cultivars, however, the higher grain yields were found elsewhere.

Figure 4.2 may give a better idea of the relationships between plant density and tiller production.

These results coincide with previous work done by Kirby (1967), in which the number of tillers per plant in barley, was reduced by increased plant density.

4.1.2.2.- Tillers per Square Meter.- Heavier applications of N in the soil increased significantly the number of tillers m^{-2} (Appendix, Table 3) from a mean number of 87.33, obtained at the lowest level of N (0 Kg N ha^{-1}) to 122.22 when the highest level of N (68 Kg N ha^{-1}) was added to the soil. All these differences were detected on basis of the DNMRT at the 5% level and considering five cultivars at three plant densities.

There was no significant difference in the number of tillers between the highest and the lowest densities; the number of plants compensated for supressed tillering

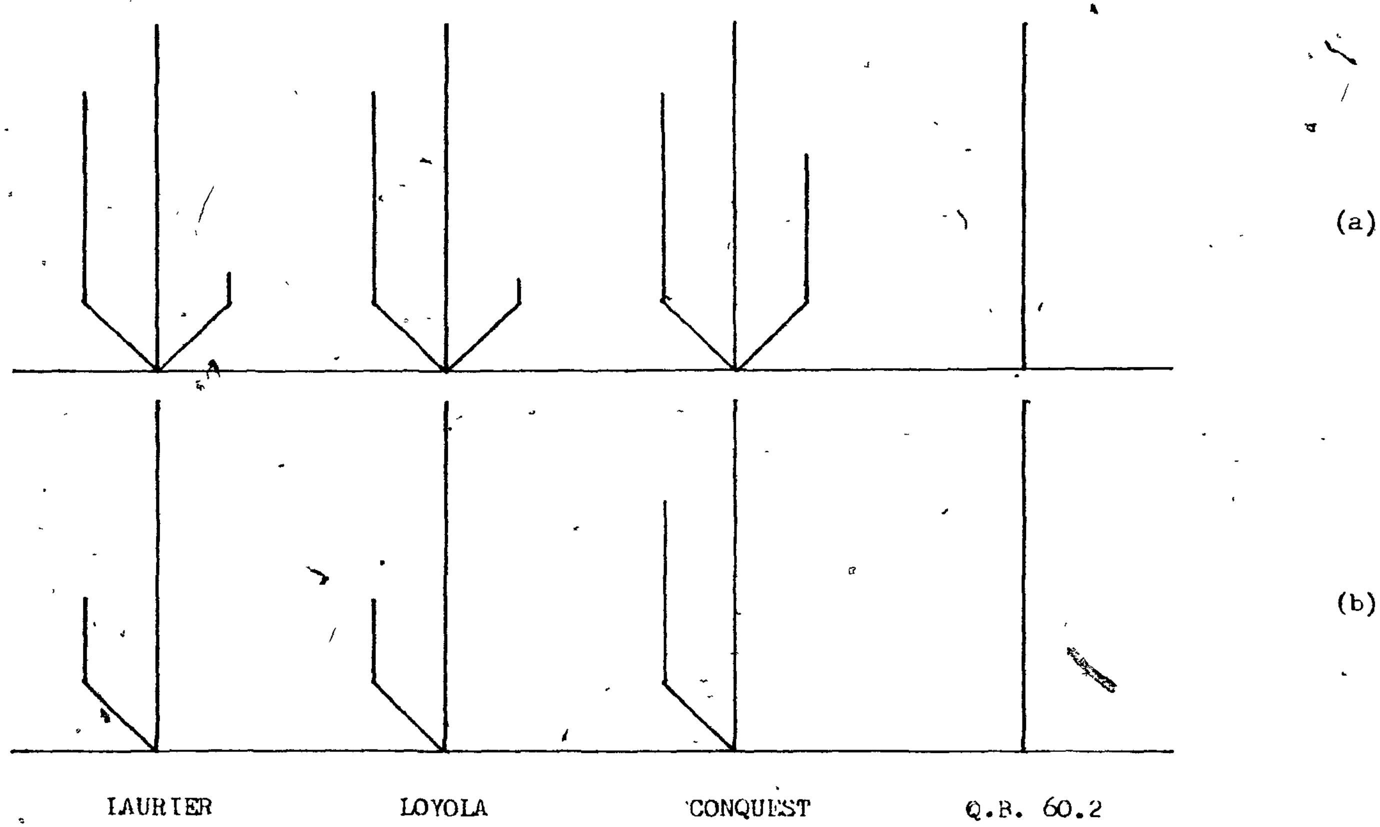

Figure 4.2.- Effect of plant density (a, lowest density; b, highest density), on the number* of tillers per plant of Laurier, Loyola, Conquest and Q.B.60.2.

*Means of three levels of nitrogen and three replicates.

in the higher population and viceversa; nevertheless, the mean tiller number was higher in the wider spacing, with 124.09 and lower in the densest populated plots, giving 106.99 tillers per square meter.

In general, Conquest has the largest mean number of tillers per plant. Thus, the maximum number of tillers per unit of ground area, was attributed to Conquest. This cultivar produced 226.70 tillers, significantly more than Laurier (160.00) and Loyola (150.40). Of course, the uniculm cultivars, Q.B.60.2 and Q.B.59.28 did not produce any tillers.

The interaction D x C showed no significance. However, a DNMRT was done and produced significant results. At higher densities still Conquest produced more tillers than any other cultivar, with 235.55; in second place Laurier and Loyola with 163.75 and 130.00, respectively; at the lowest density there were no significant differences and all cultivars, with the exception of the uniculm, produced the same number of tillers, ranging from 193.33 to 241.11 tillers m^{-2} (Table 4.3).

Table 4.3.- Duncan's New Multiple Range Test for the comparison of cultivar means* for number of tillers m^{-2} at two densities.

Cultivar	147 plants m^{-2}	257 plants m^{-2}
Conquest	241.11 a	235.55 a
Laurier	193.75 a	163.75 b
Loyola	193.33 a	130.00 b
Q.B.60.2	0.00 b	0.00 c

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and three replicates.

4.1.3.- Days to Heading.- Ear emergence was not significantly affected by nitrogen fertilization (Appendix, Table 4); however, in the plots in which the higher rate of N was added, the plants showed a slightly earlier ear appearance.

Though a non significant effect on days to heading was detected for plant densities, the higher populated plots had earlier ear emergence.

The only significant difference found was that for cultivars. Q.B.59.28 was the earliest cultivar, heading in 53.48 days, and was significantly different from Conquest (54.59 days) and Laurier (54.96). The most tardy cultivars were Q.B.60.2 (55.37 days) and Loyola (58.18 days).

4.1.4.- Ear Number

4.1.4.1.- Ears per Plant.- The analysis of variance (Appendix, Table 5) for this variable showed a significant value for the effect of plant density. Increased plant density produced a consistently lower number of ears per plant from 1.45 to 1.24 to 1.08 at 147, 175 and 257 plants m^{-2}, respectively.

In general, the cultivars had almost the same number of ears per plant, in spite of the especially high number of tillers per plant observed in Conquest; however, this cultivar had the largest number of ears per plant. The differences among cultivars within plant density are shown in the Table 4.4.

Table 4.4.- Duncan's New Multiple Range Test for the comparison of cultivar means* for number of ears per plant at two densities.

Cultivar	147 plants m^{-2}	257 plants m^{-2}
CONQUEST	2.00 a	1.16 a
LAURIER	1.67 b	1.13 a
LOYOLA	1.62 b	1.12 a
Q.B.60.2	1.00 c	0.98 a

Means within columns followed by the same letter are not significantly different at the 0.05 probability level.

*Means of three levels of nitrogen and three replicates.

Under conditions of high density (257 plants m^{-2}) the cultivars produced a similar number of ears per plant and the differences were not significant, resembling a uniculm plant in ear number. Figure 4.3 represents some morphological characteristics of the cultivars at different densities.

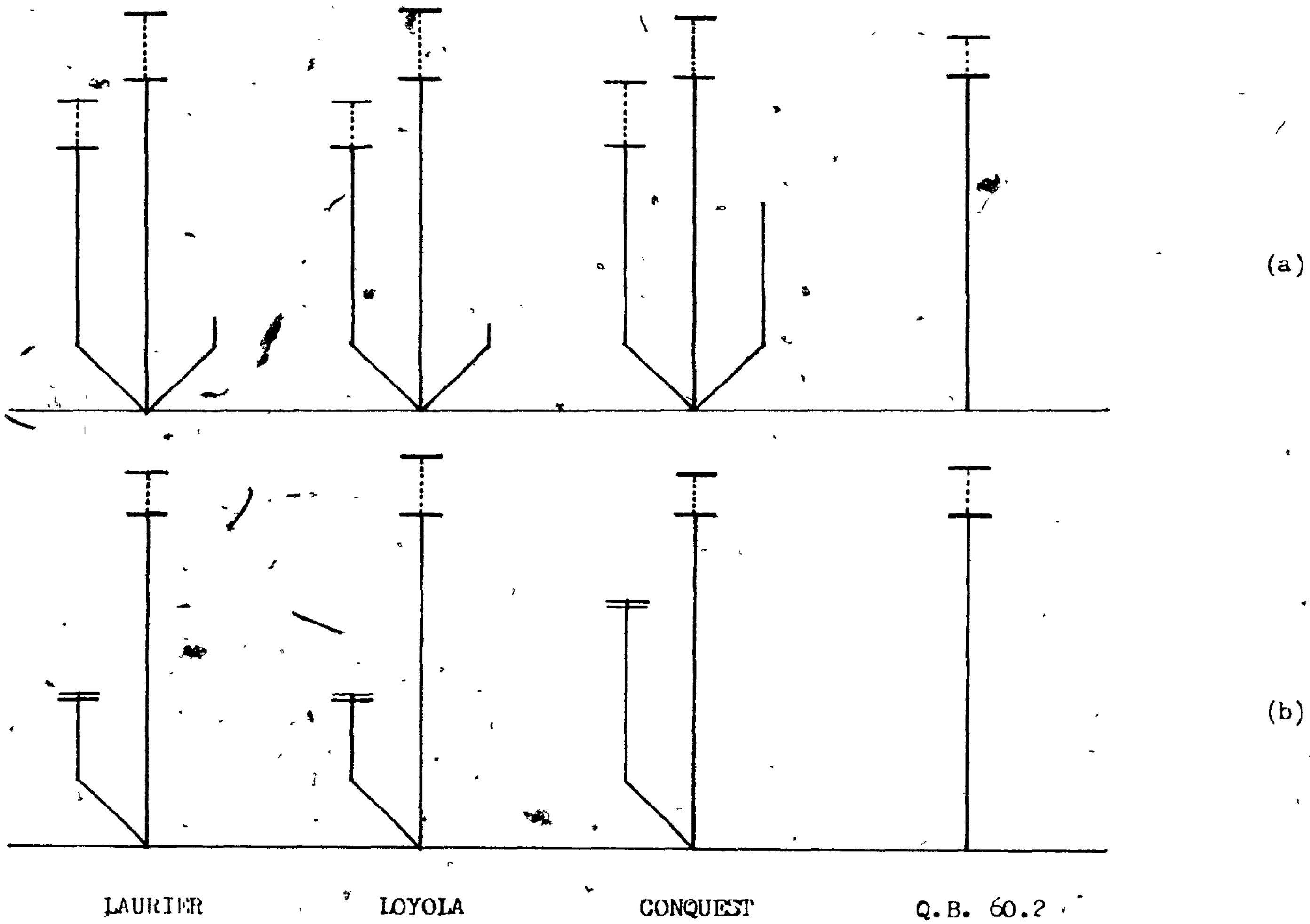

Figure 4.3.- Effect of plant density (a, lowest density; b, highest density), on the number* of ears per plant of Laurier, Loyola, Conquest and Q.B.60.2

*Means of three levels of nitrogen and three replicates.

The effects of N on this variable were not significant. Nevertheless, in the present study, the number of ears per plant was slightly increased by the highest dosage of fertilizer.

4.1.4.2.- Ears per Square Meter.- In correspondance with Kirby (1967, 1969), Willey and Holliday (1971) and other workers, (see Literature Review), the final number of ears per unit of ground area was increased with increasing plant density. In general, this number was up to 276.50 in the densest treatment, while 210.23 ears m^{-2} were counted for the lowest density. The analysis of variance for this parameter showed the difference as significant (Appendix, Table 6).

Conquest was detected as the maximum producer of ears m^{-2} with 287.00, as a consequence of its higher number of ears per plant at all densities.

In second place, Laurier and Loyola produced a significant equal number of ears with 262.40 and 246.30, respectively. Q.B.60.2 and Q.B.59.28 were the lowest with only 190.00 and 164.60, respectively.

Although the nitrogen effect was not significant, in general, heavier dosages of N increased the number of ears m^{-2} in all densities. However, the significant interaction of N x D, indicated after the DNMRT was done, that at the medium application of N (34 Kg ha^{-1}) the ear number was depressed in the highest density and the ear number between highest and lowest densities was only significantly different at the lowest and highest applications of nitrogen. This may be interpreted as an effect of the low levels of soil moisture in the densest treatment. However, in all densities the ear number was increased by the highest level of nitrogen.

Figure 4.4 represents the effects of plant density on the number of shoots m^{-2}, number of ears m^{-2} and number of tillers m^{-2}.

4.1.5.- Grain Number.

4.1.5.1.- Grains per Ear.- The variance analysis (Appendix, Table 7) for this parameter showed that the number of grains per ear was significantly affected by plant density. Previously, it has been established that an increase in number of ears per unit of area is generally associated with reductions in ear size, (Kirby, 1967, 1969; Willey and Holliday, 1971).

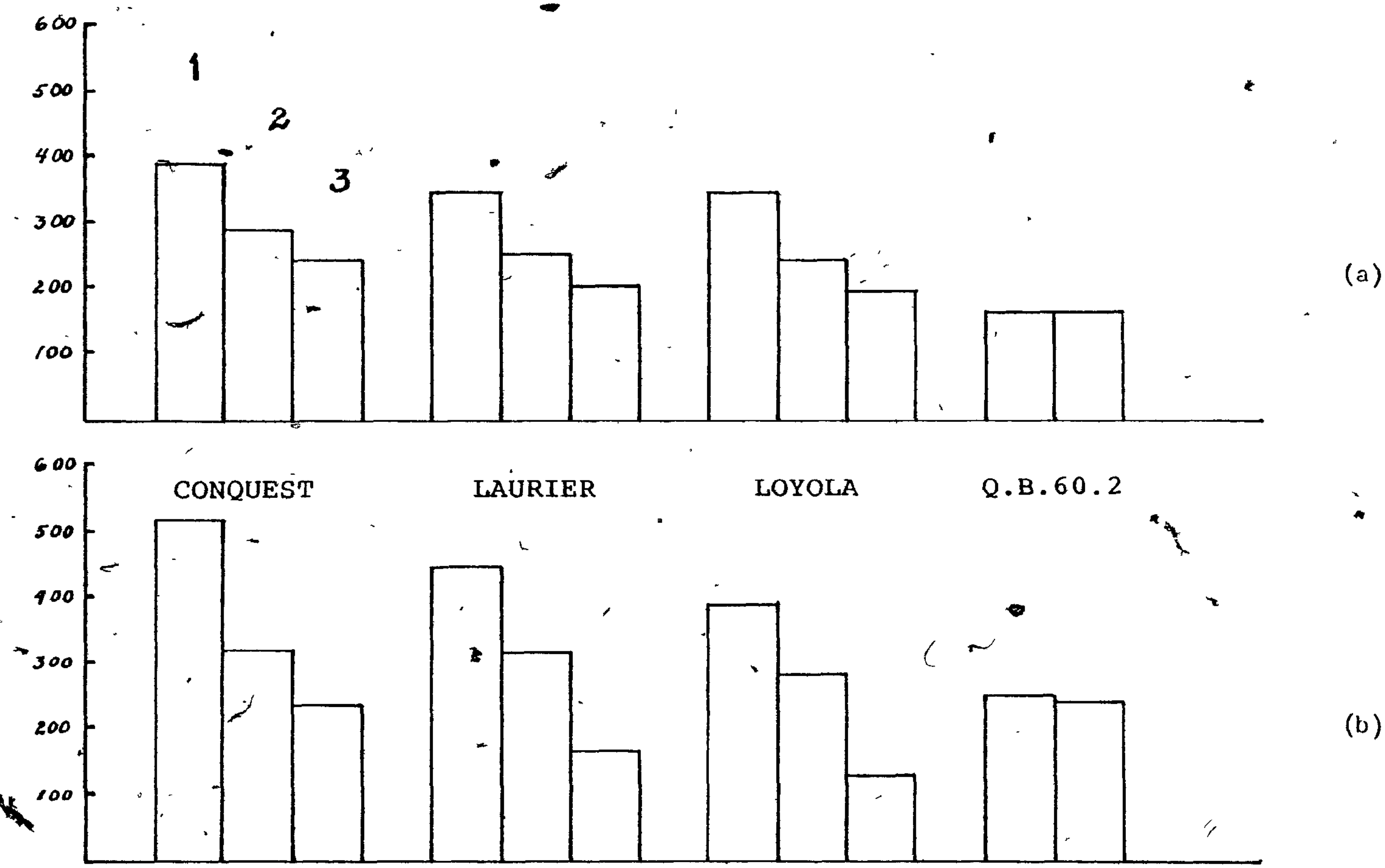

Figure 4.4.- The responses in the number* of shoots per square meter, 1; number of ears per square meter, 2; and number of tillers per square meter, 3, of the cultivars to the lowest density, (a), and the highest density, (b).

*Means of three levels of nitrogen and three replicates.

In this experiment, this variable, an important yield component, was reduced in general from 17.57 in the 147 plants m^{-2} treatment to 16.00 in the 175 plants m^{-2} density and 14.44, when the plant density was 257 plants m^{-2}, being significantly different only in the former and the latter.

For cultivars, a significant difference was evident, in general, for Loyola, the largest producer of grains per ear (Table 4.5).

Table 4.5.- Duncan's New Multiple Range Test for the comparison of cultivar means* for number of grains per ear at two densities.

147 plants m^{-2}		257 plants m^{-2}	
Loyola	21.35 a	Loyola	17.79 a
Laurier	20.03 a	Q.B.60.2	15.10 a, b
Conquest	19.11 a	Conquest	13.17 b
Q.B.60.2	13.27 b	Laurier	12.90 b

Means within columns followed by the same letter are not significantly different at the 0.05 probability level.
*Means of three levels of nitrogen and three replicates.

Under the lowest density all cultivars produced a similar number of grains per ear, except Q.B.60.2, which was lower than Loyola by about 38%; however, at the highest density only Loyola and Q.B.60.2 had equal number of grains per ear, and furthermore, these cultivars were the only ones which maintained a significant similar number of grains when the DNMRT was applied in the comparison of both densities within each cultivar.

The small increase in grain number per ear accounted for by Q.B.60.2 at the highest density, despiting the plant density effect observed for the other cultivars, may be partially explained on the basis that the uniculm plants in barley present a greater degree of ear abnormalities (see Literature Review) at lower densities (Badra, 1978, personal communication), which affects the grain number.

4.1.5.2.- Grains per Square Meter.- In conformity with the analysis of variance (Appendix, Table 8), for this parameter, a highly significant interaction of plant density by cultivar was detected. In all cultivars, with the exception of Q.B.60.2 and Q.B.59.28, this variable was reduced by plant density. In general, the higher number of plants per unit area and the larger number of ears per unit area observed at the higher plant density, were overcome by the reduction in grain number per ear, resulting in a decreased final number of grains per square meter (Table 4.6).

Table 4.6.- Duncan's New Multiple Range Test for the comparison of cultivar means* for number of grains per square meter at two densities.

147 plants m^{-2}		257 plants m^{-2}	
Conquest	5343.62 a	Loyola	4730.76 a
Loyola	5087.55 a	Conquest	4139.31 a, b
Laurier	4715.87 a	Laurier	3966.43 b
Q.B.60.2	2131.43 b	Q.B.60.2	3547.85 b
Q.B.59.28	1685.94 b	Q.B.59.28	2780.63 c

Means within columns followed by the same letter are not significantly different at the 0.05 probability level.
*Means of three levels of nitrogen and three replicates.

When the means were compared between plant densities, only the difference between 5087.55 and 4730.76 was not significant. Loyola was the multiculm cultivar least affected by density, in spite of the fact that it produced the lowest mean number of ears m^{-2} among the multiculm cultivars. Certainly, its greater capacity to produce more grains per ear than any other cultivar, has resulted in a superior performance at high densities. Moreover, the analysis showed also a significant interaction of N x D x C for this variable, and the DNMRT at the 5% level indicated that Loyola responded to the highest level of nitrogen, producing significantly more grains (6537.04) at the lowest density in comparison to the lowest level of nitrogen with only 4230.62 grains m^{-2} (Appendix, Table 8).

4.1.6.- Grain Size.- In general and according to the analysis of variance, (Appendix, Table 9), plant density significantly affected grain size. The 1000 - grain weight was lowered from 36.48 g at the lowest density to 34.06 g at the intermediate, down to 31.41 g at the highest density. This reduction was brought in by the greater plant competition in the more densely populated plots (see Literature Review).

In general, the largest grains were those of Laurier with 37.93 g being followed by and statistically different Q.B.60.2 with 36.26 g, Loyola with 33.98 g, Q.B.59.28 with 33.27 g and Conquest with 28.85 g. Loyola and Q.B.59.28 were not significantly different.

The effect of plant density on the size of barley grain has been widely discussed and the results presented here are in agreement with the findings of Kirby (1967, 1969), Willey and Holliday (1971), and Finlay et al. (1971).

The variance analysis allowed the detection of a significant interaction of N x C, in which the cultivar Q.B.60.2 responded in a different way to N fertilization. Usually, heavier applications of N are found to decrease grain size (Murata, 1969; Andersen and Køie, 1975) and according to Murata, heavy N fertilization increases the formation of "yield containers" (grains or ears) more than the capacity for production, distribution and storage of assimilates in the developing grain.

Recently, Pearman et al. (1977) have found that generally N fertilization increases the net photosynthetic rates by means of an enlarged leaf area; however, the "sink" size is not adequate to store the carbohydrate surplus, this latter being depleted from the leaves and stems by an increased respiration rate, that may possibly be even higher at closer row spacings.

In this study, Q.B.60.2 and Q.B.59.28 produced larger grains at heavier applications of N (Table 4.7).

Table 4.7.- Duncan's New Multiple Range Test for the comparison of cultivar means* for 1000 - grain weight (g) at three levels of nitrogen.

0 Kg ha^{-1} N			34 Kg ha^{-1} N			68 Kg ha^{-1} N		
Laurier	38.28	a	Laurier	38.76	a	Q.B.60.2	37.29	a
Q.B.60.2	36.87	a	Q.B.60.2	34.61	b	Laurier	36.93	a
Loyola	35.05	b	Q.B.59.28	33.56	b	Q.B.59.28	33.59	b
Q.B.59.28	32.70	c	Loyola	33.41	b	Loyola	33.48	b
Conquest	28.51	d	Conquest	29.31	c	Conquest	28.73	c

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three plant densities and three replicates.

4.1.7.- Grain Yield.- According to the analysis of variance for grain yield (Appendix, Table 10), larger amounts of N in the soil did not significantly affect final grain yield. Low rainfall conditions and a rather clayey soil, resulted in little N effect in 1977. Nevertheless, the DNMRT at 0.05 probability level indicated that, in general, considering the means of five cultivars and three plant densities, the heaviest rate of N (68 Kg ha^{-1}) increased non-significantly grain yield from 108.99 g m^{-2} at 0 Kg N ha^{-1}, to 138.19 g m^{-2} (Figure 4.5).

Grain yield may be expressed in terms of its components, i.e., plant number, ear number per plant, grains per ear and grain size. The response of the latter three components to a change in the number of plants per unit area (plant density) and/or nitrogen fertilization will regulate and determine grain yield.

In conformity with the partial results exposed before in this work, it has been seen that larger amounts of nitrogen increased significantly the number of tillers per square meter, increased also the number of ears per square meter, and more grains per square meter were obtained (Figure 4.6 a). The number of grains per ear was unaffected and grain size was reduced, Q.B.60.2 and Q.B.59.28 being the only exceptions. These results coincide partially with the work of Thorne and Blacklock (1971); in their study, nitrogen decreased the weight per grain, but had no effect on the number of grains per spikelet (in wheat) or per ear.

The number of ears per square meter was increased by nitrogen. In agreement with the results reported here,

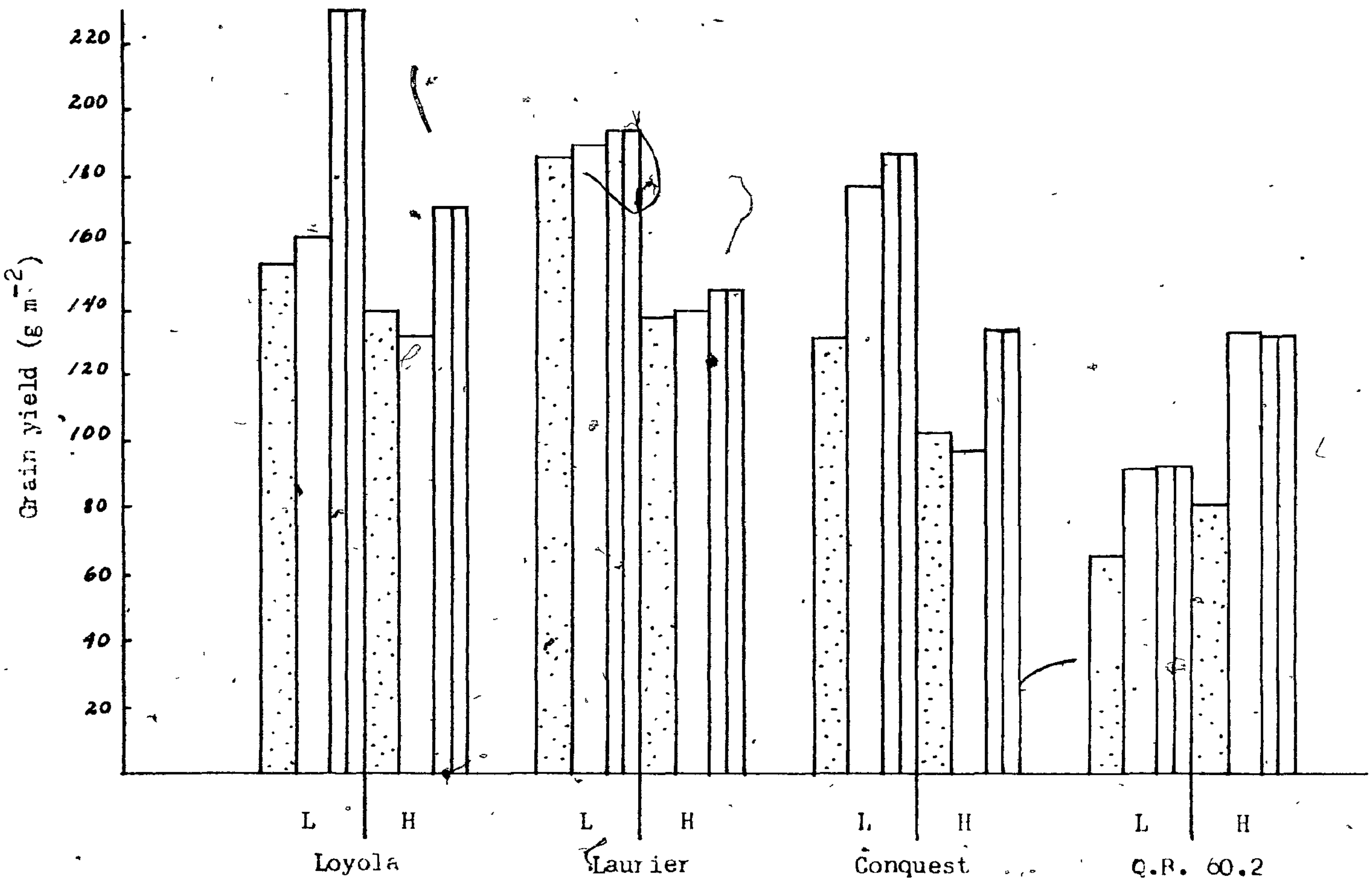

Figure 4.5.- Grain yield response to nitrogen fertilization and plant density. (L), lowest density; (H), highest density. ⚃, 0 Kg N ha^{-1}; ☐, 34 Kg N ha^{-1}; ◫, 68 Kg N ha^{-1}.

Means of three replicates.

a non significant interaction of N x D was observed.

According to Figure 4.6 a, all cultivars had larger ear numbers at higher nitrogen levels. This increment was attained by means of a higher number of ears per plant and more fertile culms. Although all cultivars showed an increased response in number of ears per square meter to nitrogen; the DNMRT at the 0.05 level for each cultivar, in consideration of means of three densities, showed that only Loyola responded significantly to the highest level of nitrogen, giving the largest number of ears per unit area. Also, it was shown previously, that Loyola produced a significantly higher number of grains per square meter at the lowest density, in response once more to the highest level of nitrogen; therefore, Loyola was the only cultivar which had a significant response to nitrogen fertilization in grain yield. This was attained at the lowest density and highest rate of nitrogen.

Something that calls for a closer look is the response in grain number of Q.B.60.2 (Figure 4.6 b). It is the only cultivar in which a reduction in grain number was recorded. Higher levels of nitrogen were found associated with reductions in the number of grains per ear and consequently grain number per square meter. No drastic reductions in grain yield at higher nitrogen levels

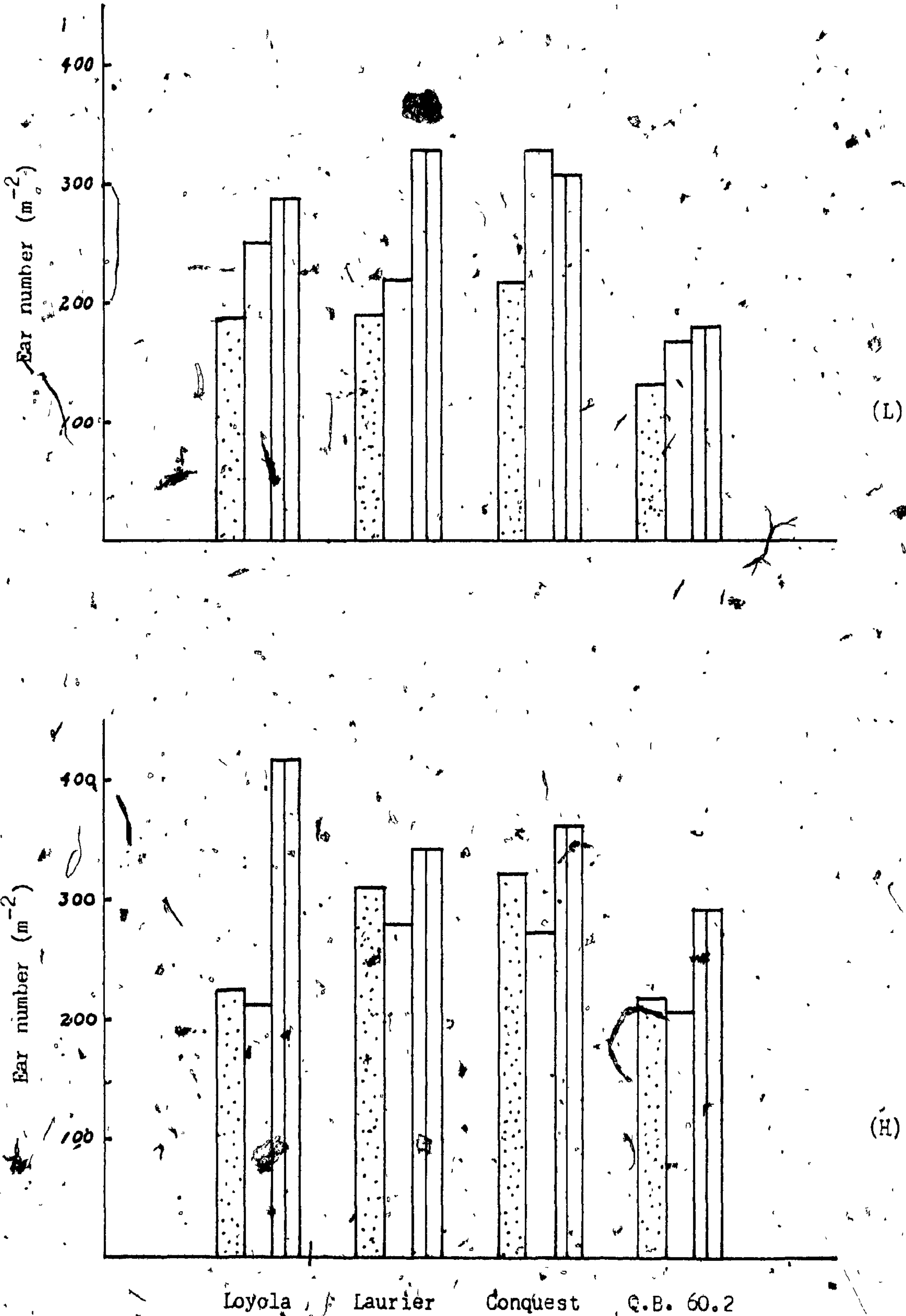

Figure 4.6 a.- Responses in the number of ears per square meter to plant density and nitrogen fertilization. (L), lowest density; (H), highest density. ⊡, 0 Kg N ha^{-1}; □, 34 Kg N ha^{-1}; Ⅲ, 68 Kg N ha^{-1}. Means of three replicates.

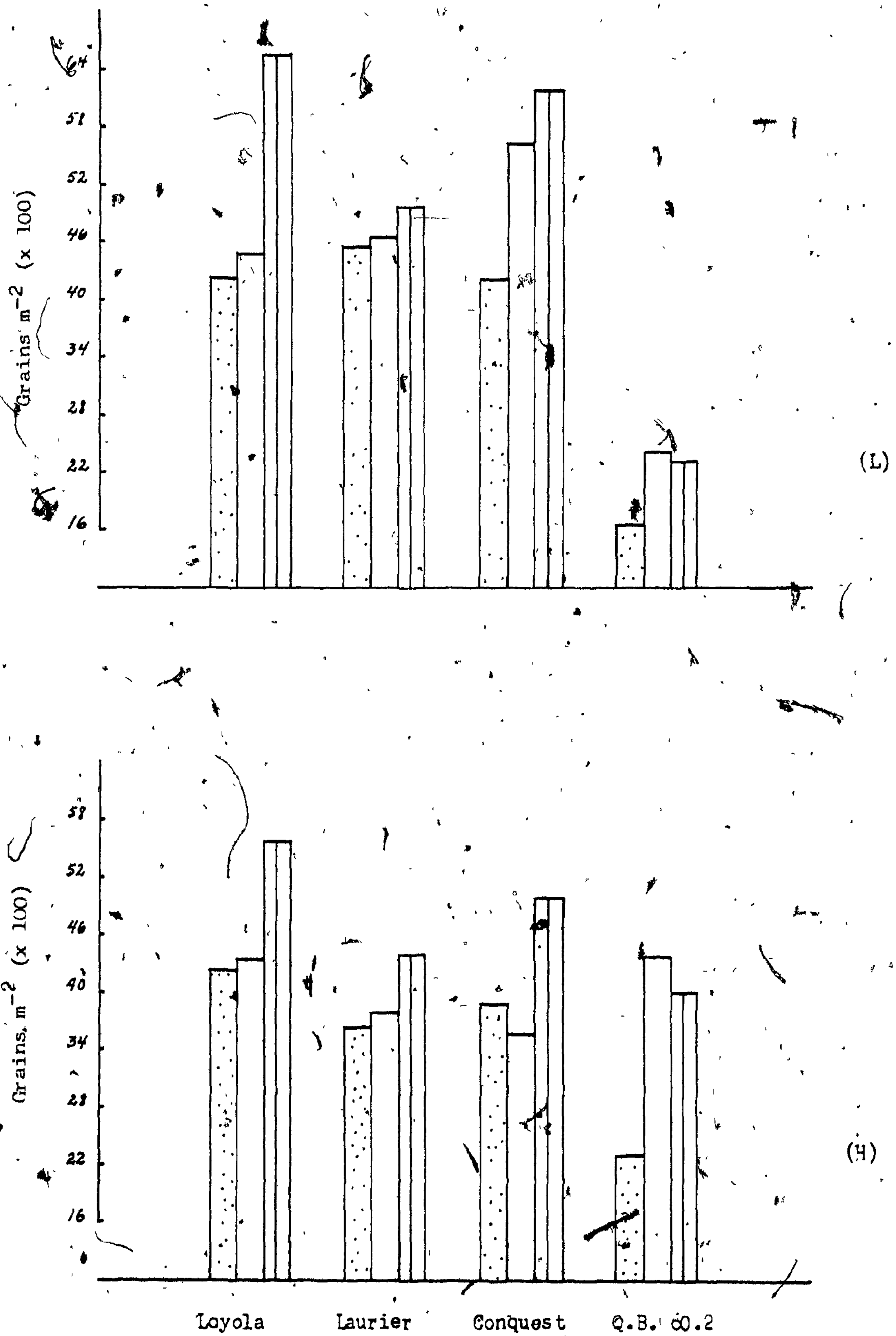

Figure 4.6 b.- Responses in the number of grains per square meter to plant density and nitrogen fertilization:
(L), lowest density; (H), highest density. ⊡, 0 Kg N ha^{-1}; □, 34 Kg N ha^{-1}; ◫, 68 Kg N ha^{-1}.
Means of three replicates.

were noticed, due to the good grain weight of Q.B.60.2.

Although Conquest produced the largest mean number of ears per square meter and a considerable number of grains, its grain yields were consistently lower than those of Loyola and Laurier, due to its very small grains and relatively few grains per ear.

The differences in grain yield for the interaction of D x C were significant (Appendix, Table 10) and the DNMRT at the 0.05 level, indicated in general, Laurier and Loyola as the best cultivars (Table 4.8).

Table 4.8.- Duncan's New Multiple Range Test for the comparison of cultivar means* for grain yield (g m^{-2}) at two densities.

147 plants m^{-2}		257 plants m^{-2}	
Laurier	190.01 a	Loyola	147.82 a
Loyola	182.43 a, b	Laurier	141.83 a
Conquest	165.40 b	Q.B.60.2	115.37 b
Q.B.60.2	82.84 c	Conquest	111.37 b

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

* Means of three levels of nitrogen and three replicates.

The differences in grain yield between densities for each cultivar were significant and all the multiculm plants gave their maximum grain yields at a low density; whereas, Q.B.60.2 produced more grain yield at a high density.

The effects of plant population on grain yield and its components are presented in Figure 4.7.

The effect of increasing density was to increase the number of ears in all cultivars. However, the number of grains per ear, grain number and 1000 - grain weight responded in the opposite manner in the multiculm cultivars, these producing lower grain yields at higher plant populations. On the other hand, the significant interaction of cultivars by plant densities indicated that not all cultivars responded in the same way to density; Q.B.60.2 produced more grains per ear, more grains per square meter and higher grain yields at closer spacings, though a reduced grain size was observed.

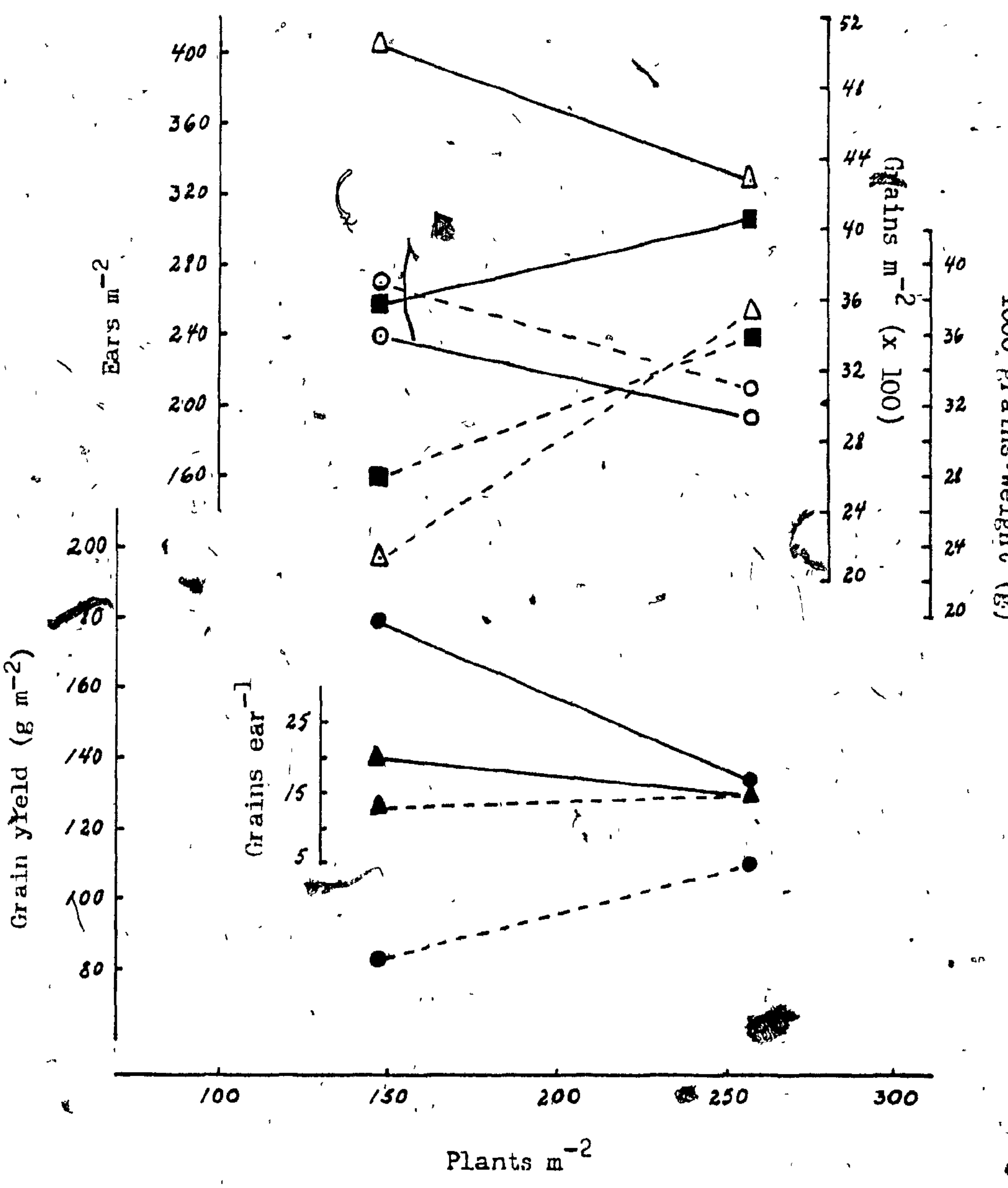

Figure 4.7.- The effect of plant density on grain yield and grain yield components. ___, multiculm cultivars. ---, Q.B.60.2. ●, grain yield. ■, ears per m 2. ▲, grains per ear. △, grain number. ○, 1000 - grain weight. Means of three levels of nitrogen and three replicates.

An explanation of the reduction in grain yield at higher densities in the case of multiculm cultivars may be found in the response of the different yield components, particularly grains per ear and 1000 - grain weight, because the third component, ear number showed consistent increments, in accordance with the results of Kirby (1967, 1969) and Willey and Holliday (1971 a, b).

In Q.B.60.2 the grain yield at low density is evidently lower in comparison with the multiculm types, and is due mainly to the inability of the uniculm type to produce tillers and its lower grain number. Increments in ear number by means of increasing plant density improved grain yield, grain size remaining as the only limiting factor to grain yield at higher densities for Q.B.60.2.

In this experiment there is strong evidence that grains per ear is closely related with the grain yield response of both plant types; although grain size limits grain yield in both multiculm and uniculm cultivars at higher densities, a correlation analysis between grain yield and grain number for all cultivars at the highest density and all levels of nitrogen gave a coefficient of r=0.94, which is significant at 0.05 level.
This coefficient was only 0.18 for 1000 - grain weight. The r value for all cultivars and all levels of nitrogen

at the lowest density between grain yield and grain number was slightly higher, 0.97. These correlation values suggest that ear capacity and ear number play the most important role in grain production at any density. The r value for 1000 - grain weight at the widest spacing was even lower, - 0.09, showing a decreased importance.

The importance of ear capacity in the form of grains per ear in relation to grain yield was also analyzed, giving a correlation value of 0.37, which was higher than r value for 1000 - grain weight with only 0.18 at the highest density, for all cultivars and three levels of nitrogen.

This coefficient at the lowest plant population produced a value of 0.72 for grains per ear and - 0.09 for 1000 - grain weight.

From this brief analysis, it is suggested that although grain size is an important factor in grain production at a high density, it can be seen that the number of grains per ear is a major determinant of grain yield.

Kirby (1967) concluded that the most important factor in reducing grain yield at high densities is the size of the grain, mainly because he found an over-production of grains in the higher density treatments relative to the medium density which gave the higher grain yields suggesting that "... unless the size of the grain was determined before grain filling, the yield reductions (at higher densities) is not due to the smaller size of the sink".

This asseveration is contrary to the opinion of Willey and Holliday (1971 a, b), who did not find reductions in barley grain yield when the plants were shaded during the grain filling period, demonstrating that grain yield may be determined earlier, that is, during ear development. Growth reductions during this period due to plant competition may reduce the capacity of the ear and consequently, a reduction in the number of grains per ear may be observed.

These theories will be discussed further on basis of information, from experiments done in 1978, where a wider range of plant populations were studied.

The quite low yields observed in this experiment and the sudden reductions in grain yield in the multiculm cultivars even at low populations may be explained by the experiments of Pelton (1969) and Kirby (1970). In Pelton's experiment, reductions in grain yield by increasing density were related to a dry environment. He showed that although different densities of wheat used almost the same total amount of water, the high density treatments used more water at the initial stages of growth (coinciding with the dry spell reported in this work). This earlier onset of a moisture deficit in the soil may have affected plant growth, resulting in lower yields from the denser treatments. Pelton's work reported consecutive reductions in grain yield of 8.5% from seed rates of 22 Kg ha^{-1} (70 plants m^{-2}) to seed rates of 100.8 Kg ha^{-1} (180 plants m^{-2}).

The higher seeding rate treatments resulted in a higher number of ears per unit area, yet there were no significant differences in the number of grains per unit area. Also, the low seeding rates resulted in heavier grains of a slightly lower protein content.

In Kirby's experiments (1970) the same trend of lower yields at high populations in relation to water deficits at the initial stages of growth was confirmed, this time with barley.

4.1.8.- Total Dry Matter Yield.- According to the analysis of variance (Appendix, Table 11), for total dry matter (weight of all above-ground material), no significant differences were found by nitrogen effect; however, heavier applications of fertilizer, increased total dry matter slightly, from 231.27 g m^{-2}, produced at the lowest level of nitrogen, considering the means of all cultivars at three plant densities, to 263.69, at medium levels of nitrogen and 298.07 at the highest nitrogen level.

No significance was found for differences in dry matter for densities. However, the cultivars responded in a different way to plant density. The differences are shown below in Table 4.9.

Table 4.9.- Duncan's New Multiple Range Test for the comparison of cultivar means* for dry matter yield (g m^{-2}) at two densities.

147 plants m^{-2}			257 plants m^{-2}		
Laurier	358.50	a	Loyola	302.11	a
Conquest	356.11	a	Laurier	292.87	a
Loyola	350.61	a	Q.B.60.2	274.72	a
Q.B.60.2	209.39	b	Conquest	256.33	a
Q.B.59.28	148.94	c	Q.B.59.28	190.87	b

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and three replicates.

All cultivars produced similar yields of dry matter within each density, with the exception of Q.B.60.2, which gave significantly lower yields at the lowest density. However, Laurier at the lowest population was the best producer in general, for grain yield and total dry matter because it was more stable. At lower applications of N its yields were the highest. Although Conquest gave a good total dry matter yield at the lowest density, its harvest index (see section 4.1.9) was lower than those of Laurier and Loyola and in consequence the grain yield of Conquest was the lowest among the multiculm cultivars.

At a higher density, Loyola ranked in the first position and Conquest was drastically lowered to last place, while Q.B.60.2 improved notably. The higher dry matter yields of Loyola were reflected in better grain yields at a high density, giving the highest harvest index of all cultivars. In addition, Loyola was the only cultivar in which total dry matter was not significantly different when comparing both densities within each cultivar. Laurier, Conquest and Q.B.60.2 changed their total dry matter yields significantly from one density to another; the yields of Laurier and Conquest being reduced at higher populations.

Loyola performed well, in terms of yield, at higher densities because it had the highest number of grains per ear and a better final grain number per unit area. On the other hand, Laurier at low density, considering the mean of three levels of nitrogen, produced higher yields, mainly because this cultivar had the largest and heaviest grains in spite of the fact that it had the lowest number of grains per unit area among the multiculm cultivars.

Conquest, meanwhile, had the highest number of ears at both densities and a good number of grains per unit area at both densities (the highest at the low population and the second at the high population) but its grains were the smallest at any treatment.

The significant interaction of nitrogen by density by cultivar for total dry matter indicates, in the first place, that Loyola had the only significant response to nitrogen, and according to the DNMRT at the 5% level, the difference was detected at the lowest density, and for the highest amount of nitrogen, which enabled Loyola to respond in a favourable way, giving higher yields.

According to the information provided by Kirby (1976), total dry matter yields increase with increasing plant density to a maximum value and at higher densities tend to remain constant, provided there are no interfering factors. Grain yield increases to a maximum value but declines as density is further increased. In this experiment, both yields decreased with further increments in plant population. This pattern has been observed only under conditions of dry weather, mainly at the beginning of the growing season (see Literature Review).

4.1.9.- Harvest Index.- This parameter is the ratio of the yield of grain to the biological yield (total dry matter yield) and according to Donald and Hamblin (1976), it provides a measure of the "efficiency" of the plant for grain production. Higher harvest indices are usually related to more "efficient" plants that produce higher grain yields.

In the present study the index was not affected by nitrogen fertilization (Appendix, Table 12). This result is not in accordance to the reports in the literature, which show reduction of harvest indices by heavier nitrogen application (Russell and Watson, 1940, as cited by Donald and Hamblin, 1976).

The generally low effect of nitrogen in this experiment may reflect also the little response of harvest index.

In conformity with the DNMRT at the 0.05 probability level, Laurier and Loyola gave the highest harvest indices, 0.51 and 0.50, respectively, which were not significantly different. They were followed by Conquest with 0.45, a value that is significantly different, and at the bottom Q.B.60.2 with 0.41, significantly lower than the other values. These differences were calculated on the basis of means for three densities and three levels of nitrogen.

The significant F value for the interaction D x C indicated that not all cultivars responded in the same manner to plant density (Table 4.10).

Table 4.10.- Duncan's New Multiple Range Test for the comparison of cultivar means* for harvest index at two densities.

	LAURIER	LOYOLA	CONQUEST	Q.B.60.2
147 plants m^{-2}	0.53 a	0.52 a	0.46 a	0.40 a
257 plants m^{-2}	0.49 b	0.49 a	0.43 a	0.42 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and three replicates.

In Table 4.10 it can be seen that at the highest density the harvest index of Laurier was depressed in a significant way, whereas that of Q.B.60.2 increased from 0.40 to 0.42 although it was not significantly different. In previous studies (Scarsbrook and Doss, 1973; Puckridge and Donald, 1967; Morrow and Hunt, 1891, as cited by Donald and Hamblin, 1976) a consistent progressive decline in harvest index has been reported at densities above the maximum grain yield. These findings indicate that the maximum plant density for maximum grain yield in Q.B.60.2 has not been reached yet, and further higher populations must be studied.

4.2.- Experiment 2.

This experiment was designed in a similar manner to Experiment 1. The main objective was to study the effects of plant density and nitrogen fertilization on spring barley yield. Nevertheless, in Experiment 2 higher plant densities were used in order to measure those effects mainly on the uniculm plant, having as a point of reference multiculm barley.

4.2.1.- Plant Number.- Although growing conditions were better in 1978 (see Section 3) than in 1977, some reductions in plant number were observed. Approximately 86% of the seeds planted in the lowest density germinated and grew normally. The percentage was slightly lower for the medium density with 81.4%. In the higher density only 68.6% of the expected plants were counted at the mature stage. It is impossible to say whether the plants died during growth or the germination was irregular. However, Cannell (1969 a) in a study of plant density in barley reported little plant death and the reductions in plant number in this experiment are assumed to be failures at the moment of germination.

In Figure 4.8 and Table 4.11 some data for plant establishment and seed rates are presented.

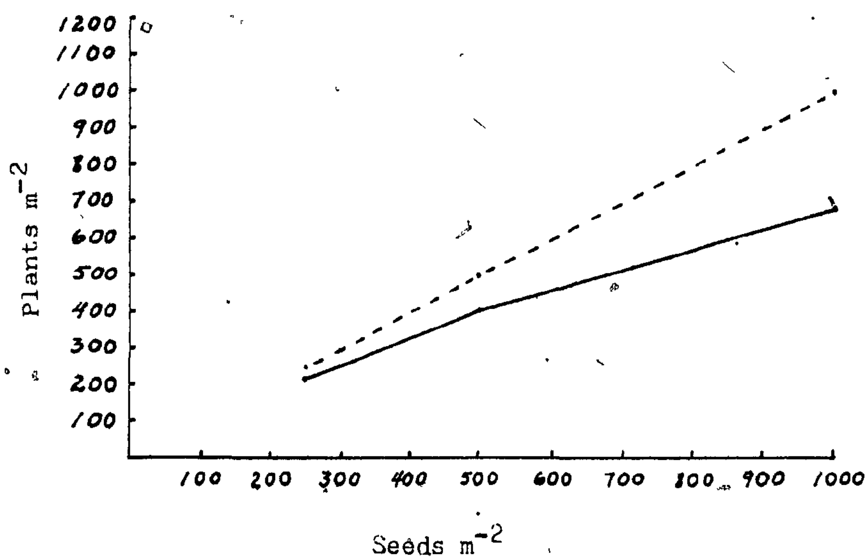

Figure 4.8.- Number of expected plants m^{-2} (assuming 100% of plant establishment), ----; actual number* of plants established (counted at maturity), ——; and number of seeds m^{-2}.

*Means of three cultivars, three levels of nitrogen and four replicates.

Table 4.11.- Mean* seed rates, seed density, mean** plant establishment, mean** plant density (at maturity) and row spacing.

SEED RATE Kg ha^{-1}	SEED DENSITY seeds m^{-2}	ESTABLISHMENT percentage	PLANT DENSITY plants m^{-2}	ROW SPACING cm
100	250	86	215	20
200	500	81.4	407	10
400	1000	68.6	686	5

*Mean of three cultivars calculated on basis of 1000 - grain weights.

**Mean of three cultivars at three levels of nitrogen.

All the results in both experiments refer to the actual number of plants at maturity, not to the number of seeds sown, for the reasons explained above.

The variance ratios for the various treatments and interactions are shown in Table 4.12.

Table 4.12.- Variance ratios of the main treatments and interactions for some of the crop parameters under study in Experiment 2.

Source of Variation	Plants per m^2	Ears per m^2	Grains per Ear	1000 Grain Weight	Grains per m^2	Total D.Matter Yield	Grain Yield
Nitrogen (N)	0.56	0.51	3.63	1.15	10.04*	14.38**	6.03*
Plant Density (D)	287.03**	136.57**	36.75**	57.80**	32.93**	13.90**	5.55*
N x D	0.37	0.16	0.00	1.21	0.49	0.59	0.33
Cultivar (C)	2.02	7.90**	6.30**	36.17**	3.18*	0.78	4.60*
N x C	0.29	0.21	0.40	3.08*	0.94	0.43	0.42
D x C	0.31	1.00	0.09	7.57**	10.71**	3.15*	3.18*
N x D x C	1.33	1.59	0.53	4.65**	1.20	0.63	0.58

*Significant at 0.05 level.

**Significant at 0.01 level.

The analysis of variance (Appendix, Table 13) for the variable number of plants per square meter shows that there were significant differences only for the treatment density (D). After the Duncan's New Multiple Range

Test (DNMRT) at 0.05 probability level was done, significant differences were found for all levels of plant density, the maximum number of plants per square meter being 686 for the highest plant density, 407 plants for the intermediate density and 215 plants per unit area at the lowest plant population.

No significant values were noted for other treatments or interactions. However, a very slight difference was present for cultivars; this was caused by Q.B.59.28, which gave a mean number of plants per square meter (considering the three levels of nitrogen and three densities) lower by 37 plants than Laurier.

Nitrogen increased the number of plants slightly from 420 (at the lowest nitrogen rate) to 442 (at the highest nitrogen rate) considering the mean for three densities and three cultivars, which is also unimportant.

4.2.2.- Tiller Number.

4.2.2.1.- Tillers per Plant.- According to the analysis of variance table for this parameter (Appendix, Table 14) Laurier was depressed in its tiller number by plant density. This cultivar produced a mean number of 0.46 tillers at the widest spacing (considering the mean of three levels of nitrogen); further increments in plant density reduced this tiller number to 0.17, which is significantly different. No further reductions were observed with increasing plant density.

The significant interaction of N x D indicates that Laurier reacted to nitrogen fertilization, producing more tillers only at the lowest density in a significant way (Table 4.13).

Table 4.13.- Duncan's New Multiple Range Test for the comparison of Laurier means* for number of tillers per plant.

	215 plants m^{-2}	407 plants m^{-2}	686 plants m^{-2}
0 Kg N ha^{-1}	0.25 c	0.10 a	0.20 a
32 Kg N ha^{-1}	0.50 b	0.20 a	0.12 a
64 Kg N ha^{-1}	0.62 a	0.20 a	0.20 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of four replicates.

At higher densities the nitrogen effect on tillering was inhibited by the higher number of plants. At the highest density, Laurier had the same mean number of tillers per plant, regardless of the nitrogen effect noted for the lowest density, where the number of tillers per plant was significantly increased.

4.2.2.2.- Tillers per Square Meter.- The analysis of variance for this variable shows a significant effect for nitrogen fertilization. In general, (considering the mean of three plant densities and Laurier) the total number of tillers per square meter was increased by heavier application of nitrogen; 83.75 tillers m^{-2} were observed at the lowest rate (0 Kg N ha^{-1}). This number was increased at the medium level of nitrogen (32 Kg N ha^{-1}) to 100.83 tillers m^{-2} and a still further increment was seen at the highest level (64 Kg N ha^{-1}), giving 123.33 tillers m^{-2}. All these values are significantly different according to the DNMRT at the 5% level; (see Table 15 in the Appendix for further details in the analysis).

The number of tillers per square meter was significantly different for the densities treatment. The highest number of tillers was obtained in the highest density with 129.58 (considering the cultivar Laurier and the mean of three levels of nitrogen). The second higher number of tillers was observed for the lowest spacing, in which a mean number of 101.67 tillers was detected. The lowest tiller number corresponded to the medium density, with only 76.67 tillers. All these differences are significantly different.

The significant interaction of N x D may give a more satisfactory explanation of the response of Laurier to plant density and nitrogen. The DNMRT indicated that this cultivar responded to nitrogen fertilization only at the lowest and medium densities, the response being very weak in the intermediate treatment. At the highest density no nitrogen effect was observed, and the largest dose of nitrogen did not produce more tillers (Table 4.14).

Table 4.14.- Duncan's New Multiple Range Test for the comparison of Laurier means* for number of tillers m^{-2}.

	215 plants m^{-2}	407 plants m^{-2}	686 plants m^{-2}
0 Kg N ha^{-1}	56.25 b	45.00 b	150.00 a
32 Kg N ha^{-1}	113.75 a	96.25 a	92.50 b
64 Kg N ha^{-1}	135.00 a	88.75 a	146.25 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of four replicates.

According to Table 4.12, the final tiller number is regulated by plant density at higher plant populations rather than by nitrogen.

4.2.3.- Days to Heading.- As indicated by the analysis of variance (Appendix, Table 16) for this parameter, the number of days for ear emergence was unaffected by nitrogen. Considering the means for three cultivars at three plant densities, the number of days for ear emergence was 45.6 when the lowest level of nitrogen was used, 45.5 days for the medium level and 45.0 days under the largest nitrogen application.

Plant density did not change the mean number of days to heading. The number of days was as follows: 45.5, 45.2 and 45.5 for the lowest, medium and highest density, respectively.

The only significant difference noted was among cultivars. Laurier headed in 44.9 days (10 days earlier than the previous year) and was the earliest cultivar; Q.B.60.2 followed Laurier with 45.2 days (10 days earlier than the previous year); the two cultivars were not significantly different. The latest cultivar was Q.B.59.28 with 46.2 days; it was significantly later than the other cultivars.

4.2.4.- Plant Height.- It is well known (Thorne and Blacklock, 1971; Pearman et al, 1977) that nitrogen promotes, in general, plant growth. In this work, and according to the analysis of variance (Appendix, Table 17), plant height was significantly affected by heavier rates of nitrogen. Considering means of three cultivars and three plant densities, 0 Kg N ha^{-1} produced plants 65.39 cm tall; 32 Kg N ha^{-1} increased plant height to 74.89 cm, a value that is significantly higher, and 64 Kg N ha^{-1} increased the height to

80.30 cm, which is not significantly different.

Plant density, on the other hand, affects cereal plants, depressing their growth rate (Kirby, 1967) and according to this finding in the present study, the shortest plants were those which grew in the most densely populated plots; they measured only 67.41 cm. At the medium level of plant density the plants had 74.44 cm of height, being significantly different from those of the highest density. The tallest plants were from the lowest density at 79.00 cm; however, they are not significantly different from those of the intermediate plant population. On these latter plants, the density effect was more severe for tiller production than for height, having finally a good plant height.

Among the cultivars, Q.B.60.2 was the tallest (considering means of three levels of nitrogen and three densities) with 75.83 cm, followed by Q.B.59.28 at 74.47 cm, not significantly different and at the bottom, Laurier, significantly shorter with 70.28 cm. In Figure 4.9 are graphically represented the effects of plant density and nitrogen fertilization on the plant height.

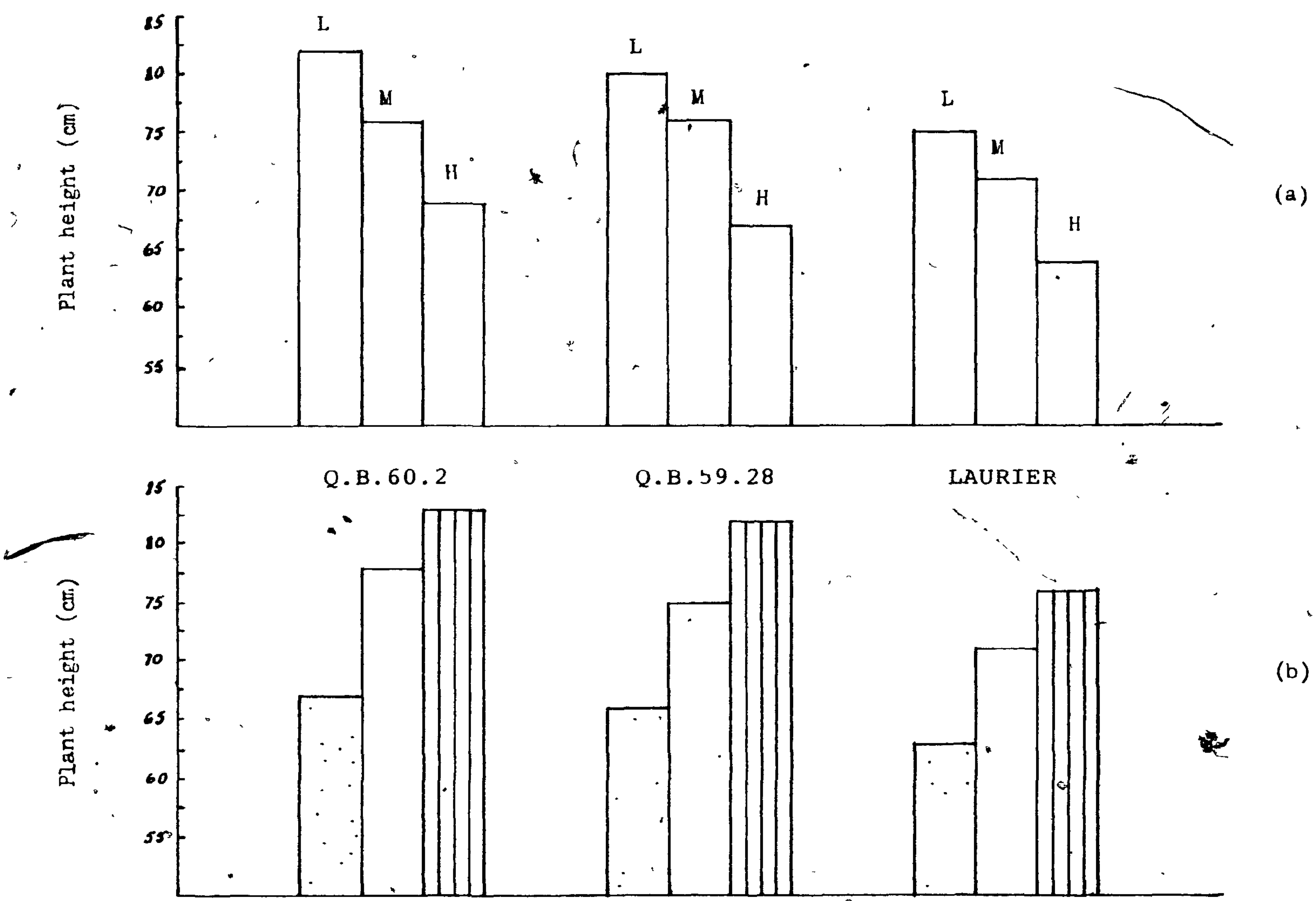

Figure 4.9.- Effects of plant density (a) and nitrogen fertilization (b) on the plant height of barley. (H), highest density; (M), medium density; (L), low density. ⚃, 0 Kg N ha^{-1}; □, 34 Kg N ha^{-1}; Ⅲ, 68 Kg N ha^{-1}.

4.2.5.- Ear Number.

4.2.5.1.- Ears per Plant.- This variable was significantly affected by plant density (Appendix, Table 18). The DNMRT at 5% level indicated that the mean number of ears per plant (considering three cultivars: Laurier, Q.B.60.2 and Q.B.59.28 at three levels of nitrogen) was significantly reduced from 1.02 in the lowest density (215 plants m^{-2}) to 0.92 in the medium density (407 plants m^{-2}). Further increments of plant density (686 plants m^{-2}), lowered this number even more, down to 0.87; significantly, the lowest.

The analysis of variance detected also significant differences for cultivars. Laurier produced the largest mean number (three densities and three rates of nitrogen) of ears per plant with 1.00; a number that was significantly higher than the ears produced by Q.B.60.2, 0.92 and Q.B.59.28, 0.89. The difference between uniculm cultivars was not significant.

Nevertheless, not all cultivars responded in same manner to plant density. The significant interaction of D x C indicated that Laurier suffered more drastic reductions of ear number per plant with increasing density (Table 4.15).

Table 4.15.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for number of ears per plant.

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Laurier	1.15 a	Laurier	0.97 a	Laurier	0.87 a
Q.B.60.2	0.97 b	Q.B.60.2	0.92 a,b	Q.B.60.2	0.87 a
Q.B.59.28	0.92 c	Q.B.59.28	0.87 b	Q.B.59.28	0.86 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

At 686 plants m^{-2} all cultivars had a similar number of ears per plant, though lower than the number in the lowest density; however, only Q.B.59.28 did not have a significant reduction in ear number when the means were compared among the three plant densities. The other cultivars did have a significant reduction of ears per plant when the same comparison was done. In other words, while Q.B.59.28 reduced its ear number from the lowest density to the highest density by only 6.5%, Q.B.60.2 suffered a reduction of 10% and Laurier, 24%.

At the highest density Laurier resembles a uniculm plant with the only probable handicap of having 0.30 shoots per plant that are unproductive, whereas Q.B.60.2 has only 0.13 unproductive shoots for one productive shoot.

At the lowest density, Laurier produced ears in only approximately 79% of its shoots and 33% of the tillers (about 99 tillers m^{-2}) did not give any.

At 407 plants m^{-2}, 83% of the shoots produced an ear and 100% of the tillers (approximately 69 tillers m^{-2}) did not.

At 686 plants m^{-2} approximately 74% of the shoots bore an ear and again, no tiller (117 tillers m^{-2}) produced any.

At a low population level the presence of a considerable number of tillers seems desirable; however, at higher plant populations the tillers that are unproductive, may be regarded as "parasites" of the main shoot at their initial stages of growth.

4.2.5.2.- Ears per Square Meter.- Although the ear number per plant was reduced by plant density, the number of ears per unit of ground area was increased.

The analysis of variance (Appendix, Table 19) indicated that this number was significantly increased by plant density, from 221.86 ears m^{-2} in the lowest population to 380.55 in the medium density. Further increases in number of plants m^{-2} gave higher number of ears m^{-2}, up to 603.43, also significantly different. These numbers are means of three levels of nitrogen and three cultivars.

This yield component is always increased with plant density (Kirby, 1967, 1969; Willey and Holliday, 1971). The fall in ear number per plant is compensated by plant number and the final number of ears per unit area is higher.

In general, when considering the means of three plant densities and three levels of nitrogen, Laurier produced a significantly higher number of ears, with 436.67. Both uniculm cultivars produced a similar number of ears with 391.17 and 371.57 ears for Q.B.60.2 and Q.B.59.28, respectively.

Although the interaction D x C is not significant, a Duncan's New Multiple Range Test was done and the results are shown in Table 4.16.

Table 4.16.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for number of ears per square meter.

215 plants m^{-2}			407 plants m^{-2}			686 plants m^{-2}		
Laurier	272.92	a	Laurier	429.58	a	Q.B.60.2	618.33	a
Q.B.59.28	200.42	b	Q.B.60.2	362.92	b	Laurier	607.50	a
Q.B.60.2	192.25	b	Q.B.59.28	349.17	b	Q.B.59.28	582.73	a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

Only at the lower densities did Laurier produce a significantly higher number of ears. The nitrogen effect on this variable showed no significance; nevertheless, heavier doses of nitrogen increased ear number slightly, mainly between the lowest and medium levels of nitrogen.

4.2.6.- Grain Number.

4.2.6.1.- Grains per Ear.- One of the most striking effects of plant density on barley yield is the reduction of ear size (Kirby, 1967). In the present study, the analysis of variance (Appendix, Table 20) shows that the number of grains per ear was significantly reduced in the higher densities. This number was lower by approximately 46% between the lowest and highest densities. The DNMRT indicates a significantly higher (0.05 level) number of grains per ear for the lowest density with 25.75, while the intermediate density gave 19.68; further increases in plant density induced even smaller heads with only 13.85 grains, considering the three cultivars at three levels of nitrogen.

In general, Q.B.59.28 had the greatest number of grains per ear with 21.88, which was significantly higher than Q.B.60.2 (19.62), and Laurier (18.00). This significant value was only evident in the intermediate density (Table 4.17).

Table 4.17.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for number of grains per ear.

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Q.B.59.28	27.17 a	Q.B.59.28	22.46 a	Q.B.59.28	15.48 a
Q.B.60.2	25.28 a	Q.B.60.2	19.47 a,b	Q.B.60.2	14.12 a
Laurier	24.79 a	Laurier	17.12 b	Laurier	12.09 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.
*Means of three levels of nitrogen and four replicates.

Although the nitrogen effect was not significant, the variance ratio (3.63) is somewhat large and the DNMRT at 5% level was applied. The results showed that the overall mean number of grains per head had increased slightly but only significantly at the highest rate of nitrogen. The number rose to 21.77 from 18.14 grains per head obtained at the lowest level of nitrogen.

4.2.6.2.- Grains per Square Meter.- According to the analysis of variance for this parameter (Appendix, Table 21), nitrogen affected significantly the number of grains per unit area. The largest number of grains was obtained when the maximum rate of nitrogen was applied. Considering the overall mean number of grains, the heaviest dose of nitrogen produced 7828.90. At the intermediate dose the number was reduced, yet not significantly, to 7041.94; the only significant difference was at the lightest nitrogen level, in which only 6002.79 grains were harvested.

We have seen before how the uniculm cultivars had the largest ears in comparison to Laurier. Now, this attribute has allowed them to produce the maximum number of grains per square meter, yet only at the higher densities (Table 4.18). In general, the average of three densities and three levels of nitrogen, indicated Q.B.59.28 as the largest producer of grains with 7193.47. In second place and not significantly different, Laurier yielded 6983.50 grains per square meter. In third position, with 6679.02, Q.B.60.2 was significantly different from Q.B.59.28, but not from Laurier.

Table 4.18.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for number of grains per square meter.

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Laurier	6532.67 a	Q.B.59.28	7639.87 a	Q.B.59.28	8667.36 a
Q.B.59.28	5396.00 b	Laurier	7231.29 a,b	Q.B.60.2	8396.87 a
Q.B.60.2	4827.60 b	Q.B.60.2	6812.58 b	Laurier	7186.54 b

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

According to Table 4.18, only Laurier was drastically affected by plant density. Its low number of grains per ear prevented this cultivar from competing efficiently at high densities. However, the uniculm cultivars increased significantly their grain number at all densities with an evident trend.

The correlation analysis indicated that in general, for the three cultivars and considering means of three densities and three levels of nitrogen, the grain number parameter had a coefficient of r=0.93, r=0.93 and r=0.94 with grain yield, for Q.B.60.2, Q.B.59.28 and Laurier, respectively. These correlations anticipate and emphasize the major importance of this variable in relation to grain yield, mainly at higher densities.

4.2.7.- Grain Size.- Smaller grains were obtained in the more dense plots. According to the analysis of variance (Appendix, Table 22), this variable was significantly affected by plant density. The weight of 1000 grains, in general, was 39.96 g at the lowest density. This number was reduced to 36.86 g by increasing density to 407 plants m^{-2}. Further increments reduced even more the weight of 1000 grains to 33.00 g. It can be seen that the reduction was more evident from the intermediate density to the highest density. All the reductions were significantly different at 0.05 probability level.

Laurier had, in general, the largest grains among the cultivars, with 38.28 g, being followed by Q.B.60.2 with grains weighing 37.06 g and significantly different. The smallest grains, significantly smaller than Q.B.60.2, were those from Q.B.59.28.

The highly significant interaction of D x C indicates variations in the response of the cultivars to plant density (Table 4.19).

Table 4.19.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for 1000 - grain weight (g).

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Q.B.60.2	41.45 a	Laurier	38.81 a	Laurier	36.25 a
Laurier	39.77 b	Q.B.60.2	37.39 a	Q.B.60.2	32.33 b
Q.B.59.28	38.67 b	Q.B.59.28	34.38 b	Q.B.59.28	30.43 c

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

The effect of plant density was much more severe for Q.B.60.2 than it was for Laurier. There was a reduction of about 22% in grain weight for Q.B.60.2 when increasing plant density. Meanwhile Laurier suffered a reduction of only 9% in grain weight. In other words, Laurier showed more stability in its response than the uniculm cultivars.

The overall effect of nitrogen, though not significant, was to reduce 1000 - grain weight in a steady way. At the highest level of nitrogen, the general mean grain weight was 36 mg; the medium level of nitrogen, increased this value to 36.7 mg and the lowest level of nitrogen produced the heaviest grains with 37 mg. This nitrogen effect is typical in barley and has been seen by many workers (see Literature Review and Section 4.1.6 in this work). However, the significant interaction of N x C indicates that the reverse trend in grain weight by increased applications of nitrogen applies only partially in this study (Table 4.20).

Table 4.20.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three levels of nitrogen for 1000 - grain weight (g).

0 Kg N ha^{-1}		32 Kg N ha^{-1}		64 Kg N ha^{-1}	
Laurier	39.98 a	Laurier	38.02 a	Q.B.60.2	37.30 a
Q.B.60.2	36.83 b	Q.B.60.2	37.04 a	Laurier	36.92 a
Q.B.50.28	34.41 c	Q.B.59.28	35.14 b	Q.B.59.28	33.93 b

Means within columns followed by the same letter are not significantly different at 0.05 probability level.
*Means of three densities and four replicates.

From Table 4.20 it can be seen how the grain weight of Laurier is consistently decreased by higher levels of nitrogen. On the other hand, Q.B.60.2 had an increased grain weight by nitrogen effect and at the highest level of nitrogen the grains of Q.B.60.2 were even heavier than those of Laurier.

If uniculm cultivars are not increasing their grain weight by nitrogen effect, at least it is less affected than Laurier grain weight.

4.2.8.- Grain Yield.- The results of this experiment are in accordance with the typical responses of cereals to nitrogen fertilization and plant density.

In the first place, nitrogen increased grain yield significantly at all densities (Appendix, Table 23). The DNMRT at 0.05 probability level indicated that on the basis of three cultivars and three densities, grain yield was increased from 219.94 g m^{-2} (b) at the lowest rate of nitrogen, to 255.47 g m^{-2} (a,b) at the medium nitrogen level. When the rate was increased up to 64 Kg N ha^{-1}, the grain yield rose to 279.37 g m^{-2} (a). No interactions of N x D, N x C, N x S x C, were detected as being significant.

The expression of grain yield by its components (plant number, ear number per plant, grains per ear and grain weight) helps to understand better the nature of grain yield. In the present study, the gains in grain yield by nitrogen effect were obtained mainly by the combined slight increase in ear number per square meter and grains per ear (Figure 4.10).

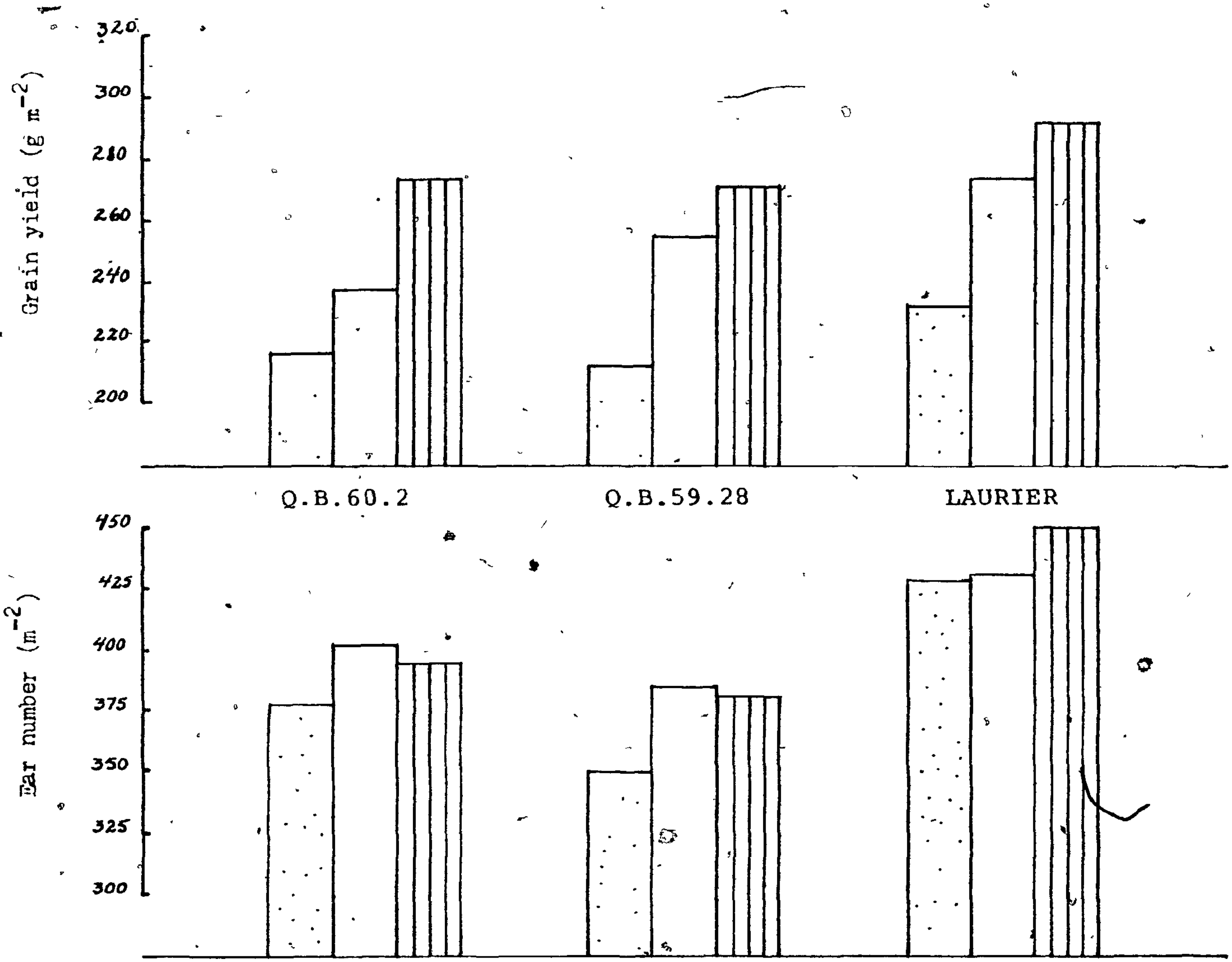

Figure 4.10.- The responses of grain yield and yield components to nitrogen fertilization, [dotted], 0 Kg N ha^{-1}; [blank], 32 Kg N ha^{-1}; [striped], 64 Kg N ha^{-1}; of Laurier, Q.B.60.2 and Q.B.59.28.

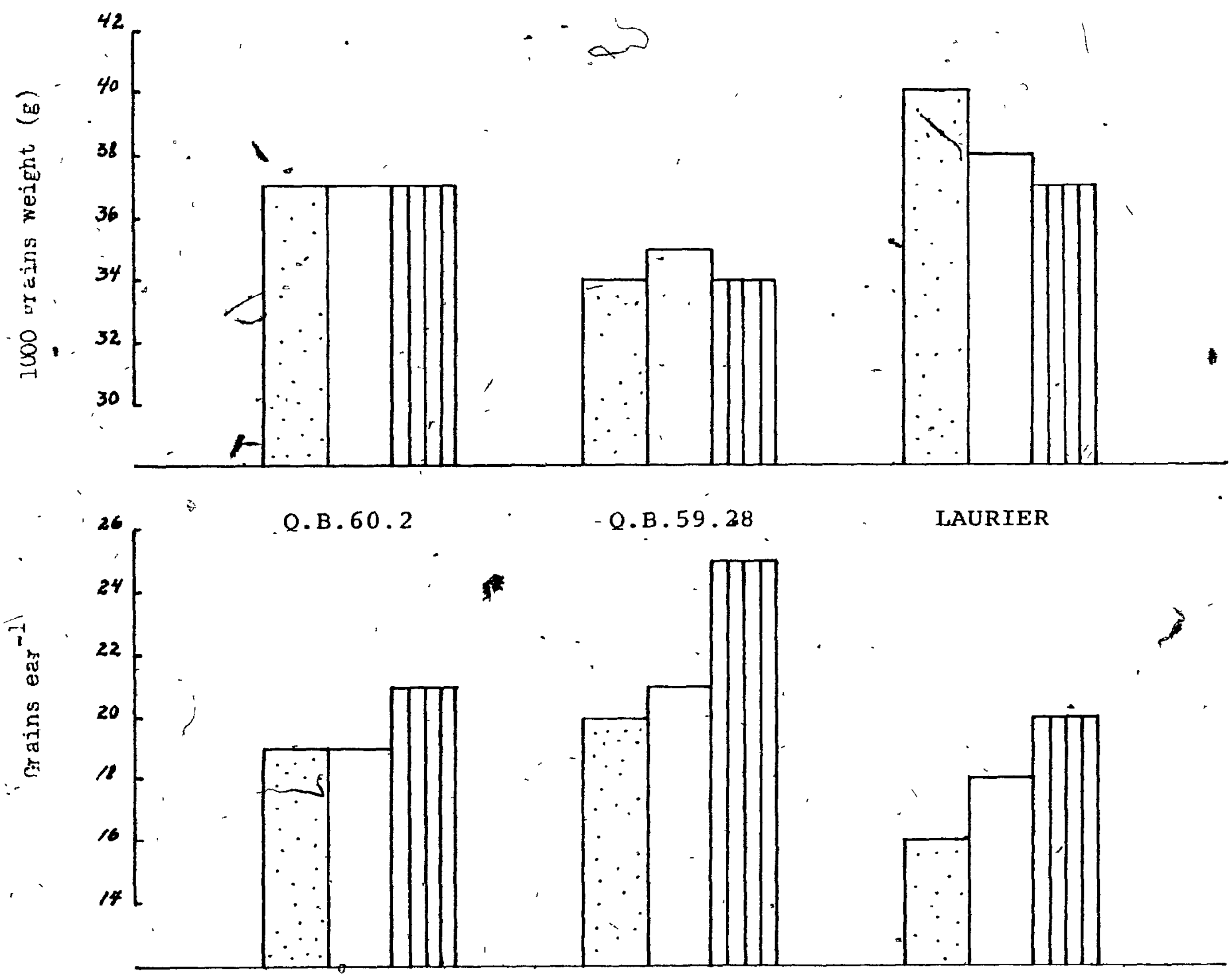

Figure 4.10.- Continues ...

According to Figure 4.10, it should be noted that uniculm cultivars are distinguished by their powerful response in number of grains ear^{-1} to nitrogen, especially Q.B.59.28, which though no data from ear abnormalities was obtained, in general showed a less degree of abnormalities than Q.B.60.2. On the other hand, the ability of Laurier to produce more ears by nitrogen fertilization is quite evident at any level of nitrogen, especially at the low population level. Secondly, the superiority of Q.B.60.2 over Q.B.59.28 for grain yield at the highest level of nitrogen is based on the much heavier grains of Q.B.60.2 and its greater ear survival.

It is also remarkable how though grain size has been decreased by nitrogen, the grain yields of Laurier increased at any level of nitrogen. Certainly, the grain yields in Laurier were closely related to the number of grains m^{-2}.

Grain yield was significantly affected by plant density and the curve response of grain yield plotted against plant population, should fit the classical parabolic curve described by many workers (see Literature Review). In other words, grain yield was increased by plant population up to the point where it did not increase further, but declined. At the lowest population and in general, grain yields were the poorest with 222.86 g m^{-2}. Further increases in plant density raised grain yield up to 266.43 g m^{-2}. In the highest density, grain yield was reduced to 265.60 g m^{-2}. No significance was found between the two higher densities, but they were significantly different from the lowest density.

Generally, Laurier produced higher grain yields with a mean production of 266.10 g m^{-2} and was significantly different from Q.B.59.28 and Q.B.60.2 with 245.92 and 242.78 g m^{-2}, respectively. However, a significant interaction of D x C was noted at 0.05 probability level, which is important and indicates that the cultivars reacted to plant density in different manners (Table 4.21).

Table 4.21.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for grain yield (g m^{-2}).

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Laurier	258.17 a	Laurier	280.25 a	Q.B.60.2	271.50 a
Q.B.59.28	209.80 b	Q.B.59.28	262.83 a	Q.B.59.28	265.12 a
Q.B.60.2	200.62 b	Q.B.60.2	256.21 a	Laurier	259.87 a

Means followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

Only at the lowest density, was the superiority of Laurier highly evident. As the plant population was increased from 215 plants m^{-2} to 407 plants m^{-2}, Q.B.60.2 and Q.B.59.28 gained 28 and 25% in grain yield, respectively; whereas Laurier increased its grain yield by only 8%. In the highest density, it can be seen in Figure 4.11 that the uniculm cultivars still increased their yields (Q.B.60.2); whereas Laurier reduced its grain yield by approximately 8%.

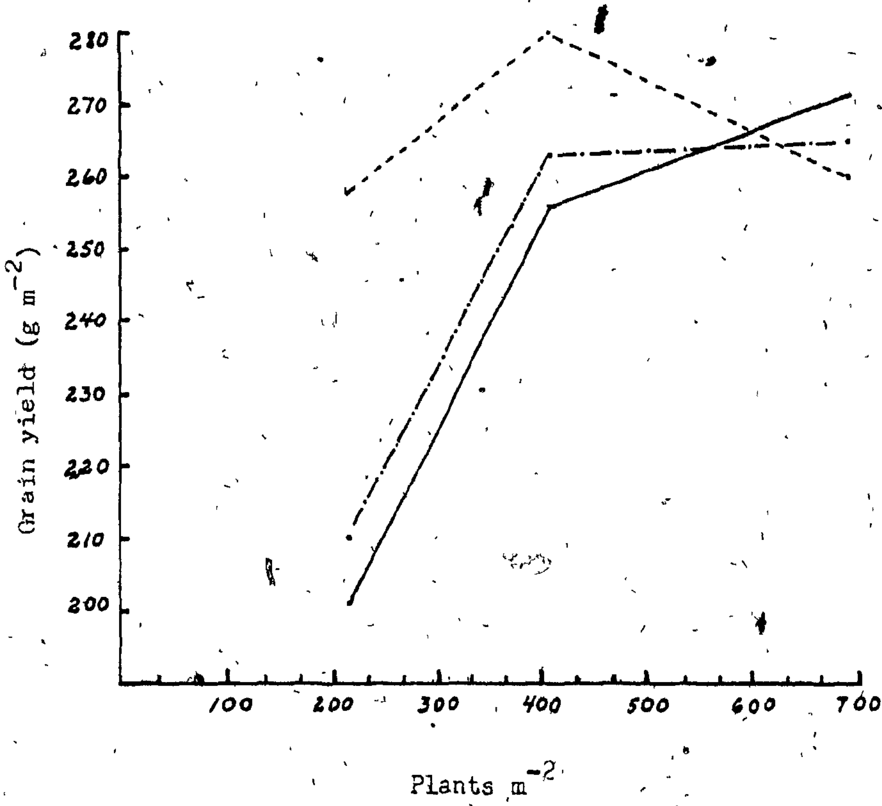

Figure 4.11.- Grain yield response of Laurier, ----; Q.B.60.2, ——; and Q.B.59.28, -.-.-., to plant density. Means of three levels of nitrogen and four replicates.

Moreover, Q.B.60.2 gave the single highest grain yield in this experiment at the highest level of nitrogen and the most populated treatment with 311.00 g m^{-2}.

The grain yield responses of the cultivars were analyzed again in terms of yield components and are graphically represented in Figures 4.12 a, b, c and d.

No significant interaction by nitrogen was evident; therefore, the results are expressed on the basis of the means of three levels of nitrogen.

In Figure 4.12 it can be seen that in all cultivars the number of ears per square meter increased with plant density. On the other hand, grains per ear and 1000 - grain weight were both reduced by denser plant populations. However, despite the fact that the two latter components were reduced by plant density, consistent increments in grain yield were observed in the uniculm cultivars with increasing density and the peak in grain yield of Laurier occurred at a higher density.

The only decrement in grain yield was observed in Laurier at the highest density. Figure 4.12 (b) shows that though Laurier had the heaviest grains at this density, its grain yield was the lowest. Thus, if ear number per square meter was increased with plant density and Laurier had a reasonably good seed weight at the densest population, the explanation of the decrease in grain yield at denser populations for Laurier must be found within the

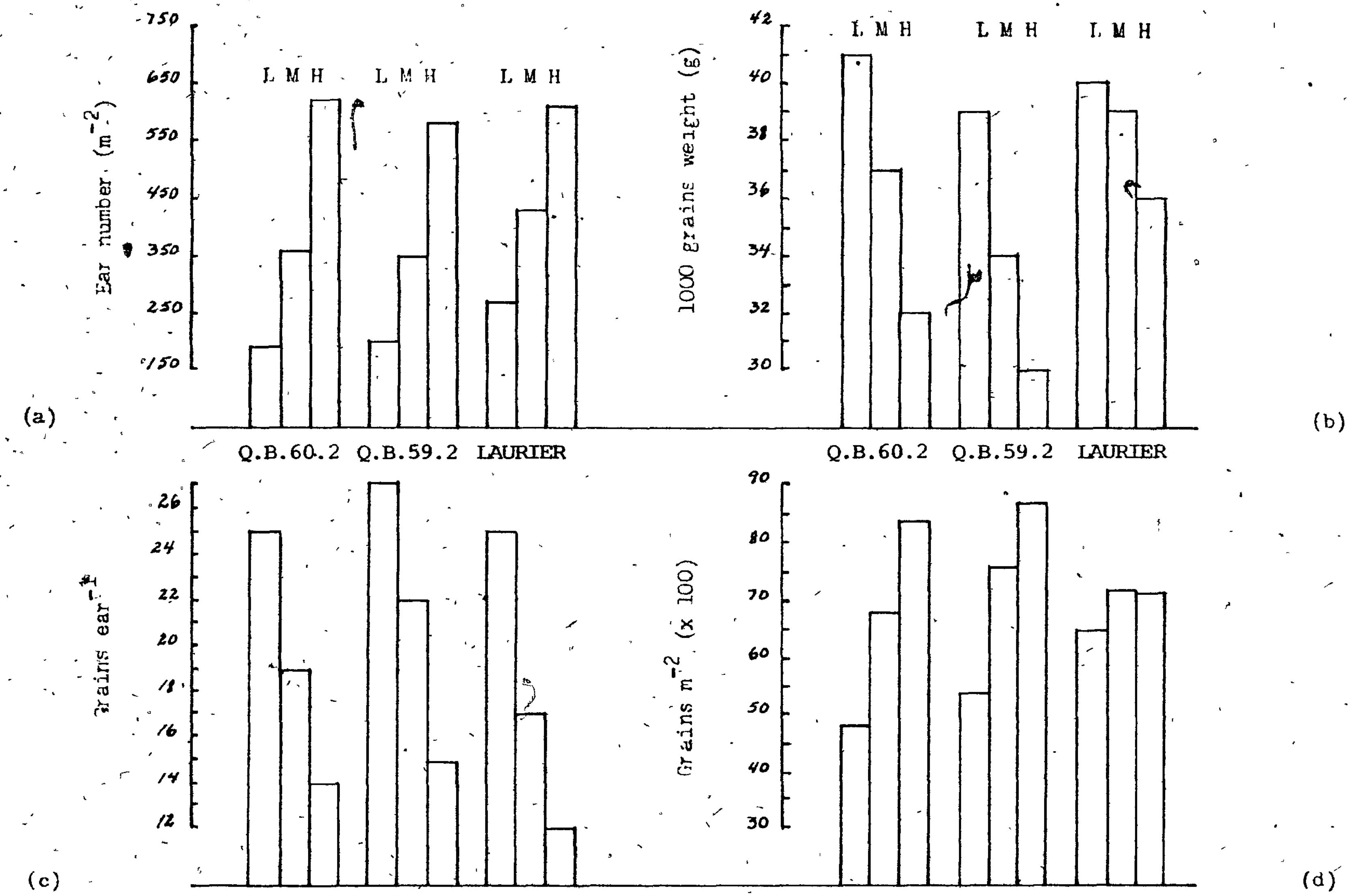

Figure 4.12.- Effect of plant density (L, low; M, medium; H, high) on the yield components of barley.

response of the number of grains per ear. Figure 4.12 (c) also shows that the reduction in grains per ear was more drastic than the reduction in 1000 - grain weight.

Nevertheless, in Figures 4.12 (b) and (c) the reductions of 1000 - grain weight and grains per ear were not associated with reductions in grain yield (uniculms). Thus, and in accordance with the findings of Willey and Holliday (1971 a), the most sensitive yield component to plant density and the one responsible for reductions of grain yield at higher densities is the number of grains per unit area (Figure 4.12 (d)).

The correlation analysis between grain yield and number of grains per square meter, considering means of three plant densities and three levels of nitrogen resulted in r values of 0.93, 0.93 and 0.94 for Q.B.59.28, Q.B.60.2 and Laurier, respectively.

4.2.9.- Total Dry Matter Yield.- It has been established that total dry matter increases with heavier fertilization of nitrogen, if levels of moisture in the soil are considered acceptable (see Literature Review). In this experiment, and in conformity with the analysis of variance (Appendix, Table 24), total dry matter or biological yield increased significantly at higher levels of nitrogen.

The lowest yield was obtained at the lowest level of nitrogen, with 500 g m^{-2}, being significantly different from 613.05 g m^{-2} at the medium rate of nitrogen and 677.34 g m^{-2} at the highest level, according to DNMRT at 0.05 probability level.

Also, it is generally known (see Literature Review) that biological yield is increased by plant density, reaching a ceiling point in which total dry matter "flattens-off" on the curve relating total dry matter to density. In the present study and due to the rather narrow range of plant populations, steady increases of biological yield (total above ground dry matter, including grain yield) were observed with increasing plant density. The lowest dry matter yield was accounted for at the lowest density with 509.14 g m^{-2} (considering means of three cultivars and three levels of nitrogen). This value rose with plant density to 625.68 g m^{-2}, being significantly different. Further increments in population gave a non-significant increase in biological yield with 655.88 g m^{-2}, which probably indicates that a maximum value was obtained.

In general, Laurier produced the largest biological yield (604.35 g m^{-2}), but was not significantly different from Q.B.60.2 (597.85 g m^{-2}) and Q.B.59.28 (586.58 g m^{-2}).

However, the significant interaction of D x C indicates different responses of the cultivars to plant density (Table 4.22).

Table 4.22.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for total dry matter yield (g m^{-2}).

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Laurier	549.29 a	Laurier	635.00 a	Q.B.60.2	687.00 a
Q.B.59.28	493.79 b	Q.B.60.2	622.21 a	Q.B.59.28	651.54 a,b
Q.B.60.2	484.33 b	Q.B.59.28	619.83 a	Laurier	628.75 b

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

Table 4.22 clearly shows that at the widest spacing Laurier had the largest growth rates. At closer spacings, the relative growth rates of Laurier were depressed by plant density, although it had a larger biological yield; that of the uniculm cultivars was much larger in comparison to the lowest density. Moreover, at the medium density the differences are not significant. The consistently higher growth rates of the uniculms at higher densities were evident at this point, when the greatest yields were accounted for by Q.B.60.2 (687.00 g m^{-2}) and Q.B.59.28 (651.54 g m^{-2}).

These results are in agreement with those of Donald (1963) and Kirby (1967). They noted that the ceiling biological yield and the maximum grain yield are generally achieved at about the same density.

The reduction in dry matter production at the highest density, observed in the case of Laurier, may be explained in terms of plant community growth concepts.

The crop growth rate (CGR), or total dry matter productivity of the stand per unit area over a period of time, is expressed in terms of its components, net assimilation rate (NAR), which is the rate of increase in the whole plant of dry matter per unit leaf area, and leaf area index (LAI), the ratio of leaf area to ground area. The NAR expresses the capacity of the plant to produce dry matter as a function of its leaf area; it represents the net result of photosynthate gain over respiratory loss; and LAI represents the proportion of total leaf area to ground area.

When plant density is increased, a greater LAI is obtained up to a certain point where the maximum CGR is reached. Further increments in plant density, generally result in reduced CGR (Kirby, 1967) because the gain in a greater photosynthetic area (+ LAI) is offset by other factors such as senescence of the leaves and greater respiratory losses. These losses may be enhanced also by a greater temperature within the crop. In the present experiment, Laurier might well have reached its "optimum" LAI at the medium density, and higher densities induced lower CGR and hence lower final yields.

In relation to grain production these principles may also apply and it has been demonstrated (Kirby, 1970) that barley plants growing at higher densities showed drastic reductions in the number of spikelet primordia when compared to plants growing at lower densities. The result was that in the same period of time, the stressed plants formed a significant lower number of spikelets.

4.2.10.- Harvest Index.- It has been widely elucidated that the application of nitrogen usually increases biological yield and depresses harvest index (see Literature Review and Experiment 1). In other words, the proportion of grain yield to above ground total dry matter is lowered by heavier rates of nitrogen.

In the present work, the harvest index was depressed by nitrogen, from 0.44 in the absence of nitrogen to 0.41 in the presence of 32 Kg N ha^{-1}; considering overall means. The difference was significant, according to DNMRT at 5% probability level. No further reductions in harvest index were seen at the maximum level of nitrogen.

"A factor likely always to be involved in the fall in harvest index at high densities is the light profile within the crops. At high densities total light interception occurs earlier and competition between plants for light is more intense. The percentage of tillers producing ears, the number of grains per ear, and grain size are all reduced, even where water and nutrients are nonlimiting" (Donald and Hamblin, 1976). This short excerpt sums up much of the work done in these experiments. We have seen before that in plant density studies a point is reached where further increases in leaf area no longer offset the reduction in net photosynthesis (NAR) due to competition for light and a greater proportion of respiratory losses from shaded or senesced leaf areas prevails.

In the present study and in accordance with Donald and Hamblin (1976), harvest index declined before the maximum grain yield was attained. At the lowest density the harvest index was 0.43 considering the means of three cultivars and three levels of nitrogen; at the medium density this value was reduced to 0.42, yet not significantly different; at the highest density, further and significant reductions were seen with 0.4.

Laurier had the largest harvest indices with a mean of 0.44 and was significantly different from Q.B.59.28 (0.42) and Q.B.60.2 (0.40).

Although the interaction D x C is not significant, DNMRT shows (Table 4.28) that the cultivars responded differently to plant density.

Table 4.23.- Duncan's New Multiple Range Test for the comparison of cultivar means* at three plant densities for harvest index.

215 plants m^{-2}		407 plants m^{-2}		686 plants m^{-2}	
Laurier	0.47 a	Laurier	0.44 a	Laurier	0.41 a
Q.B.59.28	0.42 b	Q.B.59.28	0.42 a	Q.B.59.28	0.40 a
Q.B.60.2	0.41 c	Q.B.60.2	0.41 a	Q.B.60.2	0.39 a

Means within columns followed by the same letter are not significantly different at 0.05 probability level.

*Means of three levels of nitrogen and four replicates.

According to Table 4.23, only at the lowest density are the differences in harvest index significantly different. It is known (Badra, 1978, personal communication) that at lower densities, the uniculm cultivars show greater ear abnormalities, i.e., reduced number of grains; when plant density is increased, the degree of abnormality is reduced and the uniculm cultivars show their actual potential for grain production and better harvest indices.

5.- CONCLUSIONS

1.- In both experiments, plant density reduced significantly the number of tillers per plant, plant height, ears per plant, grains per ear, 1000 - grain weight and harvest index (significantly only in 1978).

However, the number of ears per square meter was significantly increased. Grains per square meter and yield were reduced significantly by plant density in 1977; whereas in 1978 there was a significant increment followed by a reduction at the highest density.

2.- In both experiments, nitrogen increased the number of tillers per plant (significantly in 1978), tillers per square meter (significantly), plant height (significantly in 1978), also increased slightly the number of ears per plant (in 1977), ears per square meter and grains per ear (significantly in 1978). Grains per square meter and yield were significantly increased. However, 1000 - grain weight and harvest index were reduced (significantly in 1978).

3.- In general, the uniculm cultivars did not show reductions in yield by plant density. Moreover, the single highest grain yield was accounted for by Q.B.60.2 with

311 g m^{-2} at the highest density and nitrogen level in 1978.

4.- The parameter number of grains m^{-2} was more closely associated with grain yield at higher densities than any other grain yield component. On the other hand, at lower densities, grain weight was more important.

5.- Grain yields can be increased by plant density if the environmental conditions are favourable, like in 1978.

6.- Due to its great ear capacity, Loyola may be more adaptable to crowded populations.

7.- Although 1000 - grain weight played a secondary role at higher densities, it is an important limitant for higher yields in Q.B.59.28.

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7.- Appendix.

Table 1.- Plant number

Plant density:

$$Sx=\sqrt{\frac{E\ b}{\gamma\ \alpha\ \gamma}}=\sqrt{\frac{3833.8}{3x3x5}}=9.23$$

257.21 a
174.89 b
146.59 b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{\gamma\ \alpha\ \beta}}=\sqrt{\frac{2524.88}{3x3x3}}=9.67$$

Conquest	207.41	a
Laurier	204.80	a
Loyola	192.59	ab
Q.B.60.2	191.48	ab
Q.B.59.2	165.00	b

Table 2.- Tillers per plant

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r\alpha\gamma}}=\sqrt{\frac{0.276}{45}}=0.08$$

147 plants/m^2	0.88 a
257 "	0.42 b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{0.201}{27}}=0.09$$

Conquest	1.29 a
Laurier	0.98 b
Loyola	0.93 b

Plant density x Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha}}=\sqrt{\frac{0.201}{9}}=0.15$$

147 plts/m^2		257 plts/m^2	
Conquest	1.77 a	Conquest	0.89 a
Laurier	1.34 b	Loyola	0.60 a
Loyola	1.32 b	Laurier	0.59 a

Table 3.- Tillers per square meter

Nitrogen:

$$Sx=\sqrt{\frac{E\ a}{r\beta\gamma}}=\sqrt{\frac{847.25}{3x3x5}}=4.34$$

68 Kg N/Ha	122.22 a
34 "	113.10 ab
0 "	87.33 b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{3350.8}{3x3x3}}\doteq 11.14$$

Conquest	226.7 a
Laurier	160.0 b
Loyola	150.4 b

Table 4.- Days to heading

Cultivars:

$$S\bar{x}=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{0.641}{27}}=0.15$$

Loyola	58.18	a
Q.B.60.2	55.37	b
Laurier	54.96	bc
Conquest	54.59	c
Q.B.59.2	53.48	d

Table 5.- Ears per plant

Plant density:

$$Sx = \sqrt{\frac{E\ b}{r \alpha \gamma}} = \sqrt{\frac{0.646}{3x3x5}} = 0.042$$

147 plts/m^2	1.45 a
257 plts/m^2	1.08 b

Cultivars:

$$Sx = \sqrt{\frac{E\ c}{r \alpha \beta}} = \sqrt{\frac{0.072}{27}} = 0.05$$

Conquest	1.54 a
Laurier	1.40 ab
Loyola	1.35 b
Q.B.60.2	0.99 c

Table 6.- Ears per square meter -

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r\alpha\gamma}}=\sqrt{\frac{5136.42}{45}}=10.7$$

257 plts/m^2	276.5	a
147 "	210.2	b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{2515.62}{3x3x3}}=9.65$$

Conquest	287.0	a
Laurier	262.4	ab
Loyola	246.3	b
Q.B.60.2	190.0	c

Table 7.- Grains per ear

Plant density:

$$Sx=\sqrt{\frac{E\ b}{\gamma_1 \alpha \gamma}}=\sqrt{\frac{17.83}{45}}=0.63$$

147 plts/m^2	17.57 a
257 "	14.44 b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{\gamma \alpha \beta}}=\sqrt{\frac{13.09}{3x3x3}}=0.696$$

Loyola	19.83 a
Laurier	16.54 b
Conquest	16.50 b
Q.B.60.2	14.39 c

Table 8.- Grains per square meter

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r \alpha \gamma}}=\sqrt{\frac{997805.6}{45}}=148.9$$

257 plts/m^2	3854.37	a
147 "	3771.90	a

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r \alpha \beta}}=\sqrt{\frac{406416.4}{27}}=122.69$$

Loyola	4641.27	a
Conquest	4560.51	a
Laurier	4100.26	b
Q.B.60.2	2741.57	c
Q.B.59.2	2069.26	d

Table 9.- Grain size

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r \alpha \gamma}}=\sqrt{\frac{9.48}{3x3x5}}=0.46$$

147 plts/m^2	36.48	a
257 plts/m^2	31.41	b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r \alpha \beta}}=\sqrt{\frac{3.26}{27}}=0.35$$

Laurier	37.93	a
Q.B.60.2	36.26	b
Loyola	33.98	c
Q.B.59.2	33.27	c
Conquest	28.85	d

Table 10.- Grain yield

Nitrogen:

$$Sx=\sqrt{\frac{E\ a}{r\beta\gamma}}=\sqrt{\frac{8748.5}{3x3x5}}=13.9$$

0 Kg N/Ha	108.99	a
34 Kg N/Ha	120.18	a
68 Kg N/Ha	138.19	a

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r\alpha\gamma}}=\sqrt{\frac{1508.57}{45}}=5.79$$

147 plts/m^2	135.40	a
257 " "	120.37	a

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{473.4}{27}}=4.19$$

Loyola	157.92	a
Laurier	156.37	a
Conquest	132.41	b
Q.B.60.2	97.56	c
Q.B.59.2	68.78	d

Table 11.- Total dry matter

Nitrogen:

$$Sx = \sqrt{\frac{E\ a}{r \beta \gamma}} = \sqrt{\frac{26564.36}{3x3x5}} = 24.3$$

0 Kg N/Ha	231.27	a
34 "	"	263.69	a
68 "	"	298.07	a

Cultivars:

$$Sx = \sqrt{\frac{E\ c}{r \alpha \beta}} = \sqrt{\frac{2254.41}{27}} = 9.14$$

Loyola	318.44	a
Laurier	311.02	ab
Conquest	290.57	b
Q.B.60.2	233.37	c
Q.B.59.2	168.25	d

Table 12.- Harvest index

Nitrogen x Plant density x Cultivar:

$$S\bar{x} = \sqrt{\frac{\beta(\gamma-1)Ec+(\beta-1)Eb+Ea}{\gamma\beta\gamma}} = \sqrt{\frac{(3)(4)0.001+(2)0.003+0.03}{3x3x5}} = 0.03$$

	Q.B.60.2	Laurier	Loyola	Conquest	
0 Kg N/Ha	0.42 a	0.48 a	0.48 a	0.43 a	
34 " "	0.44 a	0.50 a	0.48 a	0.44 a	257 plts/m^2
68 " "	0.39 a	0.47 a	0.50 a	0.44 a	
0 " "	0.43 a	0.53 a	0.53 a	0.44 a	
34 " "	0.35 a	0.54 a	0.50 a	0.47 a	147 plts/m^2
68 " "	0.42 a	0.52 a	0.53 a	0.47 a	

Cultivars:

$$S\bar{x} = \sqrt{\frac{E\ c}{\gamma\alpha\beta}} = \sqrt{\frac{0.0011}{27}} = 0.006$$

Laurier	0.501	a
Loyola	0.496	a
Conquest	0.453	b
Q.B.60.2	0.419	c
Q.B.59.2	0.401	d

Table 13.- Plant number

Plant density:

$$S_x = \sqrt{\frac{E\,b}{\gamma \cdot \alpha \cdot \gamma}} = \sqrt{\frac{6930.78}{36}} = 13.87$$

686	$plts/m^2$	a
407	" "	b
215	" "	c

Table 14.- Tillers per plant

Plant density x Cultivar (Laurier)

$$Sx=\sqrt{\frac{(\gamma-1)Ec+Eb}{\gamma\alpha\gamma}}=\sqrt{\frac{(2)0.004+0.0035}{4x3x3}}=0.018$$

215 plts/m^2	0.46	a
407 " "	0.17	b
686 " "	0.17	b

Table 15.- Tillers per square meter,

Nitrogen x Cultivar (Laurier)

$$Sx=\sqrt{\frac{(\gamma-1)Ec+Ea}{r\beta\gamma}}=\sqrt{\frac{(2)366.4+297.64}{4x3x3}}=5.35$$

68	Kg N/Ha	123.33	a
34	" "	100.83	b
0	" "	83.75	c

Table 16.- Days to heading

Nitrogen:

$$Sx=\sqrt{\frac{E\ a}{r \beta \gamma}} = \sqrt{\frac{2.93}{4x3x3}} = 0.28$$

0 Kg N/Ha	45.64 a
34 " "	45.53 a
68 " "	45.05 a

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r \alpha \beta}} = \sqrt{\frac{0.463}{36}} = 0.11$$

Q.B.59.2	46.17 a
Q.B.60.2	45.17 b
Laurier	44.89 b

Table 17.- Plant height

Nitrogen:

$$Sx=\sqrt{\frac{E\ a}{\gamma\beta\gamma}}=\sqrt{\frac{235.68}{36}}=2.56$$

68 Kg N/Ha	80.30	a
34 " "	74.89	a
0 " "	65.39	b

Plant density:

$$Sx=\sqrt{\frac{E\ b}{\gamma\alpha\gamma}}=\sqrt{\frac{113.67}{36}}=1.78$$

215 plts/m^2	79.00	a
407 " "	74.44	a
686 " "	67.14	b

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{\gamma\alpha\beta}}=\sqrt{\frac{23.13}{36}}=0.8$$

Q.B.60.2	75.83	a
Q.B.59.2	74.47	a
Laurier	70.28	b

Table 18.- Ears per plant

Plant density:

$$Sx=\sqrt{\frac{E\ b}{\gamma\alpha\gamma}}=\sqrt{\frac{0.0046}{36}}=0.011$$

215 plts/m^2	1.02	a
407 " "	0.92	b
686 " "	0.87	c

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{\gamma\alpha\beta}}=\sqrt{\frac{0.0052}{36}}=0.012$$

Laurier	1.00	a
Q.B.60.2	0.92	b
Q.B.59.2	0.89	b

Table 19.- Ears per square meter

Plant density:

$$Sx=\sqrt{\frac{E \cdot b}{r \alpha \gamma}}=\sqrt{\frac{9535.32}{36}} = 16.27$$

215 plts/m^2	221.86	a
407 " "	380.55	b
686 " "	603.43	c

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r \alpha \beta}}=\sqrt{\frac{5053.7}{36}} = 11.85$$

Laurier	436.67	a
Q.B.60.2	391.17	b
Q.B.59.2	371.57	b

Table 20.- Grains per ear

Nitrogen:

$$S\bar{x} = \sqrt{\frac{E\ a}{r\beta\gamma}} = \sqrt{\frac{32.55}{36}} = 0.95$$

68 Kg N/Ha	21.77	a
34 " "	19.59	ab
0 " "	18.14	b

Plant density:

$$S\bar{x} = \sqrt{\frac{E\ b}{r\alpha\gamma}} = \sqrt{\frac{34.20}{36}} = 0.97$$

215 plts/m^2	25.75	a
407 " "	19.68	b
686 " "	13.85	c

Cultivars:

$$S\bar{x} = \sqrt{\frac{E\ c}{r\alpha\beta}} = \sqrt{\frac{21.376}{36}} = 0.77$$

Q.B.59.2	21.88	a
Q.B.60.2	19.62	b
Laurier	18.00	b

Table 21.- Grains per square meter

Nitrogen:

$$Sx=\sqrt{\frac{E\ a}{r\beta\gamma}}=\sqrt{\frac{2970165.58}{36}}=287.24$$

68 Kg N/Ha	7828.90	a
34 " "	7041.94	a
0 " "	6002.79	b

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r\alpha\gamma}}=\sqrt{\frac{1723130.31}{36}}=218.78$$

215 plts/m^2	5585.42	a
407 " "	7227.92	b
686 " "	8066.91	c

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{747487.46}{36}}=144.09$$

Q.B.59.2	7193.47	a
Laurier	6983.50	ab
Q.B.60.2	6679.02	b

Table 22.- Grain size

Plant density:

$$Sx=\sqrt{\frac{E\ b}{r\alpha\gamma}}=\sqrt{\frac{7.57}{36}}=0.46$$

215 plts/m^2	39.96	a
407 " "	36.86	b
686 " "	33.00	c

Cultivars:

$$Sx=\sqrt{\frac{E\ c}{r\alpha\beta}}=\sqrt{\frac{3.71}{36}}=0.32$$

Laurier	38.28	a
Q.B.60.2	37.06	b
Q.B.59.2	34.49	c

Table 23.- Grain yield

Nitrogen:

$$Sx = \sqrt{\frac{E\ a}{r \beta \gamma}} = \sqrt{\frac{5341.6}{36}} = 12.18$$

68 Kg N/Ha	279.37	a
34 " "	255.47	ab
0 " "	219.94	b

Plant density:

$$Sx = \sqrt{\frac{E\ b}{r \alpha \gamma}} = \sqrt{\frac{4016.3}{36}} = 10.56$$

407 plts/m^2	266.43	a
686 " "	205.50	a
215 " "	222.86	b

Cultivars:

$$Sx = \sqrt{\frac{E\ c}{r \alpha \beta}} = \sqrt{\frac{1253.2}{36}} = 5.9$$

Laurier	266.10	a
Q.B.59.2	245.92	b
Q.B.60.2	242.78	b

Table 24.- Total dry matter yield

Nitrogen:

$$Sx = \sqrt{\frac{\Sigma a}{r\beta\gamma}} = \sqrt{\frac{19738.12}{36}} = 23.41$$

68 Kg N/ha	677.34	a
34 " "	613.05	a
0 " "	500.90	b

Plant density:

$$Sx = \sqrt{\frac{\Sigma b}{r\alpha\gamma}} = \sqrt{\frac{15420.06}{36}} = 20.7$$

215 plts/m^2	509.14	a
407 " "	625.68	b
686 " "	655.88	b

Cultivars:

$$Sx = \sqrt{\frac{\Sigma c}{r\alpha\beta}} = \sqrt{\frac{3658.20}{36}} = 10$$

Laurier	604.35	a
Q.B.60.2	597.85	a
Q.B.59.2	586.58	a