EFFECTS OF MANAGEMENT PRACTICES ON YIELD AND YIELD COMPONENTS IN BARLEY (*HORDEUM VULGARE* L. EMEND LAM.)

by

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Short title

FIELD STUDIES ON GRAIN YIELD OF BARLEY

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ABSTRACT

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EFFECTS OF MANAGEMENT PRACTICES ON YIELD AND YIELD COMPONENTS IN BARLEY (HORDEUM VULGARE L. EMEND LAM.)

Field studies were conducted in 1981 and 1982 to determine the duration of five selected growth stages and to record yield and yield components of three cultivars submitted to various combinations of seeding date, seeding rate and nitrogen treatments at tillering.

The effect of seeding date varied over the two years. There is a good indication that the amount of precipitation during the vegetative stage, particularly during stem elongation, modified the usual response of decreased yield with delayed seeding in 1981. Nitrogen rates of 46.8 kg/ha showed grain yield increases of 8.3% compared with the 15.6 kg/ha treatment in 1981. Four-fold increases in seeding rates did not affect grain yield, with one exception caused by severe intraplant competition due to early season drought in 1982. Differential response of cultivars to seeding dates suggests that it would be beneficial to test for seeding dates in cultivar trials for local recommendations to farmers.

One thousand-grain weight variability over the two years did not permit pooling of the results, and it is suggested that this fact should be more widely recognized.

The duration of the growth stages, emergence to stem elongation and the grain-filling period, showed significant relationships to grain yields.

Grain yield was best predicted by a simple linear regression equation where the coefficient of the independent variable is grains/m² or the combination of the two ontogenically early yield components which are heads/m² and grains/head. In both years it appears that grain yield was limited by the sites of storage (sink) rather than the filling source. Thus, the factors affecting grain site development were more important than the factors affecting subsequent grain filling. Consequently, compensation for both seeding dates and seeding rates occurred mainly between the heads/m² and grain/head yield components, while compensation by 1000-grain weight is incidental rather than physiological.

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RESUME

M.Sc. MARIE CLAUDE FORTIN Phytotechnie

EFFETS DE CERTAINES PRATIQUES CULTURALES SUR LE RENDEMENT ET LES COMPOSANTES DE RENDEMENT DE L'ORGE (HORDEUM VULGARE L. EMEND LAM.)

Des essais en champs en 1981 et en 1982 eurent lieu afin de déterminer la durée de cinq différents stades de croissance de l'orge et de mesurer le rendement en grain et les composantes du rendement de trois cultivars soumis à plusieurs dates de semis, taux de semis et taux d'azote au tallage.

Les effets des dates de semis ont varié selon l'année. Le total des précipitations durant la montaison semble être le facteur expliquant cette variation lorsque le semis hâtif n'a pas donné de rendement supérieur en 1981. Un taux d'azote au tallage de 46.8 kg/ha a augmenté le rendement en grain de 8.3% comparé à un traitement de 15.6 kg/ha.

Des taux de semis variant de 400% n'ont pas eu d'effet sur le rendement sauf en 1982 à cause d'une compétition trop intensive entre talles d'un même plant lors de la sécheresse du début de saison 1982. Comme la différence variétale existe pour les effets des dates de semis, il serait donc avantageux d'inclure de tels tests lors des essais de cultivars pour les recommandations provinciales aux agriculteurs.

La variabilité observée du poids de mille grains entre les deux années n'a pas permis de combiner les deux séries de résultats et il est suggéré de tenir compte de ce phénomène à l'avenir.

La durée du stade de croissance de l'émergence à la montaison et celle de la période de remplissage des grains sont reliées significativement au rendement en grain.

Le rendement en grain est décrit le plus efficacement par une équation linéaire simple de régression où la variable indépendante est le nombre de grains/m², provenant de la multiplication des deux composantes de rendement suivantes: le nombre d'épis/m² et le nombre de grains par épi. Au cours des deux années le rendement en grain fut donc limité par la capacité de remplissage plutôt que par la source de remplissage des

grains. Dès lors, on peut affirmer que les facteurs qui ont déterminé le développement des grains ont été plus importants que les facteurs qui ont influencé le remplissage ultérieur des grains. Par conséquent, la compensation entre les composantes du rendement pour les effets des dates de semis et des taux de semis eut lieu surtout entre le nombre d'épis/m^2 et le nombre de grains/épi alors que la compensation effectuée par le poids de mille grains fut fortuite plutôt que physiologique.

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TABLE OF CONTENTS

Page

LIST OF TABLES

Table | Page

LIST OF FIGURES

I. INTRODUCTION

Spring barley (Hordeum vulgare L. emend Lam) is one of the main feed cereals grown in Quebec, supplying a large portion of high energy grain for livestock feeding. Recent cultivars are generally well adapted, although they require good fertility and adequate drainage to produce high yields.

Most of the management studies on cereal crops have not dealt with the recent high-yielding feed barley cultivars recommended in eastern Canada. The significance of the interaction of genotypes with rates of seeding and with date of seeding, both differentially affected by various nitrogen fertilizer rates in other parts of the world, created the need for evaluating recently recommended barley cultivars to varied management practices.

Grain yield per unit area is determined by three components: number of heads per unit area, number of grains per head and weight per one thousand grains. Several agronomic practices, such as seeding rate, seeding date and nitrogen fertilizer rate, as well as environmental conditions, have varying effects upon these components of yield. It is important to define how to manipulate some of these factors in order to be able to get the highest energy output per unit area under specific conditions. Therefore, three different barley cultivars were tested for yielding ability, components of yield and several other agronomic characteristics under thirty-six different treatment combinations of seeding dates, seeding rates and nitrogen fertilizer rates in order to establish the optimum cultural and fertilizer management conditions and to understand the preliminary basis for any significant increase in yield.

2. LITERATURE REVIEW

2.1 Grain yield components in cereal crops

As early as 1923, Engledow and Wadham partitioned cereal grain yield into yield components on a per plant basis (Aytenfisu, 1977). Nowadays, yield components are determined on a per plant or per unit area basis.

Grain yield is an integration in which the components are interdependent in their development. The components of grain yield in cereal crops are determined at different growth stages of the plant. The number of heads per plant or per unit area is determined largely at tillering. In barley, spikelet production determining the number of grains per head is partly fixed before head emergence. Grain size is influenced also by the vegetative stage, although it is partly determined by the post-anthesis period (Rasmusson and Cannell, 1970).

Since yield components are determined at different times, they are affected mainly by different environmental influences. As a consequence, compensatory effects of one component for a low value of a second one lead to yield stabilization in cereal crops. Adams (1967) cited several examples of these effects and discussed the developmental negative correlations existing between components. Grafius (1965) also considered that the optimal genetic level for each component would differ, depending on the type of environment to be faced.

Adams and Grafius (1971) explained how the balance among components of yield in crop plants is achieved through the oscillatory response of the sequential components to limited resources. According to them, yield improvement would come from increasing the flow of environmental resources throughout the period of need by the components and to raise by selection the capacity of a component to respond to the available resources (Adams and Grafius, 1971).

Nerson (1980) reported significant simple correlation coefficients between grain yield per plant and per unit area and some of the yield components. The yield components were also used in multiple regressions in several cereal crops (Frey, 1959; Needham and Boyd, 1976), with the number of heads per plant or per area generally showing the higher predicting value (Cannell, 1969; Jessop and Ivins, 1970; Black and Siddoway, 1977; Power and Alessi, 1978; Scott, 1978; Dougherty, Love and Mountier, 1979; Nerson, 1980).

2.2 Response of grain yield and yield components to seeding date, nitrogen fertilization and seeding rate

2.2.1 Seeding date effects

Several investigators in various parts of the world have shown that higher yields can be expected when spring cereals are seeded early in the season (Nass *et al*, 1975). Stoskopf *et al* (1974) report that early spring seeding in Ontario showed the greatest positive increase on grain yield compared with nitrogen fertilization on seeding rate for spring and winter wheat.

In barley, highest grain yields are often harvested from the earliest date of planting and decrease with later dates (Schmidt, 1960; Beard, 1961; Hoag and Geiszler, 1968; Jessop and Ivins, 1970; Zubriski et al, 1970; Beech and Norman, 1971; Comeau et al, 1974; Ridge and Mock, 1975; Nass et al, 1975; Fedak and Mack, 1977).

Very few authors report the reversal of this trend. Fertilized barley was not significantly influenced by seeding date in an experiment by Anderson and Hennig (1964) in northwestern Alberta; studies in the semi-arid Great Plains by Black and Siddoway (1977) show that extremely late seeding dates consistently decreased grain yields compared with normal seeding dates; however, they were unable to show any yield increases for early seeding dates.

Deschênes and St-Pierre (1980) state that oat grain yield can be significantly lower on a sandy loam at early seeding than at late seeding, and that early seeding contributes to significantly increase grain yield on heavy soils because high yields are mostly related to soil humidity.

Differential responses of cultivars to dates of seeding have been noted by several investigators. Harrington and Horner (1935), Frey (1959), Schmidt (1960), Beard (1961), McFadden (1970), Beech and Norman (1971), Fedak and Mack (1977) and Briggs and Aytenfisu (1979) all reported significant interaction of genotypes with date of seeding. However, Black and Siddoway (1979) reported reduced yields with delayed seeding, regardless of the cultivar used.

Lower numbers of heads per plant or per area of wheat and/or of barley are associated with delayed seedings (Jessop and Ivins, 1970; Beech and Norman, 1971; Nass et al, 1975; Black and Siddoway, 1977). In the experiment by Black and Siddoway (1977), it accounts for 92% and 85% response of two cultivars variance in grain yield associated with the effect of fertilization and seeding date. Frey (1959) and Beech and Norman (1971) noted a significant interaction of date of seeding with genotype for the number of heads per plant in oats and wheat, respectively.

Delays in seeding were also expressed mainly by reduced numbers of grains per spike in wheat or barley, according to Stoskopf et al (1974). Frey (1959) reported an interaction of seeding date with genotypes for the numbers of grains per head in oats. On the other hand, Jessop and Ivins (1970) found that the number of grains per head always increased with late sowing, irrespective of years or fertilizers, for two different cultivars. Similar but smaller effects were noted for spring barley. Black and Siddoway (1977) found no significant effect of seeding date on the number of grains per head of spring wheat in a one-year experiment at three different locations. These varying results show that it is likely that differences in environment resulting from different sowing dates at a particular stage of growth account for differences in grain numbers (Jessop and Ivins, 1970).

Delayed seeding also results in a reduction in grain weight of oats, barley and wheat, according to Frey (1959), Jessop and Ivins (1970), Zubriski et al (1970), Doyle and Marcellos (1974) and Stoskopf et al (1974). McFadden (1970) wrote that no significant difference could be attributed to seeding date for grain weight or unit volume weight in his three-year experiment in western Canada; while Nass et al (1975), in eastern Canada, reported yearly variation showing kernel weight decrease or no significant decrease as a result of later seedings.

2.2.2 Nitrogen fertilization effects

As a general rule, nitrogen fertilization increases barley grain yield (Zubriski et al, 1970; Nuttall, 1973; Calder and MacLeod, 1974; MacLeod et al, 1975; McGuire et al, 1979; Read and Warder, 1982).

The amount of increase depends on the rate of application (Dubetz and Wells, 1968; Sibbit and Bauer, 1970; Knott, 1974; Boyd et al, 1976; Heapy et al, 1976; Leyshon et al, 1980), the time of seeding (Zubriski et al, 1970), soil pH (Calder and MacLeod, 1974), the preceding crop (Needham and Boyd, 1976; Heapy et al, 1976; Read and Warder, 1982), and the time of application during the season (Dougherty, Love and Mountier, 1979) among other factors.

The optimum dressing for barley in temperate climate lies around 60 kg nitrogen per hectare (Needham and Boyd, 1976; McGuire et al 1979), although Dubetz and Wells (1968) noted that barley yield would increase up to 300 kg/ha of nitrogen in western Canada. Scott (1978) reported a linear increase up to 100 kg/ha of nitrogen under New Zealand conditions.

Boyd et al (1976) showed the effect of nitrogen on grain yield was best represented by two straight lines intersecting at the point of optimum nitrogen dressing given to barley plants. The first line represents a gradual increase in yield as nitrogen levels increase, until the second line intersects and a yield decrease is observed with further nitrogen applications. On the other hand, Sibbit and Bauer (1970), as well as Knott (1974), showed that the heaviest applications of nitrogen did not produce significant increases or decreases.

While it is generally recognized that cultivars in Canada do not show large yield differential response to fertilizer, Knott (1974) observed interactions among three wheat cultivars, locations and nitrogen treatments for yielding ability in Saskatchewan. As well, Dubetz (1972), in Alberta, has shown that Pitic 62, a lower protein utility wheat, tended to be more responsive to nitrogen in terms of yield than Manitou, a high-protein hard red spring wheat. Dubetz and Wells (1968), in a barley experiment, specify that no interaction between treatment and cultivars occurs until a nitrogen level of 60 kg/ha, after which varietal difference is markedly displayed.

Bauer (1970), in North Dakota drylands, and McNeil et al (1971), in Montana, report no nitrogen fertilization and cultivar interaction for yielding ability of five different cultivars. However, Bauer (1970) reports interaction whenever irrigation is used.

The nitrogen status of the soil influenced yield of cereal crops by modifying the relative values of one or more of the three main components of yield (Dougherty and Langer, 1974).

Favorable nitrogen nutrition usually increases spike populations in wheat (Langer, 1966; Dougherty et al, 1979; Power and Alessi, 1978), as well as Leyshon et al (1980) in barley. Dougherty et al (1979) found a linear relationship between New Zealand semi-dwarf wheat head population and the rate of nitrogen applied at tillering.

Scott (1978), in New Zealand, obtained a correlation of r = 0.76** from yield and head population in a one-year experiment under different nitrogen rates; 100 kg/ha of nitrogen gave an increase of 44% in number of heads of normal and semi-dwarf wheats. However, moderate head density obtained at moderate nitrogen levels, giving high yields, reflects the plasticity and partial compensation that exists between yield components (Scott, 1978). Differential cultivar response in increased number of heads per area with nitrogen has not been reported in recent literature.

Most nitrogen effects are directed towards the number of heads per area. Thorne and Blacklock (1971) and Dougherty et al (1974) did not record any effect of nitrogen on the number of grains per head of wheat. Power and Alessi (1978) stated that nitrogen fertilization did increase the number of grains per head in higher order tillers, while Dale and Wilson (1977) reported that low nitrogen treatment reduced the number of grains per head of both two-row and six-row barleys. Seed set was unaffected by nitrogen rate in a growth-room experiment by Campbell and Leyshon (1980). Dale and Wilson (1977) also recorded no changes in mean grain weight of the two barley types due to nitrogen treatments under Great Britain conditions, as well as Leyshon et al (1980) in growth-room experiments. Slight reductions were noted by Thorne and Blacklock (1971), Needham and Boyd (1976), Power and Alessi (1978) and Dougherty et al (1979), Read and Warder (1982). They also stated that where nitrogen is deficient, fertilizer nitrogen will increase grain weight, while excess nitrogen will decrease it. Needham and Boyd (1976) found fertilizer environmental conditions to be significant for grain weight, while McNeal et al (1971) recorded different cultivar response to nitrogen levels for grain weight among four related wheat cultivars.

2.2.3 Seeding rate effects

Most work on the relationship of cereal yield to plant density has been done under field conditions and it was soon established that the relation of grain yield to seeding rate could be best fitted by the quadratic equation, $y = a + bx - cx^2$, where y is the grain yield per unit area, x is the plant population, and a, b, c are regression parameters. This parabolic type of curve was first described by Holliday (1960) as being flat-topped and followed by a slow slope at high densities, and also by Donald (1963), Kirby (1967), Kirby and Faris (1970, 1972), Larter et al (1971) and Dougherty et al (1979). This relationship led Watson and French (1971) to write that it would be possible to decrease plant population significantly under commercial growing without reducing yields. Nerson (1980) observed a plateau of yield over a wide range of population densities in wheat grown in Israel under intensive cultivation. Under intensive cultivation, i.e., appropriate availability of water and nitrogen as well as an efficient weed control, thin populations of wheat can produce high yields since the single plant is able to express its yield potential. Nerson (1980) concludes that grain yield per unit area is not greatly affected by a wide range of densities. Many other workers, such as Woodward (1956) with irrigated plants, Jones and Hayes (1967) with oats, Finlay et al (1971) with barley, Thorne and Blacklock (1971) with wheat in England, Dougherty et al (1979) with wheat in Australia, Gebre-Mariam and Larter (1979) with triticale and wheat, as well as Briggs and Aytenfisu (1979), Done and Whittington (1980) with wheat F_1 hybrids and their parents, and Read and Warder (1982), observed similar results. Therefore, most research on the effect of seeding rate on the yield of small grains has shown that within a wide range of rates, grain yield is not greatly affected by density.

However, thin populations have an advantage in dry land farming because they permit a better utilization of the available rainfall (Pelton, 1969). As well, Kirby (1967, 1969) and Kirby and Faris (1972) have noted a greater yield increase from low seeding rates occurring in years of severe moisture stress. However, under normal growth conditions, Stoskopf et al (1974), Briggs (1975) and Faris and DePauw (1981) in Canada, as well as Harmati and Schzemes (1978) in

Hungary, reported higher yields obtained at higher seeding rates than those recommended in their areas, while McFadden (1970) observed that highest barley yields were obtained at 67 kg/ha, which is considerably below the commercial rate. On the other hand, McLeod (1982) in New Zealand, found out that despite lack of soil moisture in certain years, barley yields were increased from the highest seeding rates, 125 and 150 kg/ha.

Genotypic influence has been shown to exert a significant effect on the yield response at different densities (Donald, 1963; Jones and Hayes, 1967; Kirby, 1967; Finlay <u>et al</u>, 1971; Briggs, 1975; Baker, 1977; Gebre-Mariam and Larter, 1979; Briggs and Aytenfisu, 1979; Faris and De Pauw, 1981; Baker and Briggs, 1982). Holliday (1960), Donald (1963) and Puckridge and Donald (1967) discussed differential genotypic behaviour. At low seeding rates, cultivars demonstrate their capacity to use an extensive environment or to deal with intra-plant competition, while at high seeding rates they show a response in function of inter-plant competition. In the latter case, general favorable conditions will favor higher rates. Faris and De Pauw (1981) report that the higher the potential yield of a cultivar, the higher the seeding rate required to achieve its full yield potential. As soil fertility is increased and moisture is adequate, the optimum seeding rate rises (Holliday, 1960; Donald, 1963).

These statements explain the significant cultivar x location (Gebre-Mariam and Larter, 1979), year to year (Briggs and Aytenfisu, 1979), cultivar x density (Baker and Briggs, 1982) variability in results that led the first authors to write that an optimum cultivar density must be obtained under given environmental conditions, and the second to suggest that multi-year data are necessary to characterize specific genotype response to varied management practices such as seeding density.

Crop response to seeding rate had also been studied through the measure of yield components. The number of plants per unit area is the yield component which follows most closely the seeding rate. As such, it can condition the other yield components' response without necessarily influencing yield (Guitard et al, 1961). Jones and Hayes (1967), Kirby (1967, 1969), Puckridge and Donald (1967), Finlay et al (1971), Thorne and Blacklock (1971), Nerson (1980), Hampton (1981) Faris and De Pauw (1981) and Black (1982) described heads per unit area as being the dominant yield component. Nerson (1980) found a high positive correlation, r = 0.73, P = 0.01, between heads per square meter in wheat. Nerson (1980) also found a negative correlation between yield per plant and yield per unit area (r = -0.39, P = 0.05), and concludes that conditions which allow maximum yield potential are not those that give high yield per unit area. Therefore, some degree of plant competition is desirable (Kirby and Faris, 1972; Baker, 1977; Nerson, 1980). Faris and De Pauw (1981) also report that limited tillering is an important aspect of yield. It has been noted by several authors that the number of heads per plant decreased as seeding rate increased. As well, Gebre-Mariam and Larter (1979) were unable to correlate yield and heads per plant in triticale. Faris and De Pauw (1981) found no significant cultivar/rate of seeding interactions for both heads per unit area and heads per plant. Earlier, Finlay et al (1971) had already concluded that yearly variations in yield appeared primarily as a result of variations in the number of heads per unit area. McLeod (1982) showed that even if heads per plant, number of grains per head and weight of grain fell as the seeding rate increased, grain yield increased. In general, increased head populations at very high seeding rates are offset by a decrease in both grains per head and thousand grain weight (Holliday, 1960; Guitard et al, 1961; Kirby, 1967; Jones and Hayes, 1967; Puckridge and Donald, 1967; Thorne and Blacklock, 1971; Gebre-Mariam and Larter, 1979; Faris and De Pauw, 1981). Kirby (1967) observed a linear decrease in the number of grains per head of barley with increased density, while Gebre-Mariam and Larter (1979) observed the same relationship in triticale. Other authors, such as Kirby and Faris (1972), Briggs (1975), Dougherty et al (1979) and Nerson (1980) reported no significant effect of seeding rate on these two yield components, although they tended to decrease with increasing yield. Therefore, there is a general consensus on the fact that the two ontogenically late yield components are not major factors in determining yield at different plant densities. However, Kirby (1967) and Faris and De Pauw (1981) admit that the relatively small change in one or both can be important for reducing or increasing yield of some cultivars. In fact, Jones and Hayes (1967), with oats, and Gebre-Mariam and Larter (1979), with triticale, have noted a significant cultivar-rate interaction for thousand grain weight, while Faris and De Pauw (1981) reported the same interaction in spring wheat for both yield components.

2.2.4 Date of seeding/nitrogen fertilization/ seeding rate interaction effects

Many authors noted a date of seeding/fertilization interaction for yield. Yield reductions due to delayed seeding dates are often largest when no fertilizer is applied (Anderson and Hennig, 1964; Wells and Dubetz, 1970; Fedak and Mack, 1977). Similarly, lower yield increases due to nitrogen fertilization were obtained as seeding was delayed by Zubriski et al (1970), Black and Siddoway (1977) and Alessi and Power (1979). Therefore, early seeding is important to obtain maximum response to nitrogen fertilization for high yields, since late sown crops benefit least from higher levels of fertilizers. Anderson and Hennig (1964), however, reported that this interaction did not appear regularly, i.e., yearly.

Woodward (1956) showed that barley yield reductions caused by delayed seeding could be partially overcome by increasing that rate of seeding. No substantial yield gains by seeding rate for delayed seeding compensation could be noted in subsequent studies.

Needham and Boyd (1976), working with barley in England, reported that dense crops require less nitrogen for maximum yield. This could be explained by the results of Dougherty et al (1979), showing a declining response of head population to nitrogen at harvest as the plant population increased, while application of nitrogen increased head population at low seeding rates. As well, Dougherty et al (1979) also showed that grain set improves with increasing nitrogen rates at 250 seeds per square meter or conventional seeding rate, while at higher seeding rates, the increase in nitrogen resulted in progressively lower seed set. Therefore, the effects of seeding rate and nitrogen fertilizer at tillering are related to their common effect on spike population; at low seeding rates, nitrogen limited grain set, while at higher seeding rates, assimilates appeared to be limited (Dougherty et al, 1979). However, Read and Warder (1982), working in Saskatchewan with wheat and barley, found that fertilizer rates and seeding rates were factors operating independently with the exception of barley on fallow.

2.3 Phenology and growth responses to seeding date, nitrogen fertilization and seeding rate

2.3.1 Seeding date effects

Beech and Norman (1971) relate an increase in fertile tiller population with later seedlings in some wheat varieties. Stoskopf et al (1974) write that tillering exhibited the least decline with each delay in seeding date of wheat. The study of French et al (1979) shows a quadratic regression curve best fitting the sowing-tillering interval length with the date of sowing. The same study revealed that in that case, each day's delay in sowing reduced the number of days from tillering to flowering by 0.6 day. Moreover, French and Schultz

(1982) reported that the number of days in each interval (tillering to mid-flowering, mid-flowering to soft dough, sowing to flowering, sowing to soft dough, and sowing to harvest) was strongly correlated to sowing date. Hoag and Geiszler (1968) reported that the date of seeding has an effect on planting to heading and planting to ripening intervals, but that the difference can be attributed in both cases to the time required for the crops to emerge, while Schmidt (1960) states that it is due to variation in the rate of development prior to heading.

Ridge and Mock (1975) write that the length of the pre-flowering phase decreased with later sowings; this is illustrated by a quadratic relationship between yield and sowing date. In their experiment, sowing date accounted for 93% of the variation in the length of the pre-flowering phase. However, it could not be related to variation in yield over years.

According to Beech and Norman (1971) and Nass et al (1975), if anthesis of a given cereal occurs beyond a certain time of the year, the optimum yield cannot be realized. For both barley and wheat, yield falls from 4,000 to 1,000 lb/ac in Australia, as anthesis date is advanced from its earliest date to two months later. The optimum sowing time is thus related to the duration of the sowing-anthesis period (Beech and Norman, 1971). Moreover, early estimates of potential yield in a growing season could be made more precise if crop development is defined with meteorological values accumulated from time of sowing to flowering and could be related to the calculations of the number of days during this interval (French et al, 1979).

In general, as seeding becomes later, the time required for a crop to mature decreases to show a few days difference in time of harvesting with the earlier sown plants (Schmidt, 1960; Beard, 1961; Hoag and Geiszler, 1968; Jessop and Ivins, 1970; McFadden, 1970; Nass et al, 1975). However, Briggs and Aytenfisu (1979), working in Alberta at three different locations, report that the effect of seeding date on days to maturity is dependent on the location.

2.3.2 Nitrogen fertilization effects

In general, reports on effects of nitrogen on vegetative growth are fewer than on reproductive growth. Needham and Boyd (1976) were not able to relate mean barley population densities at early growth stages to nitrogen treatments according to germination counts. However, Syme (1972), in Australia, and Dale and Wilson (1978), in Great Britain, reported decreased rate of emergence and total leaf number with low nitrogen rates for wheat and barley, respectively.

Power and Alessi (1978) found nitrogen deficiency at early stages of tiller development to be particularly detrimental to tiller survival. They report that the primary effect of nitrogen fertilizer is to enhance T_2 and T_3 tiller survival and production of wheat varieties in the northern Great Plains. The proportion of final grain yield coming from the main tiller decreased from 60% without nitrogen to 36% at 270 kg/ha nitrogen because of increased production of spring wheat tiller 2 and tiller 3 (Power and Alessi, 1978). Cannell (1969) notes the same trend in a more humid climate. Therefore, the increase in yield due to nitrogen fertilization comes primarily from improved development of higher order tillers and larger population (Cannell, 1969; Needham and Boyd, 1976; Dougherty et al, 1978; Power and Alessi, 1978; Scott, 1978). Therefore, most nitrogen effects are directed towards the number of heads per area, resulting in an increased grain production closely related to the higher order tillers producing heads.

Needham and Boyd (1976) reported that barley tiller density increased up to 100 kg/ha nitrogen under Great Britain conditions. Nittler and Jensen (1974) showed that under controlled conditions, five barley cultivars differed significantly in the total number of stems produced without nitrogen and with a complete solution.

Nitrogen contributed to wheat flag leaf senescence due to increased water stress in Australia when the crop fails to achieve its vegetative potential under high nitrogen levels (Syme, 1972). In fact, Bole and Pittman (1980) developed a regression model in Alberta describing barley yield as a function of available water during the growth season and nitrogen fertilizer. This effect is especially important where yields are usually restricted by available moisture. On the other hand, Needham and Boyd (1976) write that when available water capacities of the soils are great enough to prevent water stress, efficiency of nitrogen use and optimal nitrogen application are not related to soil moisture, although larger optimal nitrogen dressings are often found on sites with large spring rainfalls.

Early reproductive development in normal and semi-dwarf wheat in New Zealand was unaffected by nitrogen treatments (Scott, 1978). As well, Thorne and Blacklock (1971) observed no effect of nitrogen on three related yield cultivars on spikelet initiation and anthesis date. McGuire et al (1980), in their two-year experiment in Idaho and Montana, also reported that barley heading date was not affected by nitrogen, even if there was a significant cultivar x environment interaction for heading date. However, other authors report significant effects of nitrogen on wheat reproductive development.

Knott (1974) observed at Saskatoon that all fertilized wheat plots tended to head and mature slightly ahead of the controls, while Leyshon et al (1980) report that maturity was generally delayed by high rates of nitrogen for wheat and barley in growth room experiments. In New Zealand, Scott et al (1975) and Dougherty et al (1979) frequently recorded nitrogen-induced retardation of wheat reproductive growth which might be the cause of higher rates of spikelet production also observed in the same crops. Thorne and Blacklock (1971) also report that the period of grain growth from anthesis to the disappearance of green coloration was about six days longer with 200 kg/ha of nitrogen than at 500 kg/ha in wheat. Leaf area duration, although it interacts with cultivars, was increased considerably by nitrogen, mainly because of an increase in leaf area at anthesis.

The promotion of lodging due to abundant nitrogen supply is well known and has been established in all cereal crops (Pinthus, 1973). Under moist conditions, high levels of plant available nitrogen may predispose crops to lodging, resulting in yield depressions (Dougherty et al, 1974). The effect of nitrogen on lodging is primarily on the basal culm internodes elongation, resulting in an increased shoot:root ratio conducive to lodging (Pinthus, 1973). Sibbit and Bauer (1970) noted that cultivars could be significantly different in their response to lodging. Although there exist more reports on wheat than on barley, wheat developmental pattern seems more sensitive to nitrogen applications in the soil and effects seem to be maintained throughout growth (Syme, 1972), while barley sequence seems less responsive.

2.3.3 Seeding rate effects

Crop response to plant density can be evaluated through the analysis of phenological difference, since density has far-reaching effects on growth and development of the crop throughout the growing season (Kirby, 1967).

Analysis of growth shows that the tillering phase is longer in a thin wheat population than in a usual commercial population (Puckridge and Donald, 1967; Nerson, 1980). This was also demonstrated in barley by Kirby (1967) and Kirby and Faris (1972).

The number of fertile tillers decreased as seeding rate increased (Guitard et al, 1961; Kirby, 1967; Puckridge and Donald, 1967; Kirby and Faris, 1972; Gebre-Mariam and Larter, 1979; Faris and de Pauw, 1981). Guitard et al (1961) described this decrease as curvilinear.

However, Simmons et al (1982) reported increased barley shoot and spike numbers at high seeding rates. McFadden (1970) reported a decrease in the number of tillers per plant as rate increased.

Lower seeding rate populations were shown to head more slowly (Kirby, 1967; Briggs and Aytenfisu, 1979), although Finlay et al (1971) observed a cultivar difference for heading dates at several seeding rates in barley. On the other hand, Thorne and Blacklock (1971), working on spring wheat in England, observed no effects of rate on days to heading nor on days to maturity. The small range (75 to 298 plants/m^2) of seeding rates tested could explain such results. Days to ripen decrease with increasing rate of seeding, according to other authors (Kirby, 1967; Finlay et al, 1971; Briggs, 1975; Briggs and Aytenfisu, 1979; Faris and De Pauw, 1981). Faris and De Pauw (1981) specify that the steepest slope in the decrease in days to ripen is observed at the low seeding rates. Briggs and Aytenfisu (1979) noted a significant cultivar x rate of seeding interaction for days to ripen at all three locations tested in Alberta.

It is generally reported that high seeding rates do not cause lodging directly, but whenever lodging is present, the degree to which plants are affected is increased with increasing seeding rates (Woodward, 1956; Holliday, 1960; Puckridge and Donald, 1967; Faris and De Pauw, 1981). Lodging will reduce yield and disrupt the expected yield response (Holliday, 1960). Faris and De Pauw (1981) noted a differential cultivar lodging response at various seeding rates.

3. MATERIALS AND METHODS

3.1 Treatments and experimental design

The experiment included four factors at varying levels: three seeding dates, three nitrogen fertilizer levels, four seeding rates and three cultivars of spring barley (Hordeum vulgare L. emend Lam.) and consisted of the 108 possible combinations of these factors replicated four times in a split-split-plot design.

The seeding dates were assigned to the main plot units, the fertilizer levels to the sub-plot units, and the twelve possible combinations of seeding rates and cultivars corresponded to the sub-sub-plot units.

The first seeding date was determined by the weather as the earliest date of seeding in the season. The subsequent seeding date was established as close as possible to 62 degree-days after the first one and the last seeding date, 62 degree-days after the second seeding date.

$$\text{degree-day} = \frac{(\text{maximum daily T° (°C)} - \text{minimum daily T° (°C)})}{2} - 4.4\text{°C}$$

The following seeding dates were thus established: April 27, May 8 and May 20 in 1981, and April 28, May 7 and May 15 in 1982. The nitrogen fertilizer levels were 15.6, 31.2 and 46.9 kg/ha of N in the form of ammonium nitrate applied at tillering. The seeding rates were 150, 300, 450 and 600 plants per square meter. The three cultivars of spring barley chosen, viz., Laurier, Loyola and Bruce, are all licensed cultivars in Canada and recommended in the province of Quebec. They are all six-row feed-types and a detailed description is given in Table 1.

TABLE 1. Straw length, maturity, origin and year of licensing of three cultivars of barley

Genotype	Straw	Maturity	Year licensed	Origin
Laurier	mid-long	mid-season	1975	Macdonald College
Loyola	mid-long and strong	mid-season	1972	Macdonald College
Bruce	mid-long and strong	mid-season	1977	University of Guelph

3.2 Field work

The experiment was carried at the Emile A. Lods Agronomy Research Centre of Macdonald College of McGill University (latitude 45° 26' N, longitude 73° 56' W) in 1981 and 1982. In 1981 the experiment was sown on Chateauguay clay loam mixed with Chicot shallow fine sandy loam soil, planted with corn the previous year. It was repeated in 1982 on Bearbrook clay mixed with Ste. Rosalie clay soil, previously sown to barley and wheat.

The land received a basal dressing of 300 kg ha^{-1} of 5-20-20 commercial fertilizer. Herbicidal weed control was applied when necessary at the three-leaf stage of the crop.

Each plot corresponding to the sub-sub-plot unit consisted of five rows, 3.8 meters long, spaced 20 cm apart. A 1-meter section was marked in one of the three center rows. This section was selected in a pseudo-random way since no meter which had a missing or partly missing neighbour row was chosen. The sub-sample was assumed to be representative, since it was selected with a bias towards achieving the original population density. The meter section and the rest of the three center rows were harvested separately following removal of a 0.2 meter border at each end.

3.3 Evaluation of plant characteristics

The data collected in this experiment include:

1. Number of days to emergence
2. Number of days to tillering
3. Number of days to stem elongation
4. Number of days to heading
5. Number of days to maturity
6. Number of heads/m² at harvest
7. Number of grains/head
8. 1000-grain weight
9. Grain yield

The measurements 1 to 8, inclusive, were made on the one-meter section; the measurements 9 (grain yield) was made on the total of the three center rows of each plot.

3.3.1 Phenological data

1. Number of days to emergence is recorded when 50% of the expected number of plants within the meter have emerged. This growth stage is attained when the first leaf through the coleoptile can be seen, or stage 10 according to Zadocks *et al* (1974).

2. Number of days to tillering is recorded when 50% of the plants within the marked meter have at least one tiller, or stage 21 (Zadocks *et al*, 1974).

3. Number of days to stem elongation is recorded when 50% of the plants within the marked meter are at stage 37, with the flag leaf just visible (Zadocks *et al*, 1974).

4. The number of days to heading is recorded when 50% of the plants within the marked meter have completed inflorescence emergence, i.e., the head is completely out of the boot, stage 59 (Zadocks *et al*, 1974).

5. The number of days to maturity is recorded when 50% of the plants within the marked meter have a hard caryopsis no longer dented by a thumb nail and the inflorescence has lost chlorophyll, or stage 92 (Zadocks *et al*, 1974).

3.3.2 Yield components

6 to 8. At harvest, the marked meter portion of the plot was cut to ground level, weighed and the number of productive tillers counted. This sample was threshed, the grain weighed and the number of grains

recorded. From this information, the number of heads per square meter, the number of grains per head, and thousand-grain weight, were determined.

3.3.3 Grain yield

9. Grain yield was recorded in $g/2.04\ m^2$ for all plots by adding the grain yield from the one-meter section to the grain yield from the remaining plants within the three center rows of each plot.

3.4 Statistical analysis

The coefficients of variability were computed for all the variables in order to evaluate the results obtained, especially in the case of visual ratings.

The means of the four replications gave basic information on which all the further analyses were based. When it was judged necessary, the analysis of variance was performed on certain variables.

LSD tests at the .05 level were used to locate differences among means.

A combined analysis of the two years' experiments was done when homogeneity of error variance was present. The year and soil effects were grouped under year effects. The year effects were isolated using the method described by McIntosh (1983) for combining experiments.

Stepwise multiple regression was used to find out quantitative relationships among the climatological data and some of the treatment effects and yield components.

Partial correlations among various pairs of variables were also calculated in order to eliminate the influence of other independent variables and study more closely the relationship.

Yield and yield components were also described through a multiple regression equation or a linear regression model. In both cases the variables which did not contribute significantly (P = .05) to the discriminatory power of the model in the population were not included in the equation.

4. RESULTS AND DISCUSSION

4.1 General observations

In 1981 the abundance of rainfall caused lodging and bird damage visibly affected some plots. The data from these plots were considered unreliable and were excluded from all analyses. These missing data in a relatively large experiment required especially large memories in all analyses of variance so that grain yield and grain yield components were the only variables fully described in 1981. The same problem occurred when pooling both years' results. This analysis was thus done only partially. The 1981 and 1982 homogeneous error variance terms for grain yield and grains/head permitted the pooling of these two variables only.

In neither year was the author able to detect precisely the day at which 50% of the plants in the sub-sample achieved the tillering stage. This fact was also later confirmed by a high coefficient of variability for this variable. The data from this phenological stage were excluded from all analyses.

The rainfall distribution during the growing season was different over the two years (Table 2); 1981 was an overall wet growing season with precipitation above normal from April to the end of June. On the contrary, the 1982 spring (April and May) was much drier than normal

TABLE 2. Meteorological observations for the barley growth periods in 1981 and 1982 at Macdonald College

Month	1981			1982			$\overline{X}$ (1951-1980)		
	Minimum temperature (°C) (a)	Maximum temperature (°C) (a)	Precipitation (mm) (a)	Minimum temperature (°C) (a)	Maximum temperature (°C) (a)	Precipitation (mm) (a)	Minimum temperature (°C) (b)	Maximum temperature (°C) (b)	Precipitation (mm) (b)
April	2.8	12.9	70.2	-1.3	9.8	34.8	0.8	10.6	63.5
May	8.3	19.6	73.5	11.4	21.5	24.8	7.4	18.5	63.9
June	13.4	23.8	111.9	12.2	22.0	115.3	12.9	23.6	82.2
July	15.1	26.6	72.9	14.7	26.6	81.0	15.6	26.1	90.0
Total			328.5			255.9			299.6

(a) Station Ste-Anne-de-Bellevue, Service de la météorologie, Ministère de l'Environnement du Québec.

(b) Bureau météorologique de Dorval, Service de l'environnement atmosphérique, Environnement Canada.

(Table 2). It was also especially warm in May of 1982 (Table 2), while the other periods showed around normal mean minima and mean maxima.

4.2 Grain yield

4.2.1 Seeding date effects

The important effect of seeding date on grain yield observed by many authors was confirmed in both years by high and significant variance ratios (Appendix tables 1 and 2). In 1981, grain yield was significantly higher in the second seeding date for all cultivars (Table 3), while in 1982, grain yield was significantly greater in the first seeding date (Table 4). The 1982 results confirmed most work done on seeding dates in spring cereals. A delay in seeding of 62 degree-days after the earliest possible date of seeding decreased the grain yield of cultivars Laurier, Loyola and Bruce by 12, 11 and 19%, respectively (Table 4). It is generally accepted that earliness of seeding is conducive to the production of high grain yields, since it increases the number of favourable days for the development of the crops. However, the effects of time of seeding are also related to differences in environmental conditions, especially rainfall and temperature, at particular stages of development. This is demonstrated by the 1981 results. The first seeding date yields were 11% lower than those of the second seeding date for all cultivars. The lower yields of the 1981 first seeding date compared with the yields of the second seeding date can be related to the amount of precipitation received during the stem elongation to heading period (Appendix table 3).

TABLE 3. The effect of seeding date and cultivar on grain yield of barley in the 1981 experiment

Seeding date	Laurier	Loyola	Bruce
		g/unit area[1]	
1	736.7	727.8	749.8
2	829.5	820.6	845.0
3	694.8	741.4	746.3

[1]Unit area = 2.04 m²

LSD (.05) : between two seeding date means for the same cultivar: 33.4; between two cultivar means at the same date of seeding: 33.2

TABLE 4. The effect of seeding date and cultivar on grain yield of barley in the 1982 experiment

Seeding date	Laurier	Loyola	Bruce
		g/unit area[1]	
1	893.3	872.5	971.9
2	781.1	770.6	784.4
3	782.7	744.2	793.1

[1]Unit area = 2.04 m²

LSD (.05) : between two seeding date means for the same cultivar: 32.2; between two cultivar means at the same date of seeding: 30.7.

Seeding date 1 received about half the amount of rain of seeding date 2. Significant partial correlations between grain yield and precipitation during the stem elongation to heading period are shown in Table 5. These correlations indicate a definite influence of precipitation on seeding date effects, especially for cultivars Laurier and Loyola. The 1981 results confirm the findings of Fedak and Mack

TABLE 5. Probability levels and partial correlation coefficients (adjusted for nitrogen levels and seeding rates) between grain yield and precipitation during stem elongation in 1981

Cultivar	r	Pr > F
Laurier	0.45	0.0001
Loyola	0.61	0.0001
Bruce	0.23	0.0060

(1977) relating high grain yields to soil moisture and early seeding rather than to seeding date alone. This situation is similar to that described by Dechênes et St-Pierre (1980), who related differences in oat grain yield grown on two different soils to a dry period in June at the jointing stage. Power and Alessi (1978) showed that the peak rate of water use generally occurs before heading and sometimes even before the plants are fully tillered. Singh (1981) also rated moisture-sensitive growth stages of wheat in order of decreasing sensitivity as: booting/heading, flowering to grain development and vegetative stage. Wells and Dubetz (1970) found that high soil water stress at the early boot stage gave a marked reduction in grain yield of barley. The 1981 results also agree with the findings of Baier (1967) about soil moisture being the best estimator of wheat grain yield among several climatic data for six different zones throughout Canada. Since the 1981 seeding date experiment was at one location on one soil type, we can assume that differences in soil moisture depended almost solely on rainfall.

In 1982, seeding date 1 was not threatened climatically compared with seeding date 2, although the amount of rainfall in 1982 was limited compared with 1981, in the early part of the season (Appendix table 3). Thus the expected decrease was observed as seeding date was delayed (Table 4).

The third seeding date never yielded significantly less than the first seeding date in 1981, nor than the second seeding date in 1982, with the exception of the cultivar Laurier in 1981 (Tables 3 and 4). Laurier yield in seeding date 3 in 1981 was reduced by 16% compared with seeding date 2 (Table 3).

Thus it appears that the seeding date effects are the same for all cultivars in a dry year. However, the cultivar Laurier appeared more susceptible to lodging in the wetter year and, therefore, tended to suffer more from late seeding (Table 3).

These results indicate a definite relationship in the sense that the end of April seedings favor grain yield compared with early May seedings if environmental conditions up to heading are held equal. Climate can reverse this trend since it appears that the jointing stage of spring barley requires a minimum of soil moisture in order to maximize yields. Under field conditions the effects of precipitation on grain yield during the individual periods of growth may be influenced by the moisture stored earlier when the needs of the crop were lower. However, this appears not to be the case in 1981 (Appendix table 3). This study on seeding date effects on yield strengthens the idea of Hanks and Rasmussen (1982) that even in humid parts of the world, periods of insufficient rainfall and thus water stress do occur.

4.2.2 Nitrogen rate effects

Nitrogen rate effects were significant in 1981 only (Appendix table 1). The 1982 non-significant effects (Appendix table 2) were due to the very dry period that occurred from seeding to stem elongation (Appendix table 3). It impaired the transport of ammonium nitrate to the plants and decreased the overall effect of fertilizer on growth and development. These results agree with the work of Bole and Pittman (1980) who described mathematically the dependence of yield response to nitrogen fertilizer on water. They concluded that the growing season precipitation had a 3 times greater effect on barley response to nitrogen fertilizer than did available water in spring. McLaren (1981), Heapy et al (1976) and Nuttall (1973) all demonstrated that variations among yield responses of cereals exposed to fertilizers had to be explained by soil moisture and rainfall. Terman et al (1969) showed that nitrogen will increase yield if water is adequate.

In 1981 an increase in nitrogen rates at tillering from 15.6 to 46.8 kg/ha and from 31.2 to 46.8 kg/ha increased yield significantly by 8.3% and 4.6% respectively (Table 6). These results are similar to those observed by Klinck and Martin (1980) in Québec and Dougherty et al (1979) in New Zealand, that, in general, a nitrogen application at tillering increased barley grain yields. The first and second nitrogen applications did not show significant differences in yield, probably because the levels tested were relatively small. In fact, the levels were not high enough to demonstrate a depressing effect on yield above a certain N level which is the purpose of 3-level experiments. This is probably why none of the interactions mentioned in the literature proved to be significant in 1981.

TABLE 6. The effect of nitrogen level on grain yield of barley in 1981

Nitrogen rate (kg/ha)	Grain yield (g/unit area)[1]
15.6	745.4
31.2	775.1
46.8	813.1

[1]Unit area = 2.04 m²
LSD (.05) = 30.8

4.2.3 Seeding rate effects

Seeding rates did not influence yield significantly in 1981 (Appendix table 1); however, means did show significant differences in 1982 (Appendix table 2). It is interesting to note the effect exerted by environmental factors such as density of population and season on grain yield. In this 2-year experiment, wide variations in seeding rates did not have an effect on grain yield in a wet season because the many-times-described compensating mechanism was effective at the low seeding rates. However, the yield components did not compensate for the lowest seeding rate in 1982, the drier year, since there was a significant decrease in grain yield at this subnormal rate (Table 7).

TABLE 7. The effect of seeding rate on grain yield of barley in 1982

Seeding rate (plants/m²)	Grain yield (g/unit area)[1]
150	773.3
300	831.4
450	845.2
600	836.2

[1]Unit area = 2.04 m²
LSD (.05) = 20.4

The main difference in climate between the two seasons was the early drought suffered at all seeding dates in 1982. This adverse seasonal effect is probably responsible for this absence of compensation. The medium (300 plants/m²) and higher (450 plants/m²) seeding rates, and the 1981 results, reflect the compensatory ability of barley plants during the latter parts of the season to adjust for the difference in initial population. Similar effects of early drought on cultivars bred in humid climates were previously demonstrated by Jones and Hayes (1967) with oats. These results confirm also, those of McLeod

(1982) that under dry periods highest grain yields are obtained by highest seeding rates and that dense populations do not suffer very adversely from lack of moisture compared with low populations. This statement appears to be particularly true in our case, since the drought period occurred at the early growth stages when interplant competition does not yet exist (Puckridge and Donald, 1967). Therefore, we can assume that intraplant competition for water stress was the limiting factor for the lowest seeding rate in 1982 and that tillering did not enable these plots to yield equal to the other plots.

4.2.4 Cultivar effects

Differences among cultivar means were significant in both 1981 and 1982 and were associated with a seeding date x cultivar interaction in both years as well as a nitrogen rate x cultivar interaction in 1982 (Appendix tables 1 and 2).

In 1981, no difference among cultivars occurred at the two first seedings (Table 3). Laurier yielded significantly lower in date 3 (Appendix Figure 1), suggesting that this cultivar responded differently to fluctuations of climatic factors. It has already been suggested in section 4.2.1 that the rainfall causing lodging late in the season is the reason for this difference, since Laurier proved to be more susceptible to lodging (Appendix table 4).

The 1982 cultivar means at each seeding date are shown in Table 4. Bruce shows yield superiority at the best seeding date (date 1) and was high yielding at all seeding dates (Appendix figure 1).

These results show that these three well-adapted cultivars, all bred in eastern Canada and all recommended in Quebec, still show differential response to seeding date. However, in neither year was a differential response noted at seeding date 2, which corresponds the closest to the usual seeding date in agricultural practice of the region. Significant differences among cultivar means exist when seeded later and/or earlier than the average time at which they were selected and tested. These results imply that cultivar testing with seeding date trials might be worthwhile in the future.

These results agree with the findings of Briggs and Aytenfisu (1979) that a differential response of cultivars exists for seeding date. The report by Black and Siddoway (1977) of late seedings reducing yields regardless of cultivars used was confirmed in 1982, although later seedings seemed to reduce more the yields of Bruce than of the cultivars Laurier and Loyola (Appendix figure 1).

The cultivar x nitrogen rate interaction showed a significant difference in 1982 (Appendix table 2). Laurier was the cause of the interaction (Table 8), since it yielded equal to Bruce at 15.6 and 46.8 kg/ha of nitrogen but not at 31.2 kg/ha. Since the nitrogen main effects were not significant in 1982, it is probable that these results reflect, also, a basic genotypic yielding difference, especially between Loyola and Bruce. The cultivar Bruce was significantly higher-yielding than the cultivar Loyola at all nitrogen rates (Table 8).

TABLE 8. The effect of cultivars fertilized at three rates of nitrogen on grain yield of barley in 1982

Nitrogen rate (kg/ha)	Grain yield (g/unit area)[1]		
	Laurier	Loyola	Bruce
15.6	828.3	790.7	839.4
31.2	795.3	793.8	865.9
46.8	833.6	802.8	844.0

[1]Unit area = 2.04 m^2

LSD (.05) = between 2 cultivar means at same nitrogen rate: 30.7

4.2.5 Combined analysis of the two experiments

Pooling of grain yield results over the two years was possible since the hypothesis of homogeneous error variances was not rejected at the .05 level. The combined analysis of some of the treatments is shown in Appendix table 5. Seeding date effects and nitrogen rate effects were not consistent over years and the date of seeding x year interaction and the nitrogen rate x year interaction show significant differences. These interactions prohibit the pooling of these means over the two years.

4.2.6 Relationships among treatments

Significant differences (P = 0.05) among treatments (Appendix tables 1 and 2) led to the calculation of a regression equation for each cultivar under the two different growing seasons (Table 9).

These equations are plotted in Figures 1 to 3. An equation for grain yield of each cultivar over both years was also calculated, although the models do not account for much of the variation that occurred over years.

The seeding date effect is expressed through a quadratic form in both years for each cultivar. The seeding rate effect is expressed by a quadratic form in 1982 but as a linear form in 1981 for cultivars Laurier and Bruce. Nitrogen effects did not improve the equation enough to be included in most of the equations. Combined analysis of the experiments shows a quadratic effect of both seeding date and seeding rate (Table 9).

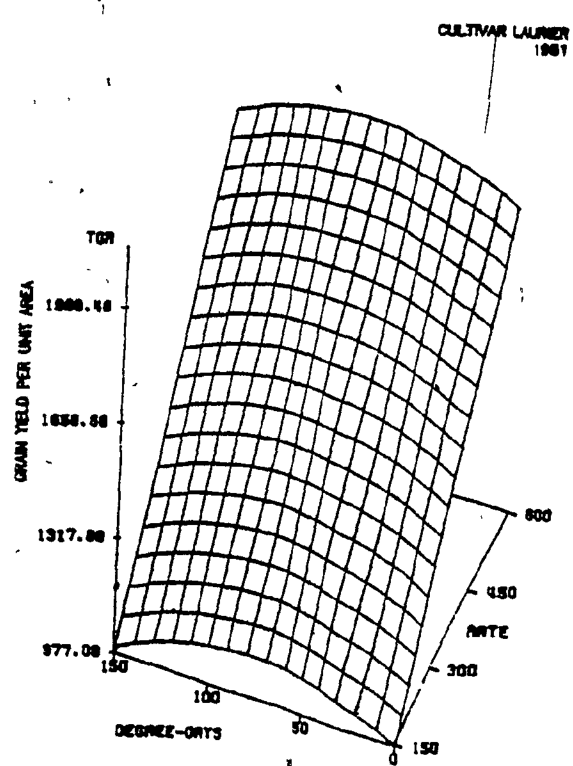
4.3 Heads/m²

4.3.1 Seeding date effects

There were significant differences among seeding date means for the number of heads/m² at harvest in 1981 (Appendix table 1) and in 1982 (Appendix table 2). In 1981, the seeding date x seeding rate interaction and the seeding date x seeding rate x cultivar interaction proved to be significant, as did the seeding date x cultivar interaction in 1982 (Appendix tables 1 and 2).

In 1981, the second seeding date always resulted in a significantly higher number of heads/m² than either or both of the two other seeding dates, with the exception of the cultivars Bruce and Laurier at 600 plants/m² and the cultivar Loyola at 300 plants/m². In these

a)



b)

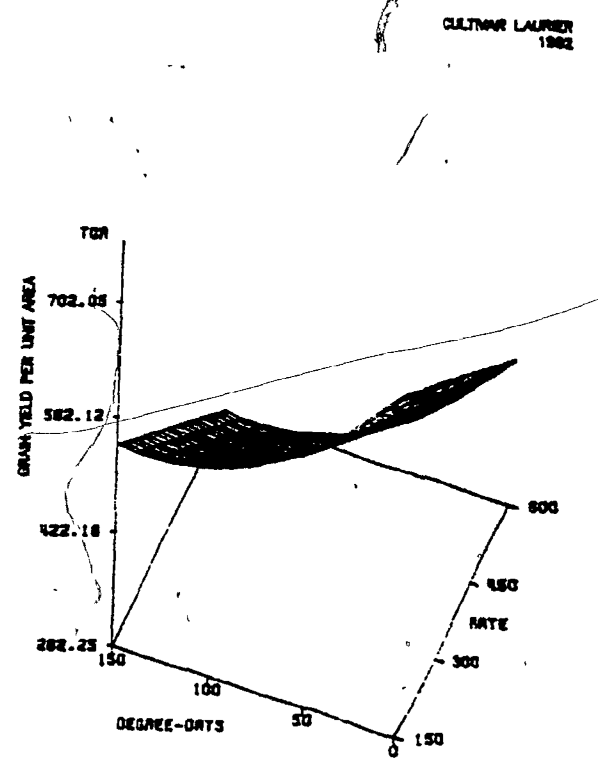
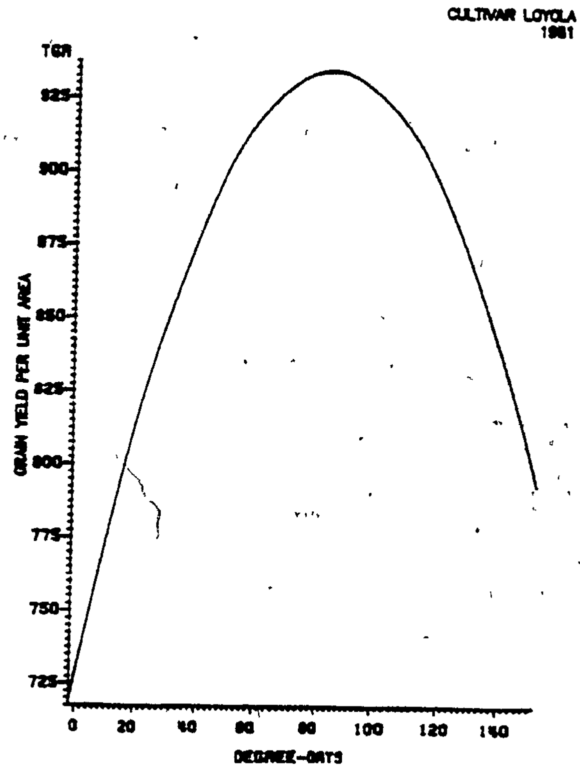


Figure 1. The regression of grain yield on seeding date and seeding rate (a) in 1981 and (b) in 1982, for the cultivar Laurier.

a)



b)

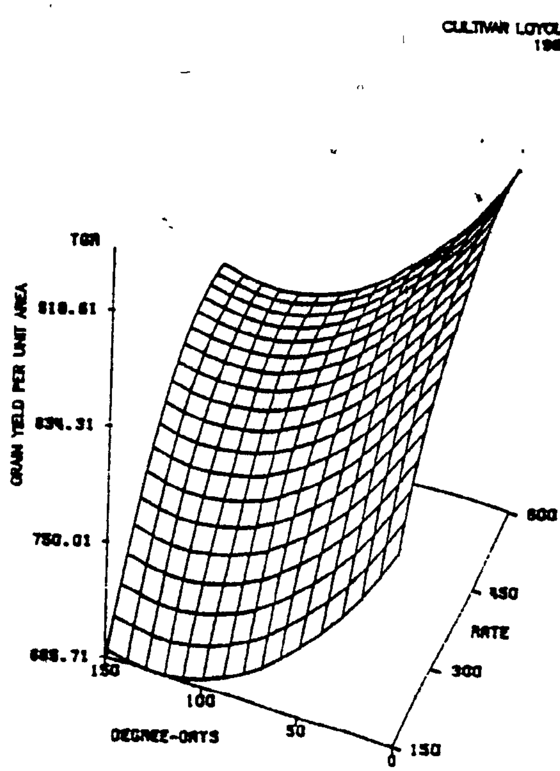
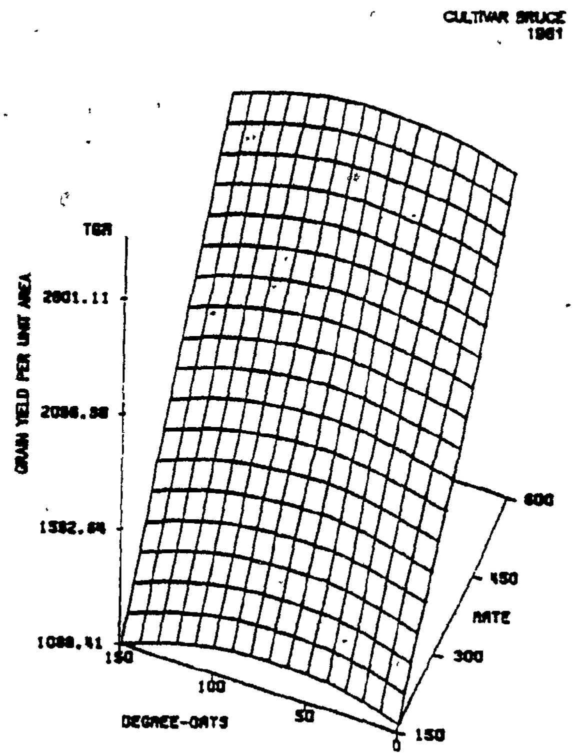


Figure 2. The regression of grain yield on (a) seeding date in 1981 and (b) seeding date and seeding rate in 1982, for the cultivar Loyola.

a)



b)

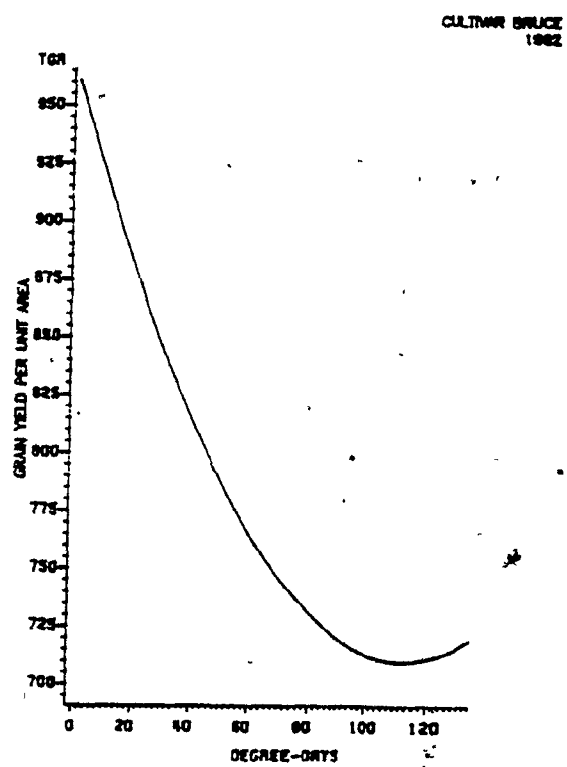


Figure 3. The regression of grain yield on (a) seeding date and seeding rate in 1981 and (b) seeding date in 1982, for the cultivar Bruce.

TABLE 9. R-square (R^2) and regression equations of grain yield[1] on seeding date[2] and/or seeding rate[3] and/or nitrogen rates[4] in 1981 and 1982 and over both years

Year	Cultivar	Equation	R^2	Pr > F
1981	Laurier	$Y = 677.08 + 3.13x - 0.02x^2 + 2.00z$	0.34	.0001
	Loyola	$Y = 727.87 + 4.98x - 0.03x^2$	0.39	.0001
	Bruce	$Y = 663.91 + 2.76x - 0.02x^2 + 3.07z$	0.30	.0001
1982	Laurier	$Y = 783.05 - 2.66x + 0.01x^2 + 0.54z - 0.0005z^2$	0.26	.0001
	Loyola	$Y = 698.11 - 2.25x + 0.009x^2 + 0.84z - 0.0008z^2$	0.40	.0001
	Bruce	$Y = 960.60 - 4.48 + 0.02\ x^2$	0.54	.0001
1981-1982	Laurier	$Y = 718.45 + 0.04x - 0.004x^2 + 0.80z - 0.0001z^2$	0.10	.0001
	Loyola	$Y = 620.31 + 1.14x - 0.01x^2 + 1.47z - 0.0003z^2$	0.13	.0001
	Bruce	$Y = 685.88 - 0.74x + 2.58w + 0.63z - 0.0007z^2$	0.17	.0001

[1]Grain yield : Y ($g/2.04\ m^2$)

[2]Seeding date: x (degree-days after earliest seeding)

[3]Seeding rate: z ($plants/m^2$)

[4]Nitrogen rate: w (kg/ha)

cases, no significant difference was observed among seeding dates (Table 10). In 7 cases out of 12, seeding date 2 resulted in a head number similar to one of the two other seeding dates (Table 10).

The simple effect of seeding date for each cultivar in 1982 is shown in Table 11. The first seeding date results in significantly higher numbers of heads/m² compared with the two other seedings for Laurier and Bruce, and compared with date 3 only, Loyola (Table 11).

In both years, the seeding date resulting in higher yields resulted also in high numbers of heads/m². Therefore, the yield component, heads/m², is somewhat responsible for the increase in grain yield as expected. In 1981, the less favourable seeding dates in terms of yield did not result automatically in a decreased number of heads/m² (Table 10). In 1982, however, the decline in the population of heads at harvest followed more closely the decline in grain yield.

In the present trials, the difference between the two years does not confirm the findings of Kirby (1969), Kohn and Storrier (1970) or Jessop and Ivins (1970), who demonstrated that head numbers generally decrease with late sowings. The present study, however, agrees with Doyle and Marcellos (1974) that head numbers are highly variable between seasons. The 1981 unclear behaviour of cultivars of various seeding dates might come from a differential response of cultivars to water accumulation at the stem elongation stage.

Wells and Dubetz (1970) also noted a differential response of cultivars seeded at different plant populations to water stress at

TABLE 10. The effect of seeding date, seeding rate and cultivar on the number of heads/m² of barley in 1981

Seeding rate (plants/m²)	Laurier			Loyola			Bruce		
	Seeding date								
	1	2	3	1	2	3	1	2	3
150	265.4	287.0	249.5	216.0	270.8	256.6	286.1	310.4	262.9
300	264.5	329.1	272.9	250.9	261.6	244.5	315.5	379.5	304.5
450	277.7	338.7	309.1	297.7	333.3	280.4	336.0	404.5	339.5
600	378.3	362.0	364.1	331.1	380.8	357.5	433.6	396.6	418.3

LSD (.05): between two seeding date means of the same cultivar at the same rate of seeding = 37.5; between two seeding rate means of the same cultivar at the same date of seeding = 37.5; between two cultivar means at the same seeding date at the same rate of seeding = 37.5.

TABLE 11. The effect of seeding date and cultivar on heads/m² of barley in 1982

Seeding date	Laurier	Loyola	Bruce
1	456.5	376.5	568.5
2	362.5	329.5	437.0
3	357.5	347.5	438.5

LSD (.05) : between two seeding date means of the same cultivar: 30.1; between two cultivar means at same date of seeding: 30.6.

5

the boot stage. However, these results confirm those of Hampton *et al* (1981) who demonstrated the importance of establishing and maintaining tiller numbers great enough to produce high-yielding crops since head populations at harvest were significantly correlated with grain yield.

4.3.2 Nitrogen rate effects

Favourable nitrogen nutrition at tillering generally acts on yield by increasing head populations at maturity through increased tiller size, greater tillering and reduced tiller mortality (Scott *et al*, 1977). However, in neither 1981 nor 1982 were heads/m² significantly affected by nitrogen rates applied at tillering (Appendix tables 1 and 2). The 1982 nitrogen rate effects were inhibited by the early dry period as mentioned earlier. On the other hand, 1981 results demonstrate that the N application was done too late in the season to affect the first yield component since the two other yield components show significant effects of nitrogen rates in 1981 (Appendix table 1).

4.3.3 Seeding rate effects

The 1981 simple effects of seeding rates at each seeding date for each cultivar are shown in Table 10. At seeding dates 1 and 3 the cultivars Laurier and Bruce both show higher numbers of heads/m² at the highest seeding rate, while the 300, 450 and 600 plants/m² rates show no significant difference at the most favourable seeding date in terms of yield (date 2) (Table 10). This absence of a significant difference among seeding rates in date 2 for Bruce and Laurier, as well as the relatively low numbers of heads produced at the 450 and 600 plants/m² rates, indicates that competition at these rates resulted in non-productive tillers. Loyola on date 2, however, shows significant differences among the 3 highest seeding rates. This indicates that under favourable conditions, Loyola withstands a higher population throughout the season, better than the two other cultivars.

At 600 plants/m², Laurier and Bruce show no significant differences among seeding dates. This implies that environmental differences did not affect the production of heads/m², probably because very little tillering was involved at this rate. More or less favourable climatic factors thus did not have significant effects.

In 1982, increased seeding rates resulted mostly in significantly higher numbers of heads/m² as has been reported in earlier studies in small cereal grains (Jones and Hayes, 1967; Kirby, 1967; Puckridge and Donald, 1967; Finlay et al, 1971; Willey and Holliday, 1971). The cultivar Loyola, however, shows no significant increase in heads/m² from 450 to 600 plants/m² and Bruce shows a significant increase in heads/m² only from 150 to 300 plants/m² (Table 12).

4.3.4 Cultivar effects

The 1981 cultivar mean differences are presented in Table 10. In general, Bruce produced more heads/m² than the two other cultivars,

TABLE 12. The effect of seeding rate and cultivar on heads/m² of barley in 1982 experiment

Seeding rate (plants/m²)	Laurier	Loyola	Bruce
150	334.5	285.5	376.5
300	359.5	327.0	428.0
450	411.5	380.5	529.0
600	464.5	411.0	592.0

LSD (.05): between two seeding rate means of the same cultivar: 34.5; between two cultivar means at the same rate of seeding: 34.5.

especially Loyola. Loyola definitely produced fewer heads/m² than the others, apart from date 3 at 150 plants/m². Laurier was intermediate to Bruce and Loyola. In general, there is a trend toward a differential behaviour for Loyola under certain conditions. As mentioned earlier, Laurier and Bruce show no seeding date effects at 600 plants/m², while Loyola shows none at 300 plants/m². At seeding dates 1 and 2, neither Laurier nor Bruce show difference in the number of heads/m² at 300 and 450 plants/m², while Loyola does. Head population differences are presumably a result of the capacity of the cultivars to produce and support tillers to maturity. Bruce appeared to have a lower level of inter-tiller competition than Laurier and Loyola at the intermediate seeding rates: 300 and 450 plants/m² and at seeding dates 1 and 2, i.e., under the seeding rates closest to the regional agricultural practice and under the seeding dates allowing a longer growth period.

The 1982 simple effects of cultivars at the same seeding rate are presented in Table 12. Again, the cultivar Bruce produced more heads than did Laurier and Loyola. Laurier produced more heads than Loyola at the higher seeding rates only (Table 12).

These results demonstrate that factors controlling the number of heads per unit area are two-fold. There is genetic variability among cultivars in the number of tillers produced, already described by Black and Siddoway (1977) and McLaren (1981) and illustrated in this experiment by the higher head production, both in 1981 and 1982, of Bruce compared with Loyola. There is also the ability to maintain a high number of head-forming tillers, that varies with environmental conditions, as demonstrated by Loyola in 1982. At seeding date 3 only, Loyola produced a number of heads/m² not significantly different from Laurier (Table 11). This occurrence of cultivar differences, coupled with a seeding date interaction in both years, confirms the finding of Baker and Briggs (1982), who recognized this dual effect in their tests of 10 cultivars of spring barley over three years.

4.3.5 Relationships among treatments

Significant ($p = 0.05$) variations due to treatments (Appendix tables 1 and 2) led to the calculation of regression equations for the number of heads/m² for each cultivar. These equations are presented in Table 13.

Head population at harvest is the first yield component to be determined during the growing season. In 1981 the importance of the

TABLE 13. R-square (R^2) and regression equation of heads/m²[1] on seeding date[2] and seeding rate[3] in 1981 and 1982

Year	Cultivar	Equation	R^2	Pr > F
1981	Laurier	$H = 259.62 + 1.03x - 0.07x^2 - 0.07z + 0.0003z^2$	0.39	.0001
	Loyola	$H = 243.75 + 1.07x - 0.007x^2 - 0.17z + 0.0005z^2$	0.52	.0001
	Bruce	$H = 239.59 + 1.00x - 0.008x^2 + 0.27z$	0.43	.0001
1982	Laurier	$H = 346.04 - 2.36x + 0.01x^2 + 0.29z$	0.40	.0001
	Loyola	$H = 269.16 - 1.21x + 0.007x^2 + 0.28z$	0.37	.0001
	Bruce	$H = 381.73 - 3.12x + 0.01x^2 + 0.49z$	0.62	.0001

[1]Heads/m² : H

[2]Seeding date = x (degree-days after earliest seeding)

[3]Seeding rate = z (plants/m²)

combined effects of climatic factors and management practices, such as the choice of cultivar and seeding rate, was well demonstrated by the complex interaction of seeding dates, seeding rates and cultivars. In 1982, however, the effects of climatic conditions were less variable during the season and the pattern for supporting more culms to maturity was clearer. In 1981, the seeding date effects appeared not to be solely related to degree-days lost in the spring and, therefore, to the length of the growing season, but also to the various amounts of precipitation accumulated during growth stages. Regression equations replacing degree-days after the earliest seeding by climatic data to represent the seeding date effect were obtained through stepwise regression (Table 14) and confirm the statement made previously on the rainfall effect during stem elongation to heading in section 4.3.1. For all three cultivars, replacing degree-days after the earliest seeding by precipitation during stem elongation gave similar multiple correlation coefficients to those of the equations using degree-days and led to a simpler equation.

With this change of variable, the multiple correlation coefficient did not improve. Further variations in heads/m² are thus probably not due to the effect of seeding date. Moreover, similar R^2 values are obtained in 1982 when the effect of seeding date is less ambiguous. This implies that some external factor caused variations of heads/m² that cannot be explained by treatments or meteorological events. It is possible that the difference in seeding rates that occurred within some plots due to mechanical seeding is partially responsible for this unexplained variation and, of course, it is mostly reflected in variation in heads/m². However, R^2 values of .39 to .62 are still very acceptable in a study of this size.

TABLE 14. R-square (R^2) and regression equations of heads/m²[1] on precipitation at stem elongation[2] and seeding rate[3] in 1981

Cultivar	Equation	R^2	Pr > F
Laurier	$H = 235.42 + 1.08a - 0.07z + 0.0003z^2$	0.39	.0001
Loyola	$H = 227.47 + 0.94a - 0.18z + 0.0005z^2$	0.51	.0001
Bruce	$H = 273.95 + 0.22a + 0.26z$	0.43	.0001

[1]Heads/m² : H

[2]Precipitation at stem elongation : a (mm)

[3]Seeding rate : z (plants/m²)

4.4 Grains/head

4.4.1 Seeding date effects

It is generally accepted in the literature that delays in seeding affect grain numbers per head, but there is much variability in the nature of effects reported. In these trials, there were significant differences among seeding date means in both years in addition to a significant seeding date x seeding rate interaction in 1982 (Appendix tables 1 and 2).

In 1981 and 1982, all seeding date means were significantly different from each other and grains/head increased from early to later seedings, with one exception in 1982 (Tables 15 and 16). A similar trend was observed by Jessop and Ivins (1970).

TABLE 15. The effect of seeding date on grains/head of barley in 1981

Seeding date	Grains per head
1	28.2
2	34.9
3	35.8

LSD (.05) = 0.8

TABLE 16. The effects of seeding date and rate of seeding on grains/head of barley in 1982

Seeding date	Seeding rate (plants/m²)			
	150	300	450	600
1	37.9	33.2	28.6	25.7
2	41.3	37.2	30.4	26.5
3	45.6	39.9	36.0	32.0

LSD (.05) : between two seeding date means at the same seeding rate: 1.6; between two seeding rate means of the same seeding date: 1.6.

4.4.2 Nitrogen rate effects

Nitrogen rate means showed significant differences in 1981 but not in 1982, as expected (Appendix tables 1 and 2). In 1981, however, the importance of the effect measured through the size of the variance ratios is small compared with other treatments (Appendix table 1). The highest nitrogen rate resulted in a higher number of grains per head (Table 17).

In this aspect, our results agree with those of Halse et al (1969) and Dale and Wilson (1978). These workers reported reduced numbers of grains per head of six-rowed barley with low nitrogen treatments. Scott (1978) also reported six more grains per head of wheat with higher nitrogen rates. According to him, the number of grains per spikelet is closely related to the level of available nitrogen in the soil during pre-anthesis floret development. Campbell and Leyshon (1980) reported that seed set in barley was not affected by nitrogen rates; thus, it appears that nitrogen would have affected the number of grain sites per head rather than the seed set.

TABLE 17. The effect of nitrogen level on grains/head of barley in 1981

Nitrogen rate (kg/ha)	Grains per head
15.6	32.4
31.2	33.0
46.8	34.7

LSD (.05) = 0.7

4.4.3 Seeding rate effects

In both 1981 and 1982, seeding rate treatments showed significant differences as well as a rate x cultivar interaction in 1981, and a seeding rate x seeding date interaction in 1982 (Appendix tables 1 and 2), as pointed out in section 4.4.1. However, in both years, increasing seeding rates resulted in decreased numbers of grains per head for all cultivars and at all seeding dates, since no interaction with cultivars was noted in 1982 (Tables 16 and 18). In 1982, increasing seeding rates decreased grains/head by 32, 35 and 29% for seeding dates 1, 2 and 3, respectively (Table 16). In 1981, however, increasing seeding rates decreased grains/head by 29, 34 and 34% for cultivars Laurier, Loyola and Bruce, respectively (Table 18). These results confirm the work of Kirby (1967), who observed a linear decrease in the number of grains per head of barley with increased density. These results also show that the cultivar x seeding rate interaction noted by Faris and De Pauw (1981) with spring wheat failed to occur in this experiment, although cultivar Laurier is less affected than Loyola and Bruce in 1981 (Table 18).

4.4.4 Cultivar effects

Cultivar differences were significant and important in both 1981 and 1982. A cultivar x seeding rate interaction pointed out in section 4.4.3 was also significant in 1981 (Appendix tables 1 and 2). In both years, the cultivar Loyola produced significantly more grains/head than did Laurier and Bruce under all seeding rates (Tables 18 and 19). In 1981, some significant differences appeared also between Bruce and Laurier at 150 and 450 plants/m^2 (Table 18).

It appears that the cultivar producing the lowest number of heads/m^2 also produces the highest number of grains/head. Loyola definitely exhibits a genotypic characteristic for producing smaller numbers of heads/m^2 and higher numbers of grains/head than the two other cultivars.

TABLE 18. The effect of seeding rate and cultivar on grains/head of barley in 1981

Seeding rate (plants/m²)	Laurier	Loyola	Bruce
150	35.4	44.3	39.5
300	33.1	39.0	34.4
450	29.1	34.2	30.7
600	25.1	28.9	25.9

LSD (.05) between two seeding rate means of same cultivar: 1.5; between two cultivar means at the same seeding rate: 1.5.

TABLE 19. The effect of cultivar on grains/head of barley in 1982

Cultivar	Grains/head
Laurier	32.7
Loyola	38.8
Bruce	32.0

LSD (.05) = 0.8

4.4.5 Combined analysis of the two experiments

Combined analysis of some of the treatments is shown in Appendix table 6. Seeding date effects are not consistent over years and the date x year interaction is significant. The means of nitrogen rates at tillering can be pooled over years. The date of seeding x nitrogen rate interaction is consistently non-significant over years. The absence of interactions at the sub-sub-plot level in both years permitted showing the effects of nitrogen at tillering on grains/head in Table 20. The highest nitrogen rate resulted in a 4 and 3%

increase in grains/head over the lower and medium nitrogen levels, respectively.

TABLE 20. The effect of nitrogen level on grains/head of barley over the 1981-1982 period

Nitrogen rate (kg/ha)	Grains/head
15.6	33.4
31.2	33.6
46.8	34.8

LSD (.05) = 0.7

4.4.6 Relationships among treatments

Significant ($p = 0.05$) differences observed among treatment means (Appendix tables 1 and 2) led to the calculation of regression equations for the number of grains per head for each cultivar (Table 21).

Compared with the multiple correlation coefficient (R^2) for heads/m^2, it appears that the yield component grains/head is more predictable than heads/m^2, since only two variables (degree-days after earliest seeding and seeding rates) account for 61 to 81% of the variation in grains/head associated with seeding date, nitrogen rate at tillering and seeding rate.

A single equation accounting for the observed data during the two-year period was developed for each cultivar (Table 21). These equations should be tested in future years.

TABLE 21. R-square (R^2) and regression equations of grains/head[1] on seeding date[2] and seeding rate[3] in 1981 and 1982 and over both years

Year	Cultivar	Equation	R^2	Pr > F
1981	Laurier	$G = 35.25 + 0.12x - 0.0005x^2 - 0.02z$	0.69	.0001
	Loyola	$G = 41.97 + 0.16x - 0.0007x^2 + 0.07z$	0.74	.0001
	Bruce	$G = 36.28 + 0.16x - 0.0008x^2 + 0.06z$	0.81	.0001
1982	Laurier	$G = 40.43 + 0.04x - 0.02z$	0.61	.0001
	Loyola	$G = 47.48 + 0.06x - 0.03z$	0.77	.0001
	Bruce	$G = 39.87 + 0.04x - 0.02z$	0.65	.0001
1981-1982	Laurier	$G = 38.39 + 0.04x - 0.02z$	0.60	.0001
	Loyola	$G = 46.51 + 0.06x - 0.03z$	0.71	.0001
	Bruce	$G = 39.73 + 0.05x - 0.02z$	0.69	.0001

[1]Grains/head : G

[2]Seeding date: x (degree-days after earliest seeding)

[3]Seeding rate: z (plants/m^2)

One is tempted from the results of 1981 to find a reason for the low number of grains/head in seeding date 1 compared with the other dates, since the numbers of heads/m^2 were so low in seeding date 1. Regression equations using meteorological data in place of degree-days lost in the spring were selected through the stepwise procedure and are presented in Table 22.

In the three cases, the replacement of the degree-days lost at seeding to account for seeding date effects on grains/head resulted in very reasonable but decreased multiple correlation coefficients. This confirms the fact that the number of grains/head responded up to a certain point, to precipitation during stem elongation. The latter variable was detrimental in the number of grains/head for seeding date 1, just as it was for heads/m², and eliminated the possibility for compensation. The fact that the seeding date 3 response is not related to precipitation during stem elongation resulted in a decreased R^2 as compared with Table 21.

TABLE 22. R-square (R^2) and regression equations of grains/head[1] on precipitation at stem elongation[2] and on seeding rate[3] in 1981

Cultivar	Equation	R^2	Pr > F
Laurier	G = 36.64 - 0.08a - 0.02z	0.49	.0001
Loyola	G = 46.83 - 0.07a - 0.03z	0.54	.0001
Bruce	G = 41.87 + 0.04a - 0.02z	0.55	.0001

[1]Grains/head : G

[2]Precipitation at stem elongation : a (mm)

[3]Seeding rate : z (plants/m²)

4.5 Weight per one thousand grains

4.5.1 Seeding date effects

In both years there were significant differences among seeding date means in addition to differences due to the following interactions: seeding date x cultivar in 1981 and 1982; seeding date x seeding rate x cultivar in 1981; seeding date x seeding rate in 1982 (Appendix tables 1 and 2).

In 1981, the decline in weight per 1,000 grains with delayed seeding was very clear (Table 23). In 1982, delaying seeding dates decreased weight per 1,000 grains for all cultivars (Table 24) and all seeding rates (Table 25). Therefore, the effect of seeding date was consistent over most managerial conditions. These results confirm those of Stoskopf et al (1974), and several others who found that grain weight declined markedly with delays in seeding date.

TABLE 23. The effect of seeding date, seeding rate and cultivar on weight per 1,000 grains (g.) of barley in 1981

Seeding rate (plants/m²)	Laurier			Loyola			Bruce		
	Seeding date								
	1	2	3	1	2	3	1	2	3
150	46.42	43.00	39.80	46.60	41.19	38.47	38.58	36.36	34.50
300	46.31	43.34	40.21	42.64	40.95	38.10	38.60	35.01	33.52
450	45.18	42.77	39.46	41.51	39.26	35.62	38.84	34.02	32.80
600	44.81	40.49	38.63	38.89	37.61	35.22	37.63	34.06	31.01

LSD (.05) : between two seeding date means of the same cultivar at the same rate of seeding: 1.32; between two seeding rate means of the same cultivar at the same date of seeding: 1.32; between two cultivar means at the same date and at the same rate of seeding: 1.32.

TABLE 24. The effect of seeding date and cultivar on weight per 1,000 grains (g.) of barley in 1982

Seeding date	Laurier	Loyola	Bruce
1	44.65	42.16	36.76
2	39.63	35.26	33.24
3	36.63	33.25	30.38

LSD (.05) : between two seeding date means of the same cultivar: 0.82; between two cultivar means at the same seeding date: 0.81.

TABLE 25. The effect of seeding date and seeding rate on weight per 1,000 grains (g.) of barley in 1982

Seeding date	Seeding rate (plants/m²)			
	150	300	450	600
1	40.68	41.16	41.54	41.39
2	35.68	35.75	36.25	36.39
3	34.85	33.53	32.98	32.31

LSD (.05) : between two seeding date means at the same seeding rate : 0.94

The mechanisms by which the weight of grains is modified by the environment are not fully understood. Chowdhury and Wardlaw (1978) found that with barley, high temperatures during grain filling reduced grain size. However, Wiegrand and Cuellar (1981) explained the dependence of 1,000-grain weight on the duration of grain filling by demonstrating that temperature in excess of 15°C commonly shortened the duration of grain filling in southern U.S.A., although the rate of grain growth increases moderately with temperatures. To check for seeding date effects, partial correlations adjusted for nitrogen rates, seeding rates and cultivars were calculated (Table 26). In our trials, the accumulation of degree-days during grain filling showed definite increases as seeding was delayed (Table 26). It appears that changes in 1,000-grain weight with delayed seeding may be due to temperature.

Wells and Dubetz (1970) and Russell et al (1982) have demonstrated that post-anthesis climatic conditions are important for

1,000-grain weight determination, so that precipitation might also be important. Lawlor et al (1981) confirmed that it is the duration of grain filling that affects grain growth.

TABLE 26. Probability levels and partial correlation coefficients between seeding date or 1,000-grain weight and selected meteorological data or duration of grain filling adjusted for nitrogen rates, cultivars and seeding rates in 1981 and 1982

	Year	Average degree-days during grain filling	Average precipitation during grain filling	Duration of grain filling (days)
Seeding date[1]	1981	0.87 (.0001)	-0.79 (.0001)	-0.07 NS
	1982	0.76 (.0001)	-0.74 (.0001)	-0.78 (.0001)
1000-grain weight	1981	-0.67 (.0001)	0.68 (.0001)	0.12 (0.0125)
	1982	-0.62 (.0001)	0.66 (.0001)	0.65 (0.0001)

[1]In degree-days after earliest seeding

In 1981, seeding dates and the duration of grain filling (heading to grain maturity period) were not correlated (Table 26) but the partial correlation (adjusted for nitrogen rates, seeding rates and cultivars) between precipitation during the grain filling period and 1,000-grain weight is highly significant: $r = 0.68$ (Table 26). The 1981 results would thus tend to associate higher grain weight with greater precipitation during grain filling. As seeding was delayed, precipitation during grain filling happened to be less ($r = -0.79$) and less, and consequently, grain weight diminished (Table 26).

In 1982, however, delayed seeding date was associated with a shorter duration of grain filling, r = -0.78 (Table 26). Therefore, the same partial correlation between 1,000-grain weight and the duration of grain filling is also very high, r = 0.65 (Table 26). It appears, then, that in 1982, higher grain weights in early seedings were associated with longer grain filling periods. However, 1,000-grain weight seems to be associated also with precipitation during grain filling, r = 0.66 (Table 26).

It appears that delaying the seeding date did not automatically reduce the grain filling period, but rather, precipitation and degree-days accumulation during grain filling, which depend on the seeding date, did influence grain weight in both years. This may imply that the duration of grain growth in 1982 was affected by the amount of precipitation or accumulation of degree-days and led to smaller grains when precipitation was less abundant or degree-days accumulation was more important.

A situation was reported previously by Lawlor _et al_ (1981) where the duration of grain growth was affected by drought. Whether or not the length of the grain filling period was related to precipitation in 1982 and/or temperature, it certainly limited the time during which assimilates were produced and transported to the grain. These results confirm the findings of Wells and Dubetz (1970) and Russell _et al_ (1982) in that post-anthesis climatic conditions do influence the 1,000-grain weight. The apparent contradiction between the results of 1981 and 1982 can be explained by Russell _et al_ (1982). They wrote that the period at which grain weight is determined is still obscure, since grain filling depends both on photosynthesis after and on the translocation of assimilates formed before anthesis. According to Russell et al (1982), translocation seems to be important in years when post-anthesis conditions are adverse for photosynthesis.

It is also possible that in 1981, when lodging occurred, it interfered with the normal length of the grain filling period and this would be reflected in the partial correlations between seeding date and 1,000-grain weight with the duration of grain filling, although it is doubtful that lodging would affect an existing relationship to that point. Further experimentation is required to determine the nature of effects of seeding date on 1,000-grain weight.

4.5.2 Nitrogen rate effects

Nitrogen rate means showed significant differences in 1981 only, although the importance of the effect is much less than that of seeding dates (Appendix Table 1). The non-significance of this treatment in 1982 has been explained earlier. The weight per 1,000 grains tended to decrease significantly with increasing nitrogen rates, from 15.6 to 46.8 kg/ha, by 2.1% (Table 27).

Published evidence showing significant increases in grain weight with nitrogen (Done and Whittington, 1980) is mainly from experiments with low or moderate nitrogen rates. In this experiment, nitrogen was not applied at high rates, but constituted a second and later application so that the effect of the extra ammonium nitrate was extended over a longer period of time, into the post-anthesis period. Thus, nitrogen depressed grain weight. These results confirm the work by Read and Warder (1982) and Scott (1978). Yield depression might well occur from excessive vegetative growth due to excess nitrogen resulting in reduced individual grain weights.

TABLE 27. The effect of nitrogen level on weight per 1,000 grains of barley in 1981

Nitrogen rate (kg/ha)	1,000-grain weight (g)
15.6	39.53
31.2	38.98
46.8	38.68

LSD (.05) = 0.39

4.5.3 Seeding rate effects

Seeding rates means showed significant differences in 1981 only, but their overall effect was relatively less important than seeding date or cultivars effects (Appendix table 1).

Increasing seeding rates tended to somewhat decrease grain weight (Table 23). The decrease is more pronounced as seeding dates are delayed for the cultivars Loyola and Bruce. Laurier shows a significant decrease at 600 plants/m² only at all seeding dates (Table 23). The results of this study suggest that when moisture is less abundant, such as in seeding dates 2 and 3 (Appendix table 3), lower seeding rates are to be preferred, at least for Loyola and Bruce. These conclusions are in agreement with those of Read and Warder (1982), who reported that lower seeding rates are best when moisture is limited, for individual grain weight.

In 1982, the later seeding dates also generally resulted in lower rainfall during grain filling (Appendix table 3). However, no seeding rate effect was observed. This confirms the findings of Singh (1981), where a crop submitted to early drought during the season is much less affected by water stress throughout the rest of its life.

4.5.4 Cultivar effects

Cultivars showed the largest significant effects in both years expressed by the magnitude of their variance ratios (Appendix tables 1 and 2). The 1,000-grain weight comparisons among cultivars were very similar over years and treatments.

Weight per 1,000 grains among cultivars decreased in the following order: Laurier, Loyola and Bruce in 1982 (Table 24) and in 1981 (Table 23), with one exception in seeding date 1 at 600 plants/m².

Wiegrand and Cuellar (1981) demonstrated that a genetic factor dominated the rate of filling and, environment the duration of filling. Moreover, they concluded in their study that if the duration of grain filling in wheat cultivars is fixed by temperature, the final grain weight will be proportional to the rate of grain filling. This was well demonstrated in this experiment; however, the correlations study did not indicate clearly whether barley cultivars would be influenced more by precipitation or by temperature (Table 26), although it is not always possible to separate the effects of the different environmental factors that occur in the field.

4.5.5 Combined analyses of the two experiments

Pooling of the 1,000-grain weight data was not possible since the hypothesis of homogeneous error variance was rejected at the .05 level of significance as mentioned in section 4.4.1. Although weight per 1,000 grains is the yield component with the smallest coefficient of variation within years (4.22% in 1981 and 5.50% in 1982) (Appendix tables 1 and 2), variation over the two years is too wide to permit pooling. Weight per 1,000 grains is often used as a reference for cultivars or for seeding rate calculations based on seed number. However, it appears that wide variations occurred from 1981 to 1982. This situation suggests that 1,000-grain weight values be revised for each crop in order for this information to be closer to reality.

4.5.6 Relationships among treatments

Significant ($p = 0.05$) variations due to treatments (Appendix tables 1 and 2) led to the calculation of regression equations for weight per 1,000 grains for each cultivar. These equations are presented in Table 28. As for the yield component grains/head, weight per 1,000 grains is very predictable since the R-square values (R^2) indicate that one to three treatments accounted for 61 to 80% of the variation associated with the treatments.

TABLE 28. R-square (R^2) and regression equations of weight per 1,000 grains[1] on date[2] and/or seeding rate[3] and/or nitrogen rate at tillering[4] in 1981 and 1982

Year	Cultivar	Equation	R^2	Pr > F
1981	Laurier	$W = 47.02 - 0.04x - 0.05w + 0.007z$	0.60	.0001
	Loyola	$W = 43.01 - 0.03x + 0.002z - 1.49 \times 10^{-5}z$	0.59	.0001
	Bruce	$W = 39.16 - 0.05x + 0.0002x^2 - 0.0002z$	0.74	.0001
1982	Laurier	$W = 44.65 - 0.09x + 0.0003x^2$	0.61	.0001
	Loyola	$W = 42.16 - 0.14x + 0.0006x^2$	0.80	.0001
	Bruce	$W = 39.08 - 0.04x - 0.004z$	0.63	.0001

[1]Weight per 1,000 grains : W (g)

[2]Seeding date: x (degree-days from earliest seeding)

[3]Seeding rate: z (plants/m^2)

[4]Nitrogen rate at tillering: w (kg/ha)

4.6 Phenological stages

The abundance of data concerning the length of growth stages led to a selection within the analysed information. The most important treatment effect for each growth stage was selected and is discussed here.

4.6.1 Seeding date effects

Highly significant and important differences among seeding date means were found for the number of days from seeding to seedling emergence and from heading to grain maturity (Appendix table 7).

The 1982 seeding date effects for these two periods are shown in Table 29. Early seeding always resulted in a larger number of days for plants to emerge. Guitard and Faris (1968) reported a high correlation coefficient for the germination times of 259 different entries of the world Barley Collection at 4, 12, 20 and 28°C. French and Schultz (1982) also defined the number of days during this interval from degree-days of maximum and mean air temperature. Similar results to those of Guitard and Faris (1968) were obtained in this experiment with a much narrower range of temperatures. The number of days between seeding and emergence is highly correlated, $r = -0.81$ (adjusted for nitrogen rates, seeding rates and cultivars), with the average of degree-days accumulated during this period (Table 30). The length of the seeding to emergence period is also, but to a lesser degree, correlated with rainfall accumulation during this period, $r = -0.50$ (adjusted for nitrogen rates, seeding rates and cultivars) (Table 30). This is an indication that emergence is conditioned primarily by temperature, and to some extent moisture, so that delaying the seeding date in a normal season should result in more rapid emergence.

It is more difficult to detect an effect of the length of the emergence period on a specific yield component. However, it clearly has an effect on the length of one of the subsequent growth stages, the period from seeding emergence to stem elongation. Time to emergence and time from emergence to stem elongation are negatively correlated (Table 31). The relationship to the subsequent growth stage, stem elongation to heading is much weaker (Table 31).

TABLE 29. The effect of seeding date and cultivar on the number of days from seeding to emergence and from heading to maturity of barley in 1982

Seeding date	Seeding to emergence			Heading to maturity		
	Laurier	Loyola	Bruce	Laurier	Loyola	Bruce
1	12.6	13.0	12.2	29.7	27.3	29.0
2	9.8	10.1	9.7	25.3	22.7	24.3
3	9.1	10.9	8.6	22.4	20.5	20.6

LSD (.05): between 2 seeding date means of the same cultivar from seeding to emergence: 1.0; between 2 seeding date means of the same cultivar from heading to maturity: 0.5.

TABLE 30. Probability levels and partial correlation coefficients between some growth stages and some meteorological data, adjusted for nitrogen rates, seeding rates and cultivars in 1982

Growth stages	Average degree-days from seeding to emergence	Average precipitation from seeding to emergence	Average degree-days from heading to maturity	Average precipitation from heading to maturity
Seeding to emergence[1]	-0.81 (.0001)	-0.50 (.0001)	-	-
Heading to maturity	-	-	-0.83 (.0001)	0.68 (.0001)

[1]In days

However, as for time to emergence, the periods from emergence to stem elongation and from stem elongation to heading do not show particular interesting relationships, either with yield components or with grain yield (Table 32). Thus, the time to emergence, even through its influence on the length of the next phenological stage, did not appear to play an important role in yield determination.

TABLE 31. Probability levels and partial correlation coefficients between time to emergence and subsequent growth stages, adjusted for nitrogen rates and seeding rates and cultivars in 1982

Period from	Emergence to stem elongation	Stem elongation to heading	Emergence to heading
Seeding to emergence	-0.54 (.0001)	0.32 (.0001)	-0.36 (.0001)

TABLE 32. Probability levels and partial correlation coefficients between growth stages and yield or yield components adjusted for nitrogen rates, seeding rates and cultivars in 1982

Period from	Grain yield	Heads/m²	Grains/head	1,000-grain weight
Seeding to emergence	0.33 (.0001)	NS	NS	0.48 (.0001)
Emergence to stem elongation	-0.13 (.0047)	-0.19 (.0001)	0.14 (.0029)	NS
Stem elongation to heading	NS	NS	0.11 (.0136)	0.16 (.0001)
Heading to maturity	0.53 (.0001)	0.53 (.0001)	0.43 (.0001)	0.65 (.0001)

Seeding date effects on the number of days from heading to maturity are shown in Table 28. Delaying the seeding date from April 28th to May 7th reduced the period of heading to maturity by 14.8, 16.8 and 16.2%, and to May 15th by 24.5, 24.6 and 28.9%, for the cultivars Laurier, Loyola and Bruce, respectively. This effect of shortening the grain filling period was also noted by Beech and Norman (1966), Syme (1972) and French _et al_ (1979). The length of the heading to maturity period is highly correlated with the average degree-days accumulated during this period, r = -0.83 (adjusted for cultivars, nitrogen rates and seeding rates) and to the precipitation, r = 0.68 (adjusted for cultivars for nitrogen rates and seeding rates) (Table 30).

These correlations indicate that both temperature and rainfall might have been important in determining the duration of grain filling in 1982 as pointed out in the discussion on weight per 1,000 grains.

This drastic effect of seeding date on the length of the post-flowering period had some consequence for yield components. The 1,000-grain weight is highly correlated with the duration of the heading to maturity period in 1982 (Table 26). Through the effects of the length of the grain filling period on weight per 1,000 grains, grain yield is also positively correlated with the length of the grain filling period, r = 0.53, adjusted for cultivars, seeding rate and nitrogen rates (Table 32). This study confirms other reports on the importance of the length of the grain filling period on grain yield (Daynard et al, 1971; Gebeheyou et al, 1982).

4.6.2 Seeding rate effects

Highly significant and important differences among seeding rate means were found for the number of days from emergence to stem elongation (Appendix Table 7). The 1982 seeding rate effects are shown in Table 33.

TABLE 33. The effect of seeding rate on the number of days from emergence to stem elongation of barley in 1982

Seeding rate (plants/ m^2)	Laurier			Loyola			Bruce		
	Seeding date								
	1	2	3	1	2	3	1	2	3
150	31.3	32.0	32.7	31.5	34.7	31.5	31.6	32.7	32.5
300	30.7	31.0	29.7	30.0	32.3	30.2	30.4	30.8	30.5
450	28.7	29.4	28.3	30.5	31.0	28.4	27.5	29.1	29.0
600	29.0	29.5	28.9	28.9	31.0	28.5	26.5	29.0	29.4

LSD (.05) : between 2 seeding rate means at the same seeding date of the same cultivar: 1.2.

The number of days from emergence to stem elongation tended to decrease with increasing seeding rates. This is mainly due to the fact that tillering lasts longer in thin populations which must compensate for a low number of seedlings. It is also interesting to note that the duration of the emergence to stem elongation period is somewhat correlated with the first two yield components, probably through the effects of the number of heads/m^2 and its negative relationship to grains/head (Table 34). Grain yield and number of heads/m^2 are negatively correlated with this period since less dense stands did produce a lower number of heads/m^2 and lower grain yield in 1982. Grains/head, on the other hand, is positively correlated with this period. These results confirm that of Gebeheyou et al (1982), who demonstrated that the duration of the vegetative period was positively associated with grains/head but negatively with heads/m^2, which in turn had some effect on yield.

TABLE 34. Probability levels, and partial correlations between the duration of the emergence to stem elongation period and yield or heads/m² or grains/head, adjusted for seeding date, nitrogen rates and cultivars in 1982

Period from	Grain yield	Heads/m²	Grains/head
Emergence to stem elongation	-0.23 (.0001)	-0.43 (.0001)	0.48 (.0001)

4.6.3 Cultivar effects

The period not yet discussed, stem elongation to heading, varied mainly with the various cultivars involved in the experiment (Appendix table 7). Bruce required more time than Loyola, and Loyola more time than Laurier, to attain heading (Table 35). The length of the stem elongation to heading period seems, therefore, to be mostly genetically fixed, although it does vary to a limited extent with seeding date, or climatic effects, and seeding rates (Appendix table 7). The length of this period is not related or is very slightly related to yield, heads/m² and grains/head (Table 36). It does seem to have a certain relationship (Table 36) with weight per 1000 grains, but the overall effects on yield are not significant. Gebeheyou et al (1982) also noted a positive relationship between the length of the vegetative period and individual grain weight.

This experiment confirms the findings of Gebeheyou et al (1982), who demonstrated a positive relationship between the duration of the vegetative period and grains/head and individual grain weight, and a negative relationship with heads/m². This experiment, however, demonstrated that under 1982 conditions the relationship between the vegetative period and the first two yield components is exerted in the early part of the period, i.e., from emergence to stem elongation (Table 34) and the relationship with 1000-grain weight is exerted later from stem elongation to heading time (Table 36).

TABLE 35. The effect of cultivar on the number of days from stem elongation to heading in 1982

Cultivar	Days from stem elongation to heading
Laurier	10.6
Loyola	12.3
Bruce	12.6

LSD (.05) = 0.2

TABLE 36. Probability levels and partial correlation coefficients between the duration of the stem elongation period and yield or yield components, adjusted for seeding dates, seeding rates and nitrogen rates in 1982

Period from	Grain yield	Heads/m²	Grains/head	Weight per 1000 grains
Stem elongation to heading	NS	0.12 (.0078)	0.15 (.0015)	-0.40 (.0001)

4.7 Relationships among yield and yield components

4.7.1 Grains/m² vs grain yield.

Grain yield was not particularly well related to the individual yield components in 1981 (Table 37). It showed a better linear relationship with the number of heads/m² in 1982 (Table 37). Very good linear relationship with the number of grains/m² was found in both years (Table 38). This indicates that in both 1981 and 1982 the factors which influenced grain site development were relatively more important than factors affecting subsequent grain filling. While 1,000-grain weight may influence yield under some circumstances, the component most closely related to grain yield was grains/m². The cultivars were pooled, since their equations for predicting yield from grains/m² were similar. Even the 1981 and 1982 equations are almost identical (Figure 4), so that the prediction of these models appears excellent over years. Thus, a yield (Y) prediction equation based on number of grains/m² can be developed from this study:

$$Y_{(g/m^2)} = 83.01 + 0.03x, \quad r^2 = 0.74$$

which accounts for variance associated with years, seeding dates, nitrogen rates, seeding rates and cultivars for 864 observations. The yield prediction equation confirms a similar report by Black (1982) on wheat subjected to years and fertilizer treatments.

Thus, the treatment effects in 1981 appeared to be mostly mediated through the effects on the number of grains/m². Similar relationships can be observed for 1982. It seems that in 1982, grain

TABLE 37. Linear regression estimates and coefficient of determination (R^2) for the relationship between grain yield and the individual yield components in 1981 and 1982

Year	Cultivar	Regression	Intercept	Slope	R^2	Pr > F
1981	Laurier	(Y)[1] vs (H)[2]	41.16	0.12	0.24	.0001
	Loyola	Y vs H	55.68	0.08	0.10	.0001
	Bruce	Y vs H	44.41	0.09	0.21	.0001
	Laurier	Y vs (G)[3]	40.99	1.22	0.20	.0001
	Loyola	Y vs G	35.03	1.25	0.31	.0001
	Bruce	Y vs G	43.84	1.05	0.20	.0001
	Laurier	Y vs (W)[4]	-	-	-	NS
	Loyola	Y vs W	-	-	-	NS
	Bruce	Y vs W	-	-	-	NS
1982	Laurier	Y vs H	40.93	0.15	0.49	.0001
	Loyola	Y vs H	44.81	0.14	0.43	.0001
	Bruce	Y vs H	59.95	0.09	0.34	.0001
	Laurier	Y vs G	-	-	-	NS
	Loyola	Y vs G	-	-	-	NS
	Bruce	Y vs G	-	-	-	NS
	Laurier	Y vs W	-	-	-	NS
	Loyola	Y vs W	-	-	-	NS
	Bruce	Y vs W	-	-	-	NS

[1]Y : grain yield (g/0.2 m^2)
[2]H : heads/m^2
[3]G : grains/head
[4]W : 1,000-grain weight

TABLE 38. Linear regression estimates and coefficient of determination (R^2) for the relationships among grain yield and grain yield components in 1981 and 1982

Year	Cultivar	Regression	Intercept	Slope	R^2	Pr > F
1981	Laurier	Y[1] vs H[2] x G[3]	11.22	.007	0.86	.0001
		Y vs H x G x W[4]	1.22	.0001	0.97	.0001
	Loyola	Y vs H x G	7.35	.007	0.84	.0001
		Y vs H x G x W	2.67	.0001	0.97	.0001
	Bruce	Y vs H x G	10.89	.006	0.87	.0001
		Y vs H x G x W	0.87	.0001	0.99	.0001
1982	Laurier	Y vs H x G	3.17	.007	0.74	.0001
		Y vs H x G x W	−0.04	.0002	0.99	.0001
	Loyola	Y vs H x G	14.88	.006	0.66	.0001
		Y vs H x G x W	0.008	.0001	0.99	.0001
	Bruce	Y vs H x G	−7.42	.007	0.78	.0001
		Y vs H x G x W	0.32	.0001	0.99	.0001

[1]Y : grain yield ($g/.2m^2$)

[2]H : heads/m^2

[3]G : grains/head

[4]W : 1,000-grain weight

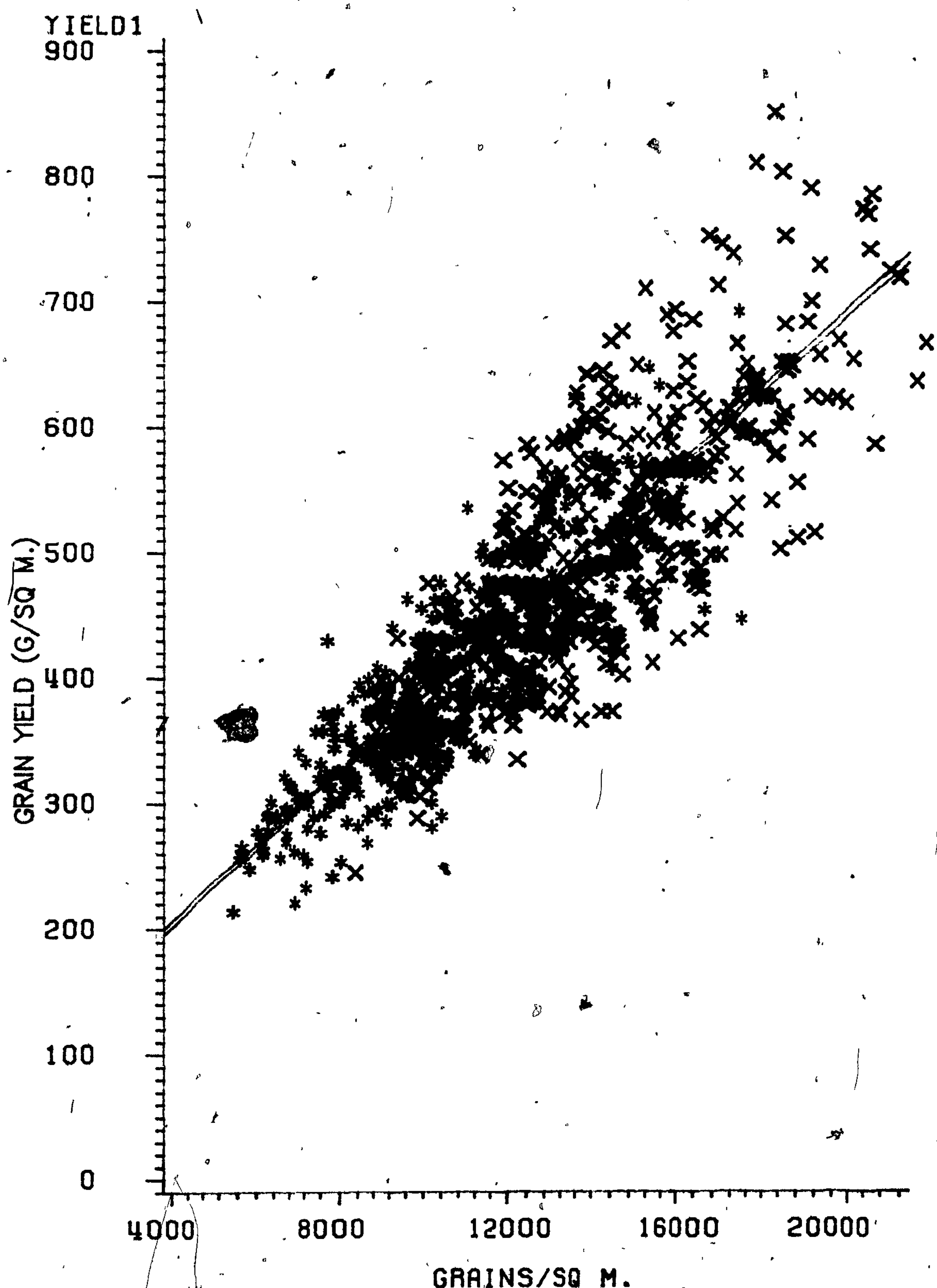


Figure 4. The regression of grain yield on grains/m² in 1981 (✱) and in 1982 (X).

yield was also limited by the sites of storage (sink) rather than the filling source (Table 38). However, in 1982, the limitations in capacity of storage (sink) depended more on the number of heads/m² than on grains/head, since heads/m² alone accounts for 49, 43 and 34% of the grain yield variance associated with the various treatments in 1982, versus 24, 10 and 21% in 1981, for the cultivars Laurier, Loyola and Bruce, respectively (Table 37). This is probably due to the fact that the 1982 early season drought that affected all seeding dates limited mostly the number of heads/m². These results confirm the findings of several authors who already related grains/m² to grain yield, such as Willey and Holliday (1971) in England, Kohn and Storrier (1970) in Australia, Scott et al (1977) in New Zealand, McLaren (1981) in England, and Black (1982) in the U.S.A. McLaren (1981) explained the linear relationship between grain yield and total number of grains/m² through the following mechanism. The source activity early in the season determines the potential sink capacity, which, in turn, influences subsequent source activity later in the season.

When all three components of grain yield were combined, 97 to 99% of the yield variance associated with the treatments in 1981 and 1982 could be explained (Table 38).

4.7.2 Compensation effects through a correlations study

In 1982, grains/head was negatively correlated with heads/m². This is an indication of compensation (Table 39). On the other hand, 1,000-grain weight was weakly or not correlated with grains/m²

(Table 39). This indicates almost a complete absence of compensation after anthesis. Still, in 1982, it is interesting to note that although grains/m² is significantly correlated with heads/m², it is very weakly or not at all correlated with grains/head, though grains/m² is the direct product of heads/m² and grains/head (Table 39). This indicates that the number of grains/head for each plot (which is a division of the number of heads/m² by the weight of grain harvested from these heads, the 1,000-grain weight being known) is an average value from very different head sizes. Differences in the size of heads appear to be a direct consequence of the factors regulating tillering and survival of tillers, which determines the head population at harvest. This situation was probably associated with the sparse rainfall during tillering and reflects the late-tillering phenomenon that could effectively be observed in the field in 1982. The cultivar Bruce exhibits the poorest relationship between grains/m² and grains/head, and was, in fact, the most able to form productive late tillers.

In 1981, heads/m² and grains/head were also negatively correlated but to a lesser degree than in 1982. The compensation mechanism was less effective (Table 40) between the first two yield components than in 1982. The 1,000-grain weight appears somewhat compensating for the cultivars Laurier and Bruce, but very little for Loyola.

Thus, in both years, compensation after anthesis does not appear to have been so important. In 1982, when it did not appear to be involved in compensation effects, weight per 1,000 grains contributed

TABLE 39. Probability levels and linear correlation coefficients among grain yield components of barley in 1982

	Cultivar	Grains/head	1,000-grain weight	Heads/m²
Heads/m²	Laurier	-.63 (.0001)	-	1.00
	Loyola	-.61 (.0001)	-	1.00
	Bruce	-.73 (.0001)	-	1.00
Grains/m²	Laurier	.21	NS	.58 (.0001)
	Loyola	.25 (.0001)	-.18 (.0001)	.57 (.0001)
	Bruce	NS	NS	.62 (.0001)

TABLE 40. Probability levels and linear correlation coefficients among some grain yield components of barley in 1981

	Cultivar	Grains/head	1,000-grain weight	Heads/m²
Heads/m²	Laurier	-.44 (.0001)	-	1.00
	Loyola	-.51 (.0001)	-	1.00
	Bruce	-.49 (.0001)	-	1.00
Grains/m²	Laurier	.49 (.0001)	-.41 (.0001)	.54 (.0001)
	Loyola	.52 (.0001)	-.18 (.0001)	.44 (.0001)
	Bruce	.46 (.0001)	-.39 (.0001)	.50 (.0001)

more to yield variability, 25, 21 and 33% for the cultivars Laurier, Bruce and Loyola, respectively (Table 38), than in 1981 (Table 40). In 1982, the cultivar Loyola appeared to be the most sensitive to environmental conditions after anthesis, since 33% of the yield variability was still to be determined during grain filling. Since seeding date only had an important effect on the 1,000-grain weight of Loyola, it seems that the duration of grain filling highly correlated with seeding date (Table 26) was more critical in 1982 for Loyola than for the two other cultivars. Compensation mechanisms need now to be studied with regard to each of the treatment effects.

4.7.3 Compensation for seeding date effects

The two ontogenically earlier yield components have been shown to be related to each other in a negative relationship in this experiment (Tables 39 and 40) and several others, such as Stoskopf et al (1974). These two components will thus be examined first. The cultivar Laurier was chosen to illustrate the seeding date effects (Figures 5 and 6) since there is no major difference among the compensation trends of the three cultivars. Figure 5 shows clearly that both the effects of heads/m² and grains/head contributed to the high yield in seeding date 2 for the cultivar Laurier in 1981. The usual negative relationship between heads/unit area and grains/head, to compensate for a lower number of heads/m², did not occur in date 1. In 1981, the differences in heads/m² between dates 1 and 2 were either non-significant or date 2 was higher than date 1 (Table 3). On the other hand, grains/head exhibited a definite significant decrease at date 1 compared with date 2 (Figure 5). This confirms the trend already described by correlation coefficients in the previous section.

We can thus conclude, as it has been suggested earlier in this study, that climatic conditions before heading, limiting heads/m² did not allow for compensation in seeding date 1 by the grains/head yield component. The drought period from stem elongation to heading suffered by seeding date 1 would explain the lower numbers for grains/m² in seeding date 1 compared with seeding date 2 (Figure 5). These results confirm the findings of Wells and Dubetz (1970) and Lawlor et al (1981) on the effects of shortages of water and it is probable that longer dry conditions later on would have had an effect also on the latest yield component, as these two authors also observed.

However, in 1982, the usual compensation relationship between the two yield components is clearly visible (Figure 6, Table 39). The environment did not interfere at any of the seeding dates to inhibit the compensation process. These results also confirm the work of Singh (1981), who observed that water stress in the early vegetative period conditioned the crop to tolerate more water stress in the booting-heading stage.

Seeding date 3 compensated for low numbers of heads/m² by a higher number of grains/head, even with receiving much less precipitation than seeding dates 1 and 2 (Appendix table 3).

In 1981, individual grain weight responded almost always to seeding date (Table 23). The decrease is therefore not related to compensation for events that occurred previously in the growing season, since grain weight responded linearly to delayed seeding (Figure 5). Since final grain yield at the different seeding dates (Table 3) reflected the behaviour of the two first components, and since grains/m² accounted for 86, 84 and 87% of the yield variance

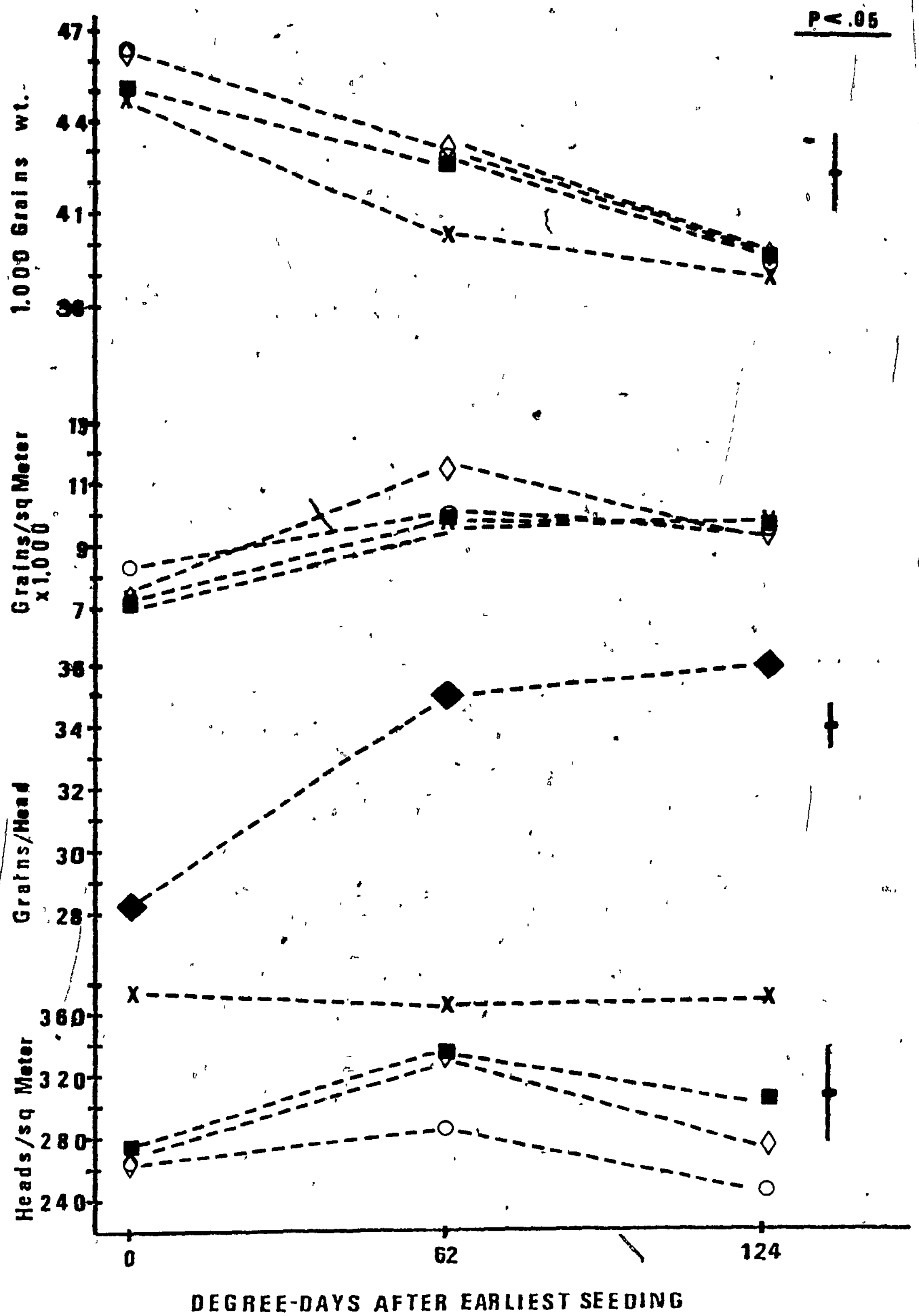


Figure 5. Yield components and grains/m² at the three seeding dates of the cultivar Laurier at four seeding rates (150 (○), 300 (◊), 450 (■), 600 (X) plants/m²), or as an average of four seeding rates (◆) in 1982.

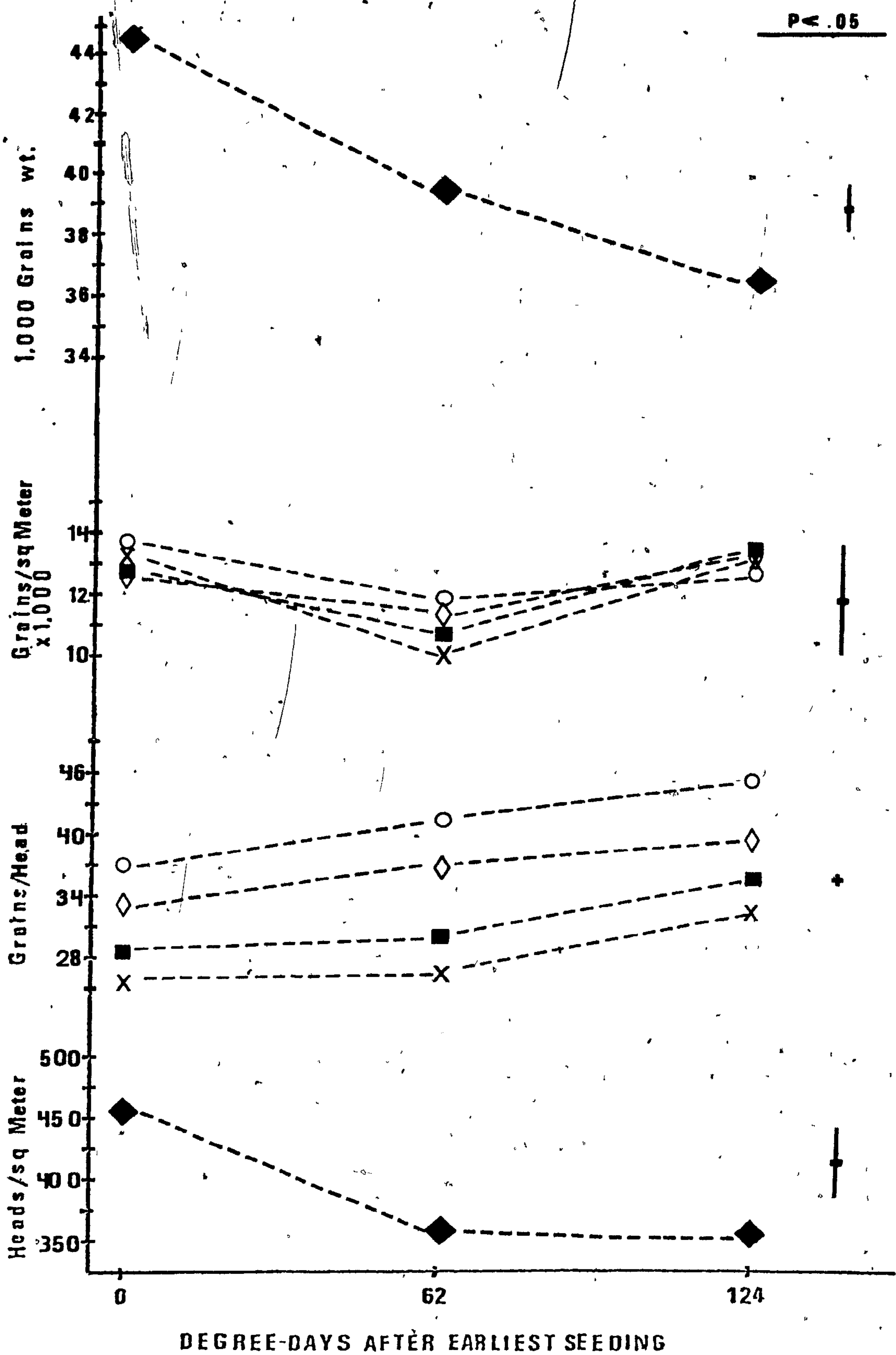


Figure 6. Yield components and grains/m² at the three seeding dates of the cultivar Laurier at four seeding rates (150 (○), 300 (◊), 450 (■), 600 (X) plants/m²) or as an average of the three seeding rates (◆) in 1982.

associated with the treatments for the cultivars Laurier, Loyola and Bruce, respectively (Table 38), it is likely that 1,000-grain weight acted incidentally to compensate partially for grain yield in seeding date 1.

In 1982, the same trend for decreasing grain weight with delayed seeding is obvious (Figure 6). It would then seem that grain weight allows for little in terms of compensation for seeding date effects and, rather, responds to climate or length of grain filling period. This confirms similar findings by Kohn and Storrier (1970) and Black and Siddoway (1977) and the tendencies described by the correlation coefficients in the previous section. The 1,000-grain weight behaviour appears to be independent of other yield components, especially in 1981. In 1982, while grains/m^2 accounted for 66 to 78% of the yield variance associated with the different treatments, 1,000-grain weight helped to compensate for the lower number of grains/m^2 in seeding date compared with date 3, and allowed seeding date 1 to produce significantly higher yields.

4.7.4 Compensation for seeding rate effects

The rate of seeding has often been reported not to affect yield (Finlay et al, 1971; Jones and Hayes, 1967) because the yield components compensated for one another. In 1981, although yield was not affected by seeding rate, heads/m^2, grains/head and 1,000-grain weight were all affected. Figures 7, 8 and 9 show clearly that the low seeding numbers were offset by high numbers of grains per head. For the cultivar Laurier, the compensating mechanism was not completely effective at 600 plants/m², since weight per 1,000 grains offset some of the remaining differences (Table 23; Figure 7). However, the differences among seeding rates were eliminated at the end of the season (Appendix table 1).

Figure 8 shows the same trend for the cultivar Loyola. Loyola relies more on the last yield component to offset high seedling numbers since the decrease in weight per 1,000 grains is significant at 450 and 600 plants/m² (Table 23). Bruce compensated for the three higher seeding rates through grains per head and 1,000-grain weight in date 2 only. In seeding date 1, almost no difference was observed among weights per 1,000 grains, and in date 3 there was no significant difference among seeding rate means for grains/m² (Figure 9).

Thus, differences among the lower seeding rates are mostly eliminated by the second yield component. This was already pointed out through the correlation coefficients (Table 40). However, further compensation by the third yield component at 600 plants/m² for Laurier, at 450 and 600 for Loyola, and at 300, 450 and 600 plants/m² for Bruce, in seeding date 2 seemed to have been effective in eliminating seeding differences in 1981.

The cultivar Bruce was chosen to illustrate (Figure 10) the seeding rate effects in 1982, since there is no major difference among the compensation trends of the three cultivars.

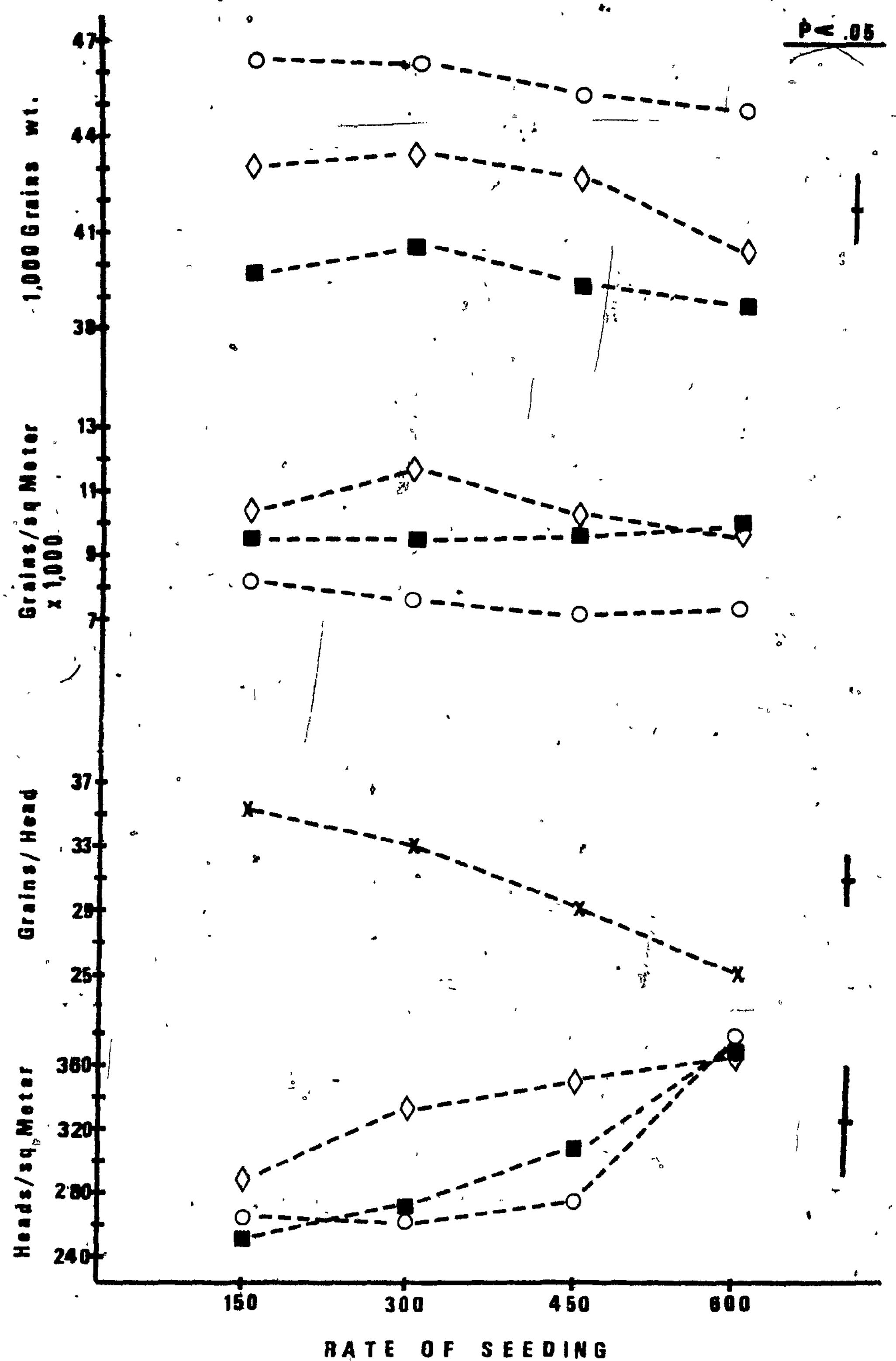


Figure 7. Yield components and grains/m² at the four seeding rates (plants/m²) of the cultivar Laurier at three seeding dates (0 (○), 62 (◇) and 124 (■) degree-days after earliest seeding) or as an average of the seeding dates (X) in 1981.

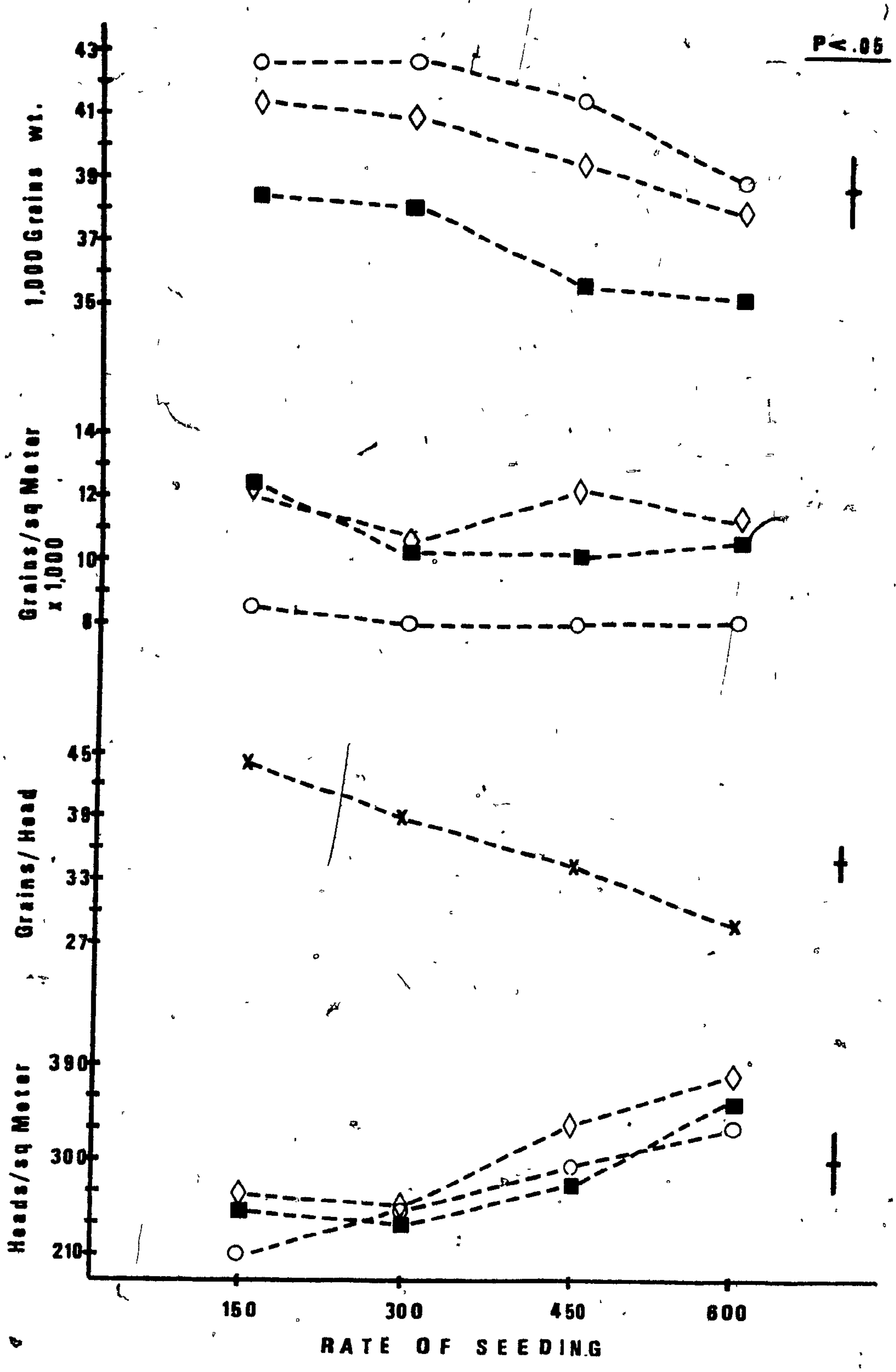


Figure 8. Yield components and grains/m² at the four seeding rates (plants/m²) of the cultivar Loyola at the three seeding dates (0 (○), 62 (◊) and 124 (■) degree-days after earliest seeding) or as an average of the seeding dates (X) in 1981.

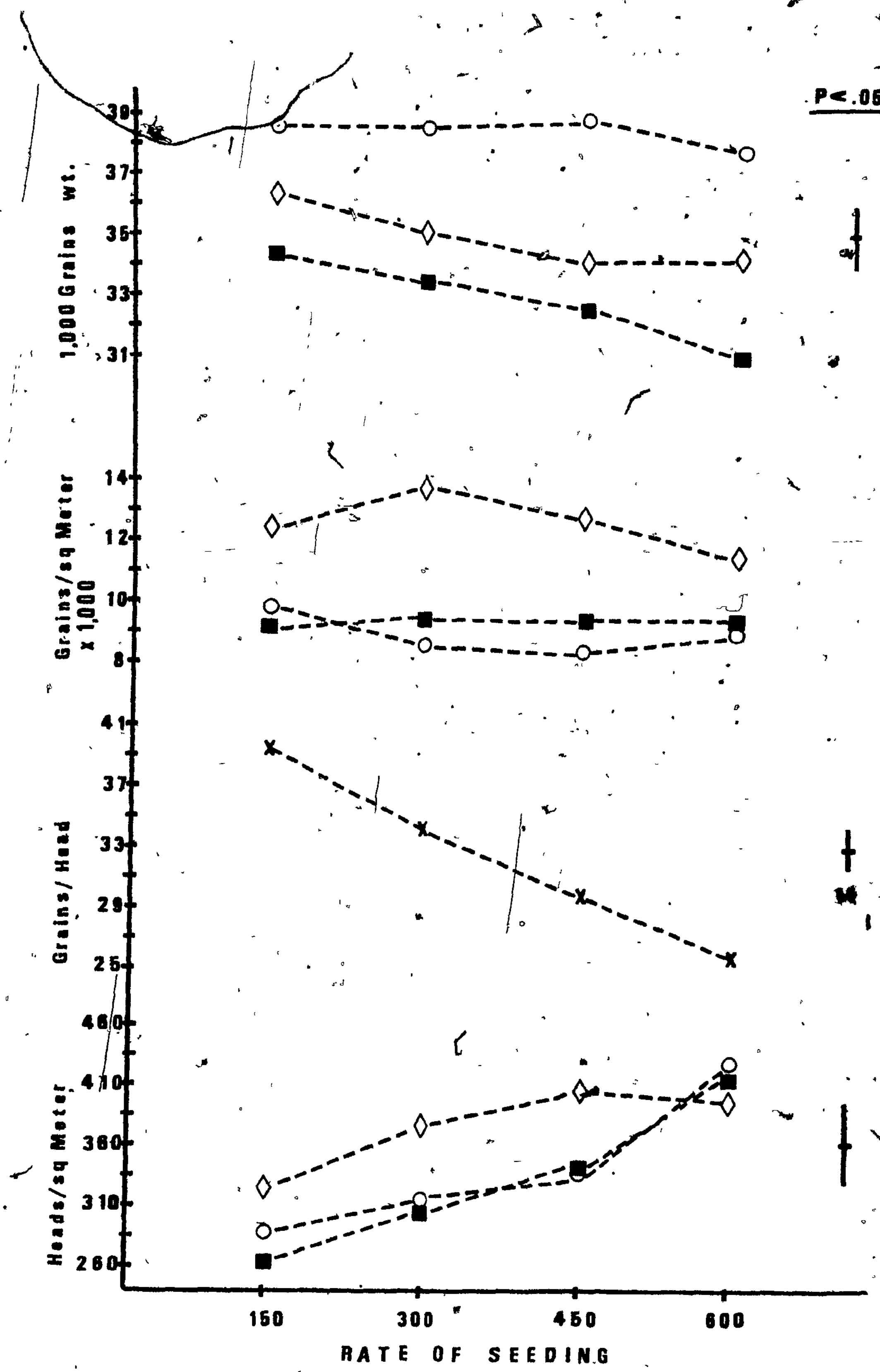


Figure 9. Yield components and grains/m² at the four seeding rates (plants/m²) of the cultivar Bruce at three seeding dates (0 (○), 62 (◇), 124 (■) degree-days after earliest seeding) or as an average of the three seeding dates (X) in 1981.

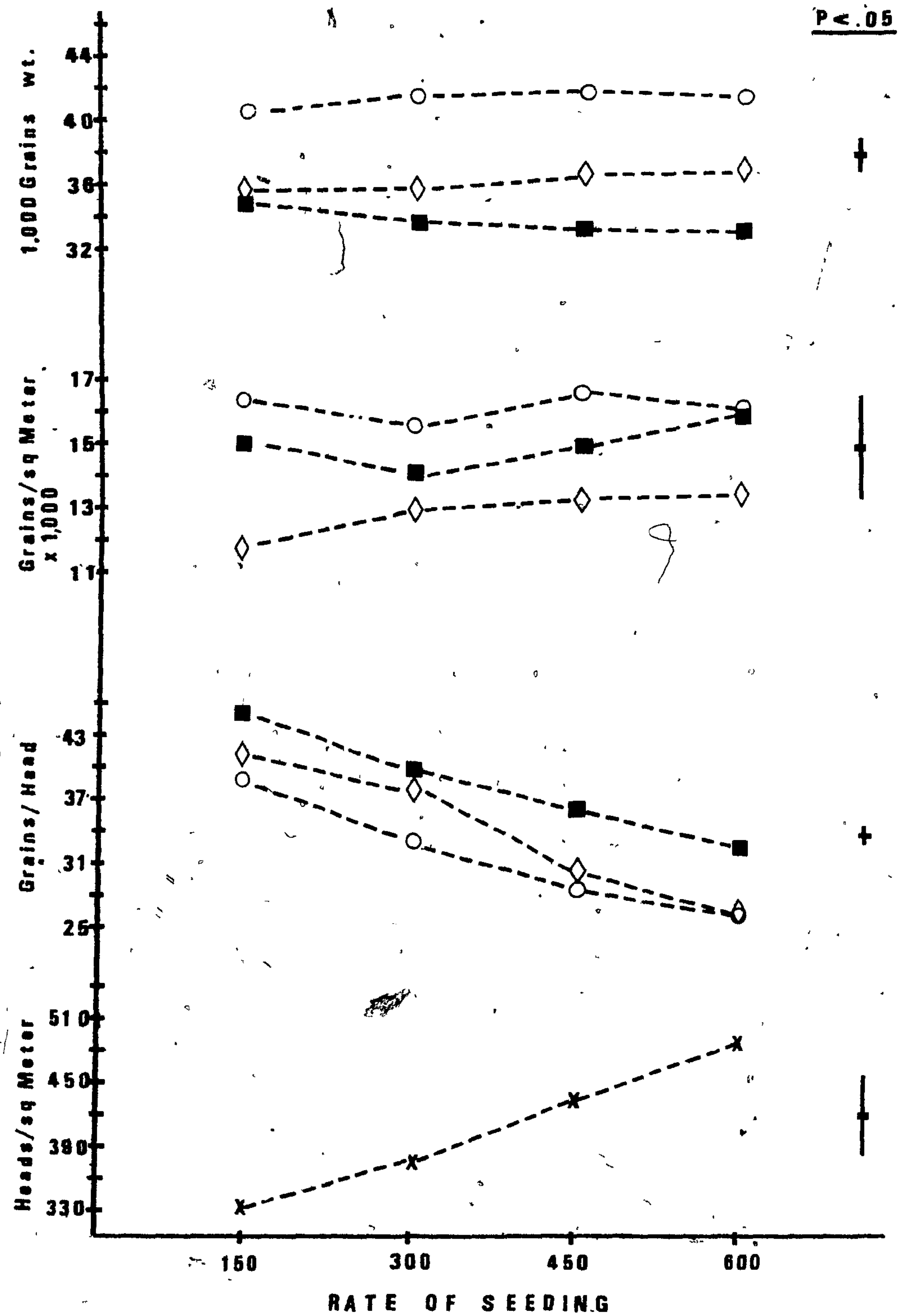


Figure 10. Yield components and grains/m² at the four seeding rates of the cultivar Bruce at three seeding dates (0 (○), 62 (◇), 124 (■) degree-days after earliest seeding) or as an average of the seeding dates (X) in 1982.

Figure 10 shows the compensatory effects of grains/head on heads/m² with increasing seeding rates in 1982. However, this compensating mechanism was not effective at the lowest seeding rate, since there was a significant decrease in the final grain yield at this subnormal rate (Table 7). There were no significant yield differences among the three other rates. These results mostly reflect the compensatory capacity of the barley plant to adjust for the difference in initial seeding rate during these successive stages of development. In 1982, weight per 1,000 grains did not respond to the different seeding rates and was not involved in the compensating mechanism (Appendix table 2).

4.7.5 Compensation for nitrogen rates

In 1981, nitrogen rates affected grains/head and weight per 1,000 grains (Appendix table 1). The highest nitrogen rate increased the number of grains/head (Table 17) and decreased the weight per 1,000 grains (Table 27). However, since final grain yield was still higher at the 46.8 kg/ha rate, nitrogen increased the grains/head component more strongly than it diminished weight per 1,000 grains, and resulted in an 8% increase in grain yield (Table 6). This was to be expected since the compensatory effects of the weight per 1,000 grains are very few in this experiment. Delayed application of nitrogen resulted in a higher number of grains/m² due to increases in grains/head only. McLaren (1981) explained this effect to be a result of more assimilates being available during floret development. Since heads/m² were not affected by nitrogen applied at tillering, it seems difficult to suggest any compensation mechanism in this case.

4.7.6 Summary

The trends for compensation mechanisms described by the correlations in section 4.7.3 were confirmed and better defined through the examination of the effect of each treatment in section 4.7.4.

In 1981 and 1982, the yield component heads/m² responded proportionally to seeding rates as expected and to seeding dates for climatic and physiological reasons. In 1982, in both cases, grains/head response was adjusted in order to compensate for a lower number of heads initiated. This confirms similar findings with oats by Jones and Hayes (1967).

In 1981, the situation was more complex. For climatic reasons, grains/head did not compensate for a lower number of heads/m² in seeding date 1. Under seeding rate treatments, grains/head responded as usual in order to compensate for lower number of heads per unit area.

On the other hand, individual grain weight did not follow a close relationship to other yield components. It does not appear to compensate. In 1982, it was not affected by seeding rate. In 1981 and 1982, its response to seeding date is explained by precipitation and/or temperature. McLaren (1981) has also pointed out some evidence that individual grain weight is associated with yield, mainly through a genotype effect. The 1982 results indicate that this may be the case, as explained earlier in this report.

However, in 1981, the 1,000-grain weight was affected also by seeding rate and nitrogen rate, which have also altered the two other components. Since the LSD (.05) value for grains/m² is not known for 1981, it is impossible to determine how significant was the effect of weight per 1,000 grains in association with grains/m² on final grain yield and its compensation following anthesis. However, in 1981, neither nitrogen nor seeding rates had a large effect on 1,000-grain weight compared with the other treatments (Appendix table 1), so that one can assume that most of the compensation occurred before anthesis. Moreover, the correlations (Table 40) indicate an absence of obvious compensation.

Whether or not the weight per 1,000 grains effect was interrelated to sink capacity in 1981, it still accounts for 13% or less of the yield variance of the three cultivars associated with seeding dates, nitrogen rates and seeding rates. Grain yield can thus be well predicted by the two first components of yield (sink capacity) through the regression equations of Table 38, as found previously by other authors (McLaren, 1981; Russell _et al_, 1982).

5. CONCLUSIONS

From this discussion, several conclusions can be drawn:

1. The success of one seeding date over another in terms of grain yield depends mainly on how well the period during which the yield components, heads/m² and grains/head are determined matches the constraints of the environment. If shortages of water in the early vegetative period of 1982 conditioned the crop to better tolerate water stress at the stem elongation stage, shortages of water at this stage in 1981 could account for yield differences among seeding dates.

2. In general, a minimum rate of 46.8 kg/ha at tillering is required to show significant differences in yield through effects on grains/head and 1,000-grain weight, provided moisture is present after the nitrogen application.

3. A four-fold increase in seeding rate did not affect yield, with one exception due to too severe intraplant competition during the 1982 early season drought. Grain yield similitudes among seeding rate treatments were associated primarily with corresponding increases in numbers of heads/m², proportionally decreased numbers of grains/head and tiller mortality at the high seeding rates. When moisture was limited during grain filling, low seed rates had an advantage in terms of individual grain weight.

4. Cultivars showed a differential response to seeding dates, especially to early and late dates. Seeding date trials could become an important part of cultivar testing for local recommendations to farmers since genotypic variability exists among cultivars recommended at present in this region. Cultivars have shown several differences in the way yield components are determined. The cultivar Bruce benefits from a lower level of inter-tiller competition at intermediate seeding rates and supports more heads/m² to maturity. At these rates, Loyola definitely shows genetic traits for producing fewer heads/m². However, at higher populations, Loyola tolerates a higher number of heads/m² to maturity. Loyola definitely produces more grains/head than the other two cultivars under most conditions tested.

5. In 1982, the period from seeding to emergence was subjected mainly to seeding date effects, but was not the source of any important effect on yield components. On the other hand, the duration of the emergence to stem elongation period was mainly conditioned by the seeding rate, since tillering was achieved during this period. The length of this period resulted in a significantly negative effect on yield through negative relationships on heads/m². Genotypes were the main source of variation in the stem elongation to heading period. The duration of this period was not correlated with grain yield, but was negatively correlated with 1,000-grain weight, a character also very much under genetic influence, so that cultivars with higher individual grain weights underwent a shorter stem elongation period. However, the duration of grain filling was primarily determined by

seeding date effects and showed an important relationship with grain yield through the 1,000-grain weight component, as opposed to the genotypic effects mentioned earlier. Temperature and rainfall both played a rôle in both years in determining the duration of grain filling.

6. Most of the relationships between grain yield, Y, and the treatments were described by regression equations of the following forms:

1981 - $Y = e + ax + bx^2 + cz$

1982 - $Y = e + ax + bx^2 + cx + dx^2$

where x represents the seeding date in degree-days accumulated after the first possible seeding, and z represents the seeding rate. Most of the relationships between yield components and the treatments were described by regression equations as linear combinations of the same two treatments in either linear or quadratic form for seeding date and mostly linear for seeding rate. The absence of interaction or failure of the response to one treatment to be the same at each level of another treatment never improved the models significantly. Nitrogen rate effects also never improved the model significantly with one exception. Models developed for individual yield components resulted in better prediction values as compared with grain yield prediction values. Moreover, the grains/m² variable showed excellent prediction value for grain yield in both years, and confirmed that the factors affecting grain site development are more important than factors affecting subsequent grain filling. In all cases, the relationship between 1,000-grain weight and grains/m² is weak or non-existent.

7. Grains/head data allowed for the development of a prediction equation for the two-year period. The value of this equation should be tested in the future and improved by tests at different locations. On the other hand, the variability of weight per 1,000 grains over years implies a wider recognition of this fact by extension workers.

8. These considerations suggest that compensation is mostly restricted to heads/m² and grains/head. While compensation mechanisms for seeding rates, i.e., differential populations, are mostly a function of two interdependent yield components, heads/m² and grains/head, the situation is more complex for seeding date effects. Seeding date effects imply (1) differences in climate and phenology and (2) as a result, a population difference equivalent to a seeding rate effect. Therefore, in 1982, when the environment was not detrimental to the early seeding, the advantage gained through the number of heads/m² and weight per 1,000 grains led to a higher yield. However, when the environment is detrimental to an early seeding date, such as in 1981, and limits the number of heads/m², it may also reduce the response of the second yield component, grains/head, which do not compensate. Thousand-grain weight, which response is determined by environment, can diminish the effect but does not compensate. Therefore, compensation mechanisms for seeding date are manifested mainly by changes in heads/m² and grains/head if climate allows, and compensation by 1,000-grain weight, if it occurs, is incidental rather than physiological.

6. SUGGESTIONS FOR FUTURE RESEARCH

Suggestions designed to improve the understanding of the effects and relationships studied in this experiment are as follows:

1. Higher levels of nitrogen applied at tillering need to be tested in order to have a better insight of their influence and to detect the possible interactions that could interfere with the relationships described here. Applications should be done near the beginning of tillering so that effects on the first ontogenical yield component can be studied.

2. Test consecutive seeding dates over several years to better distinguish the patterns contributing to high yields and to obtain more statistical data on the benefits of April seedings over a long period of time, and especially to clarify the nature of effects of seeding date on 1,000-grain weight.

3. Take into account the amount of productive and non-productive tillers at the end of the season, as well as the establishment stand early in the season, in order to better understand the factors determining the yield component, heads/m^2, in a similar experiment.

4. Test the equation for predicting the number of grains/head for each cultivar, and the equation for predicting yield from grains/m^2 by trials at different locations over years.

It should be pointed out that climate may be a nuisance to head formation at any seeding date, and that higher nitrogen rates will probably decrease yield through lodging, so that improvements in grain yield from a better understanding of cultural practices need to be accompanied by genetic improvements. The achievement of control over tillering and of lodging-resistant cultivars would procure invaluable gains in the quest for higher yields in this region.

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APPENDICES

APPENDIX TABLE 1. Variance ratios and coefficient of variability for analysis of variance of grain yield, head number/m², grain number per head and 1000-grain weight for the 1981 experiment

Source of variation	d.f.	Dependent variables			
		Grain yield (g/2.04 m²)	Heads/m²	Grains/head	1,000-grain weight (g)
Date of seeding (D)	2	33.18**	13.00**	121.92**	166.78**
Nitrogen rate (N)	2	9.50**	3.47	5.26*	5.87*
D x N	4	2.61	0.51	1.94	0.43
Cultivars (C)	2	6.64**	53.25**	100.40**	666.03**
Rate of seeding (R)	3	1.74	89.53**	251.14**	51.18**
C x R	6	1.24	1.69	3.71**	3.11**
D x C	4	3.44**	0.88	0.78	5.71**
D x R	6	1.98	2.68*	1.39	0.71
N x C	4	2.07	2.25	0.97	2.06
N x R	6	0.74	1.00	0.64	1.72
D x N x C	8	0.61	1.48	1.64	1.57
D x N x R	12	0.99	0.89	0.72	1.13
D x C x R	12	0.99	1.99*	0.50	1.79*
N x C x R	12	0.39	1.38	0.61	0.53
D x N x C x R	24	0.89	1.11	1.18	1.16
C.V.		10.55%	14.84%	10.06%	4.22%

*Significant at .05 level
**Significant at .01 level

APPENDIX TABLE 2. Variance ratios and coefficient of variability for analysis of variance of grain yield, head number/m², grain number per head and 1000-grain weight for the 1982 experiment

Source of variation	d.f.	Dependent variables			
		Grain yield (g/2.04 m²)	Heads/m²	Grains/head	1,000-grain weight (g)
Date of seeding (D)	2	24.46**	19.31**	35.57**	109.81**
Nitrogen rate (N)	2	0.28	0.12	0.56	1.90
D x N	4	2.00	1.49	1.60	0.57
Cultivars (C)	2	17.90**	114.42**	165.78**	408.25**
Rate of seeding (R)	3	19.49**	95.09**	309.46**	0.70
C x R	6	1.22	3.82**	1.17	3.53**
D x C	4	5.12**	6.46**	2.36	9.29**
D x R	6	1.84	0.61	2.15*	5.96**
N x C	4	2.47*	0.59	0.07	0.23
N x R	6	0.74	1.22	2.08	1.47
D x N x C	8	0.50	0.49	1.00	0.36
D x N x R	12	0.64	0.57	0.50	0.96
D x C x R	12	0.82	0.75	1.74	0.49
N x C x R	12	0.97	1.01	0.56	0.71
D x N x C x R	24	1.07	1.08	1.24	0.99
C.V.		9.35%	18.28%	10.10%	5.50%

*Significant at .05 level
**Significant at .01 level

APPENDIX TABLE 3. Averages[1] of the precipitation during the different barley phenological stages in 1981 and 1982

Period	Seeding date	1981			1982		
		Laurier	Loyola	Bruce	Laurier	Loyola	Bruce
1 week before seeding to seeding date	1	6.2	6.2	6.2	3.5	3.5	3.5
	2	10.0	10.0	10.0	0.0	0.0	0.0
	3	4.2	4.2	4.2	1.0	1.0	1.0
Seeding to emergence	1	29.2	29.2	29.2	12.0	12.0	11.4
	2	35.6	35.6	34.8	12.2	12.2	12.2
	3	1.0	1.0	1.0	7.8	7.8	7.8
Emergence to stem elongation	1	112.1	106.0	104.1	24.1	24.1	24.7
	2	80.1	78.9	79.5	41.1	41.1	41.1
	3	117.9	126.1	157.4	105.6	118.3	105.6
Stem elongation to heading	1	23.4	31.3	36.6	68.8	89.5	68.8
	2	53.7	60.8	52.1	85.0	86.8	85.0
	3	26.8	27.9	36.3	29.4	19.9	29.4
Heading to maturity	1	72.4	72.0	66.1	61.9	41.2	61.9
	2	45.1	35.7	34.8	33.7	31.9	33.7
	3	38.9	35.2	28.0	15.8	44.5	15.8

[1]Cultivar means at each seeding date averaged over the 4 seeding rate treatments and the 3 nitrogen treatments.

APPENDIX TABLE 4. Lodging observations during summer 1981

Treatment	Number of plots with lodging (5-9)	% of total plots with lodging
Cultivar		
Laurier	147	55.0
Loyola	85	31.8
Bruce	35	13.1
Total	267	99.9
Seeding date		
27/04	79	29.5
8/05	94	35.2
20/05	94	35.2
Total	267	99.9
Nitrogen rate (kg/ha)		
15.6	22	8.2
31.2	41	15.3
46.8	204	76.4
Total	267	99.9
Seeding rate (plants/m²)		
150	67	25.0
300	67	25.0
450	63	23.5
600	70	26.2
Total	267	99.7

APPENDIX TABLE 5. Variance ratios and F ratios used to test combined effects over 2 years for grain yield

Source of variation	d.f.	MS	Variance ratios	F ratios used for test
Blocks (R)	3			
Year (Y)	1	M1	2.84	M1/M2
Blocks/year	3	M2		
Seeding date (D)	2	M3	0.57	M3/M4
D x Y	2	M4	31.00**	M4/M5
Pooled error a	12	M5		
Nitrogen rate (N)	2	M6	1.48	M6/M7
N x Y	2	M7	5.44**	M7/M10
D x N	4	M8	11.23*	M8/M9
D x N x Y	4	M9	0.40	M9/M10
Pooled error b	36	M10		

*Significant at .05 level
**Significant at .01 level

APPENDIX TABLE 6. Variance ratios and F ratios used to test combined effects over 2 years for grains/head

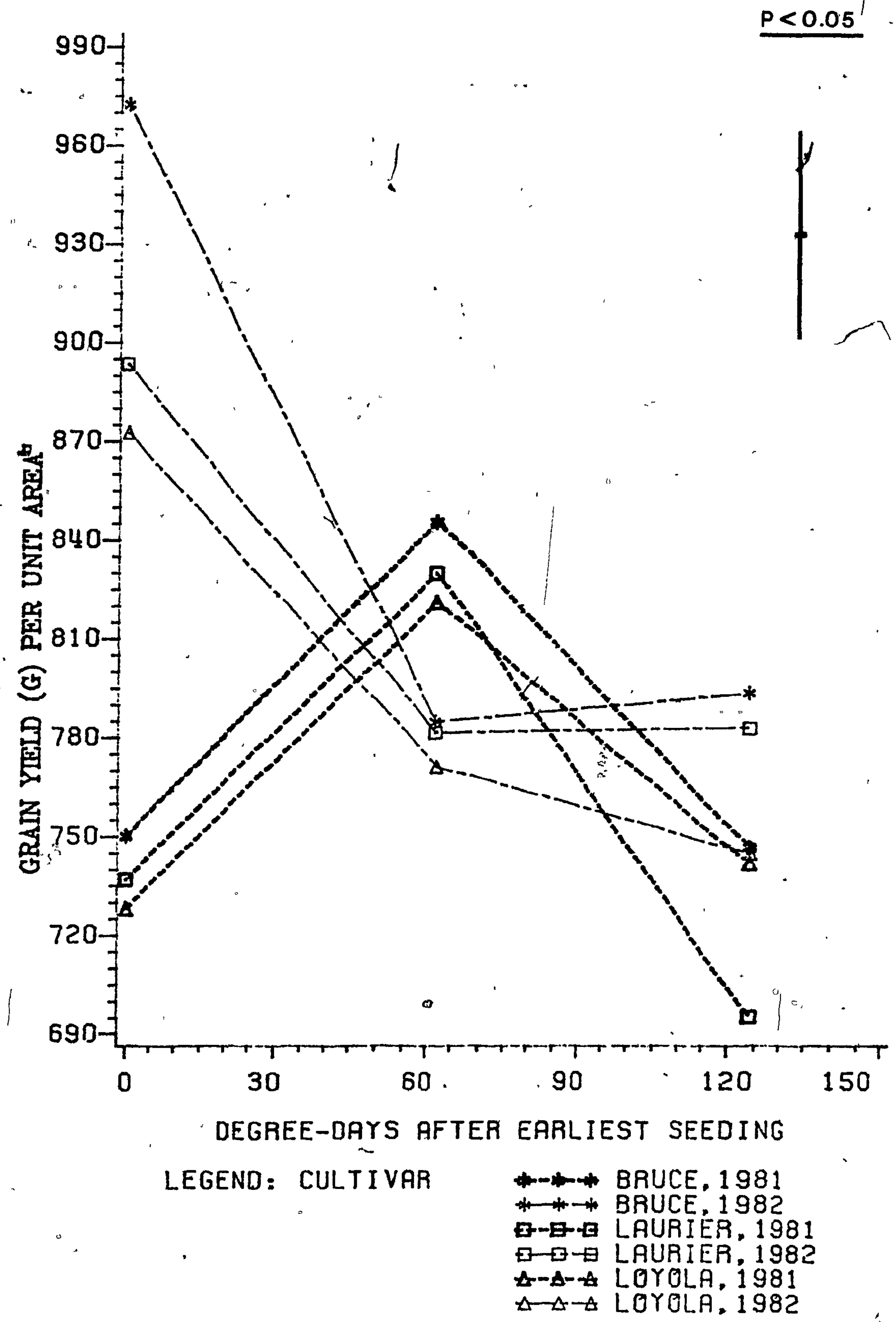
Source of variation	d.f.	MS	Variance ratios	F ratios used for test
Blocks (R)	3			
Year (Y)	1	M1	2.14	M1/M2
Blocks/year	3	M2		
Seeding date (D)	2	M3	10.29	M3/M4
D x Y	2	M4	10.11**	M4/M5
Pooled error a	12	M5		
Nitrogen rate (N)	2	M6	3.01	M6/M7
N x Y	2	M7	1.32	M7/M10
D x N	4	M8	17.25*	M8/M9
D x N x Y	4	M9	0.75	M9/M10
Pooled error b	36	M10		

*Significant at .05 level
**Significant at .01 level

APPENDIX TABLE 7. Variance ratios for analysis of variance of the different growth stages in 1982

Source of variation	d.f.	Dependent variables: Days to emergence	Days from emergence to stem elongation	Days from stem elongation to heading	Days from heading to maturity
Date of seeding (D)	2	160.86**	32.27**	19.16**	255.71**
Nitrogen rate (N)	2	0.77	0.25	0.62	0.53
D x N	4	0.49	1.34	1.01	1.39
Cultivars (C)	2	21.45**	10.22**	161.01**	107.98**
Rate of seeding (R)	3	2.54	109.57**	6.84**	64.63**
C x R	6	0.62	1.78	0.43	3.79**
D x C	4	6.44	10.79**	1.73	6.26**
D x R	6	1.40	1.54	2.32*	4.56**
N x C	4	0.35	0.60	0.47	0.61
N x R	6	0.34	0.69	0.66	0.44
D x N x C	8	0.92	0.39	0.65	0.38
D x N x R	12	0.68	1.47	1.21	0.66
D x C x R	12	1.49	2.08*	0.99	0.40
N x C x R	12	0.53	0.74	0.98	1.45
D x N x C x R	24	0.71	1.09	1.05	0.96

*Significant at .05 level
**Significant at .01 level



Appendix Figure 1. Grain yield (g/2.04 m^2) at three seeding dates for three barley cultivars in 1981 and 1982.