University of Manitoba

EFFECTS OF REDUCED PLANT HEIGHT ON BREEDING REQUIREMENTS AND AGRONOMIC BEHAVIOUR IN BARLEY, HORDEUM VULGARE, L.

by

Brian Gordon Rossnagel

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A dissertation submitted to the Faculty of Graduate Studies of the University of Manitoba in partial fulfillment of the requirements of the degree of

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ABSTRACT

Rossnagel, Brian Gordon. Ph.D., The University of Manitoba, June , 1978. Effects of Reduced Plant Height on Breeding Requirements and Agronomic Behaviour in Barley, Hordeum vulgare, L. Major Professor; Dr. S.B. Helgason.

Three barley, Hordeum vulgare, L., populations, each having one semi-dwarf parent in common, were investigated for two years at two locations. The objective was to estimate heritabilities of several agronomic parameters, their genotype by environment interactions, and their inter-relationships, with particular emphasis on plant height. Plant height was highly heritable and adversely related to all other agronomic traits except lodging. These adverse relationships, although significant, were not strong. The most serious drawbacks of reduced plant height were associations with reduced kernel size parameters and late maturity. Environmental interactions and their effects on testing procedures for all characters measured are discussed in the manuscript, as are further character interrelationships.

Three semi-dwarf and two tall genotypes were tested for response to nitrogen fertilization at three locations during two years. No genotype by fertilizer interactions

occurred for yield, but the semi-dwarfs tended to perform better under more optimum growing conditions, ie. better weed control, moisture and fertility.

One semi-dwarf and one tall genotype were tested at three locations to determine the effects of altered plant density on relative performance. Again no significant interactions occurred for yield, however, there was a tendency for the semi-dwarf to show relatively greater improvement than the tall as plant density increased. The semi-dwarf showed a negative response to adverse growing conditions.

The semi-dwarfs studied appeared to achieve yield improvements via increases in the number of spikes per unit area and kernels per spike, at the expense of kernel weight. The interrelationships of these yield components are discussed with particular reference to the semi-dwarfs, as are methods for developing high yielding semi-dwarfs with an improved balance among the yield components.

Preliminary research was conducted to determine the relationships of plant height with coleoptile length, root system size and growth rate, emergence rate and ability. Plant height was positively associated with coleoptile length. Shorter genotypes appeared to have smaller, slower growing root systems. Emergence rate and ability were not affected by reduced height. These parameters were all positively associated with kernel size.

height on these traits, in three six-rowed barley populations, each derived from a tall by semi-dwarf cross and grown in Southern Manitoba.

(2) Determine the relative association of plant height with several agronomic and quality parameters, and some of the interrelationships of these traits in these same three crosses.

(3) Evaluate these three populations and individual lines within each for several agronomic and quality characteristics.

(4) Evaluate the production potential of some selected short statured (semi-dwarf) barleys relative to tall barleys in South-Central Manitoba.

(5) Determine the response of selected semi-dwarf and tall barley genotypes to high levels of applied nitrogen fertilizer in South Central Manitoba.

(6) Evaluate the relative performance of tall and semi-dwarf genotypes when grown at various combinations of row spacing and seeding rate in South-Central Manitoba.

(7) Investigate the relationships between plant height and (a) root system size and growth parameters, (b) coleoptile length, (c) ability to, and rate of, emergence; and the interrelationships of these characteristics.

LITERATURE REVIEW

Semi-dwarf Growth Habit

The advantages of reduced plant height in several cereal crops were recognized by plant breeders and agronomists well before the discovery and introduction of dwarf and semi-dwarf germplasms. Briggle and Vogel (1968) indicated that the trend to shorter wheat cultivars in the United States began in the early 1940's. This was primarily an attempt to improve straw strength and allow more flexibility in farm management practices, especially to make better use of nitrogenous fertilizers.

The North American semi-dwarf revolution began with the release of "Gaines" wheat by Dr. O. A. Vogel in the Northwestern United States in 1961. This short strawed cultivar was developed via selection from the progeny of a cross involving a Japanese semi-dwarf wheat, "Norin 10", which had been brought to the United States by Dr. S. C. Salmon in 1946 (Reitz and Salmon, 1968). The tremendous success and exceptional yielding ability of "Gaines" drew worldwide attention.

Another widely heralded achievement was the semi-dwarf rice cultivar "IR8", released by the International Rice Research Institute in 1968 (Chandler, 1968), which led to a

new era in rice research and production. Again the purpose of the shorter straw was to allow more intensive use of farm inputs, especially nitrogen, to increase grain yields. Semi-dwarf rice varieties have led to as much as double the yields of the older standard height cultivars in some areas of Asia.

Short-strawed wheat and rice genotypes have been successful primarily due to their improved lodging resistance under conditions of both high fertility and moisture (Briggle and Vogel, 1968; Chandler, 1969). Nevertheless Briggle and Vogel (1968) indicated that the semi-dwarf wheats did have some inherent yield advantage as well.

Success with wheat and rice prompted researchers in other crops to look for a similar avenue of improvement. Mutants produced by irradiation have been the primary source of short straw in barley. Among released semi-dwarf barley varieties are "Midas" developed in the United Kingdom, offering a potential ten percent yield advantage over other varieties at the time of its release (World Crops, 1969), and "Deba Abed", a Danish variety offering greater response to nitrogenous fertilizers as compared to similarly adapted standard cultivars (Kirby, 1968).

Konishi (1976) indicated that the main barley growing areas of Japan are occupied by semi-dwarf cultivars with the "uzu" gene giving them all a semi-brachytic growth habit. The most common Japanese variety of this type is "Akashinriki".

In the United States the barley breeding project at the University of Minnesota has been the most successful in developing semi-dwarf genotypes, utilizing a semi-dwarf source produced by irradiation of the Norwegian cultivar "Jotun" at the Norwegian College of Agriculture, Vollebelsk, Norway.

This project has registered M21 and M22, two germplasms with good agronomic performance and adapted to the mid-western and northern barley growing areas of the United States (Rasmusson et al., 1973).

This same source of short straw has been utilized to develop types adapted to the Canadian prairies by the barley project group at the University of Saskatchewan in Saskatoon. Germplasm from both these institutions is being utilized at several locations throughout North America.

Heritability and Selection

The plant breeder is faced with the task of exploiting the available genetic variability and avoiding or modifying undesirable character associations in order to develop a genotype which has some advantage over presently available ones and is both agronomically and commercially acceptable. To exploit the available variability one must impose some type of selection. Since most agronomically important characters are quantitatively inherited, and therefore greatly influenced by environmental conditions (Fiuzat and Atkins, 1953), one needs a measurement to determine the

extent to which the observed variability is heritable and therefore selectable. Such a measurement is termed heritability, and, in the broad sense, is measured by the ratio of the genetic variability to the environmental variability (Allard, 1960). This measurement gives the breeder an indication of the method of selection most likely to succeed, the selection intensity required in various generations and the generation during which selection is most likely to be effective.

Heritability estimates for yield and other plant characters have been calculated in several crops (Fiuzat and Atkins, 1953). In general, characteristics such as maturity and plant height have been reported to be highly heritable, while yield and its related components have been low in heritability. It should be noted that heritability estimates in self-pollinated crops are dependant on: (1) the generation in which they are measured, since with increased homozygosity, the non-heritable (dominant) fraction of the genetic variance is decreased in comparison to the additive (heritable) fraction (Grafius et al., 1952); (2) the amount of genetic variability in the material studied, and (3) the method used to calculate the genetic variance and thus the heritability estimate (Frey and Horner, 1955).

Various investigators have reported heritability estimates for several characteristics in barley (Table 1). Heritability estimates have generally been high for plant

Table 1. Broad Sense Heritability Estimates for Agronomic Characteristics in Barley.

Investigators	Characteristics								
	Plant Height	Yield	Test Weight	Kernel Weight	%Plump Kernels	Heading Date	Days to Maturity	Lodging	Kernels per Head
Borthakur(1970)				43-46					
Bray(1963)	40								97
Briggs(1974)					low				
Crook & Poehlman (1971)				71	89				
Duwayri(1974)	int-high	low			high	high	int-high	int.	
*Fiuzat & Atkins (1953) I**	75	51		39		92	86		
II.	44	44		21		91	87		
Frey & Horner (1955) I.	75	59	78			94			
II.	68		60			83			
Jogi(1956) I.	77	61	96			90		77	
II.	64	64	81			96		40	
III.	59	60	91					83	
Manzjuk & Barsukov (1974)	74			79		83			31
*Nasr et al.(1972)	50	37	58		74			47	
Rasmusson & Glass (1967) I.	73	65			65	74			
II.	73	57			63	90			
Rutger et al.(1966)	75	48	71	89	90	49		67	
Jain & Chandra (1970)		high		high					high
Sethi et al.(1972)	high	high		high		high			
Szirtes(1972)				69	54				

* Study contained tall x semi-dwarf crosses.

** Roman numerals indicate different hybrid populations investigated.

height, days to heading and days to maturity; intermediate to high for test weight and lodging; and low to intermediate for yield. The estimates for kernel weight, number of kernels per spike, and plumpness, have been more variable, but generally have been intermediate to high.

Heritabilities for quality factors have not been extensively investigated. However, diastatic power or saccharifying activity and levels of ∝-amylase appear to be highly heritable, while barley nitrogen seems to be quite variable and in general low in heritability.

Two studies referred to in Table 1 (Fiuzat and Atkins, 1953; and Nasr et al., 1972) considered crosses involving short and tall genotypes. The heritabilities reported for this material did not deviate greatly from those reported for normal height by normal height hybrids.

Table 2 contains heritability estimates reported by several investigators from experiments involving tall x semi-dwarf wheat crosses. These heritability estimates do not differ from those reported for other crops nor from tall x tall wheat crosses, indicating that shortened straw had little or no effect on transmission of other characters. One exception to this is the very low heritability for days to maturity reported by Dyck and Baker (1975). The selection of agronomically desirable high yielding semi-dwarfs in numerous wheat breeding programs around the world (Morrison and Campbell, 1969) substantiates the conclusion that shorter culm length does not affect the heritability

Table 2. Broad Sense Heritability Estimates for Agronomic Characteristics in Tall x Semi-dwarf Wheat Crosses.

Investigators		Characteristics							
		Plant Height	Yield	Test Weight	Kernel Weight	Percent Plumpness	Heading Date	Days to Maturity	Lodging	Kernels per Spike
Anwar & Chowdhry (1969)	I*	63	61				57			
	II.	66	70				64			
	III.	50	61				62			
	IV.	65	64				60			
Bhatt (1972)	I.	77			89		85			
	II.	80			77		74			
Dyck & Baker (1975)	I.		60		77			30		
	II.		46		76			38		
Fonseca & Patterson (1968)		high	low-int.		low-int.			high		high
Johnson et. al. (1966)		61			61		81			
Panigrahi (1962)		71-90					83-87			
Reddi et. al. (1969)	I.	63			48					
	II.	51			15					

* Roman numerals indicate different hybrid populations studied.

of other characteristics in wheat.

Correlations

Altering an existing character, or bringing a new one into a breeding population immediately raises the question of how it will affect other important characteristics. Will there be any undesirable character associations? Reduced plant height is such a parameter and many investigators have reported its relationship to several agronomic and quality characteristics.

Plant height has been positively associated with yield in barley (Fiuzat and Atkins, 1953; Sharma, 1970; Duwayri, 1974 and Konishi, 1976), in wheat (Johnson et al., 1966(a), Shahs, 1967; Fonseca and Patterson, 1968; Borojevic, 1968; Kaufmann et al., 1969; Barriga, 1974; Dyck and Baker, 1975), and in oats (Wallace et al, 1954; Petr, 1959). Kiesselbach et al., (1953), and Rutger et al., (1967), both reported no association in barley as did Pepe and Heiner (1975) with wheat. Nasr et al. (1973) reported no correlation between height and yield in six of seven barley crosses, and a positive relationship in the other cross. In wheat, Hamblin and Donald (1974) reported a positive association in material at F_3, but found no relationship in the same material at F_5 under high nitrogen conditions. In fact the correlation was negative but not significant.

McNeal et al. (1974) working with improved adapted semi-dwarf wheats reported a negative correlation of plant height

with yield. This group discussed the importance of the influence of genotypic selection in correlation studies, indicating that the genotypes studied may bias correlation data. In the barley work referred to, the study of Nasr et al., (1973) involved tall x short-strawed crosses, and the short genotypes were relatively unimproved and unadapted. Konishi's study (Konishi, 1976) involved several Japanese short statured types and a normal strain of barley. He noted that the very short types were inferior while the "not so short" types were not inferior to the normal. Konishi stated, "For increasing total production of a dwarf mutant, it is necessary to have long stems to some extent, and so improve the form for light interception of the plant." Konishi noted that similar results had been reported for rice by Kawai (1963) in that all dwarf rice mutants which had stems shorter than 85 percent of the original variety showed decreased yield.

"Perhaps the most outstanding character of semi-dwarf wheats is resistance to lodging.", (Briggle and Vogel, 1968). This positive relation between shorter straw and reduced lodging in wheat has been supported by many observations. This led to a statement by Klatt (1973), to the effect that, prior to 1962, plant height and straw weakness had limited the yield potential of wheat, which was significantly increased by the first semi-dwarf varieties.

Chandler (1969) stated that, in rice, the most important single morphological feature affecting lodging resistance is

plant height, and that lodging decreased rice yield. The exceptional yield of "IR8" rice demonstrated the value of shorter straw in reducing lodging and thereby allowing increased yield, especially under growing conditions approaching the optimum.

Lodging is a problem in barley (CIMMYT Review, 1976), and can cause large reductions in yield and its components (Sisler and Olsen, 1951). Short straw has been associated with reduced lodging by Duwayri (1974), Konishi (1976); and Nasr et al. (1973) in two of seven crosses involving short and tall genotypes. The latter reported no relationship in the remaining five crosses studied. Rutger et al. (1967) likewise reported no significant relationship.

Yield components have been much investigated in agricultural crops (Adams, 1967). The yield components in cereals; heads per unit area, seeds per spike, and seed weight, have been studied most notably by Grafius and his co-workers since 1956 (Grafius, 1956), and Frey and his associates since 1962 (Frey, 1962). Since yield components are often used as units of selection, the effect of morphological changes, such as reduced plant height, on these components is of importance.

The relationship between plant height and number of heads per unit area has been investigated in the wheats. Lebsock and Amaya (1969) reported a positive relationship in one of four durum wheat crosses. Johnson et al. (1966(b)) and Fonseca and Patterson (1968) reported a positive relation-

ship in common wheat. On the other hand, McNeal et al., (1974) in studies using adapted short strawed and normal height wheats, reported a negative correlation as did Rutger et al. (1967) in a barley study. Konishi (1976) indicated all the short types he studied had as many, or slightly fewer, spikes than the normal strain.

It should be noted that the number of heads per unit area is much affected by the environment, as evidenced by its low heritability estimates (Rutger et al., 1966; Lebsock and Amaya, 1969). Since seeding rates can be easily manipulated to give variation in this component, many workers have acknowledged its importance but have chosen not to relate it to other characteristics.

Kernels per spike is the yield component with which the semi-dwarf plant types have had the least problem; probably since the material used to introduce the short culm was selected with this in mind. Rasmusson (1973) noted that the semi-dwarf mutant stock used in the Minnesota barley program had "normal spike length". Syme (1972) indicated that the semi-dwarf wheats had more kernels per spike than the talls, as did Johnson et al. (1966 (b)). Syme (1972) stated that his studies in wheat indicated there was not necessarily a direct association of kernels per spike and plant height. Other reports in wheat concur: Fonseca and Patterson (1968), Lebsock and Amaya (1969). However, Barriga (1964) indicated a positive relationship whereas the report by McNeal et al. (1974) showed a negative relationship between plant height

and kernels per spike.

Inconsistent relationships between kernel weight and plant height have been reported. A positive association has been reported in barley (Fiuzat and Atkins, 1953 and Konishi, 1976) and in wheat by several workers (Johnson et al. 1966a; Shahs, 1969; Kaufmann et al., 1969; Reddi et al., 1969). Two investigations (Fonseca and Patterson, 1968; Lebsock and Amaya, 1969) indicated a positive relationship in some wheat and durum wheat crosses, and no relationship in others, while Wallace et al. (1954) reported no association in oats, as did Crook and Poehlman (1971) in results from a barley experiment.

Konishi (1976) reported that the shorter barleys he worked with were generally inferior to the normal cultivars for grain weight per spike, but, his better semi-dwarfs had the same or slightly better grain weight per spike than the normal. High grain weight per spike results from a combination of large numbers of kernels per spike and high kernel weight.

The relationship of yield and its components with plant height is not consistent. Depending on the genotypes involved in the study and the environment in which the research was conducted, various researchers have arrived at different conclusions. McNeal et al. (1974) stated, "these data suggest that genotype determines the relationship of plant height to grain yield and yield components, as might be expected when semi-dwarf and conventional height types are

compared".

Two other important agronomic characteristics are the number of days to heading and the number of days to maturity. Barker (1964), working with barley, reported a positive correlation of plant height with number of days to heading, while Rutger et al. (1967) indicated they found no relationship between these characteristics. Konishi (1976) indicated that the dwarfing genes involved in his study retarded heading. In wheat both positive (Fonseca and Patterson, 1968; Dyck and Baker, 1975) and negative (Johnson et al., 1966(a)) relationships have been reported.

Plant height and maturity have been reported as positively associated in wheat (Johnson et al. 1966(a); Kaufmann et al., 1969), while Lebsock and Amaya (1969) reported a positive correlation in two of four crosses and no relationship in the others. Fiuzat and Atkins (1953) reported a negative association between plant height and maturity in barley.

Morphological changes may also lead to changes in quality characteristics which are important in terms of utilization and commercial acceptability. Test weight and percent plump kernels are important characteristics in barley in terms of feeding and malting quality. Nasr et al. (1973) indicated a positive correlation of height with percent plumpness existed in four of seven crosses and the same for height and test weight in two of the seven crosses. No significant associations were noted in the remaining

crosses. Rutger et al. (1967) also indicated positive relationships for these characters and plant height. Both groups reported highly significant positive correlations between test weight and percent plumpness as did Crook and Poehlman (1971). However, Crook and Poehlman (1971) reported no significant relationships between plant height and these characteristics.

Rutger, et al., (1967) reported a positive correlation between plant height and level of ∝-amylase, but no association between height and diastatic power.

The relationship of protein and plant height has not been reported in barley. However, Kaufmann et al. (1969) and Pepe and Heiner (1975), reported no effect of plant height on the protein content of wheat.

The interrelationships of the yield components and their association with yield are of importance to the plant breeder (Grafius, 1956). Quisenberry (1928) indicated the number of spikes per unit area was the most important factor in determining cereal yield, closely followed by the number of kernels per spike, with kernel weight the least important of the three components. This general statement has been supported by research to the present time.

Yield has been reported to be positively correlated to the number of spikes per unit area in wheat by several authors (Fonseca and Patterson, 1968; Lebsock and Amaya, 1969; Hsu and Walton, 1970; McNeal et al., 1974), and in barley by Fiuzat and Atkins (1953). Rutger et al. (1967)

reported a non-significant positive correlation between these parameters in a barley study.

Number of kernels per spike has been reported as positively associated with yield in barley (Jain and Chandra, 1968; Yap and Harvey, 1972; Ruzicka, 1973; Manzjuk and Barsukov, 1974) and in wheat (Fonseca and Patterson, 1968; Hsu and Walton, 1970). Rasmusson and Cannell (1970) reported both positive correlations and non-significant associations in barley, as did Lebsock and Amaya (1969) and McNeal et al. (1974) in wheat. It has also been noted that the number of kernels per spike is the yield component by which the semi-dwarf wheats primarily have achieved their increased yields (Johnson et al., 1966 (b); Syme, 1969).

Kernel weight is the yield component which has been reported to be negatively associated with yield of barley, although this was the case in only one report (Grafius and Okoli, 1974). In general, kernel weight has been positively correlated with yield in wheat (Fonseca and Patterson, 1968; Hsu and Walton, 1970), and in barley (DenHartog and Lambert, 1953; Jain, 1968; Rasmusson and Cannell, 1970; Sharma, 1970; Yap and Harvey, 1972; Manzjuk and Barsukov, 1974). Hsi and Lambert (1954) reported both positive and non-significant associations in barley as did Lebsock and Amaya (1969) in wheat. Hayter and Riggs (1973) reported no significant correlation of kernel weight with yield in barley. The lesser importance of kernel weight as a yield component is exemplified by the number of times a non-significant

relationship of it with yield has been reported as compared to the other components in which the association is generally positive.

"The occurrence of negative correlations among morphological components of yield in crop plants is a widespread phenomenon", (Adams, 1967). Such negative yield component interrelationships have been reported in barley (Fiuzat and Atkins, 1953; Rasmusson and Cannell, 1970; Ruzicka, 1973; Grafius and Okoli, 1974) as well as in wheat (Fonseca and Patterson, 1968; Lebsock and Amaya, 1969; Hsu and Walton, 1970; McNeal et al, 1974). Fonseca and Patterson (1968) reported a positive correlation between number of spikes per unit area and kernel weight; however, further analysis using path coeffients indicated that this relationship was negative.

Several agronomic studies with small grains have brought out the complex interrelationships of yield and its components with the environment. It was shown that as yield was altered by an environmental change, say increased nitrogen supply, the yield components also changed in that an increase or decrease in specific components might be compensated for by balancing decreases or increases in the other components.

Published results of wheat studies by Easton and Clements (1973) and Gardner and Jackson (1976) indicated that yield increases were due to increased spikes per unit area and kernels per spike, but kernel weight decreased. Frey's (1959) research in oats and Stanberry and Lowrey's (1965) studies in barley produced similar results. A

majority of studies have reported that yield increases were due primarily to increased number of spikes per unit area accompanied by either no change or a decrease in one or both of the other yield components. Such was the case reported by Guitard et al. (1961) in wheat, oats and barley. Reported results of Woodward (1966) and Dubetz and Bole (1973) in wheat; Foth et al. (1964) in oats; and Kirby (1968), Willey and Holliday (1971), and Gardener and Rathjen (1975) in barley are in general agreement with the findings of Guitard.

Other important agronomic character associations in barley have been reported in the literature. Hsi and Lambert (1954) reported a negative correlation between yield and number of days to heading, while Rutger et al. (1967) reported no significant relationship. Fiuzat and Atkins (1953) reported a negative association of yield and maturity in one of two barley crosses.

Yield was reported to be positively correlated with percent plumpness and test weight in barley by Rutger et al. (1967) and Nasr et al. (1973), although the latter found no relationship in some crosses investigated. DenHartog and Lambert (1953) also reported positive yield-test weight correlations in barley.

Yield-quality factor correlations in barley have also been reported. Yield and grain protein have been reported as negatively related (DenHartog and Lambert, 1953; Hsi and Lambert, 1954; Johnston and Aksel, 1964; Hayter and Riggs,

1973). DenHartog and Lambert (1953) and Rutger et al (1967) reported negative correlations of yield and diastatic power, while the latter indicated no association between yield and level of alpha-amylase.

Crook and Poehlman (1971) reported a positive correlation between percent plumpness and kernel weight. Test weight was reported to be positively correlated with kernel weight (DenHartog and Lambert, 1953; Hsi and Lambert, 1954). Rutger, et al. (1967) reported a negative association of a percent plumpness with diastatic power and a positive association with increased lodging resistance in barley.

Johnson and Aksel (1964) reported a positive correlation between protein and earliness.

The interrelationships of some of the quality factors have also been investigated. Protein was reported to be positively related to kernel weight (Metcalfe et al., 1967; Hayter and Riggs, 1973). DenHartog and Lambert (1953) and Hsi and Lambert (1954) indicated no significant correlation of protein level with diastatic power. Metcalfe et al. (1967) reported a positive correlation between protein and saccharifying activity. Hayter and Riggs (1973) reported no association between protein and levels of alpha-amylase.

Diastatic power has shown inconsistent correlations with kernel weight. Hsi and Lambert (1954) reported no correlation, Metcalfe et al. (1967) indicated a positive relation, and DenHartog and Lambert (1953) reported a negative correlation. Rutger et al. (1967) reported a positive

correlation between diastatic power and alpha-amylase levels as did Hayter and Riggs (1973).

Response to Nitrogen Fertilization

The use of nitrogenous fertilizers for increased cereal production has been carried out unknowingly since man changed from nomadic to village agriculture and began to grow crops repetitively on the same land. The return of manure, bones, ashes and crop residue to the soil constituted the use of fertilizer. Slack (1970) indicated that primitive fertilization of the soil began as early as 900 B.C. The value of legumes being grown before cereals was noted before the birth of Christ.

The "fertilizer industry" began in the 1800's with the use of potassium-nitrate mined primarily in Chile (Slack, 1970). It was used as a nitrogen source around the world until the production of fertilizers, as we know it today, began after World War II. Nitrogen was, and still is, the primary element required and utilized as fertilizer.

The effect of nitrogen fertilizer on grain yields is clearly demonstrated by corn yield data from North Carolina. Corn yields there moved progressively from 1800-2000 kg./ha. in 1945 to 3600-3800 kg./ha. in 1968, accompanied by a progressive increase in the application of nitrogen fertilizer of 24 kg./ha. in 1945 to 84 kg./ha. in 1968 (Cummings and Gleason, 1971). A similar relationship has developed in the other cereals as well.

With this increased use of nitrogenous fertilizers, agronomists and plant breeders have begun to search for genotypes which will give better response to these inputs. The cereal varieties of the 1950's and early 1960's gave dependable yield increases only at the lower levels of nitrogen application (Cummings and Gleason, 1971) since they lodged with greater fertilizer inputs. These authors stated, "the achievement of larger increases in yield requires the development of new plant types, with short height, stiff straw, and semi-erect leaves which would be able to stand upright even at higher levels of nitrogen and which would be able to capture and use the full sunlight with maximum efficiency even in dense stands".

Pendleton et al., (1953) and Chandler (1969), working with barley and rice respectively, indicated that with the standard tall cultivars the effectiveness of high levels of nitrogenous fertilizers was limited due to lodging. A large part of the success of the semi-dwarf wheats and rices has been due to their improved lodging resistance and therefore their ability to produce more grain under more fertile conditions (Briggle and Vogel, 1968; Chandler, 1969). Chandler (1969) stated "Culm length is the most important single factor affecting lodging resistance and nitrogen responsiveness.".

Fertilizer by genotype interactions have been investigated in various crops. Interactions have occured even when the genotypes studied did not differ morphologically to any

extent. Frey et al. (1951) indicated that corn varieties were recommended on the basis of soil fertility as early as 1922. In terms of fertilizer x genotype interaction, their literature review shows that fertilizer responsiveness, in particular to nitrogen, had been investigated in wheat, oats and barley with both positive and negative results.

Several studies since 1951 have indicated varying results. Working with wheat, Beutler and Foote (1963) and Syme et al. (1976) reported significant fertilizer x variety interactions, as did Pendleton et al. (1953), Woodward (1956), and Gardener and Rathgen (1975) working with barley. Others reported no fertilizer x variety interaction in wheat studies (Rhode, 1967; Bauer, 1970; McNeal et al. 1971) and in barley tests (Kirby, 1968). Kirby (1968) indicated that he did not uncover any interaction probably due to a second limiting element in the soil. Syme (1967), working with wheat, also reported no significant interaction, but suggested this was due to soil problems, in this case poor water infiltration.

It is apparent that the discovery of a fertilizer x genotype interaction is dependent on the range of genotypes included in the study and the levels of several other environmental factors, especially moisture. Stanberry and Lowrey (1965) reported that nitrogen gave a 600% increase in mean yield over all moisture levels used, while increased moisture over all nitrogen levels gave a 36% yield increase. However, the combination of high nitrogen and adequate available moisture gave a mean yield increase of more than 1700%.

Their results were from a barley trial, but similar reactions have been reported with the other cereals (Porter et al., 1964).

Frey et al. (1951) concluded, "in general, crops in which one variety has a small area of adaptation (such as corn) tend to show a significant variety by fertility level interaction, while those crops in which any one variety has a large area of production (such as oats) do not show significant variety by fertility level interactions." Wheat and barley would be in this latter category. At the time of this statement not nearly as much breeding work had been done in wheat and barley, there were not as large a number of varieties as there are at present, and the semi-dwarfs had not yet become important or available.

The introduction and use of semi-dwarf genotypes has led to a renewal of interest in the ability of individual genotypes to respond to increased levels of nitrogen fertility. As already mentioned Briggle and Vogel (1968) and Chandler (1969) have indicated that their short statured wheat and rice cultivars do respond better to higher rates of nitrogen than older standard height types, primarily due to lodging resistance. However, Briggle and Vogel (1968) indicated there was also some inherent yield advantage, and Beech and Norman, (1968) indicated that the semi-dwarf wheats showed a greater yield response to applied nitrogen in their studies in Australia.

Other workers have investigated the response of the

semi-dwarf wheats to nitrogen fertilizers. All researchers have reported significant yield increases with increased nitrogen inputs up to a certain level, with the improved and adapted semi-dwarfs yielding more than tall cultivars at all but the lowest nitrogen levels. This has especially been the case under conditions of adequate moisture, whether by irrigation or precipitation (Porter et al., 1964; Tuohey, 1973). Studies by Beutler and Foote (1963) and Woodward (1966) gave results indicating a significant interaction of genotype and fertility while Porter et al., (1964), Syme (1967), and McNeal et al. (1971), although reporting equal or greater yields for the semi-dwarfs, reported no significant interaction. Porter et al. (1964) suggested that the semi-dwarfs may be more suitable for high production levels. This was supported by Syme (1967).

Gardener and Rathjen (1975) stated with reference to barley: "the variation in yield response to nitrogen is remarkable" and "there is great scope for selecting cultivars suited to particular nitrogen levels.".

Konishi (1976) reported a fertilizer response study with short-statured barley and indicated that a fertilizer by genotype interaction occurred. The study encompassed eight different Japanese dwarf and semi-dwarf strains and one normal cultivar of barley. The interaction occurred because one of the short statured genotypes and the normal genotype showed a decreased yield at the highest fertility level while the other seven short genotypes showed a yield

increase. The amount of this increase also varied between these seven genotypes.

The effects of increased nitrogen fertility on the components of yield and other agronomic characteristics have been studied extensively in the cereals. Gardener and Jackson (1976), working with wheat, reported that the main effects of increased nitrogen on grain yield components were increased number of spikes per unit area, increased number of seeds per spike and decreased weight per individual seed. Rohde (1963) reviewed the findings reported prior to 1963 and reported the same general findings except, most workers had found either no change or an increase in kernel weight as nitrogen increased. This was due to the fact that the work prior to 1963 was done at relatively low levels of applied nitrogen. Since 1963 other reports (Porter et al., 1964; Woodward, 1966; Syme, 1967; McNeal et al., 1971; Easton and Clements, 1973) have agreed with Gardener and Jackson's statement, except that Woodward reported no change in kernel weight and Syme reported an increase in this character, as amount of nitrogen applied increased.

Frey's (1959) classical yield component study in oats also indicated that as yield increased there was an increase in kernels per spike, accompanied by decreased kernel weight. He concluded that seed weight was an insignificant variable in causing yield response to nitrogen.

In barley-fertilizer rate studies the results have been variable. Stanberry and Lowrey (1965) reported increased

number of spikes as nitrogen increased. Schreiber and Stanberry (1963) indicated that nitrogen applied at planting gave increased kernels per spike and kernel weight but lowered the number of spikes per plant. This was probably offset by increasing the number of plants and thereby effectively giving more spikes per unit area. Gardener and Rathjen (1975) reported that variation in cultivar yields with nitrogen was due to variation in ear numbers, while grain weight per ear remained constant, since changes in kernels per spike and kernel weight were of opposite magnitudes and compensated for each other. They indicated that, in general, kernels per spike increased and kernel weight dropped as nitrogen increased. Reisenauer and Dickson (1961) also reported a lower weight per kernel as nitrogen level increased.

Konishi (1976) reported that fertilization resulted in an increased number of spikes for all genotypes, but at the higher levels of fertilizer, genotypes responded differently. He also reported that the response of grain weight per spike to fertilization was variable with some genotypes responding positively and others negatively.

Konishi's final conclusion regarding the higher yielding dwarf mutants was; "the increased grain yield of dwarf mutants by heavy fertilizer application is principally due to the increase (or not decrease) in the grain weight per spike, but not by the number of spikes" (Konishi, 1976).

Increasing nitrogen fertilizer application has generally

given rise to increased nitrogen in the grain, particularly at higher levels of applied nitrogen in barley (Reisenauer and Dickson, 1961; Kirby, 1968; Gardener and Rathjen, 1975), and in wheat (Woodward, 1966; Syme, 1967; McNeal et al., 1971; Dubetz, 1972; Gardener and Jackson, 1976; Syme et al., 1976). The first increments of nitrogen fertilizer tend to give larger yield increases with a small increase in grain nitrogen content while further increases of nitrogen tend to give a reverse effect (Syme, 1967).

Plant height increases with addition of nitrogen in both tall and semi-dwarf varieties (Pendleton et al., 1953; Rohde, 1963; Woodward, 1966; McNeal et al., 1971). However, Chandler (1969) pointed out that in the nitrogen responsive semi-dwarf rice varieties the internode elongation due to nitrogen fertilizer is relatively less than that in the non-responsive tall types. Konishi (1976) indicated that all genotypes he studied responded similarly for culm length as fertilizer increased.

McNeal and Davis (1954) and McNeal et al. (1971) reported no effect of nitrogen application on test weight in wheat, while Rohde (1963), working at low rates of applied nitrogen, reported an increase in test weight as nitrogen level increased. In a barley study, Reisenauer and Dickson (1960) reported that the first 40-pound-per-acre increment of nitrogen gave an increase in kernel plumpness, while the next two 40-pound increments resulted in decreased kernel plumpness.

Stanberry and Lowrey (1965) reported that nitrogen fertilized barley headed earlier than non-fertilized at Yuma, Arizona, at the same time indicating that these results were opposite to those reported for the Mid-West and Eastern U.S.A.. In spring wheat grown in Montana, McNeal and Davis (1954) reported a delay in heading due to nitrogen in a wheat study.

In a barley quality study Reisenauer and Dickson (1961) demonstrated that diastatic power and alpha-amylase levels increased with increasing nitrogen application in accordance with a previous report (Atkins et al., 1955). They also concluded that the best quality malting barley was produced at low yield levels.

Row Spacing in Cereals

In an extensive review of research on the effect of row width on cereal yield Holliday (1963) concluded; "At constant seed rate, decreasing the row width below 7 to 8 inches (17.9 to 20.3 cm.) has, in most cases, led to a small increase in cereal yield. This has been of the order of 5 to 7%. Conversely, increasing the row width above the standard has in most cases given some decrease in yield." He also concluded, "There is evidence that the yield advantages of narrow rows are more pronounced at seed rates both below and above the normal. The falling off of yield at wide rows is more pronounced at high seed rates.". The work Holliday reviewed was carried out with standard height material.

Holliday's conclusions have generally been borne out by results obtained since his review by Baldwin (1963), Siemens (1963), and Clark, (1975) working with wheat, oats and barley. In barley studies Austenson and Larter (1969) reported similar results, as did Stickler and Younis (1966) in sorghum work; Fothe et al. (1964) in oat studies; and Koleva (1963), Furrer (1964), Stoskopf (1967), Csefalvai (1968), Furrer and Stauffer (1972), and Briggs (1975) in wheat experiments. Other reports indicated no effect of row-spacings on yield in cereals (Wichens, 1968), in wheat (Fischer et al., 1976), and in barley (Middleton et al., 1964), while Young and Bauer (1973) working with wheat reported no significant effect except where weed competition was a confounding factor giving narrow row spacings an advantage. Finlay et al. (1971) and Foth et al. (1964) concluded that the effect of row spacing was dependent on environment in that it is expressed only when conditions are favourable for crop growth.

Also of importance is the effect of genotype by row-spacing interaction on yield. This is particularly the case with novel germplasm which gives a different morphological plant type. Such interactions have been reported in the cereals (Harrington, 1941), in barley (Finlay et al., 1971), in wheat (Stoskopf, 1967) and in rice (Owen, 1968). Some researchers reported no interaction even when spacings did affect yield (Briggs, 1975).

Several researchers felt that the semi-dwarf character

might be of great significance in row-spacing effects, and research has been carried out on row-spacing by genotype interaction for yield involving genotypes differing in plant height. Working with rice, Owen (1968) reported that a semi-dwarf variety responded to narrow row spacing with greater yields while a tall cultivar did not. Stickler and Younis (1966) report a similar result with sorghum. Stoskopf (1967) reported no significant interaction in a wheat study, but there was a trend for the short-strawed high-yielders to yield more at narrow spacings.

Finlay et al. (1971) in their barley work, noted that the higher yielding cultivars displayed a greater response to narrower row spacing than did the lower yielders.

The effects of row spacing on yield components have been investigated. Decreased row spacing has been reported to give more spikes per unit area in barley (Middleton et al., 1964; Finlay et al., 1971; Ahmed, 1970), and more panicles per unit area in oats (Foth et al., 1964) and in rice (Owen, 1968). Narrower rows have been reported to decrease the number of kernels per spike or panicle (Owen, 1968; Finlay et al., 1971) while Foth et al. (1964), Middleton et al., (1964), and Csefalvai (1968) reported an increase as row spacing decreased. The above authors reported little, if any, effect of inter-row width on kernel weight.

Finlay et al., (1971) reported earlier heading of barley at narrow row spacings in one of two years. Briggs (1975) reported a trend toward earlier maturity in wheat at

narrow row spacings. Clark (1975) reported no improvement in lodging resistance at wider row spacings. Siemens (1963) reported no effect of row spacing on test weight in barley.

Young and Bauer (1973), in a wheat study, found no change in protein with row spacing, except where weeds were present; then protein decreased as row space increased. Contrary to this, Siemens (1963) reported increased protein in wheat and barley as row spacing increased. Foth et al., (1964) reported no relationship between the percentage of nitrogen, phosphorous and potassium in the plant tissue, and distances between rows of oats.

Seeding Rate in Cereals

Seeding rate studies in cereals prior to 1960 were extensively reviewed by Holliday (1960). He concluded that there is an optimum seeding rate for each crop in each environmental zone, and the higher the yield potential the higher the optima. He regards "the yield per unit area as being composed of the number of plants per unit area multiplied by the yield per plant, the latter decreasing with increasing plant density."

Kirby (1967) noted that "Grain yield reaches a maximum with increasing (plant) density, after which a further increase in density leads to a fall in grain yield.". This drop in yield would be due to a greater drop in yield per plant than could be offset by the increased number of plants.

A number of workers reported no effect on grain yield

from varying seeding rates in barley (Middleton et al., 1964; Bockstaele and Maddens, 1966; Finlay et al., 1971), in oats (Jones and Hayes, 1967) Folkins and Kaufmann, 1974), or in wheat (El-Hattab et al., 1970; Furrer and Stauffer, 1970; Fischer et al., 1976). Woodward (1956) reported the same results working with all three cereals. These results as such were due to either the experiment covering only a narrow range of seeding rates or compensation among yield components.

Guitard et al. (1961) reported a linear increase in yield up to an optimum seeding rate in wheat, oats and barley, with a significant decrease in wheat and barley yields at very high seeding rates. Briggs (1975) also reported an increased wheat yield with increased seeding rate over the range of rates used (33.6 to 100.9 kg./ha.). Kirby (1967) reported lower barley yields at very high plant densities. McFadden (1970) reported an optimum seeding rate for two barley cultivars, both above and below which yields dropped. Similar results have been reported by Woodward (1956) and Willey and Holliday (1971). Young and Bauer (1971) reported a significant yield increase when they doubled the seeding rate in a barley trial; however, the original rate was a relatively low one. Zeidan (1974) reported a significant yield decrease in wheat at higher plant densities.

On the other hand, Pelton (1969), working with wheat in the dry area of south-western Saskatchewan, reported that

lower seeding rates gave higher yields when weeds and insects were controlled, especially in years with severe moisture stress. He used seeding rates ranging from 22 to 101 kg./ha. He noted that plant survival and tillering made up for low rates, and overall there were no differences in the number of mature kernels per unit area.

Some investigations have revealed cultivar by seeding rate interactions for yield. In reporting on a seeding rate and row spacing wheat study Briggs (1975) stated, "In view of the differences in cultivar response to seeding rates for the important agronomic characteristics studied here, it is suggested that all newly licensed cultivars of wheat should be subjected to this type of test, particularly if they are of a novel germplasm type.". Such would be the case with semi-dwarf genotypes.

Cultivar by seeding rate interactions for yield have been reported for barley (Demirlicakmak et al., 1963), for sorghum (Stickler and Younis, 1966), and wheat (Malik, 1969; Zeidan, 1974). The sorghum and wheat studies involved tall and semi-dwarf genotypes and the interaction was due to shorter genotypes performing better than talls at greater plant densities. Other reports (Guitard et al., 1961; McFadden, 1970; Clements et al., 1974; Briggs, 1975; Fischer et al., 1976) indicated no interaction. Two of these studies involved short stature genotypes, one exclusively (Fischer et al., 1976) and one a range of tall and short genotypes (Clements et al., 1974).

Reports on the effect of seeding rate on the yield components have indicated that increasing seeding rate gave rise to increased number of plants per unit area, and fewer spikes per plant, associated with decreased numbers of kernels per spike and weight per kernel (Guitard et al., 1961). Increased seed rates gave increased number of spikes per unit area by the increased number of plants being greater than losses due to fewer spikes per plant. Results from work with barley by Bockstaele and Maddens (1966), Kirby (1967), Day and Thompson (1970), and Willey and Holliday (1971); work with wheat by Malik (1969), Zeidan (1974), and Fischer et al. (1976); and work with oats by Jones and Hayes (1967 and 1968); are essentially in agreement with Guitard et al. Middleton et al. (1964), working with barley, found the same with the exception of no change in kernel weight over densities. Briggs (1975) also reported no effect of densities on kernel weight in wheat, while Woodward (1956) reported increased seeding rates gave smaller spikes and smaller kernels. Yield reductions at above-optimum seeding rates are due to continuing decreases in kernels per spike and kernel weight with no further increase in spikes per unit area to compensate for the losses in the other components (Willey and Holliday, 1971). As previously stated, Pelton (1969) indicated that plant survival and tillering (i.e., increased spikes per unit area) can compensate to maintain yields at lower seeding rates.

Increased seeding rates have been reported to lead to

increased lodging in two barley experiments (Bockstaele and Maddens, 1966; Day and Thompson, 1970).

Higher seeding rates gave decreased plant height in oats (Folkins and Kaufmann, 1974), in barley (Bockstaele and Maddens, 1966), and in wheat (Pelton, 1969; El-Hattab et al., 1970), while Clement (1972) reported the opposite effect in wheat. Ahmed (1970) and Finlay et al. (1971) working with barley and Briggs (1975) working with wheat, reported either variable or no effects of density on plant height.

Woodward (1956) working with wheat, oats and barley reported that lower seeding rates resulted in higher test weight. However, Briggs (1975) working with wheat, and Middleton et al. (1964) and Day and Thompson (1970) both working with barley, reported no effect of seeding rate on test weight.

From a barley experiment Day and Thompson (1970) reported the number of days to maturity decreased as the rate of planting went up, as did Young and Bauer (1971) and Briggs (1975), both working with wheat. Finlay et al. (1971) reported a decreased number of days to heading as seed rate increased in barley, as did Clements (1972) with wheat.

Folkins and Kaufmann (1974) reported that stem size decreased with increased planting rate in an oat experiment. Woodward (1956) reported a similar decrease in straw stiffness in his work with wheat, oats, and barley.

The effect of seeding rate on yield is affected by the environment, in particular, the amount of water available. Pelton's (1969) results with lower seeding rates giving better yields when under moisture stress are evidence of this. Kirby (1970) reported no difference in total water use for the growing season with barley seeded at various rates; however, he did report that differences existed in water use at different times of the season for the different densities. He suggested that the higher density plantings used more water early in the growing period, and may then suffer moisture stress during the grain filling stage. This could present a problem in dry years or dry areas.

Day and Thompson (1970), from work with winter barley, reported that seeding date also had an effect on the optimum seeding rate. They indicated that as the seeding date was delayed the seeding rate should be increased.

Emergence, Planting Depth and Coleoptile Length in Semi-Dwarfs

Briggle and Vogel (1968) indicated that one of the problems with the semi-dwarf wheats in the Pacific Northwest was that they did not emerge well from deep planting, apparently due to shorter coleoptile length.

A close positive correlation between culm length and coleoptile length was reported by Allan *et al.* (1962), Sunderman (1964), Burleigh *et al.* (1964), and Whan (1976), in wheat studies, and by Takahashi (1946) in barley experiments.

A positive relationship between coleoptile length and the ability to emerge from greater planting depth has been reported in barley (Kaufmann, 1968) and in wheat (Sunderman, 1963; Burleigh et al., 1964; Whan, 1976).

Allan et al. (1962) reported that another associated problem was emergence rate. This group and Burleigh et al. (1964) reported that the semi-dwarf short coleoptile wheats emerged more slowly. They calculated an emergence rate index and found this to be closely related to coloeptile length.

Allan et al. (1961) indicated that the heritabilities of plant height and coleoptile length in wheat are high; and since they are apparently independently inherited, it should be possible to select for short culm length with improved coleoptile length. This view has been supported by Chowdhry and Allan (1963).

Boyd et al. (1971) indicated that seed size and time to germination were positively related to seedling vigor. This relationship between seed size and emergence characteristics in barley was previously reported by Kaufmann (1968).

Root System Size in Semi-Dwarfs

Briggle and Vogel (1968) reported that the earliest semi-dwarf wheats did not do well when grown under dryland conditions in the Central United States. They suggested this was due to problems involving moisture stress, since these varieties did well under irrigation in the same area.

Lupton et al. (1974) pointed out this could be an indication of limited root development.

Work in India reported by Subbiah et al. (1968) indicated that some of the short wheats had more extensive root systems than did the standard height genotypes, where others had poorer root systems. However, in very extensive studies of the root systems of wheat, Lupton et al. (1974) and O'Brien (1975), both working with Norin-10 derived semi-dwarf genotypes, reported no evidence of differences in the size or extent of the root systems of semi-dwarf and normal height genotypes.

MATERIALS AND METHODS

Experiment I: Components of Variance, Heritability Estimates and Phenotypic Correlations

The experiment was designed to investigate the interrelationships of various agronomic and quality characteristics, in particular the effect of reduced plant height, and to obtain estimates of genetic variance and heritability for these characteristics in three six-rowed barley hybrids, Hordeum vulgare L., each derived from a cross having one semi-dwarf parent in common. The pedigrees, descriptions of and agronomic comparisons between the parents, their sources, and the numbers of lines used in each hybrid, henceforth referred to as populations, are presented in Table 3.

The crosses were made at the University of Manitoba in 1970 and the material was carried through the segregating generations to F_5 via single seed descent. The F_2 and F_3 were grown at Winnipeg and the F_4 was grown in California. No selection was done during this period. Therefore each F_5 line traced to a separate F_2 plant.

In 1973 and 1974 the material was grown in a two-replicate completely randomized block design experiment at each of two locations, the University of Manitoba Crop Research site, Winnipeg, and at the Agriculture Canada

Table 3. Pedigrees of Crosses and Parental Lines giving rise to Populations C-70-1, C-70-2 and C-70-3, and Relative Levels of Agronomic Parameters of Parental Lines, Experiment I.

Population	Pedigree	Number of Lines	Source
C-70-1	Minn 64-62 x Bonanza	103	U. of Manitoba, Canada
C-70-2	Minn 64-62 x 66N1288	87	U. of Manitoba, Canada
C-70-3	Minn 64-62 x Br6507-55	41	U. of Manitoba, Canada

Parental Lines

Minn 64-62	Jotun/Kindred//Vantage/// Trophy////Dickson/////Minn 59-38	U. of Minnesota, U.S.A.
Bonanza	Licenced Canadian 6-row barley variety	Agr. Can. Res. Stn., Brandon, Man., Canada
66N1288	MC247/Parkland	U. of Manitoba, Canada
Br6507-55	Paragon/Parkland// C15791///Conquest	Agr. Can. Res. Stn., Brandon, Man., Canada

Comparative Agronomic Data

	Ht.(cm.)	Yield (kg./ha.)	1000 Kernel wt. (g.)	Test Wt. (kg./hl.)	Degree of Lodging (1-9)	Days to Mature
* Bonanza	87.9	3859	35.4	65.1	3.0	85.6
*66N1288	87.4	3666	36.9	67.3	3.4	86.0
*Br6507-55	67.6	3337	32.4	62.3	2.1	81.3
**Minn 64-62	66.0	3303	32.2	64.2	1.4	89.4

* Data from 1970 Western Co-operative 6-row Barley Test, Means of 17 locations.
** Weighted data calculated from results of Experiment I of this manuscript.

Research Station, Brandon, Manitoba. Growing conditions were excellent in 1973. In 1974 seeding was delayed and germination hampered by wet spring conditions at Brandon, and both sites suffered drought stress later in the season. Seeding dates in 1973 were May 8 at Brandon and May 16 at Winnipeg, and in 1974, May 25 at Brandon and May 18 at Winnipeg.

In 1973 the plots consisted of 2 rows 2.4 meters long, with 30 cm. spaces between rows and 61 cm. spaces between plots. Every fifth plot was a control genotype. In 1974 the plot design was identical except that the length of plot was 3.1 meters and controls were less frequent. All plots were seeded at rates approximating normal field planting rates based on a uniform seed number per plot.

The following measurements were taken on each plot:

(1) Plant Height - taken in cm. just prior to maturity, measured from ground level to top of spike.

(2) Yield - recorded as grams per plot. All plots were hand harvested and threshed in a Hege Combine in 1973 and in a stationary Vogel Plot Thresher in 1974. In 1973 the center 1.8 meters of both rows was harvested from each plot. In 1974 the center 2.4 meters of both rows was harvested at Winnipeg, while at Brandon only one 2.4 meter section of the row was harvested.

(3) Kernels per spike - based on hand counts of 10 spikes per plot, taken at random.

(4) 200 Kernel weight - recorded in grams; measured as the weight of 200 random, threshed, deawned kernels.

(5) Test weight - recorded as (kilograms per hectoliter) and determined by standard procedures using threshed and deawned grain samples.

(6) Percent plumpness - recorded as percent of grain remaining on top of a 2.4 x 19.0 mm. perforated oblong seive after hand shaking a 100 gram sample of threshed, deawned grain 100 times.

(7) Days to heading - recorded as the number of days from seeding till 75% of the spikes had emerged from the boot.

(8) Days to maturity - recorded as the number of days from planting till the plot was mature enough to harvest.

(9) Post-anthesis period - calculated by subtraction of the number of days to heading from the number of days to maturity.

(10) Degree of lodging - plots were rated at maturity. In 1973 a scale of one to five was used with one representing no lodging. In 1974 lodging occurred only at Winnipeg and a one to nine scale was used, again with one representing no lodging.

*(11) Alpha-amylase level - recorded in units; determined as per method outlined by Bendelow (1977).

*(Measurements 11 through 14 were taken on a bulk sample of each line from each location in 1973 and only from Winnipeg in 1974.)

*(12) Saccharifying activity - recorded as units, determined by the method outlined by Bendelow (1977).

*(13) Percent Barley nitrogen - recorded as percent; determined by the Kjeldhal procedure.

*(14) Soluble amino-nitrogen - recorded as mg. per 100 mg. of barley; determined as per method outlined by Bendelow (1977).

Analysis of variance was calculated for each characteristic in each population on the combined data over years and locations. Genetic and environmental variances were calculated using the estimated mean squares (Steel and Torrie, 1960). Heritability estimates were computed by the method of Comstock and Moll (1963) based on the components of variance. The standard errors for the heritabilities were computed by the method outlined by Pesek and Baker (1971). Missing plot data were solved for, where necessary, by the methods of Healy and Westmacott (1956).

To test for differences between genotypes and the significance of genetic variance the approximate F test (F') suggested by Cochran and Cox (1957) was used, with degrees of freedom calculated by the Satterhthwaite approximation (LeClerg et al., 1962).

Paired t-tests were used to determine whether or not population means differed from each other for the various characteristics.

Simple phenotypic correlation coefficients were computed between all combinations of characteristics within each

population, using individual line means from the whole experiment. Homogeneity of correlation coefficients was calculated as outlined by Steel and Torrie (1960), and when such were found to be homogeneous across the three populations, pooled correlation values were computed.

Data from control plots did not enter into the analyses described above. This data was used only for purposes of the breeding project from which all the material was taken.

Experiment II: Nitrogen Fertilization of Tall and Semi-dwarf Barleys

The purpose of this study was to determine the response of three semi-dwarf and two tall barley genotypes (described in Table 4) to high levels of applied nitrogen fertilizer, and to determine if any significant nitrogen fertilizer by genotype interaction occurred.

A four replicate split plot experiment was planted in five environments; the University of Manitoba Weed Research site at Carman, Manitoba in 1975 and 1976, at the Sisson's Farm Ltd. site at Portage La Prairie, Manitoba in 1975 and 1976, and at the G. Kabernick farm site at Sanford, Manitoba in 1976.

The sites are described below:

Site	Soil Type	Previous Crop	Available Soil N 0-24" (kg./ha.)
Carman 1975	Very Fine Sandy Loam	Oats	29.1
Portage 1975	Very Fine Sandy Loam	Wheat	37.0

Table 4. Genotypes used in Nitrogen Fertilizer Application Study, Experiment II.

Genotype	Pedigree	Plant Height Class
Bonanza	**	Tall
C702024	Minn 64-62 x 66N1288	Tall
C703011	Minn 64-62 x Br6507-55	Semi-dwarf
C703032	Minn 64-62 x Br6507-55	Semi-dwarf
Minn 64-62	**	Semi-dwarf

** Described in Table 3.

Site	Soil Type	Previous Crop	Available Soil N 0-24" (kg./ha.)
Sanford 1976	Clay	Flax	36.0
Carman 1976	Fine Sandy Loam	Rapeseed	24.7
Portage 1976	Fine Sandy Loam	Sunflowers	34.8

All sites were fertilized prior to seeding with a broadcast application of 11:48:0 to attempt to achieve recommended P_2O_5 levels. Planting dates were May 15 at Carman and May 16 at Portage in 1975, May 7 at Sanford, May 8 at Portage and May 19 at Carman in 1976. Growing conditions were average except for a heavy weed infestation at Carman in 1975 and severe moisture stress at both Carman and Portage in 1976.

The five main plots were rates of nitrogen fertilizer; applied as 34:0:0 broadcast and harrowed in prior to planting, at levels of 0.00, 67.26, 134.52, 201.78 and 269.04 kilograms of actual nitrogen per hectare. Sub-plots were genotypes. Plots were four rows 6.1 meters long with 30 cm. between rows and between plots. All plots were seeded at normal field seeding rates.

The following characteristics were measured for each plot at each environment: (Unless otherwise specified, measurements were taken as in Experiment I.)

(1) Plant height

(2) Yield - recorded as kg./ha. A four meter section

of both of the center rows of each plot was hand harvested and threshed in a Vogel Plot Thresher, except at Carman, 1976 where whole plots were field harvested with a "HEGE" plot combine.

(3) Number of spikes per unit area - the number of fertile heads was counted in a random one meter section of one of the two center rows of each plot. (This is equivalent to a 0.31 square meter area.)

(4) Kernels per spike

(5) 200 Kernel weight

(6) Degree of lodging - recorded as a value on a scale of one to nine, with one being no lodging. Taken in 1975 only.

(7) Test weight - recorded as kg./hl. and determined by standard procedures.

(8) Days to Heading

(9) Days to maturity

(10) Post-anthesis period

(11) Percent barley nitrogen

(12) Alpha-amylase levels - taken in 1975 only

(13) Saccharifying activity - taken in 1975 only

(14) Soluble amino-nitrogen - taken in 1975 only

Analyses of variance were computed for each character at each location to determine: (1) if differences existed between treatments and (2) if any nitrogen fertilizer by genotype interactions had occurred.

Orthogonal single degree of freedom comparisons were employed to compare genotypes where desirable. Duncan's Multiple Range test was used to determine significance of differences between treatment means and between fertilizer x genotype interaction means when a significant interaction had occured.

Experiment III: Row Spacing and Seeding Rate Study

This study was conducted to determine the effects of varying row spacing and seeding rate on the yield and agronomic characteristics of tall and semi-dwarf barley genotypes. Two genotypes were studied, one tall, cv. "Bonanza", and one semi-dwarf, Minn64-62.

A three replicate 2 x 3 x 3 factorial experiment was grown at three locations in 1976; the G. Kabernick farm, Sanford, Manitoba; the University of Manitoba Weed Research site, Carman, Manitoba; and the University of Manitoba Crop Research site, Winnipeg, Manitoba; with genotypes, seeding rates, and row spacings the respective factors. Each genotype was tested at every combination of levels of factors two and three in each replicate.

The three levels of factor two (seeding rate) were the number of germinable seeds equal to seeding rates of 56.0, 84.0 and 112.0 kg./ha. of Bonanza. The three levels of factor three (row spacings) were 15.0, 30.5 and 61.0 cm.

Plots were 6.1 meters long by 2.4 meters wide having 16 rows at the narrowest, 8 at the intermediate and 4 rows

at the widest spacing.

The experiment was planted on April 27 at Winnipeg, May 7 at Sanford, and June 3 at Carman. Weeds were controlled by chemical application at all sites to the extent possible, and hand weeding was done as the need dictated at Winnipeg and Sanford. The experiment received a 5.0 cm. irrigation thirty-four days after planting at Winnipeg. The Sanford site suffered some excess moisture stress during June. The Carman location suffered severe drought stress throughout the growing season. The Winnipeg site suffered mild hail damage just prior to harvest.

The following characteristics were measured in the same fashion as in Experiment II.

(1) Plant height (cm.)

(2) Yield (kg./ha.)

(3) Spikes/unit area

(4) Kernels/spike

(5) 200 Kernel weight

(6) Test weight (kg./hl.)

(7) Lodging - at Winnipeg only

(8) Percent barley nitrogen

Analyses of variance were used to determine significant differences between levels of the factors and of interactions among these factors. Single degree of freedom comparisons were calculated to determine the manner in which the factors "seeding rate" and "row spacing" affected the relative performances of the genotypes.

Experiment IV: Coleoptile Length Study

This experiment was conducted to determine the relationship between coleoptile length and plant height in selected tall and semi-dwarf barley genotypes described in Table 5. Four semi-dwarf and three tall genotypes were included.

The study was conducted at the University of Minnesota, U.S.A. in February, 1976. A four replicate completely randomized block design was used, each replicate consisting of six seeds of each genotype individually placed embryo upright in the center of a paper towel. This towel was then rolled up, fastened, placed in a beaker containing water and placed in a dark incubator for germination. Six seeds were used to insure a sample size of five for each replicate of each genotype. The incubator was kept at 15 degrees C for seven days, but due to this temperature, germination did not ensue and the temperature was raised to 25 degrees C for seven more days. After this, the material was removed and the following measurements were taken:

(1) Coleoptile length (mm.).

(2) Seminal root number.

(3) Root score - based on a visual rating in which roots were scored as long, medium, or short. These were given weights of three, two and one respectively, with the sum constituting the total score.

(4) Shoot length (mm.).

Analyses of variance were computed to determine dif-

Table 5. Genotypes used in Coleoptile Length Study and Emergence Study, Experiment IV and Experiment VI.

Genotype	Pedigree	Plant Height Class
Bonanza	**	Tall
C701013	Minn 64-62 x Bonanza	Tall
C703019	Minn 64-62 x Br6507-55	Tall
Minn 64-62	**	Semi-dwarf
C703032	Minn 64-62 x Br6507-55	Semi-dwarf
C703029	Minn 64-62 x Br6507-55	Semi-dwarf
C703011	Minn 64-62 x Br6507-55	Semi-dwarf

** Described in Table 3.

ferences between genotypes which were then described by a Duncan's Multiple Range Test. Single degree of freedom comparisons were calculated to determine differences between tall and semi-dwarf genotypic classes.

Simple phenotypic correlations were calculated for the parameters measured and rank correlations were determined to describe the relationship between these traits and plant height, yield, 200 kernel weight and percent plumpness. These last four parameters were determined from previously grown plots of these genotypes.

Experiment V: Root System Size and Growth Rate Study

This study was designed to determine if differences in root size existed between the members of a selected group of tall and semi-dwarf barley genotypes described in Table 6.

A five replicate completely randomized block experiment was conducted in the greenhouse in 1975. Plants were grown in five inch clay pots in a 1:2:1 soil, sand, and peat moss medium. Samples were taken once every seven days from 28 to 70 days after planting.

The plants were removed from the pots and the roots were hand washed from the medium. The roots were then removed from the plants, dried overnight at 50 degrees C, and weighed.

Analysis of variance was calculated for each sampling date to determine if differences existed between genotypes

Table 6. Genotypes used in Root Size Study, Experiment V.

Genotypes	Pedigree	Plant Height Class
Bonanza	**	Tall
Br6507-55	**	Tall
C701013	Minn 64-62 x Bonanza	Tall
C702024	Minn 64-62 x 66N1288	Tall
Minn 64-62	**	Semi-dwarf
C703011	Minn 64-62 x Br6507-55	Semi-dwarf
C703029	Minn 64-62 x Br6507-55	Semi-dwarf

** Described in Table 3.

and plant height classes.

Root growth rates were calculated as the sum of, root dry weight at sampling 1, 2, 3, 4, 5, and 6 multiplied by respective weightings of 6, 5, 4, 3, 2, and 1. Genotypes were then compared for these parameters.

Rank correlations were computed among the parameters for maximum root dry weight and root growth rate with plant height, yield, 200 kernel weight and percent plumpness, and with each other.

Experiment VI: Seeding Depth and Emergence Study

This experiment was designed to compare selected semi-dwarf and tall genotypes for the ability to emerge from various planting depths. The genotypes used are described in Table 5.

A three-replicate completely randomized block design experiment was grown in a 3:1:1 soil, sand, and peat moss medium in boxes in the greenhouse in 1975. Planting depths were 2.54, 5.08, 7.62 and 10.16 cm.

Emergence rate indexes (ERI) were calculated by the method described by Allan et. al. (1962).

Analysis of variance was used to determine genotypic differences. The relationship of ERI to plant height, coleoptile length, yield, 200 kernel weight, and percent plumpness was studied by rank correlation procedures.

RESULTS

Experiment I: Components of Variance, Heritability Estimates and Phenotypic Correlations

Components of Variance and Heritability Estimates

Means, estimates of the components of variance, and heritability estimates for ten agronomic parameters in each of the three populations; C-70-1, C-70-2 and C-70-3 are presented in Table 7. Significant genetic variance (σ^2_G) existed for all traits in each population, except for yield in C-70-3.

Significant genotype x location x year (σ^2_{GLY}) interaction variance components existed for a number of parameters in each population. The only σ^2_{GLY} which was larger than the genotypic component was for yield in C-70-2, but this did not detract from the significance of the genetic variance. The only other traits for which σ^2_{GLY} was consistently large were percent plumpness in the first two populations and test weight in populations C-70-1 and C-70-3. Rasmusson and Glass (1967) reported significant σ^2_{GLY} for percent plumpness and heading date.

In general, where no significant second order interaction existed, at least one of the first order interactions

Table 7. Components of Variance ± Std. Error and Heritability Estimates ± Std. Error, Experiment I.

Characteristic	Pop'n	Mean	Components of Variance σ^2_G	σ^2_{GL}	σ^2_{GY}	σ^2_{GLY}	σ^2_e	Heritability %
Plant Height (cm.)	C-70-1	76.10	14.80** ± 5.40	0.48 ± 0.41	1.30** ± 0.51	0.95* ± 0.54	5.40 ± 0.38	89 ± 2.0
	C-70-2	76.02	7.90** ± 1.39	-0.06 ± 0.21	1.32** ± 0.39	-0.18 ± 0.35	4.39 ± 0.24	87 ± 3.0
	C-70-3	68.35	12.95** ± 3.54	-0.23 ± 0.47	3.85** ± 1.27	0.85 ± 0.76	4.70 ± 0.52	83 ± 5.0
Yield (g./plot)	C-70-1	513.88	335.99* ± 159.87	81.65 ± 167.99	137.80 ± 173.90	-25.00 ± 253.13	3276.10 ± 228.53	40 ± 15.0
	C-70-2	540.40	593.27** ± 206.97	-144.57 ± 219.26	-65.15 ± 227.00	879.40** ± 345.59	2586.79 ± 196.39	58 ± 14.0
	C-70-3	532.83	313.05 ± 302.65	490.10** ± 247.00	601.30** ± 269.44	-21.15 ± 248.89	2028.70 ± 224.72	28 ± 22.0
Test Weight (kg./hl.)	C-70-1	67.88	0.58** ± 0.13	-0.03 ± 0.10	0.02 ± 0.10	0.22* ± 0.13	1.36 ± 0.10	68 ± 9.0
	C-70-2	67.88	0.55** ± 0.17	0.13** ± 0.08	0.35** ± 0.12	0.05 ± 0.12	1.26 ± 0.10	58 ± 10.0
	C-70-3	67.67	0.51** ± 0.22	0.13 ± 0.17	0.13 ± 0.17	0.35* ± 0.22	1.10 ± 0.12	60 ± 15.0
Kernels per Spike	C-70-1	56.17	1.40** ± 0.49	0.32 ± 0.40	0.80* ± 0.46	-0.12 ± 0.59	7.72 ± 0.54	48 ± 12.0
	C-70-2	56.50	2.61** ± 0.61	0.06 ± 0.42	0.02 ± 0.42	0.13 ± 0.65	7.47 ± 0.57	72 ± 8.0
	C-70-3	54.61	2.37** ± 1.11	0.99 ± 0.60	2.14** ± 0.84	-0.95 ± 0.73	7.29 ± 0.81	51 ± 15.0
200 Kernel Weight (g.)	C-70-1	7.01	0.038** ± 0.007	-0.001 ± 0.002	0.010** ± 0.004	-0.006 ± 0.004	0.062 ± 0.004	78 ± 5.0
	C-70-2	7.04	0.030** ± 0.010	0.000 ± 0.000	0.010** ± 0.004	-0.010 ± 0.004	0.060 ± 0.005	71 ± 7.0
	C-70-3	6.99	0.049** ± 0.015	-0.003 ± 0.004	0.018** ± 0.008	-0.002 ± 0.007	0.057 ± 0.006	77 ± 8.0

* F or F' significant at P=0.05. ** F or F' significant at P=0.01.

Cont'd.

Table 7. Continued

Characteristic	Pop'n	Mean	Components of Variance					Heritability %
			σ^2_G	σ^2_{GL}	σ^2_{GY}	σ^2_{GLY}	σ^2_e	
% Plumpness	C-70-1	84.93	10.46** ± 2.25	0.63 ± 0.85	4.80** ± 1.34	2.91** ± 1.16	9.97 ± 0.70	69 ± 6.0
	C-70-2	86.20	5.18** ± 1.36	-1.08 ± 0.61	3.40** ± 1.14	3.05** ± 0.38	7.13 ± 0.38	65 ± 9.0
	C-70-3	83.58	9.33** ± 3.63	1.57** ± 1.25	6.99** ± 2.36	1.63 ± 1.48	9.15 ± 1.01	62 ± 12.0
Days to Heading	C-70-1	54.99	0.71** ± 0.13	0.14** ± 0.05	0.07** ± 0.03	0.02 ± 0.05	0.54 ± 0.03	80 ± 4.0
	C-70-2	56.06	0.87** ± 0.17	0.17** ± 0.07	0.05 ± 0.05	0.17** ± 0.07	0.56 ± 0.04	80 ± 5.0
	C-70-3	54.53	0.35** ± 0.14	0.03 ± 0.05	0.26** ± 0.09	-0.10 ± 0.07	0.58 ± 0.06	63 ± 12.0
Days to Maturity	C-70-1	84.23	0.45** ± 0.11	-0.01 ± 0.06	0.19** ± 0.08	-0.01 ± 0.08	1.12 ± 0.08	67 ± 8.0
	C-70-2	85.06	0.54** ± 0.11	-0.12 ± 0.06	0.02 ± 0.07	0.13 ± 0.11	1.06 ± 0.08	83 ± 6.0
	C-70-3	81.68	0.89** ± 0.37	-0.18 ± 0.13	0.86** ± 0.32	0.26 ± 0.23	1.40 ± 0.11	60 ± 14.0
Days in Post-Anthesis	C-70-1	29.35	0.38** ± 0.10	-0.02 ± 0.07	0.11** ± 0.08	0.06 ± 0.11	1.33 ± 0.10	63 ± 9.0
	C-70-2	29.11	0.35** ± 0.10	0.05 ± 0.09	-0.17 ± 0.08	0.23* ± 0.13	1.20 ± 0.06	62 ± 11.0
	C-70-3	27.27	0.97** ± 0.35	-0.09 ± 0.14	0.54** ± 0.25	0.07 ± 0.23	1.77 ± 0.20	68 ± 11.0
			σ^2_G	σ^2_{GE}			σ^2_e	
Degree of Lodging	C-70-1	3.36	0.75** ± 0.14	0.08 ± 0.08			1.13 ± 0.09	78 ± 4.0
	C-70-2	2.86	0.34** ± 0.08	0.01 ± 0.08			1.08 ± 0.09	65 ± 7.0
	C-70-3	2.08	0.28** ± 0.10	0.07 ± 0.10			0.85 ± 0.08	63 ± 10.00

* F or F' significant at P=0.05.
** F or F' significant at P=0.01.

was significant. The only case in which these interactions were larger than σ^2_G was for yield in population C-70-3 in which genotype x year (σ^2_{GY}) and genotype x location (σ^2_{GL}) were both significant and larger than σ^2_G. This led to no significant genotypic variance for yield in this population.

The σ^2_{GY} was both more often significant and more consistently significant across populations than was σ^2_{GL}, in agreement with the results reported by Rasmusson and Glass (1967). The σ^2_{GY} was important in all populations for plant height, 200 kernel weight, and percent plumpness; and significant as well in populations one and three for kernels per spike, days to heading, days to maturity and days in post-anthesis. The σ^2_{GL} was relatively important only for days to heading in populations C-70-1 and C-70-2. Rasmusson and Glass (1967) reported no significant σ^2_{GY} for plant height in agreement with the present study, while they did report a significant σ^2_{GY} for days to heading in one population.

In no case were any of the interaction variance components larger than the error component of variance (σ^2_e). The σ^2_e's for test weight, kernels per spike, kernel weight, days to maturity, and days in post-anthesis were two to three times as large as were the σ^2_G estimates for these parameters, and for yield, the σ^2_e's were four to nine times greater than were the σ^2_G's. These results again are in general agreement with those reported by Rasmusson and Glass (1967) and Rutger *et al.* (1966).

The heritability estimates presented in Table 7 are

relatively high. With minor exceptions, they were of similar magnitude relative to each other, as had been the case for those previously reported (Table 1). Estimates for plant height (83 to 89%) and for 200 kernel weight (71 to 78%) were high and consistent over all populations. The estimated heritabilities of test weight (58 to 68%), percent plumpness (62 to 69%) and days in post-anthesis (62 to 68%) were lower but also consistent over the populations studied. Of these characteristics, only the estimated heritability for plant height deviated from previous reports being higher in the present study.

Contrary to the literature (Table 1), the heritability estimates for days to heading and to maturity were not consistent over the three populations. However, the intermediate to high magnitudes, 63 to 80% and 60 to 83% respectively, were consistent with previous reports (Table 1). Rasmusson and Glass (1967) reported similar variability between populations for days to heading.

The literature surveyed gave no previous indication of an heritability estimate for the parameter days in post-anthesis. The result in the present study was moderately high heritability (62 to 68%), consistent across populations.

Heritabilities for kernels per spike were variable, with population C-70-2 showing an estimate of 72% as compared to 48 and 51% for the other populations. This variability also existed in previous reports (Table 1).

Heritability estimates for yield in this study were low

(28 to 58%), as reported by most others (Table 1), and subject to large standard errors (14 to 22%). The estimate for population C-70-3 (28 ± 22%) was essentially zero, since no genetic variance for yield was detected due to large σ^2_{GY} and σ^2_{GL} components of variance. The very large σ^2_e's contributed to lower heritabilities for yield in all populations.

The heritability estimates for lodging were relatively high (63 to 78%) considering data were available from only three experiments. This is partly explained by the large amount of σ^2_G for this trait due to the strong relationship of lodging and plant height in these populations.

Standard errors of the heritability estimates were large relative to the estimates only for the traits yield and kernels per head, reflecting the difficulty of measurement of these characters due to environmental interaction. There was also a tendency for the standard error to increase as the population size decreased from C-70-1 through C-70-3.

Trait Comparisons

Means, their standard errors, and ranges for each of ten agronomic and four quality parameters measured for each of the three populations studied and the check variety, cv. Bonanza, are presented in Table 8.

The population means were not significantly different from each other for yield, kernel weight, test weight, percent

Table 8. Population Means and Ranges for Agronomic and Quality Parameters, Experiment I.

Characteristic	Pop'n	No. of Lines	Mean ± Std. Error	Range Lowest Line - Highest Line	% C.V.
Plant Height (cm.)	C-70-1	103	76.10 ± 0.57 b	58.80-84.20**	7.6
	C-70-2	87	76.02 ± 0.46 b	58.70-81.90**	5.6
	C-70-3	41	68.35 ± 0.87 a	52.70-76.70**	8.2
	Bonanza		79.40 ± 0.09		
Yield (g./plot)	C-70-1	103	513.9 ± 4.1 a	423.3-602.5*	8.0
	C-70-2	87	540.4 ± 4.9 a	418.6-635.8**	8.4
	C-70-3	41	532.8 ± 7.4 a	417.4-638.4	8.8
	Bonanza		533.2 ± 2.2		
Kernels per Spike	C-70-1	103	56.17 ± 0.24ab	49.6 -61.6**	4.3
	C-70-2	87	56.50 ± 0.29 b	50.8 -63.3**	4.8
	C-70-3	41	54.61 ± 0.47a	46.8 -60.5**	5.6
	Bonanza		57.50 ± 0.10		
200 Kernel Weight	C-70-1	103	7.01 ± 0.03a	6.21-7.81**	1.9
	C-70-2	87	7.04 ± 0.03a	5.98-7.73**	2.0
	C-70-3	41	6.99 ± 0.06a	6.11-7.95**	2.0
	Bonanza		6.93 ± 0.01		
Test Weight (kg./hl.)	C-70-1	103	67.88 ± 0.13a	64.8 -70.4**	6.5
	C-70-2	87	67.88 ± 0.14a	61.2 -70.1**	4.6
	C-70-3	41	67.67 ± 0.21a	63.7 -69.7**	6.6
	Bonanza		66.31 ± 0.05		
Percent Plumpness	C-70-1	103	84.93 ± 0.54a	69.7 -94.7**	4.5
	C-70-2	87	86.20 ± 0.43a	65.9 -92.2**	3.8
	C-70-3	41	83.58 ± 0.86a	69.2 -94.8**	5.1
	Bonanza		85.20 ± 0.14		
Degree of Lodging	C-70-1	103	3.36 ± 0.10 b	1.10-5.67*	29.2
	C-70-2	87	2.86 ± 0.08a	1.00-4.57*	25.2
	C-70-3	41	2.08 ± 0.10ab	1.00-3.43**	32.2
	Bonanza		4.46 ± 0.04		

Values in one group followed by the same letter are not significantly different, P=0.05.

* F' significant at P=0.05.

** F' significant at P=0.01.

Table 8. Continued

Characteristic	Pop'n	No. of Lines	Mean ± Std. Error	Range Lowest Line - Highest Line	% C.V.
Days to Heading	C-70-1	103	54.99 ± 0.13a	52.6 -59.8**	2.4
	C-70-2	87	56.06 ± 0.16 b	52.8 -61.0**	2.6
	C-70-3	41	54.33 ± 0.17a	53.3 -58.9**	2.0
	Bonanza		54.60 ± 0.04		
Days to Maturity	C-70-1	103	84.23 ± 0.12 b	81.3 -86.6**	1.4
	C-70-2	87	85.06 ± 0.12 b	82.1 -87.2**	1.4
	C-70-3	41	81.68 ± 0.27a	78.1 -84.9**	2.1
	Bonanza		82.95 ± 0.05		
Days in Post-Anthesis	C-70-1	103	29.35 ± 0.11 b	26.6 -31.9**	3.8
	C-70-2	87	29.11 ± 0.11 b	26.5 -31.3**	3.6
	C-70-3	41	27.27 ± 0.26a	23.3 -31.2**	6.2
	Bonanza		28.35 ± 0.05		
α-amylase Level (units)	C-70-1	103	27.59 ± 0.28a	20.70-36.33**	10.4
	C-70-2	87	25.28 ± 0.30a	18.70-35.90**	11.1
	C-70-3	40	25.78 ± 0.47a	20.10-33.30**	11.6
	Bonanza		22.97 ± 0.18		
Saccharifying Activity	C-70-1	103	208 ± 2.9 ab	156 -294**	13.9
	C-70-2	87	220 ± 2.0 a	171 -286**	8.6
	C-70-3	40	261 ± 3.4 b	222 -304**	8.4
	Bonanza		242 ± 3.0		
Barley Nitrogen %	C-70-1	103	2.05 ± 0.01a	1.90-2.35**	4.4
	C-70-2	87	2.00 ± 0.01a	1.83-2.14**	3.5
	C-70-3	40	2.04 ± 0.02a	1.88-2.25**	4.9
	Bonanza		2.07 ± 0.01		
Soluble Amino-nitrogen (mg./100 mg. Barley)	C-70-1	103	0.147 ± 0.001a	0.121-0.187	8.8
	C-70-2	87	0.137 ± 0.001a	0.111-0.164**	7.3
	C-70-3	40	0.141 ± 0.002a	0.115-0.163	7.1
	Bonanza		0.160 ± 0.002		

† Values in one group followed by the same letter are not significantly different, P=0.05.
* F' significant at P=0.05.
** F' significant at P=0.01.

plumpness, level of alpha-amylase, percent barley nitrogen and soluble amino-nitrogen. Of these traits cv. "Bonanza" differed only in that it was lower in kernel weight and alpha-amylase, and higher in percent barley nitrogen and soluble amino-nitrogen, than were the means of the experimental populations. On a mean basis, population C-70-3 was significantly shorter than the others, which were both slightly shorter than the control. Overall decreased height of population C-70-3 was emphasized by the fact that its tallest line was shorter than Bonanza. The greater mean plant height of C-70-1 and C-70-2 reflected the fact that these populations had lines taller than the control, and had more taller lines than shorter lines, relative to C-70-3 (Table 9).

Bonanza had more kernels per spike than any of the populations and C-70-3 had significantly fewer than the other populations.

C-70-2 had a greater mean number of days to heading than C-70-1 and C-70-3, which did not differ from each other or the check. Population C-70-3 was earlier maturing, with Bonanza next, followed by the other populations. The same ranking occurred for days in post-anthesis.

All populations were more resistant to lodging on a mean basis than was Bonanza. Differences between populations were difficult to determine due to large environmental influences but it seemed that C-70-3 was most resistant followed by C-70-2 and C-70-1, the least resistant.

Table 9. Mean Yields over all Environments of the Highest Yielding Lines within the Plant Height Categories (Tall, Intermediate and Semi-dwarf) for each of the Three Populations of Experiment I.

Plant Height Category (PHC)	Height (cm.)
Tall	74
Intermediate	68 to 74
Semi-dwarf	68

Control Genotype	PHC	Mean Yield ± std. error (g./plot)	No. of plots in total
Bonanza	Tall	533 ± 54	68
Minn64-62	Semi-dwarf	465 ± 56	168

Population	PHC	Best Line	Mean Yield of Best Line *(g./plot)	No. of Lines in Sample
C-70-1	Tall	C701031	603	78
	Intermediate	C701060	573	14
	Semi-dwarf	C701030	505	11
				103
C-70-2	Tall	C702024	636	61
	Intermediate	C702053	596	23
	Semi-dwarf	C702068	519	3
				87
C-70-3	Tall	C703041	523	1
	Intermediate	C703019	639	29
	Semi-dwarf	C703011	573	11
				41
Overall	Tall	C702024	636	140
	Intermediate	C703019	639	66
	Semi-dwarf	C703011	573	25
				231

* Means of 2 replicates at each of 2 locations in each of 2 years.

Data for saccharifying activity was also subject to large errors and it seemed that C-70-2, C-70-3 and Bonanza were at about the same level with C-70-1 somewhat lower.

The ranges presented in Table 8 showed that significant differences existed between lines within all populations for all traits studied except for yield in C-70-3 and soluble amino-nitrogen in C-70-1 and C-70-3.

Maximum line means in each population exceeded the control mean for all characteristics except plant height and degree of lodging in C-70-3 and level of soluble amino-nitrogen in both C-70-2 and C-70-3. In all cases population minimums were lower than the control mean.

The possibility of selecting for increased yielding ability, in particular high yielding short statured material, was tabulated in Table 9. In populations C-70-1 and C-70-2 the tall class lines were the highest yielding, with the intermediate height group close behind and above the control Bonanza, while the semi-dwarf class were lower yielding. For population C-70-3 the highest yielding line was in the intermediate height class while the lowest was the tall line. For the whole study the highest yielders from the tall and intermediate groups were no different in yield and the best yielding semi-dwarf was at least equal to Bonanza. The highest yielding line from each group of each population was higher yielding than the semi-dwarf parent Minn64-62.

Phenotypic Correlations

Simple phenotypic correlations for each population and pooled correlations between ten of the agronomic parameters, and between selected agronomic characteristics, lodging, and the four quality traits,are presented in Table 10.

Plant height was significantly, positively and homogeneously correlated with yield per plot, 200 kernel weight, test weight, percent plumpness, days in post-anthesis and degree of lodging. The relationship with yield supported reports of Konishi (1976), Fiuzat and Atkins (1953) and Duwaryi (1974), but is in disagreement with results published by Nasr et al. (1953), Kiesselbach et al. (1940) and Rutger et al. (1967). The association with kernel weight supported results of Konishi (1976) and Fiuzat and Atkins (1953), but is not in agreement with those of Crook and Poehlman (1971). Both Nasr et al. (1973) and Rutger et al. (1967) have reported similar relationships for plant height with test weight and percent plumpness, while Konishi (1976), Duwaryi (1974), and Nasr et al. (1973) all reported a similar relationship of height with lodging. These results are in general agreement with those from wheat studies (Johnson et al. 1966 (a)) and rice work (Chandler, 1969).

Plant height showed heterogeneous relationships with three traits. With kernels per spike none of the individual population values were significant and we can conclude, as

Table 10. Phenotypic correlations, Experiment I.

Characteristics Correlated	Population C-70-1 n=103	C-70-2 n=87	C-70-3 n=41	Pooled Correlation
Plant Height (cm.) with:				
Yield (kg./ha.)	.35**	.31**	.46**	.354**
Kernels/spike	.18	-.07	.29	H†
200 Kernel weight (g.)	.32**	.46**	.51**	.405**
Test weight (kg./hl.)	.40**	.31**	.54**	.397**
% Plumpness	.23*	.40**	.59**	.371**
Days to heading	-.55**	-.16	-.69**	H
Days to maturity	-.31**	.07	-.06	H
Days in post-anthesis	.30**	.32**	.35*	.319**
Degree of lodging	.51**	.46**	.56**	.500**
Level of α-amylase	.04	-.20*	-.09	-.080
Saccharifying activity	.13	.16	-.20	-.090
% Barley nitrogen	-.01	.20*	-.21	.040
Soluble amino-nitrogen	-.07	-.21*	-.12	-.129
Yield (kg./ha.) with:				
Kernels/spike	.22*	.19	.32*	.226*
200 Kernel weight (g.)	.03	.12	.04	.070
Test weight (kg./hl.)	.34**	.12	.11	.216**
% Plumpness	-.01	.10	.15	.060
Days to heading	-.38**	-.16	-.39*	-.300**
Days to maturity	-.16	-.12	.21	-.080
Days in post-anthesis	.31**	.05	.44**	.236**
Degree of lodging	.24**	.30**	.41**	.291**
Level of α-amylase	-.08	-.18	-.13	-.129
Saccharifying activity	-.07	-.21*	-.21	-.149*
% Barley nitrogen	-.40**	-.20*	-.42**	-.336**
Soluble amino-nitrogen	-.25*	-.16	-.08	-.187**
Kernels/spike with:				
200 Kernel weight (g.)	-.19	-.25*	-.19	-.216**
Test weight (kg./hl.)	-.04	-.29**	.02	-.129
% Plumpness	-.33**	-.28*	-.22	-.219**
Days to heading	-.13	.13	-.23	-.050
Days to maturity	.14	.20	.17	.168*
Days in post-anthesis	.30**	-.01	.30	.187**
Degree of Lodging	.33**	.21*	.23	.270**
Level of α-amylase	-.07	-.23*	.06	-.110
Saccharifying activity	-.08	-.24*	-.35*	-.190**
% Barley nitrogen	-.27**	-.26*	-.36*	-.280**
Soluble amino-nitrogen	-.33**	-.20	-.11	-.250**

* Significant at P=0.05

** Significant at P=0.01

H = Heterogeneous correlations, therefore could not compute pooled value.

Cont'd.

Table 10. (Continued)

Characteristics Correlated	Population C-70-1 n=103	C-70-2 n=87	C-70-3 n=41	Pooled Correlation
200 Kernel weight (g.) with:				
Test weight (kg./hl.)	.25*	.55**	.60**	H
% Plumpness	.75**	.79**	.83**	.782**
Days to heading	-.41**	-.50**	-.42**	-.446**
Days to maturity	-.07	-.20	.05	-.100
Days in post-anthesis	.41**	.48**	.32*	.422**
Degree of lodging	.28**	.41**	.38*	.345**
Level of α-amylase	-.26**	-.30**	-.20	-.264**
Saccharifying activity	-.18	-.09	-.00	-.119
% Barley nitrogen	.13	.25*	-.04	.149*
Soluble amino-nitrogen	-.22*	-.21*	-.08	-.197**
Test weight (kg./hl.)				
% Plumpness	.30**	.59**	.64**	H
Days to heading	-.51**	-.39**	-.35*	-.438**
Days to maturity	-.48**	-.28*	-.04	H
Days in post-anthesis	.13	.22*	.18	.178**
Degree of lodging	.11	.20	.37*	.187**
Level of α-amylase	-.04	-.45**	-.21	H
Saccharifying activity	.13	-.31**	-.11	H
% Barley nitrogen	.02	.21*	-.13	.070
Soluble amino-nitrogen	-.14	-.27*	-.10	-.187**
% Plumpness with:				
Days to heading	-.35**	-.44**	-.62**	-.438**
Days to maturity	-.20*	-.10	-.01	-.129
Days in post-anthesis	.20*	.44**	.38**	.327**
Degree of lodging	.01	.34**	.56**	H
Level of α-amylase	-.05	-.44**	-.31*	H
Saccharifying activity	-.01	-.25*	.03	-.010
% Barley nitrogen	.45**	.21*	.09	.310**
Soluble amino-nitrogen	-.01	-.32**	-.12	-.149*
Days to heading with:				
Days to maturity	.61**	.71**	.29	H
Days in post-anthesis	-.50**	-.56**	-.31*	-.495**
Days to maturity with:				
Days in post-anthesis	.32**	.13	.82**	.380**

* Significant at P=0.05
** Significant at P=0.01
†H = Heterogeneous correlations, therefore could not compute pooled value.

Cont'd.

Table 10. (Continued)

Characteristics Correlated	Population C-70-1 n=103	C-70-2 n=87	C-70-3 n=41	Pooled Correlation
Degree of lodging with:				
Level of α-amylase	-.24*	-.26*	-.37*	-.273**
Saccharifying activity	-.04	-.22*	-.09	-.119
% Barley nitrogen	-.20*	.18	.08	H
Soluble amino-nitrogen	-.40**	-.37*	-.33*	-.389**
Level of α-amylase with:				
Saccharifying activity	.36**	.72**	.31*	H
% Barley nitrogen	.17	.02	-.42**	H
Soluble amino-nitrogen	.66**	.74**	.60**	.686**
Saccharifying activity with:				
% Barley nitrogen	.25*	.29**	.19	.254**
Soluble amino-nitrogen	.24*	.64**	.55**	H
% Barley nitrogen with:				
Soluble amino-nitrogen	.30*	.05	-.09	.139*

* Significant at P=0.05
** Significant at P=0.01
† H = Heterogeneous correlations, therefore could not compute pooled value.

did Syme (1972), Fonseca and Patterson (1968) and Lebsock and Amaya (1969) in wheat studies, that no relationship existed. This was not surprising, since Rasmusson (1973) indicated the original semi-dwarf was selected for head type. Height showed a significant negative correlation with days to heading in C-70-1 and C-70-3 while the relationship was negative but non-significant in C-70-2. This generally negative association was reported by Johnson et al. (1966(a)) from wheat work while reports from barley studies have been either of a positive (Barker et al., 1964), or a non-significant nature (Rutger et al., 1967). Days to maturity showed no association with height except in C-70-1 in which there was a significant negative correlation. This correlation is in agreement with the report of Fiuzat and Atkins (1953).

Plant height showed only homogeneous correlations with the quality traits, all non-significant.

Associations with yield per plot showed no heterogeneous correlation groups across the three populations. Positive, significant correlations were obtained between yield and kernels per spike, test weight, days in post-anthesis and degree of lodging. Significant negative relationships existed between yield and days to heading, saccharifying activity, percent barley nitrogen and soluble amino-nitrogen. No significant association was revealed between yield and 200 kernel weight, percent plumpness, days to maturity or level of alpha-amylase.

The positive relationship of barley yield with kernels per spike had been reported by several workers including Yap and Harvey (1972) and Rasmusson and Cannell (1970). The non-significant relationship with kernel weight was previously reported only by Hayter and Riggs (1973) and in some crosses studied by Hsi and Lambert (1954). In the present study the relationship of yield and kernels/spike was significant at P=0.05 and the relationship between yield and kernel weight was not significant. This is supportive of Quisenberry (1928), who concluded that kernel weight was not as important a component of yield as was kernels per spike.

The positive correlation of yield and test weight is in agreement with the reports of Rutger et al. (1967) and DenHartog and Lambert (1953). On an individual basis only population C-70-1 showed a significant relationship.

Contrary to reports in other crops involving semi-dwarf and tall material (Chandler (1969) in rice, and Briggle and Vogel (1968) in wheat) and the report by Sisler and Olsen (1951) from a barley study, the present study showed a positive yield - degree of lodging relationship.

The negative correlation between yield and percent barley nitrogen, or protein, has been previously reported by many workers including Hayter and Riggs (1973) from barley studies.

The yield component, kernels per spike, showed a

significant negative correlation with the yield component, kernel weight, in agreement with yield component compensation and distribution of photosynthate theories (Adams, 1967), as well as being in agreement with reports by Grafius and Okoli (1974) and Rasmusson and Cannell (1970). A significant negative association of kernels per spike with percent plumpness was also shown in the present study. Test weight was negatively associated with kernels per spike in population C-70-2; however, the pooled correlation over populations was not significant.

Kernels per spike showed no relationship to days to heading, while there were positive associations between kernels per spike and days to maturity and days in post-anthesis. These correlations were not significant on an individual population basis except for kernels per spike and days in post-anthesis in population C-70-1.

Kernels per spike was positively related to the degree of lodging in the present study and generally negatively associated with the quality parameters measured, although the relationship with the level of alpha-amylase was not significant.

As reported by Crook and Poehlman (1971), this study revealed a significant positive association of kernel weight with percent plumpness, and as reported by Hsi and Lambert (1954), there was a significant positive correlation between kernel weight and test weight. Kernel weight was negatively related to days to heading and positively related

to days in post-anthesis and lodging.

Significant negative relationships were found in this study between kernel weight and levels of alpha-amylase and of soluble amino-nitrogen. A significant, but weak, positive correlation was revealed between kernel weight and percent barley nitrogen. Such a relationship was previously reported by Hayter and Riggs (1973) and Metcalfe et al. (1967).

Although the correlations between test weight and percent plumpness were heterogeneous they were all positive and significant. Similar relationships were reported by Crook and Poehlman (1971) and Rutger et al. (1967).

The significant negative association of test weight with days to heading and the positive correlation with days in post-anthesis reflected the effect of these characters in determining the grain filling period. Although previously reported as negative (Rutger et al., 1967), in this study there was a positive association between test weight and degree of lodging.

The test weight - quality factor correlations were notable in that the only population in which these were significant was C-70-2, which showed a positive correlation of test weight and percent barley nitrogen, and negative relationships between test weight and the other quality parameters.

This study showed a positive correlation of percent plumpness with days in post-anthesis and the accompanying

related negative association between plumpness and days to heading. Significant positive correlations occurred between plumpness and degree of lodging in C-70-2 and C-70-3.

Percent plumpness showed generally negative relationships with levels of alpha-amylase, saccharifying activity and soluble amino-nitrogen, again particularly in the case of population C-70-2. A negative association of plumpness with diastatic power was previously reported (Rutger et al., 1967).

There was a strong positive relationship between days to heading and days to maturity in populations C-70-1 and C-70-2. The association was not significant in C-70-3.

Days to heading was negatively associated with days in post-anthesis in all three populations. A strong positive correlation existed between days to maturity and days in post-anthesis in populations C-70-1 and C-70-3. This relationship was particularly strong (r=.82) for C-70-3. The correlation for these parameters was not significant for C-70-2.

The generally negative correlations between degree of lodging and the four quality parameters, i.e. alpha-amylase, saccharifying activity, percent barley nitrogen and soluble amino-nitrogen, reflected the positive association of lodging with the yield components and the negative associations between these quality parameters and the yield components.

The interrelationships amongst the quality parameters

themselves were generally positive. The positive relationship of barley nitrogen and saccharifying activity was previously reported by Metcalfe, et al. (1967). Rutger et al. (1967) reported a positive correlation between saccharifying activity and levels of alpha-amylase.

A significant negative relationship existed between alpha-amylase and percent barley nitrogen in population C-70-3, while in the other populations no relationship was found. Hayter and Riggs (1973) reported no association between these characteristics in their experiment.

Experiment II: Nitrogen Fertilization of Tall and Semi-dwarf Barleys

Analyses of variance (ANOVA) were computed to determine the significance of effects of rates of nitrogen (N) fertilizer on several agronomic and quality parameters in relation to genotypes representing a range of plant heights.

Single degree of freedom comparisons were used, when appropriate, to examine the significance of differences between the means of: (1) tall and semi-dwarf classes, and (2) the control, cv. Bonanza, and the other genotypes. These ANOVA and the relevant mean data are reported in Tables 11 through 53. The information is reported for each of the five environments individually due to the heterogeneity of error variances which existed. The results are presented on the basis of the individual characteristics measured.

Agronomic Characteristics

Plant Height. The ANOVA (Table 11) indicated that significant differences were obtained due to N rates at three of the five locations. This was due to the first increment of N (Table 12C), except at Carman in 1975, where a further increase in height occurred with the second increment of N. No significant increase in height occurred at Carman or Portage in 1976, but there was a trend to this with the first N increment (Table 12C). Increases in height with additional applications of N were previously reported in barley by Pendleton et al. (1953).

The genotypes showed significant height differences at all sites. Although significant differences occurred within the major height classes of tall and semi-dwarf in some experiments (Table 12A), the two height classes were distinct throughout the experiment (Table 12B).

A significant F x G interaction occurred at Portage in 1975 (Table 11). This interaction (Table 13) appeared to result from differential responses of the three semi-dwarf lines to increased levels of N. The deviation of the second highest rate from the pattern imposes some restraint on this interpretation, although no obvious explanation for this deviation is available. Some peculiar chance effects on that treatment may have been the cause.

Yield. The ANOVA (Table 14) indicated significant yield response to applied N at all sites. The mean yields

Table 11. Nitrogen Fertilizer Application Study, ANOVA for Plant Height.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	64.75	94.11	109.72	18.78	26.84
Fertilizers (F)	4	2982.53**	884.31**	242.86**	191.21	67.51
Error (a)	12	107.82	27.08	31.29	82.74	35.29
Genotypes (G)	4	1811.13**	1154.69**	2595.03**	1830.44**	1426.49**
†Talls vs semi-dwarfs	1	7017.84**	4165.94**	9576.02**	6895.26**	5040.20**
Bonanza vs C702024	1	1.60	13.23	42.03	313.60**	198.03**
Bonanza vs C703011	1	3186.23**	1221.03**	2890.00**	3841.60**	2265.00**
Bonanza vs C703032	1	2016.40**	1625.63**	2528.10**	3294.23**	2088.05**
Bonanza vs Minn64-62	1	3478.23**	3045.03**	5736.00**	4622.50**	4264.25**
F x G	16	18.29	22.26**	11.63	14.78	3.34
Error (b)	60	17.58	9.44	13.39	13.64	6.37
Total	99					
Coefficient of variability %						
(1) Error(a)		15.7	7.0	6.8	13.3	7.8
(2) Error(b)		6.3	4.1	4.5	5.4	3.3

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 12. Nitrogen Fertilizer Application Study, Means for Plant Height (cm.)

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	76.3† c	83.2 c	92.9 c	81.5 c	87.2 d
C702024	T	76.7 c	82.1 c	95.0 c	75.9 b	82.7 c
C703011	SD	58.5ab	72.2 b	75.9 b	61.9a	72.1 b
C703032	SD	62.1 b	70.5 b	77.0 b	63.4a	72.7 b
Minn64-62	SD	57.7a	65.8a	69.0a	60.0a	66.5a
B. Height Class						
Talls (T)		76.5 b	82.6 b	93.9 b	78.7 b	84.9 b
Semi-dwarfs (SD)		59.4a	69.5a	73.9a	61.8a	70.4a
C. Nitrogen Applied (kg./ha.)						
0.00		46.4a	63.1a	76.6a	64.0a	73.0a
67.26		63.6 b	75.9 b	80.6 b	66.6a	76.7a
134.52		69.9 bc	78.9 b	83.1 b	70.8a	76.8a
201.78		76.5 c	76.6 b	84.4 b	70.5a	77.4a
269.04		74.9 c	79.2 b	85.2 b	70.9a	77.4a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 13. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Plant Height (cm.) at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.) 0.00	67.26	134.52	201.78	269.04
Bonanza	73.8† b	85.3 c	86.5 c	83.8 b	86.8 c
C702024	73.5 b	83.8 c	84.8 c	82.8 b	85.5 c
C703011	55.8a	74.5 b	78.3 b	74.3a	78.0 b
C703032	55.8a	69.5ab	76.8 b	73.5a	76.8 b
Minn64-62	56.8a	66.5a	68.3a	68.5a	68.8a

B.

Nitrogen Applied (kg./ha.)	Genotype Bonanza	C702024	C703011	C703032	Minn64-62
0.00	73.8a	73.5a	55.8a	55.8a	56.8a
67.26	85.3 b	83.8 b	74.5 b	69.5 b	66.5 b
134.52	86.5 b	84.8 b	78.3 b	76.8 b	68.3 b
201.78	83.8 b	82.8 b	74.3 b	73.5 b	68.5 b
269.04	86.8 b	85.5 b	78.0 b	76.8 b	68.8 b

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 14. Nitrogen Fertilizer Application Study, ANOVA for Yield.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	354,543	292,829	3,380,561	245,297	2,542,631
Fertilizers (F)	4	14,123,504**	5,319,532**	22,210,736**	5,807,980**	6,568,348*
Error (a)	12	257,589	638,591	222,095	362,885	1,359,482
Genotypes (G)	4	179,010	645,458**	1,517,944*	757,116*	2,581,729**
†Talls vs semi-dwarfs	1		809,970**	4,457,195**	960,640**	429,701
Bonanza vs C702024	1		177,546	428,449	590,976**	7,874
Bonanza vs C703011	1		218,301	355,323	2,845,689**	3,307,860**
Bonanza vs C703032	1		889,531**	2,705,144*	744,471**	380,016
Bonanza vs Minn64-62	1		93,799	749,391	251,381	1,687,156*
F x G	16	113,520	193,034	209,461	55,643	276,633
Error (b)	60	84,501	144,268	467,649	82,162	362,816
Total	99					
Coefficient of variability %						
(1) Error(a)		23.1	24.2	10.5	19.1	27.5
(2) Error(b)		13.2	11.5	15.2	9.1	14.2

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

(Table 15C) indicated that the first increment gave a significant response at all sites, whereas the second increment produced a further significant yield increase in only the two tests at Carman.

Significant genotypic differences for yield were obtained in all tests except the one at Carman in 1975 (Table 14, 15A). At three of these four locations the tall genotypes were higher yielding than the semi-dwarfs on a mean basis (Table 15B). However, as shown in Table 15A, at no site was the yield of Minn 64-62 significantly lower than that of the talls; in fact, single degree of freedom comparisons (Table 14) indicated Minn 64-62 to be significantly higher yielding than the tall control genotype cv. Bonanza at Portage in 1976. The lower semi-dwarf mean yield resulted from the overall lower yields of C703011 and C703032.

Unlike the report of Gardener and Rathjen (1975), the present study showed no F x G interaction at any site (Table 14). However, there was a trend for the semi-dwarfs, C703011 and C703032, to show a greater response and/or need for at least the first nitrogen increment. At higher N levels this response did not continue, possibly due to another limiting factor, in this case moisture. Such lack of interaction was previously reported by Syme (1967) in wheat. The importance of moisture in the expression of nitrogen response was reported by Stanberry and Lowrey (1965).

Table 15. Nitrogen Fertilizer Application Study, Means for Yield (kg./ha.)

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	2280a†	3343ab	4642ab	3399 b	4312 bc
C702024	T	2138a	3477 b	4849 b	3156 b	4340 bc
C703011	SD	2067a	3195ab	4453ab	2866a	3737a
C703032	SD	2236a	3045a	4122a	3126 b	4117ab
Minn64-62	SD	2282a	3440 b	4368ab	3241 b	4723 c
B. Height Class						
Talls (T)		2209a	3410 b	4746 b	3778 b	4326a
Semi-dwarfs (SD)		2195a	3227a	4248a	3078a	4192a
C. Nitrogen Applied (kg./ha.)						
0.00		985a†	2392a	2691a	2339a	3363a
67.26		1714 b	3433 b	4408 b	2998ab	4078ab
134.52		2457 c	3464 b	5048 b	3173 bc	4798 b
201.78		2935 c	3535 b	5015 b	3610 c	4300ab
269.04		2911 c	3674 b	5272 b	3668 c	4691 b

† Values in a column followed by the same letter are not significantly different, P=0.05.

Spikes per Unit Area. The ANOVA (Table 16) indicated that increasing N significantly increased the number of spikes per unit area as previously reported by several workers including Konishi (1976) and Gardener and Rathjen (1975). This increase was primarily limited to the initial increment of N, except at Carman in 1975 where the response continued throughout all N increments and at Sanford in 1976 where there was a significant response to the final N increment (Table 17C).

The ANOVA (Table 16) indicated significant differences among genotypes for spikes per unit area existed, and that no F x G interaction occurred.

Further analysis (Table 16) indicated significant differences between the talls and semi-dwarfs at all sites in 1976. This difference was in favour of the semi-dwarfs (Table 17B).

Further single degree of freedom comparisons (Table 16) and the data of Table 17A show that most of the advantage of the semi-dwarfs came from Minn 64-62. C703032 showed an advantage over the talls at the 1976 sites, but semi-dwarf C703011 was, in fact, lower in spikes per unit area than the talls in three of the five experiments.

The disagreement between the analysis of Table 16 and the lack of significant differences indicated at Carman, 1975 in Table 17A arose because the test used in the latter case was less sensitive than the single degree of freedom comparison employed in Table 16. This single degree of

Table 16. Nitrogen Fertilizer Application Study, ANOVA for Spikes/unit area.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	467.72	1309.56	566.57	1513.32	2365.72
Fertilizers (F)	4	2736.06**	3135.56**	9719.93**	1587.52**	1580.43**
Error (a)	12	240.29	418.37	94.10	274.52	344.07
Genotypes (G)	4	521.32*	1822.63**	1550.48**	1312.05**	1681.26**
†Talls vs semi-dwarfs	1	205.34	82.14	4320.17**	2242.67**	932.51*
Bonanza vs C702024	1	7.23	202.50	40.00	108.90	0.40
Bonanza vs C703011	1	18.23	931.23*	748.23	32.40	230.48
Bonanza vs C703032	1	.40	270.40	697.23	1575.03**	220.90
Bonanza vs Minn64-62	1	1254.44*	2805.63**	4100.63**	1768.90**	3648.10**
F x G	16	134.78	196.54	318.46	112.89	119.78
Error (b)	60	178.12	155.56	331.25	137.50	195.48
Total	99					
Coefficient of variability %						
(1) Error(a)		18.2	20.5	8.8	22.4	19.3
(2) Error(b)		15.7	12.5	16.5	15.8	14.5

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 17. Nitrogen Fertilizer Application Study, Means for Spikes/unit area.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	83.1a	96.6ab	103.1a	69.9a	92.5a
C702024	T	83.9a	101.1 b	101.1a	66.6a	92.7a
C703011	SD	81.7a	86.9a	111.7ab	68.1a	87.7a
C703032	SD	83.3a	101.8 b	111.4ab	82.5 b	97.2a
Minn64-62	SD	94.3a	113.3 c	123.3 b	83.2 b	111.6 b
B. Height Class						
Talls (T)		83.5a	98.8a	102.1a	68.8a	92.6a
Semi-dwarfs (SD)		86.4a	100.7a	118.8 b	77.9 b	98.8 b
C. Nitrogen Applied (kg./ha.)						
0.00		69.0a	78.3a	72.3a	59.3a	82.7a
67.26		80.7ab	100.2 b	111.9 b	72.8ab	96.3ab
134.52		88.0 bc	107.4 b	117.9 b	77.4 b	106.9 b
201.78		87.5 bc	108.5 b	119.1 b	82.3 b	95.3ab
269.04		101.1 c	105.2 b	129.4 c	78.6 b	100.4ab

† Values in a column followed by the same letter are not significantly different, P=0.05.

freedom comparison indicated Minn 64-62 had significantly more spikes per unit area than Bonanza at this site as well.

Kernels per Spike. As was the case in experiments reported by Gardener and Rathjen (1975) and Schreiber and Stanberry (1963) the results of this study (Table 18) showed increased kernels per spike with increased fertilizer N. The increase was significant at three of five locations and the means in Table 19C indicate the major effect to be from the first N increment. However, at Carman 1975, the response continued to the third N level. Again no F x G interaction was indicated (Table 18).

Single degree of freedom comparisons (Table 18) revealed significant differences between genotypes and between height classes for kernels per spike. The data of table 19B showed this to be in favour of the talls. In view of the higher spike number per unit area of the semi-dwarfs, and the negative relationships between yield components (Davis, 1967), this would be expected.

At all sites C703032 and Minn 64-62 had significantly fewer kernels per spike than did the tall genotypes (Table 19A). On the other hand, the semi-dwarf C703011 had as many or more kernels per head than the talls. In fact, it had significantly more than Bonanza at Portage in 1975. This genotype, in general, had the lowest number of spikes per unit area among the lines in this test (Table 17A).

It is worth noting that, at Portage 1976, Minn 64-62

Table 18. Nitrogen Fertilizer Application Study, ANOVA for Kernels/spike.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	180.33	18.64	42.57	53.72	191.13
Fertilizers (F)	4	1547.46**	13.38	115.76**	66.51	92.80*
Error (a)	12	36.57	23.11	15.74	24.13	26.30
Genotypes (G)	4	160.62**	180.22**	132.35**	408.03**	66.12**
†Talls vs semi-dwarfs	1	313.93**	145.04**	226.44**	696.82**	61.82**
Bonanza vs C702024	1	2.50	99.23**	71.29*	25.92	21.03
Bonanza vs C703011	1	4.23	96.10**	8.28	8.28	20.45
Bonanza vs C703032	1	372.10**	75.63**	53.82*	571.54**	76.73**
Bonanza vs Minn64-62	1	235.23**	90.00**	144.40**	504.10**	16.90
F x G	16	12.70	9.73	15.11	13.55	9.05
Error (b)	60	10.17	7.34	12.49	19.87	8.44
Total	99					
Coefficient of variability %						
(1) Error(a)		12.9	9.3	7.8	9.9	9.2
(2) Error(b)		6.8	5.3	6.9	9.0	5.2

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 19. Nitrogen Fertilizer Application Study, Means for Kernels/spike.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	49.2 b	51.5 b	51.5 bc	52.1 b	56.3 b
C702024	T	48.7 b	54.7 c	54.1 c	53.8 b	57.7 b
C703011	SD	48.5 b	54.6 c	52.4 bc	53.1 b	57.7 b
C703032	SD	43.1a	48.8a	49.1ab	44.6a	53.5a
Minn64-62	SD	44.3a	48.5a	47.7a	45.0a	55.0ab
B. Height Class						
Talls (T)		48.9 b	53.1 b	52.8 b	53.0 b	57.0 b
Semi-dwarfs (SD)		45.3a	50.6a	49.7a	47.6a	55.3a
C. Nitrogen Applied (kg./ha.)						
0.00		32.6a	50.3a	47.0a	47.0a	52.8a
67.26		43.9 b	51.5a	53.1 b	48.9a	55.2ab
134.52		50.8 c	51.9a	52.5 b	51.6a	56.9ab
201.78		53.0 c	52.1a	51.7 b	51.0a	56.9ab
269.04		53.5 c	52.3a	50.4ab	50.1a	58.5 b

† Values in a column followed by the same letter are not significantly different, P=0.05.

did not have significantly fewer kernels per spike than Bonanza (Table 19A), but did have more spikes per unit area (Table 17). At this site Minn 64-62 did show yield superiority over Bonanza, though not by a significant margin (Table 14).

200 Kernel Weight. Kernel weight responses to fertilizer were significant at only three locations, whereas significant line differences were shown at all locations (Table 20, 21). The study showed increased kernel weight at the initial increments of N, followed by decreased kernel weight as the applied N increased. This general reaction has been reported in barley by Gardener and Rathjen (1975) and Reisenauer and Dickson (1960).

At Carman, 1975, there was an increase in kernel weight with N increment one, and no change thereafter. At Portage, 1975, the first increment of N gave the heaviest kernels, but in this test there was a significant decrease in kernel weight at the higher N levels. At Sanford 1976, there was a progressive decrease in kernel weight as N was increased above the control level.

At all sites, the talls had significantly heavier kernels than did the semi-dwarfs (Table 21B).

Significant F x G interactions were detected at Carman 1975 and Sanford 1976 (Table 20). The interaction at Carman, 1975 (Table 22) resulted primarily from C702024 showing no significant response to N while the other genotypes responded

Table 20. Nitrogen Fertilizer Application Study, ANOVA for 200 Kernel Weight.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	0.19	0.05	0.09	0.18	1.16
Fertilizers (F)	4	1.68**	0.77**	1.08**	0.05	0.14
Error (a)	12	0.06	0.13	0.06	0.06	0.21
Genotypes (G)	4	3.26**	1.61**	1.29**	2.36**	1.35**
†Talls vs semi-dwarfs	1	1.22**	3.38**	3.94**	6.20**	2.16**
Bonanza vs C702024	1	2.40**	0.84**	0.03	1.09**	0.90**
Bonanza vs C703011	1	10.20**	5.93**	3.03**	8.84**	5.33**
Bonanza vs C703032	1	.05	2.50**	1.44**	3.14**	0.96**
Bonanza vs Minn64-62	1	1.09**	0.84**	0.44**	2.70**	0.96**
F x G	16	0.19**	0.10	0.09*	0.03	0.04
Error (b)	60	0.07	0.06	0.04	0.03	0.06
Total	99					
Coefficient of variability %						
(1) Error(a)		4.0	5.6	3.5	3.4	6.9
(2) Error(b)		4.4	3.8	2.8	2.4	3.7

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 21. Nitrogen Fertilizer Application Study, Means for 200 Kernel Weight.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	6.37 c	6.79 c	7.10 c	7.48 d	7.05 c
C702024	T	5.88 b	6.50 b	7.15 c	7.15 c	6.75 b
C703011	SD	5.36a	6.02a	6.55a	6.54a	6.32a
C703032	SD	6.30 c	6.29 b	6.72ab	6.92 b	6.74 b
Minn64-62	SD	6.04 b	6.50 b	6.89 b	6.96 b	6.74 b
B. Height Class						
Talls (T)		6.13 b	6.65 b	7.13 b	7.32 b	6.90 b
Semi-dwarfs (SD)		5.90a	6.27a	6.72a	6.81a	6.60a
C. Nitrogen Applied (kg./ha.)						
0.00		5.49a	6.47ab	7.24 c	6,95a	6.65a
67.26		6.07 b	6.71 b	6.97 b	7.00a	6.72a
134.52		6.22 b	6.46ab	6.82ab	7.09a	6.86a
201.78		6.16 b	6.22a	6.75ab	7.01a	6.67a
269.04		6.02 b	6.25a	6.64a	7.01a	6.69a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 22. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for 200 Kernel Weight at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	5.67† b	6.35 b	6.72 b	6.67 b	6.45 b
C702024	5.77 b	6.02 b	6.20 b	5.75a	5.67a
C703011	4.60a	5.30a	5.55a	5.72a	5.65a
C703032	5.92 b	6.57 b	6.25 b	6.42 b	6.35 b
Minn64-62	5.50 b	6.12 b	6.37 b	6.25ab	5.97ab

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	5.67a	5.77a	4.60a	5.92a	5.50a
67.26	6.35 b	6.02a	5.30 b	6.57 b	6.12 b
134.52	6.72 b	6.20a	5.55 b	6.25ab	6.37 b
201.78	6.67 b	5.75a	5.72 b	6.42ab	6.25 b
269.04	6.45 b	5.67a	5.65 b	6.35ab	5.97ab

† Values in a column followed by the same letter are not significantly different, P=0.05.

significantly to the first N increment. Bonanza and C703011 maintained this increased kernel weight at the higher N levels, while C703032 and Minn 64-62 showed a decrease at the very highest N level.

At Sanford, 1976, the interaction (Table 23) arose because C703011 and Bonanza showed no significant response to N, while the other genotypes all showed a negative response to the first increment of N, with Minn 64-62 showing this negative response through to the highest N level.

C703011 was consistently lowest in kernel weight and Bonanza was highest (Table 21A). The other genotypes were intermediate, with C702024 having kernel weight not significantly different from Bonanza. The very low error in measurement of kernel weight enabled detection of the F x G interactions.

Degree of Lodging. Lodging occurred only in the two 1975 trials. ANOVA and treatment means are reported in Tables 24 and 25.

Applied N had a significant effect only at Portage, and lodging increased as did the rate of applied N (Table 25C). Each N increment gave significantly more lodging. No significant effect of N was found at Carman due to the very low lodging levels; however, a trend toward more lodging as N increased existed (Table 25C). A similar effect of N was previously reported by Pendleton et al.

Table 23. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for 200 Kernel Weight at Sanford, 1976.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	7.25† b	7.07 bc	7.12 b	7.15 c	6.92 b
C702024	7.52 b	7.35 c	6.97 b	6.97 bc	6.95 b
C703011	6.77a	6.55a	6.55a	6.47a	6.42a
C703032	7.25 b	6.87ab	6.50a	6.50a	6.47a
Minn64-62	7.40 b	7.00 bc	6.97 b	6.65ab	6.42a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	7.25a	7.52 b	6.77a	7.25 b	7.40 c
67.26	7.07a	7.35ab	6.55a	6.87ab	7.00 bc
134.52	7.12a	6.97a	6.55a	6.50a	6.97 bc
201.78	7.15a	6.97a	6.47a	6.50a	6.65ab
269.04	6.92a	6.95a	6.42a	6.47a	6.42a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 24. Nitrogen Fertilizer Application Study, ANOVA for Degree of Lodging.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	1.79	4.80	NO DATE	NO DATA	NO DATA
Fertilizers (F)	4	5.76	30.42**			
Error (a)	12	1.78	.38			
Genotypes (G)	4	8.14**	29.62**			
†Talls vs semi-dwarfs	1	20.91**	96.80**			
Bonanza vs C702024	1	10.00**	4.23			
Bonanza vs C703011	1	.63	12.10*			
Bonanza vs C703032	1	1.60	24.03**			
Bonanza vs Minn64-62	1	4.28**	57.60**			
F x G	16	1.44**	4.10**			
Error (b)	60	.57	1.59			
Total	99					
Coefficient of variability %						
(1) Error(a)		78.9	22.7			
(2) Error(b)		44.7	46.4			

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 25. Nitrogen Fertilizer Application Study, Means for Lodging.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	1.75a†	3.60 cd	NO DATA	NO DATA	NO DATA
C702024	T	2.75 b	4.25 d			
C703011	SD	1.50a	2.50 bc			
C703032	SD	1.35a	2.05ab			
Minn64-62	SD	1.10a	1.20a			
B. Height Class						
Talls (T)		2.25 b	3.93 b	NO DATA	NO DATA	NO DATA
Semi-dwarfs (SD)		1.32a	1.92a			
C. Nitrogen Applied (kg./ha.)						
0.00		1.10a	1.00a	NO DATA	NO DATA	NO DATA
67.26		1.15a	2.10 b			
134.52		2.00a	2.80 c			
201.78		1.90a	3.55 d			
269.04		2.30a	4.15 e			

† Values in a column followed by the same letter are not significantly different, P=0.05.

(1953).

As in the reports by Chandler (1969) for rice, and Briggle and Vogel (1968) for wheat, the present study indicated there was significantly more lodging in the tall genotypes than the semi-dwarfs at both sites (Table 25B).

Significant F x G interaction occurred at both sites (Table 24). At Carman the interaction (Table 26) resulted from C702024 showing increased lodging with more applied N while the other genotypes showed no significant response. At Portage the interaction (Table 27) arose due to two semi-dwarfs, C703032 and Minn 64-62, showing no response to applied N while the other genotypes, in particular the talls, responded positively to the first two N increments.

C703032 and Minn 64-62 were the most lodging resistant and C702024 the most susceptible genotypes in this study (Table 25A).

Test Weight. This character was significantly affected by applied N at only the two 1975 sites (Table 28). At both sites the initial N increment gave increased test weight, while further increments gave no change at Carman, but resulted in a decrease to original levels at Portage (Table 29C). Similar results were reported by Reisenauer and Dickson (1960) for the closely related character of kernel plumpness in barley.

As indicated by data in Table 29B, differences in favour of the talls existed between height classes at only

Table 26. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Lodging at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.) 0.00	67.26	134.52	201.78	269.04
Bonanza	1.00a†	1.00a	2.50a	2.25a	2.00ab
C702024	1.00a	1.50a	3.50a	3.25a	4.50 b
C703011	1.50a	1.25a	1.25a	1.75a	1.75ab
C703032	1.00a	1.00a	1.50a	1.25a	2.00ab
Minn64-62	1.00a	1.00a	1.25a	1.00a	1.25a

B.

Nitrogen Applied (kg./ha.)	Genotype Bonanza	C702024	C703011	C703032	Minn64-62
0.00	1.00a	1.00a	1.50a	1.00a	1.00a
67.26	1.00a	1.50a	1.25a	1.00a	1.00a
134.52	2.50a	3.50 b	1.25a	1.50a	1.25a
201.78	2.25a	3.25 b	1.75a	1.25a	1.00a
269.04	2.00a	4.50 b	1.75a	2.00a	1.25a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 27. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Lodging at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	1.00a	3.50a	3.00ab	5.00 bc	5.50 bc
C702024	1.00a	2.50a	5.25 b	6.00 c	6.50 c
C703011	1.00a	2.25a	2.75ab	2.00a	4.50 bc
C703032	1.00a	1.00a	2.00a	3.25ab	3.00ab
Minn64-62	1.00a	1.25a	1.00a	1.50a	1.25a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	1.00a	1.00a	1.00a	1.00a	1.00a
67.26	3.50ab	2.50a	2.25ab	1.00a	1.25a
134.52	3.00ab	5.25 b	2.75ab	2.00a	1.00a
201.78	5.00 b	6.00 b	2.00ab	3.25a	1.50a
269.04	5.50 b	6.50 b	4.50 b	3.00a	1.25a

Values in a column followed by the same letter are not significantly different, P=0.05.

Table 28. Nitrogen Fertilizer Application Study, ANOVA for Test Weight.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	3.04	8.20	1.16	3.58	13.53
Fertilizers (F)	4	54.12**	15.67**	0.19	0.48	8.05
Error (a)	12	5.19	1.76	1.31	1.34	9.38
Genotypes (G)	4	51.16**	4.46*	28.17**	17.94**	7.48**
†Talls vs semi-dwarfs	1	0.49	0.48	74.90**	40.87**	0.34
Bonanza vs C702024	1	17.42	0.36	31.24**	10.20**	4.49
Bonanza vs C703011	1	106.28**	5.78*	2.03	67.08**	8.10*
Bonanza vs C703032	1	6.40	1.94	16.13**	27.89**	1.60
Bonanza vs Minn64-62	1	0.03	2.40	8.84**	16.77**	4.23
F x G	16	10.38*	3.39**	0.57	0.44	0.67
Error (b)	60	4.60	1.38	0.53	0.46	1.83
Total	99					
Coefficient of variability %						
(1) Error(a)		3.8	2.2	1.8	1.8	4.7
(2) Error(b)		3.6	1.9	1.1	1.1	2.1

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 29. Nitrogen Fertilizer Application Study, Means for Test Weight (kg./hl.)

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	60.2 bc	60.9ab	65.5 c	64.4 d	65.5ab
C702024	T	58.9 b	60.8ab	67.2 d	63.4 c	64.8ab
C703011	SD	56.9a	60.2a	65.0 bc	61.8a	64.6a
C703032	SD	61.0 c	60.5ab	64.2a	62.7 b	65.1ab
Minn64-62	SD	60.2 bc	61.4 b	64.5ab	63.2 bc	66.2 b
B. Height Class						
Talls (T)		59.5a	60.9a	66.3 b	63.9 b	65.2a
Semi-dwarfs (SD)		59.4a	60.7a	64.6a	62.6a	65.3a
C. Nitrogen Applied (kg./ha.)						
0.00		56.6a	61.1ab	65.2a	62.8a	64.9a
67.26		59.8 b	62.0 b	65.3a	63.0a	65.2a
134.52		60.6 b	60.9ab	65.4a	63.1a	66.2a
201.78		60.3 b	59.9a	65.2a	63.2a	64.5a
269.04		60.0 b	59.9a	65.3a	63.2a	65.5a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Sanford and Carman, 1976. Since N had no effect at these locations, these differences were genotypic.

Significant F x G interaction occurred at both 1975 sites. The interaction at Carman, 1975 (Table 30) was due to C703011 and Minn 64-62 showing significant positive response to applied N, while the remaining genotypes did not. At Portage, 1975 (Table 31) the F x G interaction occurred as C702024 showed a negative response to N, while C703011 showed an initial positive response followed by a negative response to higher N rates. The other genotypes exhibited no significant response.

Overall, C703011 was the lowest in test weight, while the other genotypes did not differ consistently over locations (Table 29A). The small error (Table 28), gave rise to a highly sensitive test for statistical significance. These sorts of differences would not likely be critical from a practical production viewpoint.

Days to Heading. Applied N affected days to heading at both sites in 1975 and at Sanford, 1976 (Table 32). This effect was due to the first N increment at all sites (Table 33); however, the effect at the 1975 sites was to cause heading to be earlier, while at Sanford, 1976, heading was delayed. Results similar to the 1975 data were reported by Stanberry and Lowrey (1965).

At all sites, the semi-dwarfs headed sooner than the talls (Table 33B). However, it is evident (Table 33A) that

Table 30. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Test Weight (kg./hl.) at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	58.0† b	60.5a	60.5a	61.1a	60.8a
C702024	59.0 b	58.9a	59.6a	59.0a	58.0a
C703011	49.9a	57.7a	60.2a	58.0a	59.0a
C703032	59.2 b	61.7a	61.8a	61.1a	61.1a
Minn64-62	56.8 b	60.2a	61.1a	62.4a	60.8a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	58.0a	59.0a	49.9a	59.2a	56.8a
67.26	60.5a	58.9a	57.7 b	61.7a	60.2ab
134.52	60.5a	59.6a	60.2 b	61.8a	61.1ab
201.78	61.1a	59.0a	58.0 b	61.1a	62.4 b
269.04	60.8a	58.0a	59.0 b	61.1a	60.8ab

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 31. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Test Weight (kg./hl.) at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	61.1ab†	62.4a	60.8a	60.5a	59.9a
C702024	63.0 b	62.4a	60.5a	59.0a	59.0a
C703011	58.6a	61.8a	60.2a	59.9a	60.5a
C703032	61.1ab	61.4a	61.5a	59.0a	59.6a
Minn64-62	61.4ab	62.1a	61.8a	61.1a	60.8a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	61.1a	63.0 b	58.6a	61.1a	61.4a
67.26	62.4a	62.4 b	61.8 b	61.4a	62.1a
134.52	60.8a	60.5ab	60.2ab	61.5a	61.8a
201.78	60.5a	59.0a	59.9ab	59.0a	61.1a
269.04	59.9a	59.0a	60.5ab	59.6a	60.8a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 32. Nitrogen Fertilizer Application Study, ANOVA for Days to Heading.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	2.04	1.50	8.39	0.22	57.98
Fertilizers (F)	4	30.37**	13.63**	17.21**	1.12	2.89
Error (a)	12	3.63	0.96	1.46	1.45	4.82
Genotypes (G)	4	29.34**	52.61**	41.94**	11.02**	69.56**
†Talls vs semi-dwarfs	1	60.80**	23.21**	91.26**	12.33*	151.00**
Bonanza vs C702024	1	50.63**	115.60**	57.60**	12.10**	30.63**
Bonanza vs C703011	1	9.03**	1.60	8.10*	11.03**	72.90**
Bonanza vs C703032	1	3.60	1.23	18.23**	4.90**	55.23**
Bonanza vs Minn64-62	1	0.23	48.40**	0.00	42.03**	0.23
F x G	16	2.53*	1.40*	1.65	0.82	2.11
Error (b)	60	1.26	0.65	1.10	0.53	2.20
Total	99					
Coefficient of variability %						
(1) Error(a)		3.5	1.9	1.9	2.2	3.1
(2) Error(b)		2.1	1.6	1.7	1.3	2.6

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 33. Nitrogen Fertilizer Application Study, Means for Days to Heading.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	54.2ab	51.1a	62.4 b	53.2a	58.0 b
C702024	T	56.5 c	54.5 c	64.8 c	54.3 b	59.8 c
C703011	SD	53.3a	50.7a	61.5ab	54.2 b	55.3a
C703032	SD	53.9ab	51.5a	61.0a	53.9 b	55.7a
Minn64-62	SD	54.4 b	53.3 b	62.4 b	55.2 c	58.2 b
B. Height Class						
Talls (T)		55.3 b	52.8 b	63.6 b	53.7 b	58.9 b
Semi-dwarfs (SD)		53.8a	51.8a	61.6a	54.4a	56.4a
C. Nitrogen Applied (kg./ha.)						
0.00		56.6 b	53.7 b	60.9a	54.0a	57.3a
67.26		54.0a	51.9a	62.3 b	54.2a	57.1a
134.52		53.9a	51.7a	62.5 b	54.5a	57.1a
201.78		53.6a	52.2a	63.3 b	53.9a	57.4a
269.04		54.1a	51.7a	63.0 b	54.2a	58.0a

† Values in a column followed by the same letter are not significantly different, P=0.05.

this resulted primarily from the generally earlier heading of C703011 and C703032 and the late heading of C702024. Minn 64-62 headed later, and Bonanza headed early, as compared to their respective plant height category means.

F x G interaction was significant at both 1975 sites, and the means are presented in Tables 34 and 35. At Carman (Table 34) the interaction was due to Bonanza and C703011 exhibiting significantly earlier heading due to increased N while the other genotypes showed no significant response. The F x G interaction at Portage (Table 35) was caused by a similar situation, with C702024, C703011 and C703032 showing the response to N.

Days to Maturity. Data for this character were not taken at Carman, 1976. Applied N significantly affected maturity only at Carman, 1975 and Sanford, 1976 (Table 36). The effect of N was to delay maturity (Table 37C). The delay at Sanford came with the first N increment, but the effect at Carman 1975 did not occur until the second N increment.

The semi-dwarf group, in this study, matured earlier than the tall genotypes at all sites (Table 37B). However, C703011 and C703032 were consistently the earliest, C702024 and Minn 64-62 consistently the latest and Bonanza intermediate for days to maturity (Table 37A).

The Carman, 1975 F x G interaction (Table 36) is explained by the results presented in Table 38B. Bonanza

Table 34. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Days to Heading at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	57.5† b	53.8ab	53.3a	52.3a	54.3a
C702024	58.0 b	56.0 b	55.8 b	55.8 b	56.8 b
C703011	56.8ab	52.5a	52.0a	52.8a	52.3a
C703032	54.8a	53.3ab	54.3ab	53.8ab	53.3a
Minn64-62	56.0ab	54.3a	54.0ab	53.5ab	54.0a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	57.5 b	58.0a	56.8 b	54.8a	56.0a
67.26	53.8ab	56.0a	52.5a	53.3a	54.3a
134.52	53.3ab	55.8a	52.0a	54.3a	54.0a
201.78	52.3a	55.8a	52.8a	53.8a	53.5a
269.04	54.3ab	56.8a	52.3a	53.3a	54.0a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 35. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Days to Heading at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	51.8a†	50.8a	51.3a	51.0a	50.8a
C702024	56.0 c	54.0 c	53.8 b	54.8 b	54.0 b
C703011	53.0ab	50.0a	49.8a	51.0a	49.8a
C703032	53.8 b	51.5ab	50.5a	50.8a	50.8a
Minn64-62	53.8 b	53.0 bc	53.3 b	53.3 b	53.3 b

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	51.8a	56.0 b	53.0 b	53.8 b	53.8a
67.26	50.8a	54.0a	50.0a	51.5a	53.0a
134.52	51.3a	53.8a	49.8a	50.5a	53.3a
201.78	51.0a	54.8ab	51.0a	50.8a	53.3a
269.04	50.8a	54.0a	49.8a	50.8a	53.3a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 36. Nitrogen Fertilizer Application Study, ANOVA for Days to Maturity.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	2.81	9.72	9.90	NO DATA	9.93
Fertilizers (F)	4	29.06**	1.86	34.54**		10.66
Error (a)	12	2.05	4.63	1.99		5.20
Genotypes (G)	4	132.41**	159.56**	50.57**		46.89**
†Talls vs semi-dwarfs	1	143.08**	58.91**	64.03**		41.08**
Bonanza vs C702024	1	24.03**	102.40**	22.50**		27.23**
Bonanza vs C703011	1	168.10**	52.90**	24.03**		27.23**
Bonanza vs C703032	1	67.60**	25.60**	46.23**		16.90**
Bonanza vs Minn64-62	1	28.90**	160.00**	11.03**		22.50**
F x G	16	4.89**	2.93	0.78		0.61
Error (b)	60	1.24	1.71	1.03		0.81
Total	99					
Coefficient of variability %						
(1) Error(a)		1.8	2.7	1.5		2.7
(2) Error(b)		1.4	1.6	1.1		1.1

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 37. Nitrogen Fertilizer Application Study, Means for Days to Maturity.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	81.8 c	79.8 b	91.9 b	NO DATA	84.3 b
C702024	T	83.3 d	83.2 c	93.4 c		86.0 c
C703011	SD	77.7a	77.7a	90.4a		82.8a
C703032	SD	79.2 b	78.4a	89.8a		83.0a
Minn64-62	SD	83.5 d	84.0 c	93.0 c		85.8 c
B. Height Class						
Talls (T)		82.5 b	81.5 b	92.7 b	NO DATA	85.1 b
Semi-dwarfs (SD)		80.1a	80.0a	91.0a		83.8a
C. Nitrogen Applied (kg./ha.)						
0.00		80.1a	81.0a	89.5a	NO DATA	83.2a
67.26		79.6a	80.5a	91.8 b		84.1a
134.52		81.4 b	80.2a	91.9 b		84.9a
201.78		82.1 b	80.6a	92.8 b		84.5a
269.04		82.3 b	80.8a	92.6 b		85.0a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 38. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Days to Maturity at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	81.5† b	81.0 b	82.3 c	82.0 b	82.0 bc
C702024	84.3 c	81.3 b	83.5 c	83.5 bc	84.0 cd
C703011	76.5a	76.0a	77.3a	79.5a	79.0a
C703032	75.5a	77.8a	79.8 b	81.5ab	81.3 b
Minn64-62	82.5 bc	81.8 b	84.3 c	84.7 c	85.0 d

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	81.5a	84.3 b	76.5a	75.5a	82.5ab
67.26	81.0a	81.3a	76.0a	77.8ab	81.8a
134.52	82.3a	83.5ab	77.3ab	79.8 bc	84.3ab
201.78	82.0a	83.5ab	79.5 b	81.5 c	84.7 b
269.04	82.0a	84.0 b	79.0 b	81.3 c	85.0 b

† Values in a column followed by the same letter are not significantly different, P=0.05.

showed no response to N, while C702024 and Minn 64-62 showed earlier maturity in response to the first N increment but delayed maturity at higher N levels. On the other hand, C703011 and C703032 showed only a delay in maturity as N increased.

Days in Post-Anthesis. No data were calculated for this characteristic at Carman 1976. N affected this parameter only at Carman 1975 and Sanford 1976 (Table 39). At both sites, the lower increments of N lengthened the post-anthesis period, primarily via delayed maturity (Table 37); however, the effect of earlier heading at higher N levels at Carman 1975 (Table 33) was also involved.

At both 1975 sites the tall genotypes had longer post-anthesis periods than the semi-dwarfs, while in 1976 there were no significant differences at Sanford and a difference in favour of the semi-dwarfs at Portage (Table 40B).

In general, C703011 and C703032 had the shortest post-anthesis periods and Minn 64-62 had the longest (Table 40A), reflecting their differences in maturity. At Portage, 1976, although not demonstrated by the Duncan's Multiple Range test (Table 40A), the single degree of freedom comparison (Table 39) indicated that Minn 64-62 had a significantly longer post-anthesis period than Bonanza.

The F x G interaction at Carman 1975 was due to C702024 showing no significant response to nitrogen, while the other genotypes did (Table 41B). Differences between genotypes

Table 39. Nitrogen Fertilizer Application Study, ANOVA for Days in Post-Anthesis.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	3.17	8.45	3.50	NO DATA	22.41
Fertilizers (F)	4	88.21**	8.32	3.49**		9.29
Error (a)	12	5.66	7.34	0.49		5.54
Genotypes (G)	4	68.68**	48.40**	13.18**		8.97**
†Talls vs semi-dwarfs	1	20.91**	8.17*	2.41		34.56**
Bonanza vs C702024	1	4.90	0.40	8.10**		0.10
Bonanza vs C703011	1	99.23**	36.10**	4.23*		11.03*
Bonanza vs C703032	1	50.63**	38.03**	6.40*		11.03*
Bonanza vs Minn64-62	1	24.03**	32.40**	11.03**		18.23**
F x G	16	5.15**	3.60*	1.01		3.17
Error (b)	60	1.79	1.60	1.01		2.36
Total	99					
Coefficient of variability %						
(1) Error(a)		8.9	9.5	2.4		8.7
(2) Error(b)		5.0	4.5	3.4		5.7

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 40. Nitrogen Fertilizer Application Study, Means for Days in Post-anthesis.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	27.6 b	28.9 b	29.6a	NO DATA	26.3a
C702024	T	26.9 b	28.7 b	28.7a		26.2a
C703011	SD	24.4a	27.0a	28.9a		27.4a
C703032	SD	25.3a	26.9a	28.8a		27.4a
Minn64-62	SD	29.1 c	30.7 c	30.6 b		27.7a
B. Height Class						
Talls (T)		27.2 b	28.8 b	29.1a	NO DATA	26.3a
Semi-dwarfs (SD)		26.3a	28.2a	29.4a		27.5 b
C. Nitrogen Applied (kg./ha.)						
0.00		23.5a	27.4a	28.6a	NO DATA	25.9a
67.26		25.6 b	28.7a	29.5 b		27.1a
134.52		27.6 bc	28.5a	29.4 b		27.8a
201.78		28.5 c	28.4a	29.5 b		27.1a
269.04		28.2 c	29.1a	29.6 b		27.0a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 41. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Days in Post-Anthesis at Carman, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	24.0† b	27.3 bc	29.0 b	29.8 b	27.8ab
C702024	26.3 b	25.3abc	27.8ab	27.8ab	27.3ab
C703011	19.8a	23.5a	25.3a	26.8a	26.8a
C703032	20.8a	24.5ab	25.5a	27.8ab	28.0ab
Minn64-62	26.5 b	27.5 c	30.3 b	30.3 b	31.0 b

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	24.0a	26.3a	19.8a	20.8a	26.5a
67.26	27.3 b	25.3a	23.5 b	24.5 b	27.5ab
134.52	29.0 b	27.8a	25.3 b	25.5 b	30.3 b
201.78	29.8 b	27.8a	26.8 b	27.8 b	30.3 b
269.04	27.8 b	27.3a	26.8 b	28.0 b	31.0 b

† Values in a column followed by the same letter are not significantly different, P=0.05.

for this parameter diminished as N increased (Table 41A). The interaction at Portage in 1975 was due to C703032 showing a response to applied N while no other genotype did (Table 42B). Again we see the trend toward equality of genotypes as N increased (Table 42A).

Percent Barley Nitrogen. The ANOVA (Table 43) indicated that applied N significantly affected this parameter at all sites except Portage, 1976. The lack of response at that site was probably due to mid to late season moisture stress. It will be noted that, at the Carman site, where the initial soil nitrogen level was low in both years, barley nitrogen increased progressively with higher fertilizer N increments (Table 44C). At Portage in 1975, on the other hand, the grain nitrogen was relatively high, probably reflecting higher initial fertility, and there was little response to added fertilizer (Table 44A). Similar results were reported by Gardener and Rathjen (1975) and Kirby (1968).

Although significant differences between genotypes were shown for all locations, the data (Table 44A) indicate these differences were inconsistent across locations.

A significant F x G interaction was shown at Carman, 1976. This resulted from the fact that the differences between genotypes at zero N applied, were minimized through additions of fertilizer, indicating that the initially low genotypes showed a greater response to N than did the others (Table 45A).

Table 42. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Days in Post-Anthesis at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	29.3†b	30.0 b	27.5a	28.8ab	28.8a
C702024	28.5 b	28.5ab	28.8a	28.0a	29.5a
C703011	25.5a	27.0a	26.8a	27.0a	28.5a
C703032	24.5a	26.8a	27.8a	27.0a	28.5a
Minn64-62	29.0 b	31.0 b	31.8 b	31.3 b	30.3a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	29.3a	28.5a	25.5a	24.5a	29.0a
67.26	30.0a	28.5a	27.0a	26.8ab	31.0a
134.52	27.5a	28.8a	26.8a	27.8 b	31.8a
201.78	28.8a	28.0a	27.0a	27.0ab	31.3a
269.04	28.8a	29.5a	28.5a	28.5 b	30.3a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 43. Nitrogen Fertilizer Application Study, ANOVA for Barley Nitrogen.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	0.065	0.113	0.013	0.010	0.589
Fertilizers (F)	4	1.201**	0.361**	0.968**	1.093**	0.117
Error (a)	12	0.007	0.052	0.005	0.005	0.118
Genotypes (G)	4	0.030**	0.056**	0.058**	0.016*	0.026**
†Talls vs semi-dwarfs	1	0.004	0.202**	0.073*	0.019	0.004
Bonanza vs C702024	1	0.004	0.009	0.049	0.025*	0.036*
Bonanza vs C703011	1	0.016	0.196**	0.016	0.000	0.001
Bonanza vs C703032	1	0.049**	0.081**	0.049	0.004	0.004
Bonanza vs Minn64-62	1	0.016	0.081**	0.009	0.001	0.036*
F x G	16	0.008	0.010	0.010	0.010*	0.009
Error (b)	60	0.006	0.009	0.013	0.006	0.006
Total	99					
Coefficient of variability %						
(1) Error(a)		4.1	9.8	3.8	3.5	16.2
(2) Error(b)		3.9	3.9	6.0	3.6	3.5

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 44. Nitrogen Fertilizer Application Study, Means for Barley Nitrogen (mg./100 g.)

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	2.06ab	2.41 b	1.94ab	2.07ab	2.15ab
C702024	T	2.08ab	2.38 b	1.87a	2.02a	2.09a
C703011	SD	2.02a	2.27a	1.90ab	2.07ab	2.14ab
C703032	SD	2.13 b	2.32ab	2.01 b	2.09ab	2.17 b
Minn64-62	SD	2.10ab	2.32ab	1.97ab	2.06ab	2.09a
B. Height Class						
Talls (T)		2.07a	2.40 b	1.92a	2.05a	2.12a
Semi-dwarfs (SD)		2.08a	2.30a	1.96 b	2.07a	2.13a
C. Nitrogen Applied (kg./ha.)						
0.00		1.76a	2.13a	1.63a	1.70a	2.01a
67.26		1.92 b	2.30ab	1.78 b	1.97 b	2.09a
134.52		2.10 c	2.36 b	2.04 c	2.12 c	2.15a
201.78		2.28 d	2.45 b	2.08 c	2.25 d	2.17a
269.04		2.34 d	2.45 b	2.14 c	2.27 d	2.21a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 45. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Barley Nitrogen at Carman, 1976.

A.

Genotype	Nitrogen Applied (kg./ha.)				
	0.00	67.26	134.52	201.78	269.04
Bonanza	1.63a†	2.01a	21.5a	2.27a	2.28a
C702024	1.61a	1.87a	2.08a	2.25a	2.26a
C703011	1.79 b	2.02a	2.13a	2.17a	2.25a
C703032	1.74ab	2.03a	2.16a	2.25a	2.27a
Minn64-62	1.73ab	1.94a	2.06a	2.29a	2.27a

B.

Nitrogen Applied (kg./ha.)	Genotype				
	Bonanza	C702024	C703011	C703032	Minn64-62
0.00	1.63a	1.61a	1.79a	1.74a	1.73a
67.26	2.01 b	1.87 b	2.02 b	2.03 b	1.94 b
134.52	2.15 bc	2.08 c	2.13 bc	2.16 bc	2.06 b
201.78	2.27 c	2.25 d	2.17 bc	2.25 c	2.29 c
269.04	2.28 c	2.26 d	2.25 c	2.27 c	2.27 c

† Values in a column followed by the same letter are not significantly different, P=0.05.

QUALITY CHARACTERISTICS

Quality determinations were made on only three parameters on samples from the 1975 trials.

Levels of Alpha-amylase. Applied N had no effect on this character (Tables 46 and 47C), contrary to the report of Reisenauer and Dickson (1960).

The tall genotypes were significantly and substantially superior in alpha-amylase to the semi-dwarfs at both locations (Tables 47A and 47B). Bonanza was the highest and Minn 64-62 the lowest of the genotypes.

The F x G interaction at Portage (Table 46) reflected the significant response of C703032 to applied N in comparison with a minimal response of the other lines (Table 48B).

Saccharifying Activity. ANOVA (Table 49) indicated significant fertilizer effects at both sites. The response was positive, and continued to the highest level of applied N (Table 50C). These results are in general agreement with those reported by Reisenauer and Dickson (1960).

ANOVA (Table 49) indicated significant differences between the plant height classes, but the difference was opposite in direction at the two sites (Table 50B). This was mainly due (Table 50A) to a major shift in the value for Bonanza between sites. Overall, C702024 and C703011 were high in saccharifying activity, while Minn 64-62 was low.

Table 46. Nitrogen Fertilizer Application Study, ANOVA for α-amylase.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	134.51	250.53	NO DATA	NO DATA	NO DATA
Fertilizers (F)	4	66.06	18.41			
Error (a)	12	23.10	18.36			
Genotypes (G)	4	352.02**	295.90**			
†Talls vs semi-dwarfs	1	1247.62**	451.01**			
Bonanza vs C702024	1	24.96	136.16**			
Bonanza vs C703011	1	378.23**	189.23**			
Bonanza vs C703032	1	644.81**	127.45**			
Bonanza vs Minn64-62	1	964.32**	1127.84**			
F x G	16	11.29	11.57*			
Error (b)	60	10.86	5.91			
Total	99					
Coefficient of variability %						
(1) Error(a)		14.8	15.7			
(2) Error(b)		10.2	8.9			

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 47. Nitrogen Fertilizer Application Study, Means for α-amylase.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	37.6 c	31.8 c	NO DATA	NO DATA	NO DATA
C702024	T	36.0 c	28.1 b			
C703011	SD	31.4 b	27.5 b			
C703032	SD	29.6ab	28.3 b			
Minn64-62	SD	27.8a	21.2a			
B.						
Height Class						
Talls (T)		36.8 b	30.0 b	NO DATA	NO DATA	NO DATA
Semi-dwarfs (SD)		20.6a	25.6a			
C.						
Nitrogen Applied (kg./ha.)						
0.00		30.2a	26.7a	NO DATA	NO DATA	NO DATA
67.26		32.0a	26.5a			
134.52		33.1a	27.0a			
201.78		31.9a	28.1a			
269.04		35.1a	28.7a			

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 48. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for α-amylase at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.) 0.00	67.26	134.52	201.78	269.04
Bonanza	32.1† b	31.8 b	31.7 b	31.7 b	31.8 c
C702024	26.6a	26.6 b	26.8 b	29.2 b	31.5 bc
C703011	26.6a	27.3 b	29.0 b	27.5ab	27.0 b
C703032	25.3a	27.1 b	27.3 b	28.8 b	32.8 c
Minn64-62	22.6a	19.4a	20.4a	23.2a	20.4a

B.

Nitrogen Applied (kg./ha.)	Genotype Bonanza	C702024	C703011	C703032	Minn64-62
0.00	31.1a	26.6a	26.6a	25.3a	22.6a
67.26	31.8a	26.6a	27.3a	27.1ab	19.4a
134.52	31.7a	26.8a	29.0a	27.3ab	20.4a
201.78	31.7a	29.2a	27.5a	28.8ab	23.2a
269.04	31.8a	31.5a	27.0a	32.8 b	20.4a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 49. Nitrogen Fertilizer Application Study, ANOVA for Saccarifying Activity.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	388.69	1528.42	NO DATA	NO DATA	NO DATA
Fertilizers (F)	4	27652.86**	12816.64**			
Error (a)	12	776.98	1014.26			
Genotypes (G)	4	11175.00**	15042.04**			
†Talls vs semi-dwarfs	1	12549.23**	9118.20**			
Bonanza vs C702024	1	8294.40**	11.03			
Bonanza vs C703011	1	3496.90**	902.50			
Bonanza vs C703032	1	2402.50*	540.23			
Bonanza vs Minn64-62	1	8179.60**	34869.03**			
F x G	16	787.28	762.29**			
Error (b)	60	454.91	321.70			
Total	99					
Coefficient of variability %						
(1) Error(a)		10.2	11.4			
(2) Error(b)		7.8	6.4			

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 50. Nitrogen Fertilizer Application Study, Means for Saccharifying Activity.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	273.2 bc	219.3a	NO DATA	NO DATA	NO DATA
C702024	T	302.0 d	292.4 b			
C703011	SD	291.9 cd	300.8 b			
C703032	SD	257.7ab	284.0 b			
Minn64-62	SD	244.6a	232.3a			
B.						
Height Class						
Talls (T)		287.6 b	355.8a	NO DATA	NO DATA	NO DATA
Semi-dwarfs (SD)		264.7a	272.3 b			
C.						
Nitrogen Applied (kg./ha.)						
0.00		218.8a	244.2a	NO DATA	NO DATA	NO DATA
67.26		256.8 b	269.7ab			
134.52		284.7 c	279.6 bc			
201.78		294.1 cd	298.4 bc			
269.04		314.9 d	308.9 c			

† Values in a column followed by the same letter are not significantly different, P=0.05.

The F x G interaction at Portage (Table 49) was caused by Minn 64-62 showing no significant response to N while the other genotypes showed a positive and significant response (Table 51B).

Soluble Amino-Nitrogen. Fertilizer significantly increased soluble amino-N at both sites (Table 52) and added increments of N led to progressively higher levels (Table 53). Minn 64-62 was consistently lower than the other genotypes in soluble amino-N by a significant margin.

Experiment III: Row Spacing and Seeding Rate Study

ANOVA were used to determine the significance of differences between genotypes, seeding rates, row spacings and interactions of these for each of the seven parameters measured. Single degree of freedom comparisons were used to elucidate differences between the factor levels when ANOVA indicated these to be significant.

Plant Height

Genotypic height differences were significant at all sites (Table 54), as expected based on the choice of lines. Seeding rate effects were not significant, but row-spacings effects were at two of the three locations (Table 54).

The row-spacing effects were opposite, in that at Carman the plants were significantly shorter at the widest

Table 51. Nitrogen Fertilizer Application Study.
Fertilizer X Genotype Interaction Means for Saccharifying Activity at Portage, 1975.

A.

Genotype	Nitrogen Applied (kg./ha.) 0.00	67.26	134.52	201.78	269.04
Bonanza	258.0a†	289.0 b	293.8 b	304.8 b	311.0 b
C702024	251.8a	270.3 b	291.8 b	314.8 b	333.3 b
C703011	259.8a	299.3 b	307.0 b	315.0 b	323.0 b
C703032	231.0a	262.0ab	279.8 b	308.0 b	339.0 b
Minn64-62	220.3a	228.0a	225.5a	249.3a	238.3a

B.

Nitrogen Applied (kg./ha.)	Genotype Bonanza	C702024	C703011	C703032	Minn64-62
0.00	258.0a	251.8a	259.8a	231.0a	220.3a
67.26	289.0ab	270.3ab	299.3ab	262.0ab	228.0a
134.52	293.8ab	291.8 bc	307.0 b	279.8 b	225.5a
201.78	304.8ab	314.8 bc	315.0 b	308.0 bc	249.3a
269.04	311.0 b	333.3 c	323.0 b	339.0 c	238.3a

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 52. Nitrogen Fertilizer Application Study, ANOVA for Soluble Amino-nitrogen.

Source of Variation	df	MEAN SQUARES				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Replicates	3	0.028	0.039	NO DATA	NO DATA	NO DATA
Fertilizers (F)	4	0.108**	0.056*			
Error (a)	12	0.005	0.011			
Genotypes (G)	4	0.046**	0.127**			
†Talls vs semi-dwarfs	1	0.082**	0.056**			
Bonanza vs C702024	1	0.001	0.025**			
Bonanza vs C703011	1	0.001	0.001			
Bonanza vs C703032	1	0.016	0.016*			
Bonanza vs Minn64-62	1	0.121**	0.361**			
F x G	16	0.006	0.001			
Error (b)	60	0.006	0.002			
Total	99					
Coefficient of variability %						
(1) Error(a)		13.1	21.2			
(2) Error(b)		14.0	9.9			

* F significant at P=0.05.
** F significant at P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 53. Nitrogen Fertilizer Application Study, Means for Soluble Amino-nitrogen.

A. Genotype	Height Class	Environments				
		Carman 1975	Portage 1975	Sanford 1976	Carman 1976	Portage 1976
Bonanza	T	0.58 b	0.55 b	NO DATA	NO DATA	NO DATA
C702024	T	0.59 b	0.50 b			
C703011	SD	0.57 b	0.56 b			
C703032	SD	0.54 b	0.51 b			
Minn64-62	SD	0.47a	0.36a			
B.						
Height Class						
Talls (T)		0.58 b	0.53 b	NO DATA	NO DATA	NO DATA
Semi-dwarfs (SD)		0.52a	0.48a			
C.						
Nitrogen Applied (kg./ha.)						
0.00		0.44a	0.44a	NO DATA	NO DATA	NO DATA
67.26		0.53 b	0.46ab			
134.52		0.56 b	0.49ab			
201.78		0.57 b	0.56 b			
269.04		0.64 c	0.54 b			

† Values in a column followed by the same letter are not significantly different, P=0.05.

Table 54. Seeding Rate - Row Spacing Study, ANOVA for Plant Height.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	0.90	91.35	9.19
Genotypes (G)	1	6913.35**	7776.00**	8919.19**
Seeding Rates (SR)	2	24.80	5.63	10.13
† SR1 vs SR2	1			
SR1 vs SR3	1			
SR2 vs SR3	1			
Row Spacing (RS)	2	3.02	96.07*	28.07*
RS1 vs RS2	1		5.76	26.01*
RS1 vs RS3	1		110.25*	51.84**
RS2 vs RS3	1		166.41**	4.41
G x SR	2	0.91	6.22	19.02*
G x RS	2	7.35	0.89	9.85
SR x RS	4	12.07	22.60	1.30
G x SR x RS	4	2.07	23.36	3.69
Error	34	17.38	19.65	5.50
Total	53			
Coefficient of Variability %		5.0	6.6	2.5

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

row spacing, while at Winnipeg the plants were significantly shorter at the narrowest row spacing (Table 55).

A significant genotype by seeding rate interaction occurred at Winnipeg (Table 54) due to Bonanza showing a negative response to increased row width, while Minn 64-62 showed little response, and if anything a slight positive response to the intermediate seeding rate.

Yield

ANOVA (Table 56) indicated significant differences between the genotypes at two of the locations. At Carman, this was in favour of the tall, and at Winnipeg, in favour of the semi-dwarf (Table 57). At Sanford the semi-dwarf outyielded the tall, but due to the large error mean square (Table 56), this difference was not statistically significant. Environmental conditions were ideal at Winnipeg, adequate at Sanford and extremely poor at Carman. Also, the seeding date at Carman was considerably later. These responses are in agreement with the reports of Syme (1967) and Porter et al. (1964) which suggested that semi-dwarf wheats performed best under conditions conducive to high productivity.

Seeding rates affected yield only under the adverse conditions of late seeding and drought stress at Carman (Table 56), with the highest seeding rate giving the greatest yield (Table 57). There was also a trend to higher yields at higher seed rates at Sanford. These

Table 55. Seeding Rate - Row Spacing Study, Means for Plant Height (cm.).

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	95.1* b	79.2 b	105.2 b
Minn64-62	72.5a	55.2a	79.5a
Seeding Rates (SR) kg./ha.			
(1) 56.0	84.8a	66.7a	93.1a
(2) 84.0	83.9a	67.1a	92.4a
(3)112.0	82.6a	67.8a	91.6a
Row Spacing (RS) cm.			
(1) 15.0	83.3a	68.1 b	91.0a
(2) 30.5	84.1a	68.9 b	92.7 b
(3) 61.0	83.9a	64.6a	93.4 b

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	96.0	73.8	78.4	54.9	107.0	79.2
Seeding Rate (2)	95.2	72.7	79.8	54.4	104.2	80.6
Seeding Rate (3)	94.1	71.0	79.3	56.2	104.4	78.8

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	94.7	72.0	80.1	56.1	103.2	78.8
Row Spacing (2)	94.8	73.4	80.7	57.1	105.3	80.0
Row Spacing (3)	95.8	72.0	76.8	52.3	107.1	79.8

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	85.0	84.0	81.0	66.5	69.0	68.8	92.0	91.3	89.7
Row Spacing (2)	84.3	85.3	82.7	67.3	70.2	69.2	93.3	92.3	92.3
Row Spacing (3)	85.3	82.5	84.0	66.2	62.2	65.3	94.0	93.5	92.8

* Values in a column followed by the same letter are not significantly different, P=0.05.

Table 56. Seeding Rate - Row Spacing Study, ANOVA for Yield.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	267,246	1,183,900	47,931
Genotypes (G)	1	963,897	1,293,849**	8,394,884**
Seeding Rates (SR)	2	488,530	1,007,190*	4,108
† SR1 vs SR2	1		236,196	
SR1 vs SR3	1		1,954,404**	
SR2 vs SR3	1		831,744	
Row Spacing (RS)	2	9,876,339**	6,650,258**	3,890,740**
RS1 vs RS2	1	81	335,241	22,500
RS1 vs RS3	1	14,791,761**	11,614,464**	5,461,569**
RS2 vs RS3	1	14,861,025**	8,003,241**	6,185,169**
G x SR	2	168,294	135,762	101,574
G x RS	2	228,206	167,743	41,693
SR x RS	4	254,057	517,187	172,171
G x SR x RS	4	195,930	662,661*	152,163
Error	34	482,082	222,295	105,252
Total	53			
Coefficient of Variability %		15.1	18.3	5.4

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 57. Seeding Rate - Row Spacing Study, Means for Yield (kg./ha.).

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	4458a*	2733 b	5628a
Minn64-62	4725a	2423a	6416 b
Seeding Rates (SR) kg./ha.			
(1) 56.0	4431a	2369a	6024a
(2) 84.0	4584a	2531ab	6035a
(3)112.0	4760a	2835b	6006a
Row Spacing (RS) cm.			
(1) 15.0	5018 b	3021 b	6265 b
(2) 30.5	5021 b	2828 b	6316 b
(3) 61.0	3736a	1885a	5486a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	4354	4509	2527	2211	5716	6333
Seeding Rate (2)	4338	4829	2771	2291	5611	6459
Seeding Rate (3)	4682	4838	2901	2769	5556	6456

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	4819	5217	3073	2969	5876	6654
Row Spacing (2)	4823	5219	3072	2585	5965	6664
Row Spacing (3)	3734	3740	2055	1716	5041	5931

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	4665	5139	5249	2670	3083	3311	6425	6278	6092
Row Spacing (2)	4791	5030	5243	2421	3001	3063	6136	6332	6476
Row Spacing (3)	3838	3582	3789	2016	1510	2131	5512	5497	5448

* Values in a column followed by the same letter are not significantly different, P=0.05.

results are in agreement with previous reports by Guitard et al. (1961); however, as has been the case in yet other studies (Finlay et al. 1970 and Woodward, 1956) the seeding rates used did not cover a wide enough range to give significant differences at two of the sites. The result at Carman, where seeding was delayed, supported the report of Day and Thompson (1970) who found that as seeding was delayed the seeding rate needed to be increased.

Row spacing affected yield at all sites (Table 56). The significant effect at all sites was due to lower yield at the widest row spacing (Table 57). Similar results were reported by Holliday (1963). The results (Table 57) indicated no advantage of the narrowest row spacing compared to the intermediate, contrary to the findings of Holliday (1963). However, at Carman, under adverse growing conditions with heavy weed infestations, there was a trend toward the narrowest spacing yielding more.

No significant first order interactions occurred (Table 56). However, the results of Table 57 indicated a trend towards the semi-dwarf being more responsive to seeding rate increases, particularly under the near-optimal conditions at Winnipeg, in which the tall variety showed a negative response to increased seeding rate. Such trends were reported by Stickler and Younis (1966) with sorghum genotypes differing in plant height. The genotype x row spacing means (Table 57), for Carman, also showed a trend to higher semi-dwarf yield at the narrowest row spacing,

while the tall showed virtually no yield difference between the narrowest and the intermediate spacings. Similar results were reported from a wheat study by Stoskopf (1967).

A significant genotype x seeding rate x row spacing interaction occurred at Carman (Table 56). This interaction was due to Bonanza consistently outyielding the semi-dwarf at all levels of all seeding-rate - row-spacing combinations except for the combination of the narrowest row space and the highest seeding rate. At this treatment combination Minn 64-62 outyielded Bonanza by an amount equal to that by which the reverse had occurred at all other treatment combinations. This effect was probably due to the adverse growth conditions at this site, resulting in particular stress on the semi-dwarf due to early weed competition. At the narrow row spacing and higher seeding rate the semi-dwarf was able to compete with the weeds as well as the tall genotype and thus yielded more grain at that treatment combination. Similar results were reported from a wheat study (Young and Bauer, 1973).

Spikes per Unit Area

At Sanford and Winnipeg the semi-dwarf had significantly more spikes per unit area than the tall (Table 58).

In agreement with the findings of Guitard *et al.* (1961) a positive effect on spikes per unit area resulted from increased seeding rates (Table 59), although the change was

Table 58. Seeding Rate - Row Spacing Study, ANOVA for Spike/unit area.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	809.9	1,983.7	5,790.2
Genotypes (G)	1	8,387.6**	93.4	22,489.0**
Seeding Rates (SR)	2	21,690.0**	3,614.1	7,248.2**
† SR1 vs SR2	1	14,616.8**		11,728.9**
SR1 vs SR3	1	42,973.3**		9,920.2*
SR2 vs SR3	1	7,465.0*		76.7
Row Spacing (RS)	2	40,992.1**	50,424.4**	34,646.9**
RS1 vs RS2	1	12,454.6**	15,277.0**	13,584.4**
RS1 vs RS3	1	80,883.4**	99,225.0**	69,063.8**
RS2 vs RS3	1	29,756.3**	36,634.0**	21,433.0**
G x SR	2	1,886.8	394.7	195.9
G x RS	2	745.2	72.5	2,125.4
SR x RS	4	3,256.9	300.2	4,840.4**
G x SR x RS	4	931.0	1,817.9	2,378.0
Error	34	1,399.0	1,422.4	1,215.0
Total	53			
Coefficient of Variability %		14.5	24.8	11.2

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 59. Seeding Rate - Row Spacing Study, Means for Spikes/unit area (1.22 m^2).

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	245.8a*	150.7a	290.3a
Minn64-62	270.7 b	153.4a	331.1 b
Seeding Rates (SR) kg./ha.			
(1) 56.0	221.8a	136.7a	287.6a
(2) 84.0	262.1 b	154.8a	323.7 b
(3)112.0	290.9 c	164.7a	320.8 b
Row Spacing (RS) cm.			
(1) 15.0	302.2 c	200.8 c	352.8 c
(2) 30.5	265.0 b	159.6 b	314.0 b
(3) 61.0	207.5a	95.8a	265.2a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	197.7	245.9	131.9	141.6	266.3	308.8
Seeding Rate (2)	253.7	270.4	158.8	150.8	300.4	346.9
Seeding Rate (3)	286.0	295.8	161.6	167.8	304.0	337.6

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	282.7	321.8	201.8	199.9	323.1	382.4
Row Spacing (2)	258.0	272.0	157.6	161.6	290.9	337.1
Row Spacing (3)	196.7	218.3	92.9	98.7	256.8	273.7

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	254.0	295.3	357.3	183.3	201.8	217.3	366.0	346.3	346.0
Row Spacing (2)	221.0	292.0	282.0	138.0	168.0	172.7	267.3	333.0	341.7
Row Spacing (3)	190.3	198.8	233.3	88.8	94.5	104.0	229.3	291.7	274.7

* Values in a column followed by the same letter are not significantly different, P=0.05.

not significant at Carman.

At all sites decreased row spacing gave rise to significantly more spikes per unit area. Finlay et al. (1971) reported a similar result.

No significant genotype by treatment interactions occurred (Table 58), but the first increment in seeding rate showed a greater response than the second for both genotypes at all sites, particularly at Winnipeg (Table 59). The results also indicated a greater negative response to increased row width at the second increment as compared to the first. These trends indicated movements toward and away from the optima respectively.

At both Sanford and Carman the combination of highest seeding rate and narrowest row width gave the greatest number of spikes per unit area. However, a significant seeding rate X row spacing interaction occurred at Winnipeg (Table 58). The interaction resulted from seeding rate having a negative effect at the narrowest spacing but a positive effect at wider spacings. This resulted from the ideal conditions eliminating much of the difference due to the seeding rates at this site. Tillering was sufficient to compensate for fewer plants, particularly at the narrowest row spacing in which there would also be less intra-row crowding of plants.

Kernels per Spike

Table 60 contains the ANOVA for kernels per spike.

Table 60. Seeding Rate - Row Spacing Study, ANOVA for Kernels/spike.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	17.41	15.39	9.27
Genotypes (G)	1	4.92	571.68**	.60
Seeding Rates (SR)	2	255.88**	129.91*	19.04*
† SR1 vs SR2	1	262.44**	112.78	5.76
SR1 vs SR3	1	479.61**	250.91**	27.69*
SR2 vs SR3	1	32.49	27.25	15.21
Row Spacing (RS)	2	17.17	66.74	4.85
RS1 vs RS2	1			
RS1 vs RS3	1			
RS2 vs RS3	1			
G x SR	2	58.91*	39.24	1.55
G x RS	2	62.43*	1.00	7.20
SR x RS	4	18.06	27.73	1.84
G x SR x RS	4	5.54	12.77	17.52*
Error	34	12.52	30.23	5.24
Total	53			
Coefficient of Variability %		6.9	12.0	4.5

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Genotypes differed significantly only at Carman, where Bonanza averaged approximately six more kernels per spike than the semi-dwarf (Table 61). This behaviour, different from that at the other sites, as well as the lack of interactions at Carman, can be attributed to the inability of the semi-dwarf to cope with the high levels of stress at this site.

Significant reductions in kernels per spike occurred at all sites as seeding rates increased (Table 61). A similar result was previously reported by Guitard et al. (1961).

Row spacing did not significantly affect kernels/spike in this study (Table 60).

Significant genotype by seeding rate and genotype by row spacing interactions occurred at Sanford (Table 60). The first of these occurred due to the tall genotype's kernel number per spike declining significantly with each seeding rate increase, while the semi-dwarf's declined only with the first increment, and did not drop as much (Table 61). The second interaction occurred because the semi-dwarf showed fewer kernels per spike as row spacing narrowed, while the tall genotype showed the reverse (Table 61).

A second order genotype by seeding rate by row spacing interaction occurred at Winnipeg (Table 60). The semi-dwarf had more kernels per spike at the narrowest row spacing and lowest seeding rate, and as the seeding rate increased at that spacing the tall genotype became superior in kernels

Table 61. Seeding Rate - Row Spacing Study, Means for Kernels/spike.

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	51.1a*	49.0 b	51.2a
Minn64-62	51.7a	42.5a	51.0a
Seeding Rates (SR) kg./ha.			
(1) 56.0	55.6 b	48.7 b	52.1 b
(2) 84.0	50.2a	45.1ab	51.3ab
(3)112.0	48.3a	43.4a	50.0a
Row Spacing (RS) cm.			
(1) 15.0	50.3a	46.5a	50.7a
(2) 30.5	52.1a	47.2a	51.0a
(3) 61.0	51.8a	43.5a	51.7a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	56.8	54.4	51.3	46.0	52.0	52.1
Seeding Rate (2)	50.4	50.0	50.1	40.2	51.7	50.8
Seeding Rate (3)	46.0	50.6	45.6	41.2	50.0	50.1

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	51.3	49.3	50.0	43.0	51.0	50.3
Row Spacing (2)	52.6	51.6	50.2	44.1	51.6	50.4
Row Spacing (3)	49.3	54.2	46.7	40.3	51.1	52.3

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	55.0	47.2	48.7	49.0	47.0	43.4	51.1	51.0	49.8
Row Spacing (2)	55.1	52.7	48.5	48.4	48.1	45.0	51.8	51.5	49.7
Row Spacing (3)	56.7	50.8	47.8	48.5	40.3	41.8	53.2	51.3	50.5

* Values in a columnfollowed by the same letter are not significantly different, P=0.05.

per spike. There was little difference at the intermediate row spacing. At the widest row width the tall genotype had more kernels per spike at the lowest seed rate while the semi-dwarf had the most at the highest seeding rate at this row width.

200 Kernel Weight

Significant differences occurred between genotypes and seeding rates at Carman and Sanford (Table 62). No other significant differences or interactions resulted.

At both sites where differences were found, the tall genotype had heavier kernels (Table 63). This was expected from previous results with these genotypes (Experiments I and II). Under more ideal growing conditions at Winnipeg no differences occurred. The absence of any effect of row spacing on seed weight was previously reported by Finlay et al (1971).

The decreased kernel weight with increased seeding rate at Sanford and Carman (Table 63) in the present study is in agreement with the report of Guitard et al (1961). Although not significant, a similar trend existed at Winnipeg (Table 63).

Test Weight

ANOVA (Table 64) indicated no significant effect of either row spacing or seeding rate on this parameter as was the case in reports by Siemens (1963) and Middleton et al.

Table 62. Seeding Rate - Row Spacing Study, ANOVA for 200 Kernel Weight.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	0.026	0.079	2.426
Genotypes (G)	1	0.427**	6.545**	0.031
Seeding Rates (SR)	2	0.214**	1.147**	0.418
† SR1 vs SR2	1	0.320**	0.860**	
SR1 vs SR3	1	0.320**	2.250**	
SR2 vs SR3	1	0.000	0.320	
Row Spacing (RS)	2	0.046	0.042	0.335
RS1 vs RS2	1			
RS1 vs RS3	1			
RS2 vs RS3	1			
G x SR	2	0.107	0.254	0.154
G x RS	2	0.027	0.025	0.019
SR x RS	4	0.027	0.072	0.193
G x SR x RS	4	0.012	0.064	0.310
Error	34	0.038	0.088	0.180
Total	53			
Coefficient of Variability %		2.8	4.3	6.0

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 63. Seeding Rate - Row Spacing Study, Means for 200 Kernel Weight (g.).

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	6.95 b*	7.31 b	7.05a
Minn64-62	6.77a	6.61a	7.10a
Seeding Rates (SR) kg./ha.			
(1) 56.0	6.99 b	7.23 b	7.25a
(2) 84.0	6.80a	6.92a	7.01a
(3)112.0	6.80a	6.73a	6.97a
Row Spacing (RS) cm.			
(1) 15.0	6.82a	7.02a	6.99a
(2) 30.5	6.86a	6.92a	7.00a
(3) 61.0	6.92a	6.95a	7.23a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	7.17	6.81	7.71	6.76	7.31	7.19
Seeding Rate (2)	6.84	6.76	7.24	6.60	6.89	7.13
Seeding Rate (3)	6.84	6.76	6.98	6.49	6.96	6.98

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	6.94	6.69	7.33	6.70	6.93	7.06
Row Spacing (2)	6.94	6.77	7.31	6.53	6.99	7.01
Row Spacing (3)	6.97	6.87	7.29	6.61	7.23	7.23

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	6.98	6.75	6.72	7.27	6.98	6.80	7.00	7.08	6.90
Row Spacing (2)	6.97	6.85	6.75	7.12	7.00	6.65	7.38	6.77	6.85
Row Spacing (3)	7.02	6.80	6.93	7.32	6.78	6.75	7.37	7.18	7.15

* Values in a column followed by the same letter are not significantly different, P=0.05.

Table 64. Seeding Rate - Row Spacing Study, ANOVA for Test Weight.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	2.001	1.437	27.337
Genotypes (G)	1	0.012	25.764**	29.630**
Seeding Rates (SR)	2	0.797	0.007	9.546
† SR1 vs SR2	1			
SR1 vs SR3	1			
SR2 vs SR3	1			
Row Spacing (RS)	2	0.565	1.175	2.630
RS1 vs RS2	1			
RS1 vs RS3	1			
RS2 vs RS3	1			
G x SR	2	1.156	0.118	5.902
G x RS	2	0.128	0.459	2.568
SR x RS	4	0.369	0.286	2.688
G x SR x RS	4	0.195	1.974*	3.295
Error	34	0.876	0.528	3.507
Total	53			
Coefficient of Variability %		1.5	1.2	2.9

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

(1963). The genotypes differed significantly for test weight at Carman and Winnipeg (Table 64), in favour of Bonanza at Carman and in favour of Minn 64-62 at Winnipeg (Table 65). This contradictory result is explained again by the tall genotype being more tolerant of the stresses at Carman while the ideal conditions at Winnipeg allowed the later-maturing semi-dwarf to continue growth and complete its grain filling period there.

The significant second order interaction at Carman (Table 64) occurred because differences were consistent over seeding rates at row spacing one, but variable over seeding rates at the other row spacings.

Percent Barley Nitrogen

Significant differences occurred between genotypes at all locations (Table 66), with Bonanza having more grain nitrogen at Winnipeg and less at the other locations (Table 67). Of particular interest are the higher protein levels at Winnipeg despite the high yields at this site, indicative of the more ideal conditions and higher fertility levels there.

No differences attributable to either row spacing or seeding rate for percent barley nitrogen were found, as was the case in a report by Young and Bauer (1963) from a wheat study.

A significant genotype by seeding rate interaction occurred at Carman because percent barley nitrogen for

Table 65. Seeding Rate - Row Spacing Study, Means for Test Weight (kg./hl.).

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	63.9a*	62.9 b	64.9a
Minn64-62	63.9a	61.6a	66.3 b
Seeding Rates (SR) kg./ha.			
(1) 56.0	64.1a	62.3a	66.4a
(2) 84.0	64.0a	62.3a	65.4a
(3)112.0	63.7a	62.2a	65.0a
Row Spacing (RS) cm.			
(1) 15.0	63.9a	62.5a	65.7a
(2) 30.5	63.7a	62.2a	65.2a
(3) 61.0	64.1a	62.0a	65.9a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	64.3	63.8	63.0	61.6	66.1	66.7
Seeding Rate (2)	64.0	64.0	62.9	61.7	64.0	66.8
Seeding Rate (3)	63.4	63.9	63.0	61.5	64.5	65.5

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	63.9	64.0	63.3	61.7	65.1	66.4
Row Spacing (2)	63.8	63.6	63.0	61.5	64.8	65.6
Row Spacing (3)	64.1	64.1	62.5	61.5	64.7	67.1

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	64.1	64.1	63.7	62.5	62.5	62.6	66.1	66.4	64.7
Row Spacing (2)	64.2	63.5	63.5	62.0	62.3	62.3	66.1	64.6	64.8
Row Spacing (3)	64.0	64.3	63.9	62.3	62.0	61.8	67.0	65.1	65.5

* Values in a column followed by the same letter are not significantly different, P=0.05.

Table 66. Seeding Rate - Row Spacing Study, ANOVA for % Barley Nitrogen.

Source of Variation	df	Mean Squares		
		Sanford 1976	Carman 1976	Winnipeg 1976
Replicates (R)	2	0.015	0.094	0.110
Genotypes (G)	1	0.170**	0.073*	0.247**
Seeding Rates (SR)	2	0.018	0.033	0.001
† SR1 vs SR2	1			
SR1 vs SR3	1			
SR2 vs SR3	1			
Row Spacing (RS)	2	0.007	0.039	0.007
RS1 vs RS2	1			
RS1 vs RS3	1			
RS2 vs RS3	1			
G x SR	2	0.000	0.083*	0.001
G x RS	2	0.014	0.014	0.003
SR x RS	4	0.018	0.025	0.004
G x SR x RS	4	0.016	0.007	0.022
Error	34	0.009	0.021	0.011
Total	53			
Coefficient of Variability %		4.7	6.7	4.6

* F significant P=0.05.
** F significant P=0.01.
† Single degree of freedom comparisons are orthogonal, but not all from the same mutually orthogonal set.

Table 67. Seeding Rate - Row Spacing Study, Means for % Barley Nitrogen.

	Locations		
	Sanford 1976	Carman 1976	Winnipeg 1976
Genotypes			
Bonanza	1.92a*	2.12a	2.35 b
Minn64-62	2.03 b	2.19 b	2.21a
Seeding Rates (SR) kg./ha.			
(1) 56.0	2.00a	2.19a	2.28a
(2) 84.0	1.94a	2.17a	2.29a
(3)112.0	1.98a	2.11a	2.28a
Row Spacing (RS) cm.			
(1) 15.0	1.96a	2.20a	2.26a
(2) 30.5	1.97a	2.16a	2.28a
(3) 61.0	2.00a	2.10a	2.30a

Genotype X Seeding Rate	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Seeding Rate (1)	1.95	2.06	2.22	2.15	2.35	2.21
Seeding Rate (2)	1.88	2.00	2.12	2.21	2.35	2.23
Seeding Rate (3)	1.92	2.04	2.01	2.20	2.35	2.20

Genotype X Row Spacing	Bonanza	Minn64-62	Bonanza	Minn64-62	Bonanza	Minn64-62
Row Spacing (1)	1.92	2.00	2.18	2.21	2.32	2.20
Row Spacing (2)	1.93	2.00	2.09	2.23	2.34	2.22
Row Spacing (3)	1.91	2.09	2.07	2.13	2.39	2.22

Seeding Rate X Row Spacing	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)	SR(1)	SR(2)	SR(3)
Row Spacing (1)	1.97	1.90	2.02	2.17	2.26	2.16	2.29	2.25	2.26
Row Spacing (2)	1.96	1.97	1.97	2.21	2.20	2.08	2.26	2.31	2.26
Row Spacing (3)	2.08	1.96	1.96	2.19	2.04	2.08	2.29	2.31	2.31

* Values in a column followed by the same letter are not significantly different, P=0.05.

Bonanza dropped consistently as seeding rate increased, while for Minn 64-62, it went up with the first seed rate increment and remained constant thereafter.

Experiment IV: Coleoptile Length Study

The ANOVA, presented in tables 68 through 71, indicate that significant differences existed between the genotypes studied for coleoptile length, root number, root score and shoot length. Significant differences existed between the means of the two plant height groups (tall and semi-dwarf) for coleoptile length and root number. The talls had longer coleoptiles and more roots (Table 72). However, one tall genotype, C703019, contributed greatly to the significant differences between height groups in this experiment (Table 72). Takahashi (1946) previously reported a positive association of plant height and coleoptile length in barley.

Correlations (Table 73) indicated that, for the genotypes studied, coleoptile length was significantly and positively related to root number, kernel weight and percent plumpness. Contrary to Takahashi's (1946) report, no significant correlation was detected between plant height and coleoptile length in the present study. However, as previously stated, there was a significant difference between height classes in favour of the talls.

Rank correlation also indicated that no relationship existed between coleoptile length and yield or emergence

Table 68. ANOVA for Coleoptile Length, Experiment IV.

Source of Variation	df	Mean Square
Replicates (R)	3	298.5
Genotypes (G)	6	662.0**
Tall vs Semi-dwarf	1	2695.5**
R x G	18	81.6
Error	112	67.2
Total	139	

Coefficient of Variability = 15.5%.
* Significant at P=0.05.
** Significant at P=0.01.

Table 69. ANOVA for Root Number, Experiment IV.

Source of Variation	df	Mean Square
Replicates (R)	3	0.56
Genotypes (G)	6	1.46**
Tall vs semi-dwarf	1	1.10*
R x G	18	0.53*
Error	112	0.25
Total	139	

Coefficient of Variability = 8.3%.
* Significant at P=0.05.
** Significant at P=0.01.

Table 70. ANOVA for Root Score, Experiment IV.

Source of Variation	df	Mean Square
Replicates (R)	3	11.38
Genotypes (G)	6	32.76**
Tall vs Semi-dwarf	1	11.5
R x G	18	5.32
Error	112	3.49
Total	139	

Coefficient of Variability = 14.8%.
* Significant at P=0.05.
** Significant at P=0.01.

Table 71. ANOVA for Shoot Length, Experiment IV.

Source of Variation	df	Mean Square
Replicates (R)	3	1614.4
Genotypes (G)	6	2364.4**
Tall vs Semi-dwarf	1	1246.3
R x G	18	605.6
Error	112	456.0
Total	139	

Coefficient of Variability = 17.2%.
* Significant at P=0.05.
** Significant at P=0.01.

Table 72. Means for Experiment IV.

Genotypes	Coleoptile Length (mm.)	Number of Roots	Root Score	Shoot Length (mm.)
	†			
Bonanza	52.0ab	5.85ab	11.2a	117.1ab
C701013	57.4ab	5.95ab	11.1a	125.6ab
C703019	62.8 b	6.55 b	14.8 b	139.0 b
Minn 64-62	48.3a	5.90ab	12.8ab	132.0ab
C703032	50.2a	6.20ab	13.2ab	118.8ab
C703029	49.2a	5.85ab	12.7ab	128.1ab
C703011	46.6a	5.80a	13.0ab	105.9a
Plant Height Class				
Tall	57.4 b	6.12 b	12.3a	127.2a
Semi-dwarf	48.6a	5.94a	12.9a	121.2a

†Values in one group followed by the same letter are not significantly different at P=0.05.

Table 73. Correlation Coefficients (r) and Rank Correlation Coefficients (r_s) for Coleoptile Length Study, Experiment IV.

A. Variables Correlated	r
Coleoptile Length with:	
Number of roots	.765*
Root Score	.256
Shoot Length	.631
Number of Roots with:	
Root Score	.728
Shoot Length	.589
Root Score with:	
Shoot Length	.389

B. Variables Correlated	r_s
Coleoptile Length with:	
Plant Height	.536
Yield	.143
200 Kernel weight	.893**
% Plumpness	.857*
Emergence Rate Index	.143
Root Number with:	
Plant Height	.045
Yield	.277
200 Kernel weight	.491
% Plumpness	.652
Emergence Rate Index	-.080
Root Score with:	
Plant Height	-.357
Yield	.786*
200 Kernel weight	-.429
% Plumpness	-.143
Emergence Rate Index	-.286

* Significant at P=0.05.
** Significant at P=0.01.

Cont'd.

Table 73. (Continued)

B Variables Correlated	r_s
Shoot Length with:	
Plant Height	-.214
Yield	-.107
200 Kernel weight	.107
% Plumpness	.179
Emergence Rate Index	.395
Emergence Rate Index with:	
Plant Height	-.107
Yield	-.429
200 Kernel weight	.071
% Plumpness	-.071
Plant Height with:	
Yield	.250
200 Kernel weight	.643
% Plumpness	.750*
Yield with:	
200 Kernel weight	-.143
% Plumpness	.214
200 Kernel Weight with:	
% Plumpness	.857**

* Significant at P=0.05
** Significant at P=0.01.

rate index (ERI).

The results tabulated in Table 73 indicated that coleoptile length was strongly and positively associated with both kernel weight and percent plumpness, and that plant height was positively associated with plumpness. A positive significant relationship also existed between root score and yield for these genotypes and between the two kernel size parameters, kernel weight and plumpness.

Although no significant rank correlation was indicated between coleoptile length and plant height, a positive relationship did occur between these traits in terms of the plant height classes, as evidenced by the ranking data of Table 74. The rank correlation was non-significant due to within height-class variation. The talls did have longer coleoptiles. Note also the demarcation of the height groups as regards kernel weight and plumpness, the talls having heavier, plumper kernels. (Table 74).

Experiment V: Root System Size and Growth Rate Study

ANOVA for root dry weight (Table 75) and root growth rate (Table 77) indicated that little or no difference existed between the genotypes studied for these traits. The error involved in these experiments was very high as evidenced by the coefficients of variability (Tables 75 and 77). Even where a difference was shown to exist at week nine for root weight (Table 75), the range test employed in

Table 74. Ranks of Genotypes used in Coleoptile Length Study, Experiment IV., and Seeding Depth Study, Experiment VI.

Genotype	Plant Height Class	Coleoptile Length	Number of Roots	Root Score	Shoot Length	Plant Height	Yield	Kernel Weight	%Plumpness	Emergence Rate Index
Bonanza	Tall	3	5.5	6	6	1	4	2	3	6
C701013	Tall	2	3	7	4	2	6	1	1	2
C703019	Tall	1	1	1	1	3	1	3	2	3
Minn 64-62	Semi-dwarf	6	4	4	2	5	5	5	5	5
C703032	Semi-dwarf	4	2	2	5	6	3	4	4	7
C703029	Semi-dwarf	5	5.5	5	3	7	7	7	7	1
C703011	Semi-dwarf	7	7	3	7	4	2	6	6	4

Table 75. ANOVA for Root Dry Weight, Root Size Study, Experiment V.

Source of Variation	df	Mean Squares for Weeks from Planting						
		Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10
Replicates	4	.0002	.0003	.0004	.0656	.0748	.0647	.0125
Genotypes	6	.0002	.0018	.0019	.0095	.0143	.0468*	.0150
Error	24	.0003	.0010	.0018	.0380	.0247	.0183	.0147
Total	34							
Coefficient of Variability %		24.2	22.9	23.5	40.0	25.0	19.5	30.3

* Significant at P= 0.05

Table 76. Genotype Means for Root Dry Weight (mg.), Root Size Study, Experiment V.

Genotype	Plant Height Class	Weeks from Planting							Maximum Root Weight
		4	5	6	7	8	9	10	
Bonanza	Tall	.0768	.1530	.1706	.4616	.5748	.6986a !	.4749	.6986
C701013	Tall	.0703	.1055	.1761	.5033	.6991	.8749a	.5228	.8749
C702024	Tall	.0721	.1586	.1904	.4836	.6766	.6328a	.5891	.6766
Br6507-55	Tall	.0698	.1335	.1977	.4039	.6125	.7665a	.5805	.7665
Minn 64-62	Semi-Dwarf	.0810	.1432	.1729	.5021	.6075	.6016a	.5470	.6075
C703011	Semi-Dwarf	.0697	.1507	.2067	.5306	.6135	.6516a	.4614	.6516
C703029	Semi-Dwarf	.0614	.1230	.1491	.5239	.6215	.6305a	.4615	.6305

! Values followed by the same letter are not significantly different at P=0.05, by Duncan's Multiple Range Test, although ANOVA indicated differences did exist.

Table 77. ANOVA for Root Growth Rates from Root Size Study, Experiment V.

Source of Variation	df	Mean Squares
Time intervals	5	1.572**
Genotypes	6	0.003
Error	30	0.027
Total	41	

Coefficient of Variability = 44.3%.
** Significant at P=0.01

Table 76 did not indicate this difference. Similar results have been reported in wheat (Lupton et al. 1974 and O'Brien, 1975).

Nevertheless, the means in Table 76 and 78 along with the ranking data of Table 79 indicated that a trend existed for the tall genotypes to have larger and faster growing roots than did the semi-dwarfs.

Further support for this association existed in the correlation data (Table 80), in which a significant positive association was found between root growth rate and plant height.

Of note from the data of Table 78 was that the reduction in root growth rate of the three semi-dwarfs occurred one week previous to that for the talls.

Also notable were the strong associations of the root growth parameters and the kernel size parameters, as well as the positive relationship of plant height and plumpness.

Experiment VI: Seeding Depth and Emergence Study

ANOVA presented in Tables 81 and 82 indicated that differences existed between planting depths over all genotypes studied for both numbers of seedlings emerged and emergence rate index (ERI). Only the deepest of the four seeding depths significantly reduced the number of seedlings emerging (Table 83). ERI dropped consistently as seeding depth increased, although the drop from the first depth to

Table 78. Root Growth Rates (mg./wk.) for Root Size Study, Experiment V.

Genotype	Plant Height Class	Time Interval (Week X - Week X+1)						
		4-5	5-6	6-7	7-8	8-9	9-10	Mean
Bonanza	Tall	.4572	.0880	1.1640	.6396	.2476	-.2237	.3955
C701013	Tall	.2112	.3530	1.3088	.5874	.3516	-.3521	.4100
C702024	Tall	.5190	.1590	1.1728	.5790	-.0856	-.0437	.3834
Br6507-55	Tall	.3822	.3210	.8248	.6258	.3080	-.1860	.3793
Minn 64-62	Semi-Dwarf	.3732	.1485	1.3168	.3162	-.0118	-.0546	.3481
C703011	Semi-Dwarf	.4860	.2800	1.2956	.2487	.0762	-.1902	.3661
C703029	Semi-Dwarf	.3696	.1305	1.4992	.2928	.0180	-.1690	.3569

Table 79. Ranks of Genotypes used in Root Size Study, Experiment V.

Genotype	Plant Height Class	Root Growth Rate	Maximum Dry Weight of Roots	Plant Height	Yield	Kernel Weight	%Plumpness
Bonanza	Tall	2	3	1	3	2	2
C701013	Tall	1	1	3	6	1	1
C702024	Tall	3	4	2	1	4	3
Br6507-55	Tall	4	2	4	4	3	4
Minn 64-62	Semi-dwarf	7	7	6	5	6	5
C703011	Semi-dwarf	5	5	5	2	7	6
C703029	Semi-dwarf	6	6	7	7	5	7

Table 80. Rank Correlations (r_s) for Root Size and Root Growth Rate Study, Experiment V.

Variables Correlated	r_s
Root Growth Rate with:	
Maximum root dry weight	.943**
Plant height	.857*
Yield	.214
200 Kernel weight	.857*
% Plumpness	.893**
Maximum Root Dry Weight with:	
Plant height	.679
Yield	.071
200 Kernel weight	.857*
% Plumpness	.786*
Plant Height with:	
Yield	.571
200 Kernel weight	.679
% Plumpness	.857*
Yield with:	
200 Kernel weight	-.179
% Plumpness	.018
200 Kernel Weight with:	
% Plumpness	.857*

* Significant at P=0.05.
** Significant at P=0.01.

Table 81. ANOVA for Number of Seedlings Emerged, Seeding Depth Study, Experiment VI.

Source of Variation	df	Mean Square
Replicates (R)	2	2.48
Depths (cm) (D)	3	17.95**
2.54 vs 5.08	1	0.03
2.54 vs 7.62	1	1.21
2.54 vs 10.16	1	40.34**
5.08 vs 7.62	1	0.88
5.08 vs 10.16	1	38.31**
7.62 vs 10.16	1	27.56**
Error(a)	6	1.94
Genotypes (G)	6	0.55**
Talls vs Semi-dwarfs	1	0.17
D x G	18	0.68**
Error (b)	48	0.06
Total	83	

** Significant at P=0.01

Table 82. ANOVA for Emergence Rate, Seeding Depth Study, Experiment VI.

Source of Variation	df	Mean Square
Replicates (R)	2	10428.0
Depths(cm) (D)	3	261512.3**
2.54 vs 5.08	1	71.0
2.54 vs 7.62	1	109456.3*
2.54 vs 10.16	1	588779.5**
5.08 vs 7.62	1	103952.6
5.08 vs 10.16	1	575921.2**
7.62 vs 10.16	1	190512.9*
Error(a)	6	18120.2
Genotypes (G)	6	3558.7
D x G	18	5488.6
Error(b)	48	5327.3
Total	83	

* Significant at P=0.05
** Significant at P=0.01

Table 83. Mean Number of Seedlings Emerged and Mean Emergence Rate for each Seeding Depth, Experiment VI.

Seeding Depth(cm)	Number of Seedlings Emerged	Emergence Rate Index
2.54	9.86 b	436.9 c
5.08	9.81 b	434.3 bc
7.62	9.52 b	334.8 b
10.16	7.90a	200.1a

Values in a group followed by the same letter are not significantly different, P=0.05.

the second was not significant (Table 83).

Significant differences existed between genotypes for number of seedlings emerged (Table 81). These differences were not such as to give rise to a significant difference between the plant height groups (Table 84).

No differences existed for ERI between genotypes or plant height groups, contrary to results reported by Allan et al. (1962) and Burleigh et al. (1964) from wheat experiments.

A significant genotype by seeding depth interaction occurred for number of seedlings emerged (Table 81). The means (Table 85) indicated the interaction occurred because genotypes Bonanza, C703019, and Minn 64-62 showed fewer numbers emerged from the third than from the second planting depth while the other genotypes did not.

C703013 showed an increased number of seedlings emerged as it was planted progressively deeper, to the third depth (Table 85). This probably resulted from inadequate watering or viability problems rather than a genuine depth effect.

Contrary to reported studies with wheat (Allan et al., 1962), in the present study emergence rate was not significantly correlated with coleoptile length (Table 73B).

Table 84. Genotype Means for Number of Seedlings Emerged and Emergence Rate, Seeding Depth Study, Experiment VI.

Genotype	Plant Height Class	Number of Seedlings Emerged	Emergence Rate Index
Bonanza	Tall	9.25ab	340.5a
C701013	Tall	9.67 c	366.2a
C703019	Tall	9.08ab	365.4a
Minn 64-62	Semi-dwarf	9.33 b	341.0a
C703032	Semi-dwarf	9.00a	326.3a
C703029	Semi-dwarf	9.25ab	373.6a
C703011	Semi-dwarf	9.33 b	347.8a
Mean of Tall Genotypes		9.33a	357.4a
Mean of Semi-dwarf Genotypes		9.23a	347.2a

Values in a group followed by the same letter are not significantly different, P=0.05.

Table 85. Mean Numbers of Seedlings Emerged for Genotype X Seeding Depth Interaction, Seeding Depth Study, Experiment VI.

Seeding Depth(cm)	Bonanza	C701013	C703019	Minn64-62	C703032	C703029	C703011
2.54	9.67 bc	9.33 b	10.00 c	10.00 c	10.00 b	10.00 c	10.00 b
5.08	10.00 c	9.67 bc	10.00 c	10.00 c	9.67ab	9.67 bc	9.67 b
7.62	9.33 b	10.00 c	9.00 b	9.33 b	9.67ab	9.33 b	10.00 b
10.16	8.00a	8.33a	7.00a	8.00a	9.33a	7.33a	7.33a

Values in a column followed by the same letter are not significantly different, P=0.05.

DISCUSSION

Experiment I: Components of Variance, Heritability Estimates and Phenotypic Correlations

Components of Variance and Heritability Estimates

These values were determined to establish whether hybrids involving reduced plant height would lead to changes in the breeding behaviour of other agronomic parameters, since previous investigations have dealt primarily with standard height materials. Furthermore, a desire existed to determine the heritability of the measured characters, in order to speculate upon the optimum testing procedures required to select genotypes with desired levels of these traits from barley populations.

The significance of the various genotype by environment interaction components and the magnitudes of the heritability estimates for the traits studied are in general agreement with previous reports, in particular those of Rasmusson and Glass (1967) and Rutger et al. (1966). Involving reduced plant height apparently did not appreciably alter the overall breeding behaviour of the other characteristics in the present study.

The design of this study had two replications at each

of two locations for two years. Except for plant height, percent plumpness and days to heading, the σ^2_e (error) variance components were very large relative to their respective σ^2_G (genotypic) and genotype by environment interaction components, indicating one major drawback of the design employed may have been insufficient replication and/or sampling.

High heritability estimates for most of the parameters examined in this study were not unexpected since; one, the materials involved were in advanced generations; two, ample genetic variation existed for these traits; three, variance components were used to calculate the estimates; and four, the experiment was grown at more than one location for more than one year. According to the literature, these circumstances should combine to give maximum heritability estimates (Grafius et al., 1956; Frey and Horner, 1955; and Rasmusson and Glass, 1967).

Heritability estimates for plant height, kernel weight, test weight, and percent plumpness were consistent across populations since these parameters can be measured accurately and deviations between years or locations were deviations in magnitude rather than ranking.

The following discussion of genotype by environment interactions, heritabilities and testing procedures is grouped by character or characters which behaved in a similar fashion.

Plant height. The very high heritability estimates

plus the low σ^2_e values relative to respective σ^2_G values for all populations suggested the design employed was more than adequate in characterizing these lines for height, despite the significant σ^2_{GY} in all cases. This interaction arose due to differences in magnitude, not in rank, between years, caused by the less than ideal growing conditions in 1974 giving rise to shorter plants. The lack of any significant σ^2_{GL} combined with the readily explainable σ^2_{GY} further suggested that one year of testing at one location with two replicates would have been sufficient to determine the relative plant heights of these genotypes.

The heritability estimates were larger than most reported in the literature. This occurred because, one, plant height in barley is simply inherited; and two, since the populations involved were derived from parents differing widely for height, both the variance and absolute height range were larger than in most other studies. Such high heritability for height could, then, alter the breeding behaviour of other closely related characters.

Kernel weight. Despite significant levels of σ^2_{GY}, again the result of differences in magnitude rather than ranking between years, kernel weight was highly heritable. These factors, plus the lack of significant levels of σ^2_{GL} and σ^2_{GLY}, indicated that the procedure used in this study was adequate in determining genotypic levels of this parameter. However, it appears from the relative size of the σ^2_e values that larger samples and/or more replication would

have increased the precision of the estimates.

Degree of lodging. The data indicated that the design, two replicates and three station-years, was adequate for lodging estimation, giving relatively high heritability and no significant genotype by environment interactions. However, this may be related to the nature of the materials involved, since plant height was a major variable and differences in lodging were closely associated with height differences. It would therefore be unwise to assume that the conclusions derived from these data would be widely applicable. Again the σ^2_e was larger than the respective σ^2_G in all cases suggesting a more precise measurement and/or more replication was needed.

Test weight and percent plumpness. Although these traits were moderately to highly heritable, the results suggested that testing for them required more than one year and location. Significant σ^2_{GY} for test weight in C-70-2 and for percent plumpness in all crosses, along with the σ^2_{GL} and σ^2_{GLY} levels for plumpness, reduced heritabilities and increased the respective standard errors. The inability of C-70-3 to cope with the drought and heat stress of 1974, relative to C-70-1 and C-70-2, in part accounts for the greater σ^2_{GY} for that population.

Days to heading. The significance of the various genotype by environment interaction components indicated a need for testing for this trait at more than one location and year, despite the high heritability estimates in C-70-1 and C-70-2;

in these populations two locations for two years were sufficient. Less genetic variance and a strong σ^2_{GY} gave rise to lower heritability in C-70-3. The σ^2_{GY} again reflected the effects of the stress conditions of 1974 on C-70-3. Generally low levels of σ^2_e indicated the replication used was sufficient.

Days to maturity and days in post-anthesis. Heritability was lower in C-70-1 and C-70-3 than in C-70-2, in which it was very high. This difference reflected a large σ^2_{GY} in both C-70-1 and C-70-3, probably a result of response to environmental stress in 1974. The more intense effects of drought on C-70-3 were further indicated by the larger σ^2_e component for that population.

The heritability of days in post-anthesis will be governed by the effects of the environment on both days to heading and maturity, since these components were used to calculate this parameter.

Over the three populations studied, the general lack of σ^2_{GL} significance combined with the generally significant levels of σ^2_{GY}, suggested that testing for more than one year was necessary to evaluate days to maturity and days in post-anthesis, while the need for more than one location was doubtful. More replication should be used when the calculation of days in post-anthesis is to be carried out since it's σ^2_e can be inflated by errors in the estimation of both days to heading and maturity.

Kernels per spike. This trait was highly heritable and

showed no environmental interaction in C-70-2. However, in C-70-1 and C-70-3 heritabilities were low and subject to large standard errors; in C-70-1 the low level of σ^2_G combined with the large σ^2_{GY} was primarily responsible. A very large σ^2_{GY} was the culprit in C-70-3. This again pointed to the effects of stress on C-70-3; a similarly high genotype by year interaction was found in that cross for days to heading. In 1974 C-70-3 headed earlier and had fewer kernels per spike than in 1973.

The significant levels of σ^2_{GY} in C-70-2 and C-70-3 indicated that testing for kernels per spike required more than one year of data, while the lack of significant levels of σ^2_{GL} suggested that one location was sufficient. The undesirably large σ^2_e may have resulted from lack of adequate replication, sampling size, or a combination of these.

Yield. Genotype by environment interaction has often been implicated in difficulties in differentiating among yield levels in various crops. Nevertheless, the results of the present study tended to agree with those of Rasmusson and Glass (1967). In all three populations the error component (σ^2_e) of variance was larger than the genotype by environment interaction components, suggesting that more replication and/or larger plot size would have been a more efficient way to increase the heritability of yield than the utilization of more locations and/or years of testing. This was particularly the case in C-70-1.

Heritability was relatively high (58 $\pm$ 14.0) and σ^2_{GLY}

was significant for C-70-2, indicating a need to test for yield at more than one location and for more than one year. Significant levels of σ^2_{GL} and σ^2_{GY} for C-70-3 led to a similar conclusion. In this case these interactions, combined with the large error component, in fact gave rise to a heritability (28 $\pm$ 22.0) essentially equal to zero, despite the fact that this population had the largest yield range (Table 9).

The overall result suggests that, with the possible exception of C-70-2, the methodology employed was inadequate for a precise assessment of the yielding ability of these lines. To overcome this problem, ways of reducing the error variance would have to be found. In view of the very large numbers of lines involved a design utilizing blocking within replications, as well as increased plot size and number of replications, might also have aided in reducing this error.

It also appeared from the significance of the various genotype by environment interactions in C-70-2 and C-70-3 that the utility of more environments increased as the number of lines tested decreased. This may be largely the effect of reduced range of variability concurrent with the decrease in line numbers, thus increasing the impact of a large error term in distinguishing differences.

The results of this experiment may have limited application with respect to general yield testing in barley, because the genetic variances and ranges of yield obtained were greater than those normally encountered in critical

yield testing experiments. Furthermore, it is quite probable that, were the improvements suggested to reduce the levels of σ^2_e successful, the levels of the genotype by environment interaction components might increase, more strongly indicating a need for testing over more environments. This experiment did not give sufficient evidence to indicate whether the number of years and locations used were sufficient to accurately measure the yielding ability of these genotypes, and in fact, the low heritability estimates and their large standard errors indicate that the results were not as good as might have been expected in view of the make-up of the materials involved.

Trait Comparisons

Plant breeders produce segregating populations in an attempt not only to select the superior individuals, but also to select those which are in some way superior to the best available cultivar, often used as a control.

In the present study lines were identified as superior to the control variety Bonanza for each of kernels per spike, kernel weight, test weight, plumpness, degree of lodging, days to heading, days to maturity, days in post-anthesis, yield, levels of alpha-amylase, saccharifying activity, percent barley nitrogen and soluble amino-nitrogen. With plant height, since selection would be for shorter lines, again, all three populations contained superior (shorter) individuals.

The possibility of obtaining single genotypes with simultaneous improvements in two or more characters was not examined.

Selection of higher yielding lines should have been possible in C-70-1 and C-70-2. Heritability for yield was moderately high in C-70-2, was at a useful level in C-70-1, and in both there was significant genetic variance. The low level of heritability in C-70-3 indicated that, through the experimental procedure used, improvement over Bonanza could not be made. However, despite C-70-3 having the smallest sample size (41 lines compared to 103 and 87), the range of line mean yields was the greatest. In fact C-70-3 contained the highest yielding line in the study on a mean basis. Therefore, it appears reasonable that more thorough testing of this population would be justified to ascertain it's potential despite the low heritability estimated for yield.

An underlying objective of this study was to determine whether high yielding short strawed genotypes could be selected from these populations. The results showed trends indicating that yield improvements could be made in all height classes within each population. The highest yielding lines were in the tall and intermediate height categories. Nevertheless, as evidenced by C703011, the possibility of producing significantly shorter material apparently equal in yield to the control did exist.

The low number of semi-dwarf lines involved was a drawback in the present study. This, particularly in C-70-2,

could in part account for the poor showing of the semi-dwarfs. On the other hand, a similar argument holds for the low yield of the best tall line in C-70-3.

Overall, it appears reasonable that intensive selection of short types, thereby providing larger numbers of lines to test for yield, would greatly enhance progress toward short, high yielding genotypes, since the small sample obtained randomly in the present study contained some good material.

Statistically, since both Bonanza and Minn64-62 are homozygous and their mean yields were calculated from large numbers of plots at each site, their standard errors should be a good estimate of the environmental error for yield over the whole study. With this standard error a least significant difference for yield could be computed. Such computation gave a least significant difference equal to 110 grams per plot. On this basis, there were no significant differences between the highest yielding lines: among the height categories, among the populations, or across the whole experiment. This result again stresses the need for further, more effective, yield testing of this material and indicates the inadequacy of the techniques used to characterize the true yielding ability of these genotypes.

The population mean plant heights and yields indicated the possibility of yield potential in the short strawed material. Although the mean height of C-70-3 was significantly shorter than for C-70-1, C-70-2 and Bonanza (in fact C-70-3 contained no line as tall as Bonanza), it's mean

yield was essentially the same. This result is particularly noteworthy in view of the fact that C-70-3 was earlier maturing on a mean basis, a character normally associated with lower yield.

Phenotypic Correlations

Due to the sample sizes involved, the absolute values of correlations required to be significant were small. The values required to be significantly different from zero ranged from 0.130 to 0.304 and from 0.171 to 0.393 at the five and one percent probability levels respectively. Although significant, such relatively small correlations are of little direct importance to a breeder. Even with $r = 0.50$, the coefficient of determination (r^2) is only 0.25, indicating that twenty-five percent of the variation in the characters in question is concomitant. On the other hand, discussion of the inter-relationships expressed by these correlations is valuable in identifying the intricacy and background of character associations in regard to the selection of improved and adapted short-strawed barley, as well as the selection of improved taller genotypes from crosses involving short-strawed types as a parent.

The following is a discussion of some of the character relationships which were revealed in the present study.

Plant height. The positive associations of height with yield, kernel weight, test weight, plumpness and days in post-anthesis are not encouraging. However, although

significant, the correlations were generally small, resulting in small r^2 values. Furthermore, the relationships were strongest in C-70-3, where all the genotypes were shorter than standard height, indicating that the very short material was lacking in these traits but that moderate height reduction did not adversely affect important agronomic characteristics.

The absence of any significant correlations of plant height with kernels per spike may have resulted from the fact that selection for large spikes was emphasized in developing the semi-dwarf parent used (Rasmusson, 1973). Nevertheless, a large amount of variation existed for this parameter, and the error in determining its values may in part account for the lack of relationship.

Reduced plant height did effectively reduce lodging. This positive correlation may be partially due to the fact that the lodging encountered was the late season type caused by the straw not being strong enough to support the heavier spikes of the higher yielding lines. The positive height to yield and yield to lodging relationships may have contributed to the height to lodging association. The relationship was stronger in C-70-1 and C-70-3, both of which had more very short types than C-70-2.

According to the correlations, the shorter material in C-70-1 and C-70-3 headed later. The height to heading association was also negative, but non-significant, in C-70-2. The lack of significance may have been due to the

small number of short lines in that population. The overall negative association was one of the results of the observed slower, prostrate early growth and generally slower development of the shorter lines.

The negative correlation between height and maturity in C-70-1 represented a continuation of the slower development of the short statured segregates. The tendency for most of the genotypes in C-70-3 to ripen off early despite heading at about the same time as C-70-1 gave rise to the lack of a significant relationship in C-70-3. The correlation for C-70-2 was non-significant, indicating that the differences in maturity in that population were not related to height differences.

The generally negative relationships of height with heading and maturity, as well as the observed slower development of the short statured lines, combined with the fact that the semi-dwarf parent headed and matured later, suggested linkage between these parameters and height in this material. Following in the same vein, the tendency for much of C-70-3 to ripen off under stress was the habit of the taller parent in that cross.

The consistent positive association of height with days in post-anthesis resulted primarily from the late heading of the shorter materials without proportionate delays in maturity. The importance of this association may be in the association of short stature with reduced kernel size.

The absence of any significant correlations between

height and the quality parameters studied indicated that reducing plant height in barley should not adversely affect the attainment of malting quality. However, the physical aspects of malting quality, kernel size, plumpness and test weight, appear to be adversely affected in these semi-dwarf genotypes.

The effects of plant height on the breeding behaviour of the populations in question may now be more clear. Since the populations are structured to give high and consistent heritability estimates for plant height, it follows that any traits strongly correlated with height would also tend to be highly and/or consistently heritable. Such was the case for kernel weight, test weight, plumpness, days in post-anthesis and degree of lodging in the present study.

Yield. In the final analysis, yield is the critical trait in any breeding program, and a primary criterion in evaluating materials for use as germplasm.

The relationship with plant height in this study has been discussed.

The positive association between yield and kernels per spike is not unexpected since the latter is one of the components of yield. Yield equals the total weight of kernels per unit area of crop. Therefore, if the average weight of the kernels and the number of spikes per unit area remain relatively stable, changes in the number of kernels per spike will give corresponding changes in yield.

In view of the positive height to yield and height to

kernel weight associations, as well as the association of post-anthesis period with both yield and kernel weight, the lack of significant correlation between yield and kernel weight was surprising. This indicated that this yield component was not of primary importance in determining yield in these populations. The lack of precision in measuring yield may also, in part, account for the lack of significant association.

Although significant when pooled, and homogeneously positive over all populations, the correlation between yield and test weight was significant on an individual population basis only in C-70-1. Such association may be the result of heavier test weight lines having plumper and hence larger kernels, which would add to total yield.

The negative association of yield with days to heading indicated early heading was advantageous and suggests that the post-anthesis period may have been the critical yield determining period. This is further supported by the positive yield to days in post-anthesis correlations. However, since both kernel weight and plumpness were positively associated with days in post-anthesis, the lack of association between these parameters and yield casts doubt upon this explanation. The negative yield to heading relationship may in fact be a reflection of the positive yield to height and negative height to heading associations.

Furthermore, the relationship in question may have been influenced by the growing conditions encountered during the

trial period. The area in which the trials were conducted tended to have a hot dry period at the time the material was maturing. These conditions forced earlier maturity, and the later heading lines had grain filling terminated prematurely. Hence, lines which headed, and therefore flowered, earlier, were subjected to less heat and moisture stress for more of their filling period than lines which headed later.

The positive yield to post-anthesis association would be expected since post-anthesis is essentially a measurement of the grain development stage, and the longer this period is, the more fully developed the grain should be. However, neither kernel weight nor plumpness, both positively associated with days in post-anthesis, were significantly correlated with yield.

Apparently the yield to post-anthesis relationship occurred as did the yield to heading association. In fact, on an individual basis, only those populations showing a significant negative yield to heading relationship showed the corresponding yield to post-anthesis association. This is not surprising as days to heading is used in the calculation of days in post-anthesis. These results suggested that measurement of days to heading may be of greatest value when selecting for high yielding lines destined for production under conditions similar to those encountered in this study, particularly when large kernel size is a desired character.

The positive correlation of lodging with yield occurred primarily because lodging was an effect rather than a cause.

The lodging occurred when the straw of the higher yielding lines was unable to support their larger heavier spikes late in the season. Lodging discussed in most other reports occurred earlier in the season and caused lower yield by giving rise to reduced kernel development (Sisler and Olsen, 1951). In the present study, lodging was also strongly and positively related to height, and the negative height to yield associations may have been reflected in the yield to lodging relationships.

Although this type of lodging did not lead to yield reductions, it is likely to result in harvest losses and inconvenience at the farm level. Breeding for resistance to lodging at the late stage, through height reduction, would therefore be a worthwhile goal.

Higher yields result from increased carbohydrates in the grain, with consequent lowering of the nitrogen level on a percentage basis. Hence, the negative associations between yield and nitrogen and two nitrogen-related quality parameters, soluble amino nitrogen and saccharifying activity are readily explained.

Kernels per spike. The negative correlations between this trait and kernel weight, plumpness and test weight probably resulted from competition within the spike for photosynthate during grain filling.

The significant positive correlations of kernels per spike with days to maturity and days in post-anthesis were weak. In fact, that with maturity was not significant in

any specific cross. However, they did exist, and may have occurred because the longer the grain development period was, especially the latter part of that period, the more kernels per spike actually survived. In those lines in which maturity was forced to be earlier some kernels may not have completed development giving rise to fewer kernels per spike, since only completely developed kernels were counted.

The positive relationship of kernels per spike with lodging occurred because those lines which lodged did so, at least partly, because they couldn't support their larger heads.

The significant negative associations between kernels per spike and barley nitrogen, saccharifying activity and soluble amino-nitrogen are surprising. As the number of kernels per spike increases, kernel size normally decreases, as was the case in this study, and generally higher levels of these nitrogen related parameters are associated with smaller kernels. However, as will be discussed later, the evidence in this study, (particularly from population C-70-2), suggested that these general relationships may not always be as strong or consistent as is often presumed. Furthermore, kernels per spike is one of the major components of yield, and yield itself was significantly negatively related to these same three quality parameters in this study.

Kernel weight. The positive association of kernel weight with plumpness is indicative of size being due to extension of kernel width rather than length. The positive

association with test weight can be partially accounted for in a similar fashion, but the main explanation comes from the association of kernel weight and plumpness, since, plump kernels have an increased width to length ratio, therefore pack more tightly and have a higher weight per unit volume. Since the plumper kernels in this material were the heavier kernels, the association of kernel weight and test weight would be expected.

The correlation of kernel weight with days in post-anthesis probably reflects the fact that the weight of the kernels develops during this period. The negative relationship with heading date existed because, the earlier a genotype flowered in a finite growing season, the longer was it's grain development time.

The positive relationship between kernel weight and lodging was due to the type of lodging measured and the nature of the material studied.

Negative associations existed between kernel weight and alpha-amylase and soluble amino-nitrogen levels, in particular in C-70-1 and C-70-2, suggesting that lines with heavier kernels become heavier via increased carbohydrate deposition at the expense of nitrogenous compounds. However, the significant positive association between kernel weight and percent barley nitrogen in C-70-2 indicated that, at least in that population, nitrogen deposition was not hampered in the heavier kernel lines, suggesting that the yield to nitrogen negative relationship may not be either

as strong nor as consistent as is often suggested.

Test weight. With the exception of some previously discussed interrelationships the correlations between test weight and most other traits measured tended to be inconsistent. Further exception to this occurred regarding it's negative associations with days to heading and maturity. The relationships with heading date indicated that the earlier part of the grain development period was more critical to the achievement of high test weight, particularly in the finite growing season encountered in this study.

The explanation for the association with maturity probably lies in the fact that most later maturing lines were unable to complete kernel development under the growing conditions encountered. Hence, these grain samples tended to contain a greater percentage of smaller, less dense kernels which gave rise to lower test weight.

The positive association between test weight and lodging reflected the correlations between test weight and plant height, and height and lodging. This was particularly evident in population C-70-3 where height and lodging were more strongly related.

The negative correlations between test weight and the malting quality parameters suggested the selection of high quality malting lines with high test weight might be difficult in this material, especially in population C-70-2.

Plumpness. The associations of this trait with heading date and days in post-anthesis indicated the positive in-

fluence of the length of the grain filling period on plumpness, particularly the earlier part of the filling period.

The positive relationships of plumpness and lodging in C-70-2 and C-70-3 probably reflects the association of plumpness with kernel weight and the contribution of that trait to the type of lodging which occurred.

The selection of plump seeded malting lines in this material, in particular C-70-2, may be difficult. The positive association of plumpness with barley nitrogen however is of interest since it suggests that plump seeded barley with an acceptable protein level can be obtained. This type of barley is desireable in the feed industry.

Days to heading. A strong positive relationship between this trait and days to maturity for populations C-70-1 and C-70-2 reflected similar developmental patterns within genotypes in these crosses. The lack of significance in C-70-3 may have been a reflection of the difference in the relationship between heading and maturity in that population.

The significant negative association with days in post-anthesis existed since fewer days to heading leads to more days in post-anthesis particularly when the range in days to maturity is truncated by environmental stress.

The consistency of the relationships of heading date

with several critical agronomic parameters measured throughout this study indicate the value of this trait in selecting barley genotypes in breeding programs. Perhaps this is one easily measureable trait which has not been fully utilized in our breeding programs here in western Canada in particular.

Days to maturity. This trait was also positively correlated with days in post-anthesis since increasing days to maturity tends to give a longer post-anthesis period.

Lodging. The associations between lodging and alpha-amylase, saccharifying activity and soluble amino-nitrogen were likely reflections of the negative associations of these traits with kernel weight, test weight, and plumpness, combined with the positive relationships between these agronomic traits and lodging.

The negative correlation of lodging with barley nitrogen in C-70-1 was a reflection of the positive yield to lodging and negative yield to barley nitrogen associations.

Quality parameters. With the exception of the alpha-amylase to barley nitrogen correlation in C-70-3, the interrelationships in the present study were generally positive. This would be expected since the traits are essentially measures of nitrogen and enzyme levels which are generally dependent on the nitrogen status of the plant.

The negative relationship between alpha-amylase and barley nitrogen in C-70-3 may have been merely fortuitous, or could have been the result of the early senescence characteristic of that population. In the other populations,

the indication was that total barley nitrogen was not significant in determining alpha-amylase. If this relationship holds one could then expect to obtain genotypes with high levels of alpha-amylase and low protein. That relationship is desireable for malting quality.

Overall. With the exception of some of the relationships with lodging, the phenotypic correlations reported from the present study are in general agreement with those present in the literature.

Reduced plant height did give rise to superior straw strength in this material, as was the case in the study by Konishi (1976). This effect may have been partially related to the lower yields also associated with reduced height in the present study.

Several other undesirable correlations existed between plant height and agronomically important characteristics. The major problem with the shorter genotypes in the material investigated appears to be in the kernel development stage. The basis of this problem is in the association of short stature with delayed heading and a shorter post-anthesis period. The semi-dwarf habit may be linked to this lateness. This was disadvantageous, particularly under the growing conditions encountered. The later heading apparently was due to the slow and somewhat prostrate early growth of the shorter-strawed segregates relative to their taller sister lines.

The correlations found between the days to heading,

maturity and days in post-anthesis parameters, and the other agronomic characters in this study are interesting, particularly as they tend not to agree with previous reports. Past evidence has suggested early heading is associated with early maturity and hence lower yield. On the other hand, it has been postulated that a long post-fertilization period should lead to higher yields through more kernel development. The evidence of this study supports the latter hypothesis.

The results suggest that the breeder should attempt to select lines which head early but do not necessarily mature early, in an attempt to maximize the grain development period. Obviously one must be aware of the problems associated with "late" maturity, particularly in Western Canada, and lengthening the post-anthesis period by means of later maturity may be undesirable. One would have to arbitrarily choose an optimum maturity date and attempt to achieve a maximum post-anthesis period by combining that with the earliest heading possible.

In view of the positive association found between days to heading and maturity, perhaps "early" by "late" crosses would give rise to larger numbers of lines with various combinations of heading time and maturity, and a broad range of post-anthesis periods. The post-anthesis periods would also occur at slightly different times of the growing season. With this type of material one could perhaps better define the relationships involved and determine, not only the ideal length of the grain development period, but also define which

part of that period is most critical.

From a breeding viewpoint, this type of cross might be useful in attempting to develop genotypic combinations particularly suited to the environmental conditions normally encountered during the barley growing season in Western Canada. This author feels that the post-anthesis period is critical, particularly in relation to the climatic pattern. Of this period, the first part is the most critical, since, in the area in question, heading time and the period following that are normally the warmest, driest parts of our growing season. Therefore a genotype which headed earlier could take advantage of slightly less stressfull growing conditions for a few more days than one which headed later. During years when conditions are more optimum for a longer part, or all of the post-anthesis period, such a genotype should still be superior to a later heading type. It is also reasonable to expect that, regardless of environmental conditions, in terms of kernel quality such a genotype would be generally at an advantage.

The preceeding discussion also illustrates some of the reservations one must have regarding correlation values, particularly when sample sizes are large. It is not always a simple task to define cause and effect relationships which can be very complex, involving the simultaneous effects of several traits. Such complexity was obvious in the interpretation of these data; since few relationships, although significant, were strong; and individual parameters were

significantly related to several others, themselves interrelated; but these interrelationships were not always equipollent.

Experiment II: Nitrogen Fertilization of Tall and Semi-dwarf Barleys

As reported by Chandler (1969) in rice, Briggle and Vogel (1968) in wheat and Konishi (1976) in barley, the most valuable effects of reduced plant height have been increased lodging resistance and improved response to applied nitrogen fertilizer (N). Response to N varies with crop, environment and genotype, and may or may not affect the expression of each of several important agronomic and quality parameters. The following is a discussion of the results of experiments conducted to determine the responses of selected semi-dwarf and tall barley genotypes to various levels of applied nitrogen under field conditions in South-Central Manitoba.

Plant Height

As applied N increased so did plant height, presumably because increased nitrogen gives rise to increased vegetative growth. This was the case at all five sites, although the increase was not significant at the Carman and Portage sites in 1976.

The very heavy weed infestation at Carman in 1975 indirectly gave rise to continued plant height response beyond N increment one. Carbyne, a wild oat chemical used

to control wild oats at Carman was partly responsible. Carbyne is known to control the wild oats by setting them back and thereby decreasing their competitive ability with the crop. High fertility enhances this effect, (E.H. Stobbe, personal communication), and therefore the more fertile treatments in the study grew taller because they were less affected by the wild oats.

The shorter heights of all genotypes at all N levels at Carman reflected the less than ideal growing conditions, due to drought and weeds, and the lower initial levels of available N at that site. The mid and late season drought at Portage in 1976 probably caused the smaller amount of height variation there, although there may have been other contributing factors.

Since there was generally no fertilizer by genotype (F x G) interaction for height we assume that the shortness of straw, relative to the tall genotypes, was maintained as applied N increased. On the other hand, height increased with added N, meaning the height of the semi-dwarfs increased as well as that of the talls. This might reduce their lodging resistance. The significant interaction at Portage in 1975, occurred because C703011 and C703032 showed a tendency towards greater height increases as applied N increased than did Minn64-62, the other short genotype considered. The evidence leads us to conclude that it would be necessary to evaluate the lodging resistance of short strawed material despite the strong relationship of this trait with plant height, part-

icularly when more optimum growing conditions may be encountered.

Yield

Response to applied N was similar at all sites: large and significant increases with the first N increment, followed by continuous but progressively smaller gains as N levels increased. The combined effects of the lower original soil N level and the weed infestations at Carman, which at the zero applied N level severely suppressed the growth of the barley; led to significant and large yield response to N at that location in both years. This was particularly so in the 1975 test, in which the wild oats and green foxtail lowered yields most severely when fertility was inadequate. These stress factors were reflected in overall lower yields at Carman in both years, but particularly in 1975 when all genotypes yielded very poorly. This, in turn, gave rise to no significant yield differences between genotypes in that experiment.

At the other sites the two tall genotypes and Minn64-62 produced the highest yields, while yields of the other two semi-dwarfs were lower. The lower yield of these latter genotypes was responsible for the significantly lower yield of the semi-dwarfs as a group at three of the four sites where this was the case. The lower yielding semi-dwarfs matured earlier than Bonanza whereas the higher yielding Minn64-62 was later maturing. Since early maturity is

usually associated with lower yields, this may have been a substantial factor influencing the yield of these lines.

The maturity factor and the total lack of F x G interaction for yield are important from the breeder's viewpoint. The results indicated that early maturing, semi-dwarf barley selections may not yield as well as standard height genotypes. Furthermore, these shorter genotypes apparently will need inherently superior yielding ability, since they did not respond differently than the talls to applied N, to be superior in yield to the best tall genotypes.

On the other hand, when given adequate nutrition and reasonable growing conditions, the later maturing semi-dwarf, Minn64-62, performed well. Furthermore, the improved straw strength of the semi-dwarfs would make them superior, since the critical fact is that semi-dwarfs which are equal to tall genotypes under normal growing conditions should yield more, and better grain when grown under conditions which induce lodging.

It should also be noted that at Sanford in 1976, where good growing conditions existed, even the late high-yielding Minn64-62 was lower yielding (not statistically significant) than the tall genotypes. However, at Portage in 1976, the case was reversed, indicating that the interrelationship of height and yield is not without complexity.

Spikes per Unit Area

Since significant yield differences were obtained it

would be useful to know the relative contribution of the various yield components to the result. This information would be of help to the breeder in selecting parental material and in selecting within and among segregating populations.

At all sites, as applied N increased, so did the number of spikes per unit area; with the initial increment of N giving the greatest response. This was particularly the case at Carman in both years, where moisture stress and weed competition had major effects. The further significant increase due to the upper N increments at Carman in 1975 probably resulted from improved competition with weeds in these treatments. The significantly greater numbers of spikes per unit area induced by the highest N level at Sanford may be attributed to a more adequate moisture supply. This resulted in a longer vegetative period which allowed more tillers to be produced, survive and produce spikes. At these higher N levels at both sites, kernel weight was lower, and at Sanford the number of kernels per head dropped, relative to the other N treatments.

The genotypes all responded similarly to applied N. However, Minn64-62 and C703032 generally had more spikes per unit area than the talls at all sites. This was particularly the case for Minn64-62. The result offers some explanation for the relatively high yield of Minn64-62, particularly as compared to the other semi-dwarfs. C703011 was consistently the lowest of the three in spikes per unit area except at

Sanford, where under better growing conditions, it had a number of spikes per unit area greater than the talls and the same as C703032. With this advantage, C703011 was the highest yielding semi-dwarf at that location.

Minn64-62's large number of spikes per unit area was probably related to it's slower early development and overall lateness relative to Bonanza and the other genotypes. These characteristics may in fact be the very reason why Minn64-62 had the advantage in terms of spikes per unit area. From an agronomic viewpoint, this association of good performance with poor early competitive ability and late maturity would be undesirable, in Western Canada. With this in mind the plant breeder attempting to develop the best genotype would have to select for what he considered to be an optimum number of spikes per unit area, rather than a maximum number.

Kernels per Spike

There was evidence of yield component compensation in this study. Those genotypes which had large numbers of spikes per unit area tended to have significantly fewer kernels per spike.

Adding N tended to increase spike size, and again the initial N increment was the most effective. All genotypes responded to added N in essentially the same manner. The Carman site was again influenced the most, probably due to the poor growing conditions.

Kernel Weight

Added N had little effect on kernel weight after the first N increment, at all sites except Sanford. There, kernel weight became progressively lower with added increments of applied N.

Yield component compensation was again in evidence. As the spikes per unit area and kernels per spike increased with increasing N, kernel weight was reduced.

On a height class basis the semi-dwarfs had inferior kernel weight, particularly when compared to Bonanza. Within the semi-dwarfs kernels per head appeared to have more effect on kernel weight reduction than spikes per unit area, since the genotypes with more kernels per head had the lowest kernel weight.

The F x G interaction at Sanford indicated that C703032 and Minn64-62 were more susceptable to loss of kernel weight as N increased than was the high yielding Bonanza. This occurred despite the fact that both these genotypes had lower numbers of kernels per head than Bonanza at that site, suggesting that kernel weight was the yield component which must be improved in these lines to bring them to competitive yield levels under these conditions. It was also a reflection of the larger number of spikes per unit area of those genotypes.

In general, the specific yield components involved in the yield component compensation varied depending on the

environment. Any conclusion regarding which component has the greatest effect on any other then may have to do with the potential "sink" of a given genotype or group of genotypes. The complexity of these relationships may have been compounded in the semi-dwarfs by linkage between kernel weight and the semi-dwarf habit.

Yield Components

Overall the more successful semi-dwarfs appear to be such because they have larger numbers of spikes per unit area, which increased with added N. In conjunction with this there was a reduction in spike size, but more seriously a reduction in kernel weight. From an end use standpoint reduced kernel weight could not be tolerated and, since maximum yield will only be achieved by an efficient balance among the components, the semi-dwarfs must be altered to improve kernel weight, even at the expense of the other yield components provided that yield can be maintained or increased.

Lodging

The lodging encountered was the late season type caused by the inability of the straw to support filling and/or filled spikes. Lodging can then be partially accounted for by yield level, with the higher yielding treatments suffering increased lodging. However, the superior lodging resistance of the shorter strawed material was clearly demonstrated at Portage, where Minn64-62 did not lodge despite yielding as

much as the tall genotypes. Also the F x G interaction at both sites in 1975 demonstrated the superior standing ability of the semi-dwarfs under high yielding (higher N) conditions. This was especially noticeable at Portage where lodging was most prominant.

Within the height groups there was variable lodging and response to N. Bonanza was stronger than C702024 and among the semi-dwarfs Minn64-62 was more lodging resistant than C703011 and C703032. In fact C703011 showed a rather high level of lodging at the highest N level at Portage, although not as severe as that of the tall genotypes. This again indicates the plant height to lodging association is not always constant and it is apparent that there are many factors besides plant height which have a strong influence on lodging resistance. In terms of breeding methodology, therefore, selection pressure for lodging resistance must accompany selection for semi-dwarfism to achieve the potential in lodging resistance that is possible in this type of material. The effects of other factors, such as environment under which the material is grown, was evidenced by the Sanford and Portage 1976 locations in the present study. There, despite better growing conditions and higher yield levels, no lodging occurred at all, demonstrating the difficulty encountered when attempting to effectively select for lodging resistance.

Test Weight

Being closely correlated with kernel weight, test weight was affected by N in a similar fashion. The increased test weight resulting from providing adequate N fertility demonstrated that improved fertility gives rise to improved physical kernel quality in barley.

Bonanza was the superior genotype and the semi-dwarfs, especially C703011 (larger spike size), were lowest for test weight, again indicating the need to improve the kernel type of these semi-dwarfs.

The F x G in 1975 suggested that applying N brought all genotypes to a similar level for test weight, implying that the semi-dwarfs tested had a greater need for improved fertility to achieve desirable test weight.

Days to Heading, Days to Maturity and Days in Post-Anthesis

Although there was little effect of applied N on the number of days to heading, increasing N did tend to increase the number of days to maturity and the length of the post-anthesis period.

At the 1975 sites the zero N treatments headed slightly later probably because the lower fertility led to slower early development of the material in those treatments. The reverse occurred at Sanford due to overall higher fertility, combined with the timing of rainfall (just prior to heading) at that site.

The effects of N on maturity and hence post-anthesis were the results of the growth promoting effects of the applied N. Genotypic differences were notable only in that those genotypes with the shorter post-anthesis periods, namely C703011 and C703032, were also those with the lowest kernel weights. The F x G interactions in 1975 indicated that given adequate N all the genotypes studied had nearly equal post-anthesis periods.

Quality Parameters

As was the case in the report of Reisenaur and Dickson (1960) higher N levels significantly increased the levels of nitrogen, saccharifying activity, and soluble amino-nitrogen of the grain. A similar, though non-significant, trend existed for levels of alpha-amylase.

The genotypes had significantly different grain nitrogen levels at all sites, though the differences were quite small. The evidence from Carman, 1976, further suggested that when N was abundant these differences were yet smaller.

The variable results for each genotype across locations suggested that alpha-amylase levels are subject to modification by the environment and that genotypes may differ in the degree of environmental reaction. This may be of importance in the interpretation of alpha-amylase tests when selecting for malting quality.

All genotypes, except Minn64-62, responded to each increment of N for saccharifying activity. Minn64-62 had

low levels of this parameter at both sites and did not respond to increased N at Portage.

Minn64-62 was the only genotype with a more desirable level of soluble amino-nitrogen as compared to Bonanza.

On an overall basis, C703011 and C703032 would appear to be equally suited for use in breeding programs emphasizing malting quality. C703032 may have an added advantage, since at high N levels it showed superiority in alpha-amylase and saccharifying activity, yet no increase in protein. The other semi-dwarf, Minn64-62, had serious limitations in terms of malting quality, particularly in its low levels of alpha-amylase and saccharifying activity.

Overview

Examining this experiment as it was conducted, it would appear that the most serious stress factor which hampered the evaluation of the semi-dwarfs studied was weed competition. This occurred primarily at Carman, most severely in 1975. The semi-dwarfs appeared to be less competitive and were more affected by the highly competitive weeds, particularly wild oats. However, the addition of nitrogen improved the general growing conditions and alleviated much of this problem, so that more meaningful genotypic performance comparisons could be made.

The findings discussed in Experiment I relative to the semi-dwarf type probably being most advantageous for growing conditions conducive to lodging and high yields, combined

with the overall results of this experiment, lead to the conclusion that semi-dwarf varieties should be evaluated under more optimum conditions, (i.e. high fertility), in order to identify the superior genotypes.

Testing under stressful conditions, like those at Carman in 1975, makes meaningful decisions concerning genotypic superiority difficult. However, since such conditions may be encountered at the farm level, the author feels that new selections should be checked out under these situations prior to being released. Since the genotypes are tailored for areas with relatively optimum conditions, failure to perform under less than ideal conditions should not necessarily stop the release of such a cultivar. However, prospective growers should be made aware of their intolerance of such stress conditions. Thus, initial screening under optimum conditions would identify the inherently superior genotypes most useful under intensive management, with further testing identifying stress reactions.

As regards the plant type and growth habit of the semi-dwarfs, the results of this experiment again indicated the need for a more optimum balance among the yield components. Of the genotypes studied the better performer, Minn64-62, achieved its performance primarily through a large number of spikes per unit area. In so doing its kernel size was less than ideal. This imbalance must be improved in a phenotype of this nature. The lateness of Minn64-62 also contributed to its performance level. This factor is not

such a major drawback under more ideal conditions in which the growing season is not generally terminated abruptly by environmental stresses; nevertheless, lateness is not a desirable trait and one suspects the material would have to be improved for this parameter as well.

The ability of a genotype such as Minn64-62 to respond to high levels of nitrogen fertilizer obviously rests in its capability of producing a large number of spikes under these more optimal growing conditions. One could then speculate that this factor, combined with the kernel weight inadequacy and the negative association between spike size and kernel weight, suggests the ideal genotype for optimum growing conditions might be one which has the ability to produce large numbers of tillers, thereby producing a larger number of spikes per unit area; but these spikes should have fewer kernels each in order to maintain and/or achieve adequate kernel size.

On the other hand this type of approach may be too simplistic and rather unrealistic, particularly if taken to the extreme. There has in fact been an intensive effort to increase the grain number per spike in semi-dwarfs, in general negating the above proposal. Perhaps it then might be wise to produce hybrids with parents which have large, plump grain and select intensively in the segregating populations for the most desirable combination of the yield components and height.

Experiment III: Row Spacing and Seeding Rate Study

Phenotypically novel germplasm, like that of the semi-dwarf, may respond differently to variations in row spacing and/or seeding rate (Stoskopf, 1967; Briggs, 1975). Since a plant breeder wants to test a genotype using procedures which do not limit it's performance and mask its true potential, these interactions are important. They are also invaluable in making agronomic recommendations to the producer about these novel types so that their potential may be fully exploited. It was with these considerations in mind that this study of selected tall and short genotypes was conducted to measure the effect of various row spacings and seeding rates on several agronomic parameters.

Plant Height

Since the main purpose of developing semi-dwarfs is to improve straw strength, which is associated with shorter straw, knowledge of factors influencing the height of a semi-dwarf is desirable. Therefore, the effects of various spacings and seeding rates on plant height was important.

Varying row spacing and seeding rate did not alter the height relationship between the two genotypes. However, the different environmental conditions encountered did lead to variable behaviour. At both Sanford and Winnipeg, under good growing conditions, both genotypes were taller than at Carman,

and the treatments which increased the number of plants per unit of row length showed increased height, with Bonanza the more responsive. At Carman, the combined effects of late seeding, drought and early weed infestation gave the opposite effect, with both genotypes responding and the widest row spacing having the shortest plants. The early weed infestation which limited growth and utilized much of the available moisture appeared to be the main cause of this reaction.

The lack of significant seeding rate effects demonstrated the ability of the material to compensate for those differences. However, under stress conditions at Carman the semi-dwarf showed a trend towards taller plants at the highest seeding rate, while Bonanza had the greatest height at the intermediate seed rate. This suggested that the semi-dwarf may require higher seeding rates when grown under stress. At Winnipeg, under very ideal conditions, Bonanza was tallest at the lowest seeding rate, while Minn64-62 showed no height difference across seeding rates.

The very short stature of Minn64-62 under the stress conditions at Carman raises the question of whether such a height may be too short for practical purposes. Such a very short genotype might, under adverse conditions, be less desirable than one of an intermediate height in terms of suitability for modern harvesting procedures.

Yield

It is considered important to determine whether such a

drastically changed phenotype as the semi-dwarf requires changes in agronomic practics to maximize yield. The relative yielding abilities of the specific genotypes investigated were also of interest.

At Sanford and Winnipeg, where growing conditions were adequate to ideal, Minn64-62 outyielded Bonanza by 6.0 and 14.0 percent over the whole of each experiment respectively. At Carman, where late seeding, drought and weeds led to very poor growing conditions, Bonanza outyielded the semi-dwarf by some 13.0 percent. These results suggest, as did those of Porter et al. (1964) with wheat, that the semi-dwarf may not be suited to growth under stress conditions, particularly weed competition and drought. In the present material, this is probably a result of generally poor competitive ability due to slow and prostrate early growth and perhaps a less extensive root system. However, under conditions of adequate to good moisture and fertility, and with good weed control, the semi-dwarfs may have a higher potential yield. Such results are important relative to recommendations to farmers regarding the production of such semi-dwarfs.

As previously noted by others, seeding rates, particularly of the narrow range used, affected yield only when conditions were adverse. This was the case at Carman, where increased seeding rates gave higher yields. A similar, though non-significant, trend was shown at Sanford, but no differences of consequence were shown under the more ideal conditions at Winnipeg.

Although no significant genotype by seed rate interaction was detected, Minn64-62 tended to show more response than Bonanza, especially under the near ideal Winnipeg conditions, where Bonanza showed a negative yield response to increased seed rates. Combining all three sites Minn64-62 showed a 4.0 and 8.0 percent yield response to each respective seeding rate increase, while Bonanza showed only a 1.0 and 4.0 percent response to each increase.

Combining the two genotypes, no significant differences were detected between yields at the 15.0 cm. and 30.0 cm. spacings at any site. However, at Carman, there was a non-significant (6.8%) yield increase at the narrower row spacing. In all the trials, even under near ideal conditions at Winnipeg, there was a drastic yield reduction at the widest row spacing.

Although no significant genotype by row spacing interaction was shown, Minn64-62 did show a positive (15.0%) response to narrower rows under the stress conditions at Carman, while the tall genotype showed little response. This was likely due to the semi-dwarf being more able to compete with the weeds when planted at narrower row spacings at that site.

The results suggest then, that there should be some examination of the row widths and seeding rates used in testing procedures in relation to the evaluation of material with a wide range of height variation. Furthermore, the results suggest that semi-dwarfs of the Minn64-62 type

should not be recommended for production in areas with severe moisture stress, and that adequate weed control is an absolute necessity when growing such a cultivar.

Yield Components

The number of spikes per unit area and the number of kernels per spike were most affected by changes in seeding rates and row spacings. In general, as one increased, the other decreased.

Kernel weight was relatively unaffected except at Carman. There, due to late seeding and environmental stress, kernel weight was reduced at higher seeding rates, and was particularly low for Minn64-62. With the exception of Winnipeg, where the better conditions allowed Minn64-62 to complete its longer life cycle, Minn64-62 had lighter kernels than Bonanza. In general, as the numbers of spikes per unit area and/or kernels per spike increased, the kernel weight decreased.

The number of spikes per unit area was the most important component influencing yield, as shown by the 6.0 percent superior yield of Minn64-62 over Bonanza at Sanford. At that site the two varieties were equal in the number of kernels per spike and Bonanza had higher kernel weight than Minn64-62, making spikes per unit area the sole reason for the yield advantage of Minn64-62. Furthermore, at Winnipeg, where both its kernel number per head and its kernel weight were equal to those of Bonanza, Minn64-62 outyielded Bonanza

by some 14.0 percent.

These results suggested then, that the breeder, in developing semi-dwarf barleys, must attempt to maintain kernel size and number per spike, but increase the number of spikes per unit area. This happens when the seeding rate is increased, leading to the genotype which can produce the best spikes with adequate kernels having the greatest yield potential. The breeder must obtain an adequate balance among the yield components and at the same time maximize the yield.

On the other hand, the results of this study provided a warning that under less than ideal conditions the ability to produce more spikes per unit area may be disadvantageous. The other yield components may suffer too much in such situations, leading to decreased yields. Furthermore, even if total yield does not drop, kernel size and weight likely will. This alone is undesirable from a grain quality standpoint in barley.

Test Weight and Percent Barley Nitrogen

These parameters were unaffected by altered row spacing and seeding rate, except for slight variations related to changes in kernel size. Test weight decreased and barley nitrogen increased as kernel weight went down. Minn64-62's higher test weight at Winnipeg likely occurred because this genotype was later maturing, and at that site was able to complete its growing cycle under the less stressful conditions.

Experiment IV: Coleoptile Length Study

One of the problems which has existed with the semi-dwarf wheat in the U.S.A. has been poor emergence due to shortness of the coleoptile, shown to be associated with reduced plant height (Allan *et al*, 1962). This can present a problem for the producer, particularly if deep seeding is required to reach moisture.

Despite the lack of a significant correlation between plant height and coleoptile length for the genotypes studied in the present experiment, the ranking data and significant difference between height classes indicated that the tall genotypes did have longer coleoptiles. However, due to the strong positive relationships between coleoptile length and the kernel size parameters, and the strong positive relationships between these and height, the question arises as to whether the height to coleoptile length relationship was direct or indirect. The results indicated that it was possibly indirect, caused by the short statured genotypes having smaller, lighter kernels, and therefore shorter coleoptiles. This relationship could present further problems as higher yielding semi-dwarfs are developed, since, as shown in experiments discussed earlier, the kernel size component of yield suffered the greatest reduction as overall yield increased. This was particularly the case for the higher yielding semi-dwarfs in Experiment II.

The positive association in this experiment between root

score and yield on a rank correlation basis, hinted at the possibility of using this parameter as a selection criterion. For this to become a reality, further and more extensive research would have to be carried out in that area.

The lack of association between coleoptile length and emergence rate index for these genotypes is encouraging. However, the method of determination and the limited scope of the study involved in the calculation of emergence rate index, as well as the use of rank correlation procedures, were inadequate to obtain conclusive results.

Experiment V: Root System Size and Growth Rate Study

One of the fears expressed by several dryland area plant breeders regarding semi-dwarfs is that the root systems of these genotypes may not be adequate to withstand the droughthy conditions often encountered.

Although not statistically significant, due to the difficulty involved in the measurement of these parameters, the trends which developed indicated that, for these genotypes, the fears of the breeders may be justified. The semi-dwarfs apparently had both smaller and slower-growing root systems. Of particular note was the tendency of the semi-dwarfs to show drastically reduced root growth rates at week seven, while the talls did not show this reduction until week nine. This may in part be associated with the tendency for the specific semi-dwarfs studied to ripen off quickly.

The association between root growth rate and plant height also supported the contention that the semi-dwarfs had slower developing root systems. However, as was the case in Experiment IV with coleoptile length, the strong positive associations of the root growth and size parameters and plant height with kernel weight and plumpness suggested once again that the relationship may be indirect, caused by the tendency of the semi-dwarfs in question to have smaller kernels, giving rise to less vigorous seedlings.

Caution should be exercised in drawing conclusions from these results due to the large errors encountered in measuring these parameters under the conditions of the experiment. It should also be noted that the root systems were restricted in growth by pot size; hence the extrapolation of these data to field conditions may not be possible.

Experiment VI: Seeding Depth and Emergence Study

Accompanying the suspected coleoptile length problem of semi-dwarfs, researchers have voiced fears that these genotypes will be unable to emerge from deep planting or that they will not emerge quickly.

The results of this study indicated that no differences existed between the talls and semi-dwarfs for emergence ability or rate. All genotypes were capable of emerging from 7.6 cm. and all had equal difficulty from 10.2 cm. In fact, C703032 and C703011, both semi-dwarfs, were superior to the other genotypes in emergence. These results suggest

that, despite differences in coleoptile length, the semi-dwarfs were capable of emerging as well as the talls.

Caution should be observed in drawing conclusions from these results since the study was carried out in the greenhouse under relatively ideal conditions, and the sample and replicate sizes were small. The limited numbers of lines representing each height class represent yet a further limitation.

GENERAL DISCUSSION

Since desired changes in plant type can affect the attainment of other desirable goals, or may influence the methodology which must be employed to attain them in a breeding program, the clarification of the interrelationships of plant type with agronomic and quality parameters is important. The initial investigation reported was carried out to determine whether semi-dwarfism is a phenotypic change that involves such effects.

The methodology employed in the present study was inadequate for the estimation of genotypic values for some of the traits investigated. This inadequacy lay partially in the techniques employed during the investigation; however, the effects of reduced plant height did complicate matters in some instances.

The nature of the populations involved led to an inflated heritability estimate for plant height. The breeding behaviour of other characteristics closely related to height was somewhat affected by this, and their heritabilities were also high. The results further indicated that involvement of reduced plant height in hybrid barley populations would not necessitate a radical departure from conventional selection methods to attain desirable levels of any of the other

parameters investigated. The very high heritability of plant height suggested that the selection of short statured genotypes should present no problems. On the other hand, the overall breeding procedure may have to be somewhat altered to attain the usual performance objectives in populations involving short-statured genotypes. Among the reasons for this are: the small proportion of short types derived from some crosses; the low competitive ability of semi-dwarfs relative to the tall segregates; and the large number of undesirable character associations with reduced plant height.

Within the scope of the sample investigated, which was small by plant breeder's standards, the ideal combination of short height and adequate levels of other important agronomic parameters was not found. However, considering the total number of short strawed lines included in the study, the results were encouraging.

The small proportion of semi-dwarf types may have resulted from the adverse conditions (salinity) encountered during the F_4 increase in California. Several lines which were increased either were not returned or produced insufficient seed to be included in the study. This salinity may have particularly affected the semi-dwarfs, due to their inability to perform well under stress conditions, as was demonstrated throughout the study.

Although the height difference between the tall and the semi-dwarf in barley is generally assumed to be simply

inherited, observation of this material indicated the influence of modifier genes which led to the occurrence of stable genotypes of intermediate height as well as recovery of the parental classes. These intermediate height genotypes were in fact the most agronomically desirable group in the present study.

The results from all three populations investigated, in particular C-70-3, indicated that lines with a desirable combination of performance characteristics occured with greatest frequency among genotypes in this intermediate height category. These lines had improved straw strength relative to the taller lines, yet also had acceptable levels of yield and kernel size parameters and more acceptable maturity. This was exemplified by C-70-3, in which the majority of derived lines fell in the intermediate height class. Despite this the population means and ranges for most of the other characteristics were similar to those obtained among lines from the other two crosses, lodging being an exception, but on the favourable side (Tables 8 and 9).

The high heritability of plant height and the lack of competitive ability of semi-dwarfs relative to tall genotypes, suggest modifications of breeding procedures may be required in attempting to improve and adapt semi-dwarfs by hybridizing them with better performing taller genotypes available. The low incidence of true semi-dwarfs indicated a need for large F_2 populations, perferably at lower plant

densities, to facilitate the selection of sufficient numbers of appealing short statured types in order to make progress toward improved agronomic performance. Larger populations would also be required by the breeder desiring to select intermediate height genotypes, since these were also shown to occur at a lower frequency than tall segregates.

An additional problem with the material investigated was the apparent linkage between shortened stature and late heading and maturity, which was probably partially responsible for the strong association of reduced plant height with reduced kernel size and plumpness. This lateness was associated with an observed slow and prostrate early growth habit. The kernel parameters suffered in the short material, particularly among early maturing lines and those showing high yield levels. Some lines did not suffer these kernel size problems, but these were most often lower yielders. The lower yield resulted from the production of fewer spikes per unit area; the yield component by which the better yielders apparently achieved that yield. The number of kernels per spike was not a significant problem since parental genotypes had adequate spike size. The semi-dwarf parent, Minn64-62, was below optimum in kernel size.

Based on the associations shown, a special effort may be required to improve kernel size in semi-dwarf segregates by intensive selection for improvement throughout the segregating generations among large numbers of semi-dwarf lines. The ease of visual selection for plant height

indicated by this study suggests that early-generation selection of the larger numbers of semi-dwarfs required would not be difficult. This intense selection could then be followed by the sorting out of other less heritable parameters in the later generations of the breeding program.

The ideal genotype would have many spikes per unit area, many kernels per spike, high weight per kernel and be of the desired height. However, due to yield component compensation, maximization of all three components in a single genotype will not be easy. From a practical standpoint, a reasonable balance of the components is desirable. In terms of individual components, kernel weight must be at a certain level for end use acceptability. Kernel weight is important because heavy, plump kernels mean less fiber and more energy per pound of grain. This is important both from a feed and a malting viewpoint. High levels of the other components are obviously desirable, but only because of their contribution to yield potential.

The evidence obtained suggests that adverse inter-character relationships shown would make the task of selecting for the desired character combination directly from an initial semi-dwarf by tall cross very difficult, and perhaps rather impractical. It is proposed that a more realistic approach would be a step-wise one, which might be more time consuming, but would be more certain of success.

This approach involves the simultaneous development of two or more short-strawed genotypes with the desired levels

of different yield components in each, followed by intercrossing these to achieve the desired goal of high yield of plump barley. These second-stage crosses would minimize some of the previously discussed problems, since all the material would be short statured.

The barley project at the University of Saskatchewan has, and is following such a procedure (Dr. B.L. Harvey, personal communication). By selecting against lateness and slow, prostrate, early growth but maintaining good spike size (in the original crosses), selections with acceptable levels of kernel weight and number of kernels per spike were obtained. However, a lower number of spikes per unit area limited their yielding ability. Short statured genotypes (similar to those used in the present study) with large numbers of spikes per unit area, good spike size, but lacking kernel weight were obtained from the University of Minnesota program, and hybridized with the Saskatchewan lines. This procedure has minimized the need for selection for height or spike size (both parents had desirable levels) and now at F_3 the breeder can concentrate on selecting toward an optimum balance between spikes per unit area and kernel weight, toward the objective of maximum yield.

Among the materials in the present study were short-statured lines which embodied the desired levels of individual components. These could be intercrossed, or crossed to complementary types like those of the Saskatchewan program, to attain desired levels of all components within

individual lines.

It is generally considered that a minimum goal would be for semi-dwarfs to exceed the yield level of regionally adapted tall cultivars in trials under average conditions. Such an increase in yield requires a change in the basic sink of the crop and this may initially be hard to achieve. On the other hand the high tillering semi-dwarf may be more capable of providing a larger sink under more ideal growing conditions. Even if the sink is not increased the semi-dwarf stature would be desirable in terms of yield stability. Short stature contributes strongly to lodging resistance, and lodging, whether of the early or late season type, frequently is a serious problem. This is especially the case in regions where barley is well adapted and therefore highest yields are expected. As previously discussed the semi-dwarf types would likely be most suited to and most useful in these highly productive areas. Development of semi-dwarf lines with high levels of lodging resistance and achieving a yield level comparable to that of the better tall genotypes under conditions free of lodging, would be a valuable achievement, and should be the initial goal in any breeding program attempting to develop useful short statured genotypes.

The results obtained indicate the possibility of selecting an adapted, short-strawed, barley genotype with acceptable yield. Several genotypes of intermediate and short height showed high yield levels, but they were undesirable due to

reduced kernel size and lack of yield stability, particularly under conditions of stress. A procedure for overcoming these faults has been suggested above.

The semi-dwarfs investigated agronomically appeared to require special attention to cultural procedures to achieve maximum performance, particularly when growing under unfavourable environmental conditions. Adequate weed control was a necessity since the short statured genotypes were poor competitors. The semi-dwarfs in question seemed to have a definite minimum fertility requirement. Unfortunately, they did not appear to respond to high nitrogen levels to any greater degree than did the tall cultivars.

The slow early growth of the sample of semi-dwarfs investigated was particularly disadvantageous under less than ideal conditions. This slow growth was associated with the high spikes per unit area type, hence, a more desirable balance of yield components might be expected to reduce this problem. However, since spikes per unit area appeared to be the most influential of the yield components, the lack of competitive ability of high yielding semi-dwarfs may be difficult to overcome. The tillering component is important in providing a means of response to more ideal environments, particularly to optimum levels of moisture and fertilizer.

As previously stated, the greatest advantage of the semi-dwarfs would be in the areas best suited to barley production. In Western Canada these are the regions where straw strength is important, characterized by a con-

sistent supply of adequate moisture. For the dryer areas, in fact, semi-dwarfs may be at a disadvantage in yield relative to tall cultivars, and may also be undesirably short for modern harvesting procedures. It was observed that the short statured material investigated performed relatively better under conditions of adequate to high moisture.

The trend for improved performance of the semi-dwarf at narrow row spacings and high seeding rates again reflected their lack of competitive ability. Row spacing would not present a serious problem to the producer since the narrowest one in the study is the common row width used by producers. Seeding rate can be easily altered, but would raise costs slightly.

The seeding rate and row spacing effects need to be considered in relation to the nitrogen responses obtained. It seems probable that, had the nitrogen trials been carried out at greater plant densities, the semi-dwarfs would have shown greater response than the talls, particularly if severity of lodging had been accentuated.

The seeding rate and row spacing results may also have implications regarding the procedures used in the evaluation of genotypes for purposes of varietal release. This is especially so when the shorter types are being evaluated side by side with tall genotypes as is now the general case. Also, for ease of handling, several institutions use row spacings which may not allow the semi-dwarfs to express

their true potential.

The general lateness of the higher yielding, short-strawed genotypes may also be a disadvantage, particularly in the more northerly barley producing areas. Early short strawed types can be isolated (several existed in population C-70-3), but they tend to be lower yielders. However, the yield of an early short strawed line should be compared to that of early maturing tall varieties before any decisions are made. This general lateness of the better short types will necessitate a recommendation of early seeding even in areas with a longer growing season, due to the lateness of heading as well as lateness of maturity.

On the basis of limited research and data, it is also possible that short stature in barley may be associated with slower growing and less extensive root systems. This again suggested these types would not be suited to the areas with stress types of environment. On the other hand, these parameters were associated with small kernel size and improvement of this component may result in the improvement of the root parameters as well.

It appears then that short strawed barley could be a viable plant type in the barley growing areas of Western Canada, particularly in the most productive regions where lodging is frequently a limiting factor. There will be need to make producers aware of the unique field management practices required to provide an environment suitable for these types in order to achieve maximum performance. The

possibility of improved input response with semi-dwarfs exists and future breeding efforts will undoubtly be directed toward taking advantage of this potential.

SUMMARY AND CONCLUSIONS

Experiment I: Components of Variance, Heritability Estimates and Phenotypic Correlations

Three populations of barley, developed from crosses involving one semi-dwarf parent, were grown at each of two locations for two years. The data were used to estimate heritabilities and variance components for plant height and several other agronomic parameters as well as to define the interrelationships of these parameters by correlation procedures. Some malting quality traits were included in the correlation study.

The objective was to determine the effects of involving reduced plant height in barley on breeding procedures and on other parameters of concern to breeders. Further to this was the objective of individual genotypic evaluation.

The introduction of reduced plant height into the barley populations studied was interpreted as not appreciably affecting the variances and heritabilities of other agronomic characteristics studied.

Plant height itself was highly heritable, as was kernel weight. Days to heading, and maturity were generally highly heritable, while test weight, plumpness and lodging were somewhat less heritable. Yield had the lowest heritability.

Testing at one site for one year was judged to be sufficient to estimate genotypic values for height, kernel weight and lodging in the material studied, while test weight, plumpness and kernels per spike required more than one years data. Heading date, maturity and days in post-anthesis required data from at least two locations in two years. Yield showed evidence of a requirement of testing in more than one location in more than one year. More replication would have likely improved the estimates for all characters, but would have been particularly beneficial for kernels per spike, kernel weight, maturity and lodging.

All three populations studied contained genotypes superior to the control for each characteristic studied. The highest yielding short statured lines from these populations were of intermediate plant height relative to the semi-dwarf Minn64-62 and the tall control, the most commonly grown well adapted tall variety of the region, "Bonanza".

All significant associations with reduced plant height were undesirable with the exception of lodging. However, the correlations, despite being significant, were not large, and it should be possible to select acceptable shorter genotypes. C-70-3 was the most promising population studied in that regard, but more because of prevalence of short lines than because of character interrelationships.

Reduced plant height had no detectable effect on the

barley quality parameters examined.

The greatest problems with the shorter material studied were later heading and maturity, and reduced kernel size. These problems were most severe in the higher yielding lines. The interrelationships among the other characteristics studied were sometimes affected indirectly by reduced plant height.

It is suggested that a better balance among the yield components of the higher yielding lines is required in order to meet the kernel size requirements of a good barley sample. Given the ranges of each component in the limited sample of short statured types studied, such a balance should be ultimately attainable by plant breeders. Maturity characteristics of the semi-dwarfs fall into the same category.

The greatest asset of the short material is its improved straw strength, which should be particularly valuable in the areas most suited to barley production where high yields can be achieved in the absence of lodging. The strong, short-statured genotypes offer increased stability of yield, even without advances in basic yield.

Experiment II: Nitrogen Fertilization of Tall and Semi-dwarf Barleys

Concomitant with improved straw strength of short statured genotypes in other cereal crops has been their improved ability to respond to higher levels of fertility. An experiment was conducted over five station-years to compare the responses of three semi-dwarf and two standard

height genotypes to high nitrogen levels.

Nitrogen Response

In general, at all sites and for all traits studied, the significant response to applied N was limited to the first increment of N applied except where growing conditions were below average. This occurred at Carman. There, significant response to N continued with the higher increments. At all sites response continued as applied N increased up to the third and fourth N level, but the responses were not always significant.

Plant height, yield, spikes per unit area, kernels per spike, lodging, days in post-anthesis, percent barley nitrogen, alpha-amylase levels, saccharifying activity and levels of soluble amino-nitrogen all responded positively to added nitrogen.

Kernel and test weights tended to respond positively to the first N increment, but then showed negative responses to increased levels of N.

Days to maturity tended to increase or not to respond to nitrogen, while the response of days to heading depended on the environmental conditions at each location.

Genotypic Differences and Genotype x Fertilizer Interaction

The results indicated that, for the semi-dwarfs to be competitive in terms of yield, increased levels of management

inputs would be required, since they appeared to perform best under more ideal growing conditions. The semi-dwarfs were not as able to handle stresses imposed by weed competition, low fertility or drought. Although no fertilizer by genotype interactions occurred for yield or its major components, trends indicated that the short-statured material had a greater requirement for at least the first increment of nitrogen relative to the tall genotypes. At the higher nitrogen levels this extra response did not continue.

The two semi-dwarfs which performed best in this trial, C703032 and Minn64-62, gained their yield primarily from production of more heads per unit area than the talls. They had fewer kernels per head and lower kernel weight at most sites. Increased N did alleviate some of these differentials when growing conditions were adequate; however, kernel weight was least favourable at the highest yield levels.

On the average, Minn64-62 was the highest yielding genotype. However, its drawback was its lateness, since, except under good growing conditions, it was unable to complete its growing cycle, resulting in greatly reduced kernel size.

When lodging occurred, the semi-dwarfs exhibited superior resistance, which continued as the fertility level increased. The gap between the lodging levels of the tall and short types increased with N level, particularly for Minn64-62, which showed no increase in degree of lodging as N increased.

In terms of the other parameters examined in this experiment the genotypes responded in a similar manner relative to one another.

The semi-dwarfs did lack competitive ability particularly when grown under adverse conditions. This led to the conclusion that weed control would be even more important when growing such types than when producing taller types.

Experiment III: Row Spacing and Seeding Rate Study

Changes in plant morphology can have large effects on the optimum plant density required to achieve maximum production. To obtain information on the impact of short straw in this context, one semi-dwarf and one tall genotype were compared at several combinations of row spacings and seeding rates at three locations.

Varying seeding rate and/or row spacing had little or no practical effect on plant height, kernel weight, test weight and protein content of either the tall or the semi-dwarf genotype.

Increased seeding rate showed: significantly increased yield under adverse growing conditions at Carman, a trend to the same with average conditions at Sanford, and no differences at Winnipeg under near optimal growing conditions. Despite the lack of a significant seeding rate by genotype interaction, the semi-dwarf tended to show greater positive response to seeding rate than the tall.

At all sites for both genotypes the 61.0 cm. row spacing was inferior to the more narrow ones for yield. There were no significant differences between the 15.0 and 30.0 cm. widths at any site, although the semi-dwarf did show a trend towards higher yields at narrower row spacing under the adverse conditions at Carman.

In general, yield improvements were brought about by increased numbers of heads per unit area. This was accompanied by fewer kernels per head, and where the compensation was not equal, a higher yield resulted.

Experiment IV: Coleoptile Length Study

Short coleoptiles have been associated with decreased plant height in wheat and with a reduction in the ability and rate of emergence. In the present study a group of standard height and semi-dwarf barley genotypes, chosen to represent a wide range of yield levels, were checked for coleoptile length.

The results of this experiment indicated that the tall barleys had longer coleoptiles than the short statured ones. The evidence gathered suggested that the shorter coleoptiles of the semi-dwarfs may have been the result of their small kernel size.

For the genotypes studied the short coleoptiles of the semi-dwarfs did not affect their emergence rate.

Experiment V: Root System Size and Growth Rate Study

Concern has been expressed by dryland area breeders about the size and extent of the root systems of the semi-dwarfs in wheat and barley. An attempt was made to compare the root systems of several semi-dwarf and tall genotypes.

The semi-dwarfs studied appeared to have smaller and slower growing root systems than the tall genotypes. This again may be related to the association of plant height with kernel size parameters.

The root systems of the semi-dwarfs also stopped growing sooner than the talls. This may have been affected by restrictions imposed by pot size.

Experiment VI: Seeding Depth and Emergence Study

The semi-dwarf wheats do not have ability equivalent to the tall types to emerge from deep plantings. Preliminary research was carried out to compare these plant height types in barley for this ability.

No differences existed between the tall and semi-dwarf genotypes studied for emergence ability or rate.

All genotypes emerged well from the 2.54, 5.08, and 7.62 cm. depths. All emerged equally poorly from the 10.16 cm. depth.

SUGGESTIONS FOR FUTURE RESEARCH

1. Selection for short statured genotypes should be carried out in large F_2 populations of tall by semi-dwarf crosses since the number of semi-dwarf segregates is small. These small numbers represent a natural barrier to selection of a short line with the desired level of yield or any of its components. The nurseries should also be sparsely planted since the shorter segregates are less competitive and may be overlooked under crowded conditions.

   Selection of a single short-strawed line with the desired yield component balance may be possible, but the author feels a more reasonable approach might be to select short lines with a desired level of each individual component and intercross these to obtain the desired end product.

2. To improve upon the research conducted in the present study it might be advised to use specific numbers of lines (preferably isolines) from each height category; tall, intermediate and semi-dwarf. It would also be useful to use more than one parental source for short straw.

3. Attempts should be made to select genotypes with early heading dates and longer post-anthesis periods, but with acceptable maturity.

4. Research should be conducted investigating and clarifying the value of heading date as a selection tool for breeders selecting superior genotypes in Western Canada.

5. Further tests are required on a broad range of lines to determine the importance of fertilizer and plant density effects on semi-dwarf and tall genotypes, particularly in the most productive barley growing areas. These factors should also be studied in combination with one another.

6. Further research should be conducted on larger samples to determine the relationships of root parameters and seedling growth with reduced plant height in barley. Concomitant with this is the need for research into improved techniques to be used in the determination of root growth parameters in cereal crops in general.

7. Further clarification is needed in regard to the effect of seed size on the seedling and root growth parameters in barley.

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APPENDIX

Appendix. Genotypic Means for Agronomic and Quality Parameters, Populations C-70-1, C-70-2, and C-70-3, Experiment I.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
*														
C701001	76.2	497.1	57.9	6.70	86.7	54.3	3.33	54.8	83.6	28.8	2.09	28.9	232	0.144
002	78.9	495.9	60.5	6.81	79.3	51.9	3.67	55.8	85.1	29.6	1.92	30.2	179	0.137
003	74.5	523.0	56.8	7.32	88.2	52.2	2.90	55.2	84.9	29.9	2.04	26.3	156	0.130
004	73.9	509.6	58.6	6.68	75.1	51.6	3.67	55.7	85.5	29.8	1.94	28.4	175	0.147
005	79.9	491.5	56.0	7.27	88.6	52.7	4.57	53.0	83.4	30.4	2.03	27.3	182	0.140
006	59.4	394.8	55.0	6.66	80.9	51.3	1.43	60.0	86.3	26.6	2.12	26.6	247	0.141
007	73.8	564.6	61.6	6.57	81.0	51.5	3.77	55.2	84.1	29.1	1.90	25.0	199	0.145
008	59.9	477.7	53.0	6.62	86.2	51.2	1.77	57.2	85.6	28.4	2.14	29.2	221	0.162
009	78.5	504.5	55.6	7.39	84.2	53.7	3.43	54.1	83.8	29.6	1.95	26.4	169	0.143
010	75.0	581.4	58.0	6.96	84.8	53.1	3.33	53.7	83.1	29.4	1.97	31.5	207	0.149
011	79.7	525.7	56.8	7.48	87.3	52.4	4.33	55.5	84.4	29.4	1.95	27.2	183	0.142
012	78.0	449.3	52.8	7.81	94.7	53.5	2.90	54.5	83.5	29.2	2.21	27.4	227	0.150
013	77.9	505.6	55.2	7.61	93.6	52.9	2.57	54.1	83.3	29.3	2.14	27.8	178	0.147
014	77.8	524.4	56.2	7.14	86.0	53.0	2.57	56.0	83.5	30.3	2.03	26.6	227	0.149
015	79.2	447.9	58.3	7.21	88.5	52.0	4.90	53.7	84.6	31.0	2.08	24.0	208	0.142
016	78.8	533.7	57.6	7.01	84.7	52.7	2.90	55.0	83.5	28.5	2.13	26.8	220	0.152
017	59.3	498.1	55.5	7.10	83.1	51.0	3.10	57.1	86.6	30.1	2.09	25.0	205	0.141
018	59.4	496.6	51.3	6.74	86.3	52.7	1.33	58.0	85.4	27.4	2.07	26.0	171	0.130
019	64.0	442.5	53.6	6.96	88.3	51.3	1.67	55.0	83.5	28.8	2.23	29.7	194	0.155
020	77.7	478.8	55.3	6.87	89.6	52.8	2.57	56.0	83.7	28.0	2.27	32.3	254	0.177
021	75.6	593.4	58.3	7.31	87.3	53.5	4.10	54.6	84.9	30.6	1.97	21.5	188	0.118
022	76.8	543.7	56.9	6.86	83.7	52.1	3.10	54.8	83.8	29.3	1.95	25.5	169	0.137
023	74.5	512.5	54.5	7.03	88.8	52.9	2.67	56.8	85.3	29.1	2.01	31.8	205	0.141
024	59.2	458.6	54.4	7.11	83.7	52.2	2.57	55.4	83.8	28.4	1.94	28.4	175	0.148
025	79.8	507.8	53.6	6.87	85.8	54.0	2.90	54.9	83.3	28.6	1.95	29.5	213	0.148
026	79.1	498.5	54.3	7.07	89.2	54.0	3.23	54.9	83.0	28.1	2.12	30.9	233	0.138
027	78.8	453.3	55.6	7.30	89.9	53.2	3.33	55.9	83.2	27.3	1.99	30.0	187	0.155
028	77.1	429.5	56.0	7.19	90.2	53.1	1.33	53.1	81.6	28.5	2.35	28.4	240	0.168

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C701029	67.3	504.7	51.7	7.28	86.9	51.5	2.90	56.1	85.5	29.6	2.00	27.5	182	0.156
030	78.3	602.5	56.1	6.81	82.8	53.7	2.77	55.3	82.6	27.3	1.92	29.5	199	0.149
031	78.1	512.9	53.4	7.24	92.0	54.0	3.00	53.7	82.6	29.1	2.20	32.1	189	0.159
032	79.3	516.1	54.1	6.37	80.0	54.6	2.00	53.8	81.9	28.3	2.20	36.3	261	0.187
033	77.4	488.2	54.6	7.42	91.0	52.1	4.23	53.3	84.9	31.9	2.18	29.1	235	0.155
034	76.2	520.3	54.9	6.92	84.7	52.5	2.77	56.5	84.1	27.6	2.09	31.7	228	0.166
035	78.8	536.1	53.9	7.05	88.3	53.3	3.23	53.7	83.6	29.9	2.08	26.5	213	0.150
036	74.6	491.1	54.8	7.01	83.3	52.9	2.77	54.8	83.6	29.0	2.00	27.9	205	0.152
037	62.0	477.9	57.9	6.66	82.1	51.6	1.10	57.2	86.4	29.5	2.01	24.7	226	0.142
038	81.0	558.7	56.0	7.16	85.5	51.4	3.67	55.2	85.3	30.6	2.02	24.8	182	0.132
039	80.8	513.1	57.4	7.06	87.5	54.1	2.77	53.6	83.9	30.3	1.98	24.9	167	0.140
040	71.0	447.8	57.3	6.61	74.6	51.5	3.10	57.0	86.1	29.2	1.99	27.4	214	0.130
041	71.1	468.6	60.0	6.59	81.5	50.3	4.43	56.2	85.1	28.9	2.12	29.6	222	0.152
042	82.1	519.5	58.9	6.66	75.0	51.4	4.90	55.2	84.0	28.8	1.94	30.1	183	0.147
043	79.6	493.8	52.1	6.97	88.8	51.2	2.67	55.9	84.6	28.7	2.06	31.9	191	0.171
044	79.5	494.9	54.4	7.24	88.1	52.9	2.43	55.3	84.1	28.9	2.13	32.8	208	0.176
045	65.4	457.4	56.4	7.08	92.9	50.3	2.10	57.2	85.9	29.0	2.17	24.9	166	0.134
046	58.8	436.0	52.9	6.21	60.2	50.2	1.77	59.1	85.2	26.6	1.97	27.5	180	0.155
047	61.7	478.8	55.6	6.56	81.1	50.6	1.43	57.5	85.9	28.4	2.00	32.0	221	0.160
048	76.4	475.1	54.9	6.63	73.1	50.7	2.77	56.3	84.3	28.2	1.94	27.1	172	0.150
049	76.6	555.1	60.5	6.53	72.2	51.1	4.33	55.4	85.0	29.6	1.98	28.8	167	0.141
050	72.6	531.6	56.9	7.13	86.6	53.5	4.23	54.3	84.9	30.9	2.03	29.0	230	0.132
051	79.2	579.8	54.5	6.53	72.7	54.1	4.23	53.1	83.4	30.3	1.93	26.3	205	0.146
052	72.4	549.1	55.4	7.24	86.4	53.5	2.67	54.9	85.6	30.7	1.96	28.8	193	0.161
053	79.7	559.8	56.4	6.55	80.9	52.7	3.00	55.8	85.7	30.1	1.95	26.8	161	0.138
054	79.2	504.7	51.8	7.08	89.5	53.1	3.90	53.0	81.3	28.3	2.16	25.8	168	0.150
055	79.3	536.3	56.8	6.97	85.3	52.3	4.67	55.0	85.1	30.1	2.17	29.6	170	0.156
056	77.6	503.1	51.9	7.68	91.9	54.0	3.23	54.7	84.7	30.2	2.08	24.7	161	0.130

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C701057	75.5	561.3	55.4	7.39	91.3	54.0	3.23	53.3	82.7	29.6	2.08	25.4	211	0.138
058	77.6	500.0	59.1	7.29	89.2	54.0	4.23	54.1	85.1	31.3	2.07	22.5	202	0.119
059	74.5	572.8	55.9	6.85	83.1	53.9	4.23	52.6	81.3	29.0	2.56	25.6	197	0.131
060	80.6	494.5	55.0	7.30	89.3	51.5	3.90	53.8	84.5	28.2	2.12	23.4	192	0.147
061	71.3	485.3	58.8	6.55	81.4	53.1	1.90	54.3	83.0	28.8	2.16	26.9	228	0.151
062	75.5	550.7	52.6	6.64	85.4	53.7	1.77	55.1	85.1	30.0	2.05	27.5	206	0.148
063	71.0	546.3	57.9	6.82	84.0	54.3	3.90	55.0	83.2	28.3	2.01	24.2	201	0.124
064	77.8	532.8	57.5	6.97	83.4	53.7	3.67	55.1	85.3	30.1	2.03	27.4	191	0.152
065	77.3	603.8	56.9	6.88	84.2	53.7	3.33	53.2	83.9	31.0	2.03	23.2	173	0.137
066	75.8	542.6	59.8	7.29	80.5	53.3	3.43	54.0	84.3	30.3	1.96	27.1	169	0.133
067	80.6	491.1	57.5	6.69	62.2	52.9	5.10	56.0	85.2	29.2	1.97	25.9	206	0.137
068	77.8	504.6	58.0	6.56	75.9	51.2	4.77	56.3	85.5	29.2	1.99	26.5	236	0.140
069	79.4	579.5	61.3	7.10	78.7	53.2	4.10	54.5	85.3	31.1	1.94	25.9	223	0.128
070	80.8	500.7	56.4	7.13	85.8	53.0	2.23	55.7	84.3	28.6	1.97	26.2	244	0.153
071	76.6	507.8	55.1	7.31	90.0	53.6	3.43	53.7	84.7	31.3	2.06	26.7	221	0.136
072	82.0	561.7	54.7	7.43	89.3	52.6	4.43	53.9	83.6	29.6	1.97	24.8	219	0.139
073	77.3	423.3	56.9	6.90	86.9	51.7	5.67	53.5	83.3	29.9	2.09	25.2	186	0.124
074	84.2	475.1	52.8	7.54	91.4	52.0	4.00	56.3	86.1	30.1	2.27	27.0	198	0.141
075	80.1	513.3	58.4	6.74	83.9	52.2	4.00	53.4	82.1	28.9	2.11	31.5	294	0.137
076	79.5	577.2	54.9	7.33	88.0	51.6	4.77	53.3	82.3	29.1	1.96	27.5	187	0.147
077	78.8	592.0	55.9	7.02	86.8	52.5	3.57	54.5	85.0	31.0	1.99	25.1	221	0.135
078	81.3	488.0	57.4	6.92	85.9	52.7	4.57	55.6	84.0	28.5	2.05	26.7	195	0.130
079	80.4	544.8	59.1	7.23	82.2	52.5	3.33	56.0	85.8	29.8	2.02	26.5	228	0.141
080	81.7	477.4	53.6	7.39	91.3	52.7	4.10	55.0	83.8	28.9	2.10	25.1	236	0.135
081	77.1	535.3	49.6	6.90	88.8	52.5	3.33	56.2	83.5	27.6	2.04	25.2	209	0.134
082	78.1	511.9	56.4	7.09	86.6	53.1	4.90	53.8	84.6	30.8	2.09	28.1	239	0.130
083	73.3	560.1	56.1	6.84	82.6	52.8	2.67	54.1	83.1	29.1	2.07	23.5	200	0.124
084	76.8	538.0	55.6	6.63	83.5	53.2	3.90	56.1	84.8	28.7	2.10	20.7	215	0.128

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C701085	79.8	507.6	59.6	7.50	89.7	53.5	4.43	52.9	83.7	30.8	2.10	21.2	173	0.113
086	78.5	495.3	56.0	6.88	88.8	53.2	3.43	55.6	83.2	27.6	2.10	34.2	262	0.156
087	77.5	529.1	55.6	7.26	85.5	52.4	4.67	54.4	84.6	30.2	2.07	25.4	210	0.132
088	80.3	516.6	52.8	7.13	90.4	51.9	3.90	54.7	84.6	29.9	2.11	27.1	177	0.131
089	77.0	511.3	54.5	7.36	88.6	52.5	3.33	54.9	83.8	28.8	2.05	24.7	225	0.140
090	76.2	491.0	55.1	7.09	85.2	53.3	2.10	54.6	83.8	29.3	1.96	27.0	262	0.134
091	84.0	525.3	58.7	6.98	86.9	52.3	2.57	55.2	85.2	30.0	2.14	32.2	232	0.144
092	79.7	524.6	60.4	6.67	77.4	51.6	4.23	54.8	84.9	30.1	1.99	26.5	244	0.144
093	79.5	485.6	55.4	7.15	82.4	51.8	5.10	53.5	84.2	31.0	2.03	26.9	274	0.151
094	78.3	473.3	55.2	6.82	81.1	53.5	3.90	55.0	82.1	27.4	2.09	33.1	280	0.166
095	80.4	562.8	57.5	7.33	88.5	53.2	4.10	55.7	83.9	28.2	2.00	29.9	218	0.147
096	78.0	593.9	56.1	7.19	87.6	53.0	3.23	53.0	82.6	29.7	2.00	29.1	202	0.136
097	80.6	573.3	57.3	7.02	88.6	53.2	2.57	55.8	85.2	29.7	1.97	29.1	248	0.144
098	74.1	570.7	58.9	7.06	85.7	51.5	3.33	54.8	84.5	29.7	2.00	30.8	197	0.137
099	78.6	487.7	58.3	6.76	80.6	53.3	2.33	56.1	85.4	29.3	2.06	30.4	212	0.143
100	80.2	548.4	55.6	7.47	90.4	53.3	3.43	53.6	84.4	30.8	2.11	27.5	216	0.140
101	76.9	532.8	61.4	7.37	89.3	53.1	4.90	54.0	85.1	31.3	1.96	25.6	218	0.121
102	77.3	548.9	60.8	6.52	78.4	53.4	3.10	54.7	82.1	27.7	2.10	31.0	245	0.129
103	80.3	526.1	57.8	7.03	84.6	52.1	4.23	54.8	85.6	30.8	2.02	32.3	255	0.139
Mean	76.1	513.9	56.2	7.01	84.9	52.6	3.36	55.0	84.2	29.4	2.05	27.6	208	0.147

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
**														
C702001	80.5	547.6	56.1	7.61	89.4	52.2	4.23	56.2	86.1	29.9	2.08	26.1	240	0.141
002	79.9	553.1	59.9	7.01	85.1	52.5	3.10	56.3	85.7	29.3	2.14	22.8	223	0.126
003	75.8	579.3	55.4	6.93	84.8	52.6	3.43	56.8	84.9	28.1	2.09	28.2	226	0.134
004	74.6	523.3	56.1	7.05	81.9	53.2	3.67	56.9	83.6	26.7	1.99	25.6	206	0.142
005	74.5	546.2	58.6	7.12	87.0	53.0	3.77	55.8	84.6	28.8	2.13	26.5	261	0.143
006	73.7	561.4	62.6	6.81	80.7	52.6	2.33	55.4	86.0	30.8	1.98	27.8	223	0.139
007	80.8	556.1	59.6	7.15	87.4	51.8	3.77	57.1	86.2	29.1	2.06	22.0	200	0.111
008	81.4	572.8	52.2	7.35	92.0	53.7	3.10	55.9	85.8	30.2	2.09	21.4	218	0.122
009	77.6	541.2	59.3	7.05	87.4	53.2	3.67	56.1	86.3	30.2	2.02	19.8	194	0.116
010	79.8	570.0	55.8	6.58	81.8	52.6	2.10	57.3	86.0	28.8	2.04	26.4	222	0.133
011	58.7	441.1	55.7	5.98	65.9	47.4	1.00	61.0	87.2	26.5	2.03	35.9	286	0.164
012	73.2	568.4	61.2	6.99	83.9	52.5	2.77	55.4	85.2	27.3	2.04	25.8	229	0.136
013	75.4	540.8	50.8	7.73	91.2	53.3	2.90	54.9	84.4	29.8	2.02	26.5	234	0.141
014	78.6	474.7	52.8	7.15	90.2	52.0	3.10	56.0	86.0	30.0	2.14	28.3	216	0.145
015	79.3	511.8	53.8	6.53	75.1	52.1	2.90	56.5	83.8	27.4	2.13	30.0	232	0.136
016	77.3	574.6	54.0	6.91	87.3	53.4	2.33	56.4	84.9	28.5	1.99	27.6	225	0.156
017	82.3	551.6	52.3	7.01	89.6	53.2	3.10	56.1	85.0	28.9	1.97	27.3	208	0.128
018	76.1	559.6	54.6	6.71	87.7	53.1	2.10	56.4	84.9	28.5	1.92	25.6	196	0.134
019	73.4	579.8	54.4	7.08	88.1	51.8	2.57	54.1	83.8	29.7	1.98	30.4	246	0.137
020	77.5	468.6	52.6	7.05	86.4	53.8	1.77	57.6	85.3	28.2	2.10	27.9	255	0.152
021	78.8	545.0	54.9	7.42	89.4	53.5	3.77	53.6	83.5	30.1	2.09	27.0	251	0.149
022	74.1	441.5	56.4	7.01	87.4	53.5	2.67	55.5	83.6	28.3	2.00	27.7	222	0.148
023	78.0	549.9	53.8	7.31	89.1	54.2	3.43	54.0	84.9	31.0	2.02	25.6	228	0.138
024	79.2	635.8	57.9	6.84	82.7	52.7	2.90	56.4	84.9	28.5	1.94	25.2	241	0.145
025	71.7	578.6	57.6	7.21	87.5	54.2	3.33	53.8	82.1	28.3	1.99	22.3	192	0.119
026	75.3	523.6	58.9	7.06	88.6	53.9	2.57	58.1	85.6	27.8	2.06	22.8	198	0.135
027	77.3	551.1	54.1	7.14	89.9	54.3	3.10	56.8	85.8	29.3	1.97	23.7	208	0.130
028	67.8	452.6	55.0	6.88	87.1	52.4	1.67	58.9	87.1	28.2	1.92	23.9	215	0.141

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C702029	79.8	429.6	50.9	7.04	90.8	53.6	2.90	53.4	83.8	30.5	2.08	26.9	233	0.132
030	80.6	552.2	53.4	6.88	87.4	53.1	2.77	57.5	85.8	28.3	1.93	18.7	200	0.121
031	78.2	547.8	57.7	7.13	89.1	52.3	3.67	56.6	86.2	29.9	2.04	21.5	205	0.119
032	76.9	578.4	58.0	7.00	84.8	52.3	2.77	55.8	85.4	29.8	1.94	23.9	208	0.130
033	76.5	597.2	58.3	7.00	85.4	52.8	2.77	55.1	84.9	29.8	2.09	25.3	236	0.139
034	76.8	512.0	57.8	6.66	80.0	51.6	2.33	57.8	85.0	27.2	1.94	27.5	227	0.141
035	74.8	492.5	54.2	7.16	88.6	53.8	2.43	56.1	84.9	28.8	2.09	23.7	213	0.138
036	82.4	535.3	51.0	7.43	90.5	53.4	1.90	57.1	85.9	28.8	2.03	22.6	220	0.128
037	75.0	513.9	56.6	7.18	84.5	53.3	2.10	54.6	84.1	29.4	1.89	25.2	212	0.130
038	76.6	533.4	59.9	7.12	87.0	52.7	3.43	56.6	85.3	29.0	2.00	24.8	207	0.139
039	74.7	526.8	58.4	7.32	89.6	53.2	2.77	55.9	85.2	29.5	2.03	21.6	206	0.132
040	75.6	541.8	60.4	6.87	87.2	52.9	2.43	56.9	85.3	28.3	1.92	22.1	193	0.129
041	72.0	562.4	57.3	6.91	87.1	53.5	2.33	57.0	85.6	28.8	1.99	24.7	214	0.141
042	73.3	557.6	58.3	7.14	88.1	51.9	3.10	54.6	84.3	30.0	2.00	25.5	201	0.142
043	80.8	493.8	57.1	7.10	85.5	53.7	3.67	57.6	86.5	29.1	2.00	22.9	190	0.119
044	71.3	474.7	54.5	7.01	86.1	54.0	1.90	54.7	82.4	28.0	2.04	28.2	219	0.141
045	80.7	547.1	59.7	6.99	83.8	52.8	3.10	58.2	86.9	29.0	2.02	22.5	195	0.134
046	79.8	580.4	54.6	7.29	89.3	54.1	3.67	55.8	85.4	29.6	2.03	23.3	203	0.133
047	74.5	556.2	57.9	6.73	83.1	52.9	2.23	58.3	85.6	27.3	1.91	24.7	205	0.140
048	76.8	611.8	54.9	6.89	86.5	52.1	3.43	56.8	84.8	27.9	1.94	26.6	227	0.129
049	72.7	544.5	58.6	6.93	82.5	52.4	3.33	55.1	83.6	28.7	1.96	25.9	239	0.134
050	77.4	575.6	56.0	7.49	90.6	53.6	2.10	53.7	84.5	31.1	1.99	25.3	231	0.146
051	71.5	584.1	52.7	7.13	83.1	54.1	2.43	53.7	82.1	28.6	2.00	25.0	212	0.147
052	77.1	583.2	58.7	6.84	84.0	51.7	3.90	54.7	84.9	30.2	1.98	24.7	201	0.137
053	73.9	595.6	57.8	6.86	85.3	52.0	3.77	55.6	84.8	29.2	1.99	24.0	212	0.134
054	78.3	571.3	54.7	6.78	86.5	52.2	1.67	57.1	85.7	28.6	1.97	24.5	208	0.143
055	77.1	532.1	54.7	6.80	86.3	53.2	2.77	56.4	85.0	28.8	2.04	22.3	194	0.135
056	76.6	518.5	55.7	7.08	88.7	51.8	2.67	54.8	85.3	30.5	2.07	24.6	223	0.154
057	75.0	621.7	58.1	7.17	88.0	52.0	2.67	56.6	84.8	28.2	2.00	24.6	210	0.137
058	76.8	541.5	56.1	7.15	88.3	52.5	3.43	54.0	83.4	29.4	1.95	24.9	212	0.134

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C702059	73.9	504.0	53.3	7.14	86.2	54.2	1.77	52.8	84.1	31.3	1.99	27.4	236	0.143
060	79.3	558.1	55.5	7.15	86.2	52.2	3.10	57.6	86.3	29.1	1.98	21.3	194	0.120
061	70.0	418.6	54.8	6.76	82.5	49.8	1.67	59.6	86.8	27.4	1.89	30.5	243	0.147
062	74.3	583.2	61.1	6.63	79.8	50.5	1.90	56.9	84.9	28.0	1.93	30.7	247	0.161
063	78.9	614.6	57.2	7.49	88.5	53.8	2.77	56.1	83.2	27.6	1.87	25.2	219	0.134
064	76.7	544.2	63.3	7.10	82.9	51.9	3.90	56.3	86.3	30.5	1.86	21.5	189	0.121
065	79.0	609.3	60.8	6.81	85.8	50.8	4.00	56.7	86.3	29.6	1.83	24.5	171	0.130
066	78.0	496.3	56.3	7.41	92.2	52.5	3.23	54.6	85.7	31.2	2.00	23.1	228	0.136
067	60.1	519.3	55.3	6.70	84.1	52.5	1.33	57.4	86.7	29.6	1.91	20.8	205	0.115
068	59.9	445.6	57.8	6.68	85.3	52.5	1.77	58.0	86.1	28.2	1.97	21.6	205	0.134
069	82.3	548.8	58.1	7.49	91.1	53.6	3.10	56.4	86.5	30.6	2.05	20.2	210	0.120
070	71.4	523.2	55.2	6.85	85.7	51.2	2.57	54.3	82.5	28.2	1.96	26.5	223	0.143
071	75.9	551.8	55.3	7.31	91.0	53.5	2.43	54.4	83.6	29.1	1.92	29.7	227	0.138
072	75.8	517.8	58.5	7.10	88.7	52.2	3.10	53.8	84.6	30.8	1.95	27.4	230	0.133
073	76.1	600.5	54.3	7.28	87.4	52.1	3.23	55.1	84.6	29.6	1.93	28.7	232	0.155
074	78.1	598.4	53.3	7.51	91.0	52.2	3.00	56.6	84.8	28.2	2.01	27.7	238	0.149
075	75.1	530.9	58.7	6.60	78.9	50.8	3.33	55.2	84.4	29.4	1.95	25.8	222	0.136
076	79.1	548.3	57.1	6.89	85.2	50.7	2.77	57.1	86.3	29.5	1.89	26.6	231	0.144
077	76.3	543.0	54.2	6.99	86.1	52.4	4.57	54.9	84.3	29.4	2.01	28.5	235	0.142
078	78.5	578.8	58.6	6.76	83.0	52.4	2.67	57.0	86.0	29.1	1.96	26.8	233	0.139
079	78.7	465.5	52.3	7.42	89.7	52.9	3.33	54.7	85.3	30.9	2.15	27.7	245	0.154
080	74.6	590.9	55.2	7.00	87.3	53.4	3.67	56.6	86.2	29.6	1.99	24.3	234	0.132
081	76.6	524.5	58.0	6.96	89.3	52.7	2.23	55.4	84.3	28.9	2.06	24.7	238	0.144
082	75.6	493.5	59.1	6.90	86.8	52.5	3.10	55.8	85.3	29.4	1.98	25.9	234	0.138
083	80.0	454.3	59.8	7.21	86.9	52.2	3.57	57.1	86.3	29.4	1.98	25.2	218	0.136
084	78.4	543.9	60.3	7.05	86.5	52.8	4.33	56.5	86.0	29.5	2.02	22.6	225	0.127
085	77.2	527.8	56.3	6.88	75.4	51.8	2.00	58.0	85.7	30.3	1.91	27.2	229	0.154
086	75.0	516.5	58.6	6.15	85.8	51.4	2.00	54.0	82.7	28.7	1.96	27.7	237	0.143
087	74.8	550.8	57.5	7.05	88.3	52.4	2.67	55.1	85.2	30.1	1.98	23.7	223	0.134
Mean	76.0	540.4	56.5	7.04	86.2	52.6	2.86	56.1	85.6	29.1	2.00	25.3	220	0.137

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
***														
C703001	68.7	459.4	60.5	6.88	79.5	52.7	1.10	53.9	80.7	26.8	2.03	27.2	238	0.122
002	69.2	502.4	55.3	7.28	90.2	52.1	2.43	53.8	82.5	28.7	2.21	26.0	267	0.149
003	67.4	509.9	51.3	7.15	86.3	53.3	1.57	54.3	79.2	25.2	2.09	24.8	245	0.140
004	73.8	537.7	56.2	7.31	86.7	53.5	3.33	54.3	84.3	30.3	1.99	23.1	225	0.115
005	72.8	499.6	50.3	7.53	90.4	53.3	2.43	54.1	80.8	26.7	----	----	---	-----
006	72.1	545.9	56.3	6.74	73.6	51.8	2.10	56.3	83.9	27.6	1.86	31.1	273	0.144
007	70.7	543.9	55.6	6.50	77.9	51.4	1.67	53.8	80.0	26.5	1.88	33.3	253	0.150
008	71.2	551.7	54.1	7.10	88.2	53.4	3.43	53.8	80.1	26.4	2.19	28.1	298	0.139
009	70.5	576.3	54.5	7.19	87.4	53.9	2.10	54.2	82.5	28.3	1.96	28.5	239	0.154
010	74.6	582.9	56.9	6.68	79.8	52.3	2.23	53.8	80.6	26.8	2.05	25.7	251	0.142
011	66.1	572.6	59.6	6.46	77.5	52.0	2.00	55.6	81.6	26.5	1.92	29.4	280	0.158
012	71.2	527.4	54.8	7.06	81.2	51.6	1.23	54.7	81.5	27.1	1.92	32.0	261	0.163
013	57.1	532.2	55.4	6.11	69.2	50.4	1.00	56.1	83.8	27.7	2.17	25.8	251	0.141
014	68.7	549.0	57.8	6.93	80.6	52.9	1.33	54.3	79.9	25.9	1.93	31.7	304	0.165
015	73.8	535.1	56.6	7.48	87.8	52.4	3.00	54.6	81.6	27.2	2.01	27.7	245	0.137
016	61.9	500.7	53.7	6.48	77.4	52.9	1.00	56.5	82.5	26.0	1.94	24.0	223	0.126
017	66.1	507.3	52.9	7.03	76.7	50.4	1.57	54.9	78.2	23.3	2.16	25.0	226	0.137
018	69.1	531.8	58.8	6.76	82.7	53.1	2.00	53.9	71.4	27.6	1.99	24.8	222	0.141
019	73.5	638.4	55.8	6.98	85.4	53.9	3.43	53.4	80.6	27.2	2.11	20.1	238	0.123
020	72.1	498.9	50.8	7.17	89.5	53.8	1.77	54.1	80.7	26.6	2.05	25.4	300	0.139
021	72.0	532.8	55.9	6.84	85.1	52.7	2.23	54.1	80.8	26.7	2.11	26.2	277	0.142
022	69.7	519.3	53.2	7.95	94.8	53.7	1.67	54.0	84.9	31.2	2.02	24.4	251	0.132
023	70.8	544.3	52.9	7.03	90.2	53.2	2.33	54.6	80.3	26.3	2.25	23.4	257	0.143
024	72.9	585.1	51.5	7.11	87.6	51.9	2.57	54.3	80.9	26.9	2.17	22.7	264	0.132
025	71.6	594.3	58.6	6.75	83.3	52.4	2.90	54.6	84.5	29.9	1.95	21.8	234	0.129
026	71.6	602.1	55.8	6.90	85.9	52.2	2.33	53.6	82.3	28.8	1.97	21.9	245	0.140
027	65.1	492.0	52.1	7.21	85.6	53.2	1.33	54.5	79.7	25.5	2.13	23.5	269	0.151
028	72.0	569.8	54.3	7.56	89.7	54.0	2.10	54.2	81.3	27.1	2.03	23.0	258	0.142

Appendix continued.

Genotype No.	Plant Height (cm)	Yield (g/plot)	Kernels/ Spike	200 Kernel Weight (g)	Percent Plumpness	Test Weight (lb./bu.)	Lodging (1-7)	Days To Head	Days To Ripe	Days in Post-Anthesis	Percent Barley Nitrogen	Alpha-amylase (units)	Saccharifying Activity (units)	Soluble amino-Nitrogen (g/100g grain)
C703029	52.7	417.4	46.8	6.66	74.3	52.0	1.43	58.9	82.1	23.7	2.16	25.8	290	0.151
030	73.1	559.2	54.6	7.47	90.0	53.0	2.67	53.9	84.2	30.8	1.97	24.8	258	0.139
031	68.1	558.0	53.4	7.26	84.6	52.5	2.00	53.6	80.6	27.1	1.96	26.5	290	0.150
032	57.8	557.6	48.8	6.84	83.5	51.3	1.90	55.3	83.8	28.4	2.01	29.7	270	0.142
033	55.0	509.8	47.1	6.35	75.2	49.4	1.10	55.6	83.8	28.2	1.97	28.8	275	0.141
034	58.9	507.3	50.1	7.03	82.6	51.2	1.67	55.1	81.8	26.9	2.04	24.2	268	0.138
035	70.8	559.8	56.1	7.18	87.6	51.9	2.90	53.3	80.6	27.4	2.00	23.3	279	0.145
036	68.1	577.5	55.5	6.93	81.9	53.1	2.57	53.6	82.5	28.9	1.97	23.3	261	0.134
037	69.4	613.3	57.9	7.06	80.8	52.3	2.57	55.1	83.3	28.3	1.96	24.2	247	0.130
038	62.3	443.8	59.6	7.13	80.1	53.4	1.76	55.6	81.8	26.5	2.04	26.1	261	0.140
039	69.7	451.3	52.6	6.86	86.2	52.0	2.77	54.4	81.2	26.8	2.20	24.7	281	0.147
040	64.0	464.8	51.5	6.64	81.7	51.8	1.43	53.7	78.1	24.8	2.21	23.5	297	0.141
041	76.7	523.3	54.0	7.24	88.2	53.1	2.43	54.2	84.3	30.1	1.97	25.3	256	0.141
Mean	68.4	532.8	54.6	6.99	83.6	52.5	2.08	54.3	81.7	27.3	2.04	25.8	261	0.141
Minn64-62	61.5	464.8	55.1	6.60	81.5	51.0	1.67	58.2	86.7	28.5	2.02	22.7	212	0.133
Bonanza	79.4	532.2	57.5	7.00	85.2	51.5	4.46	54.6	83.0	28.4	2.07	23.0	242	0.160
Br6705-55	65.3	480.3	52.1	6.90	82.5	49.8	2.07	53.7	78.9	25.2	2.15	26.1	279	0.142
Conquest	80.5	493.2	55.0	7.10	87.1	50.8	4.30	53.6	83.2	29.6	2.16	30.3	233	0.157

* C701--- equals population 1 (Minn64-62 x Bonanza).
** C702--- equals population 2 (Minn64-62 x 66NI288).
*** C703--- equals population 3 (Minn64-62 x Br6705-55).